# Impacts of Changes in Sea Level and Storminess

## 5.1 Introduction

In this chapter, the possible changes in morphology, biology, and coastal defense efforts for the hydrological scenarios under the assumption "Business As Usual - BAU" are described. To this end, appropriate parameters that characterize morphology, biology and coastal defense in the Wadden Sea were selected. The results represent the expert opinion of the working group members. For most of the parameters almost no quantitative data and/or scientific outcomes exist, either because there is no monitoring of appropriate parameters or monitoring has only started recently. Hence, it was only possible to achieve qualitative estimates based on the present state of knowledge and (practical) experience. Consequently in Table 5.1 no absolute figures but percentage ranges or, for biologic parameters and storminess, signs (positive, neutral or negative) indicate the expected relative changes for each scenario. The present situation has been set at 100%. Under the 10 cm scenario no or only minor changes are expected, as this scenario represents the continuation of present sea level rise.

In sections 5.2 and 5.3 the expected changes in physical and biologic parameters under the three hydrological scenarios are presented. The consequences for safety, fresh water run-off and harbor/shipping and salinity for each hydrological scenario are described in Section 5.4.

All results have been summarized in the overview Table 5.1.

## 5.2 Physical consequences

To characterize the possible physical consequences for the Wadden Sea under the three hydrological scenarios, six parameters have been selected by the working group:

- flooding time intertidal flats (the period with salt water cover);
- spatial extent intertidal flats (surface area between mean low and mean high water level);
- tidal channel cross-section;
- salt marsh accretion (changes in height of the salt marshes);
- salt marsh cliff erosion (horizontal development of seaward salt marsh edge);
- barrier retreat (migration of barriers).

### 5.2.1 Flooding time intertidal

The flooding time of the intertidal flats is expected to increase by 2.5 to 7.5% under the 25 cm scenario, and between 5 and 15% under the 50 cm scenario. This increase will be further aggravated if storminess increases as well. However, the working group stresses that the changes will strongly differ from one tidal basin to another (Fig. 5.1), depending on the amount of sediment available to balance sea level rise. Some tidal basins already seem to suffer from a sediment deficit. Hence, the flooding time in these tidal basins will probably be much more affected than suggested by the mean values mentioned in the table.

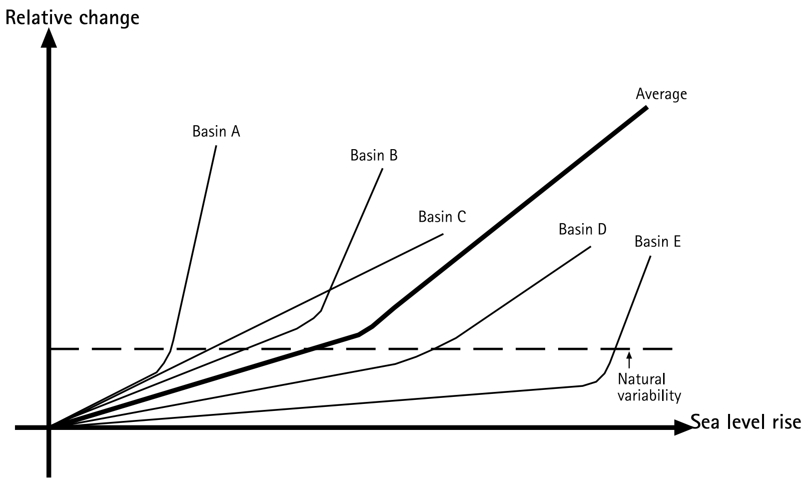



**Figure 5.1:** Possible changes in geomorphological and biological parameters for individual tidal basins under sea level rise. Up to a certain „break point" parameters react slowly and within the range of natural variability. After the break point, which differs for different tidal basins, reaction to SLR is evident but again different for the individual tidal basins.

### 5.2.2 Surface area intertidal

The effects of rising sea levels on the surface area of the intertidal flats are expected to be the same as for the flooding time. Hence, the spatial extent might, under the 50 cm scenario, diminish by up to 15% or 720 km$^2$ compared to the present situation (4,800 km$^2$). This will, obviously, significantly influence the biological parameters (Ch. 5.3). Under the "worst case" scenario the Wadden Sea might start to evolve from an ecosystem characterized by large intertidal areas, towards a more open water, lagoon-like environment.

### 5.2.3 Tidal channel cross-section

A well-known parameter to characterize tidal channels is the tidal channel cross-section (Fig. 5.2). In general it is expected that a rise in sea level will result in a (relatively small) increase in the cross-sectional areas of the tidal channels. An increase in storminess might, on the other hand,

**Table 5.1: Overview of expected changes in physical, biological and socio-economic parameters under three hydrological scenarios under Business as Usual (BAU) policies.**

*1) The change is given as either absolute, relative (Situation in 2000 = 100%), qualitative (+,-, 0) or descriptive. The range given is an average (compare figure 5.1).

*2) Qualitative indication of additional effect increase (frequency/intensity).

*3) Generally sea level rise will increase erosion. A sea level rise of 25 cm to 50 cm will cause an additional retreat of ca. 1.50 m per year or more. Along the western shores of Amrum, Eiderstedt barriers and Dithmarschen retreat is balanced by a strong sediment input from the longshore drift. Rise in sea level will not have a large affect on the accretion at the west coast of Rømø and Fanø, with a sea level rise of 50 cm a decrease of accretion, or even erosion, can be expected.

*4) For each country the relative share of expenditure for each of these categories is given in Table 5.2.

| | Present situation | Change 2050 compared to present situation *1) | | | Storms *2) | Remarks |
|---|---|---|---|---|---|---|
| | | 10 cm/50yr scenario | 25cm/50yr scenario | 50 cm/50yr scenario | | |
| **I. PHYSICAL ASPECTS** | | | | | | |
| Flooding time intertidal area | | 0 | +2.5 to +7.5% | +5 to +15% | + | Assuming sedimentation. Large differences between tidal basins (0 to +25%). |
| Surface area intertidal flats | NL 1,300 km² Nds+HH 1,500 km² SH 1,300 km² DK 700 km² | 0 | -2.5 to -7.5% | -5 to -15% | - | Lister Dyb tidal basin -30% (under 50cm/50yr scenario). |
| Channel cross-section | | | 0 to +5% | Up to +10% | 0 to + | |
| Salt marsh accretion (in height) | SH +0.5 to +2.5 cm/yr | +0.5 to +2.5 cm/yr | 0 to +2.5 cm/yr | -0.5 to +0.5 cm/yr | - | In worst-case scenario less accretion and some drowning. |
| Salt marsh cliff erosion | | 0 to 2 m/yr | 0 to 2 m/yr | 0 to 4 m/yr | + | Very large local differences. |
| Barrier Retreat | | *3) | *3) | *3) | | |
| **II. BIOLOGICAL ASPECTS** | | | | | | |
| Benthic biomass | | 0 | 0 to - | - | - | Depends strongly on sediment composition (and, consequently, dynamics). |
| Birds (selected species) population size | | 0 | - | - | - | Depends on frequency of high floods (breeding birds) and benthic biomass |
| Fish nursery | | 0 | - | - | - | Temperature, change of habitat and turbulence important factors |
| Seal population size | | 0 | 0 | 0 to - | - | |
| Seagrass area | | 0 | - | - | - | Related to decrease intertidal |
| Dune vegetation | | 0 | 0 | 0 to - | - | |
| Salt marsh vegetation diversity | | 0 to + | + | + | | |
| **III. SOCIOECONOMIC ASPECTS** | | | | | | |
| Efforts to maintain present safety standards | | | | | | |
| Dikes | 100% *4) | 0 | 5 to 15% | 15 to 75% | 15% | Depends to an important degree on whether strengthening has been carried out recently |
| Other hard constructions | 100% *4) | 0 | 10 to 40% | 40 to 140% | 15% | |
| Sand suppletion (incl. Dunes) | 100% *4) | 0 | 50 to 100% | 100 to 300% | 10% | |
| Salt marsh works | 100% *4) | 0 | 5 to 10% | 10 to 25% | 30% | |
| Efforts to maintain discharge capacity | 100% | 0 | 20 to 50% | 50 to 200% | + | |
| Salinity ground water | | 0 | 0 to + | + | | |
| Dredging effort | 100% | 0 | -5 to 0% | -10 to -5% | 0 to + | |

induce a (insignificant) reduction of the cross-sectional area due to silting up of the channels. However, the changes will probably remain within the natural variability of the system.

### 5.2.4 Salt marsh accretion

Present day accretion rates on the salt marshes may vary from about 0.5 cm/yr on the barrier salt marshes to more than 2.5 cm/yr on some mainland salt marshes. With increasing sea level the time of tidal inundation and, subsequently, accumulation will increase. Hence, up to a certain limit (vertical) salt marsh accretion will be able to balance a stronger sea level rise. It is expected that under the highest sea level rise scenario (50 cm in 50 years) the salt marshes with low accretion rates will start to drown. An increase in storminess and, consequently, increased amounts of suspended material may cause a stronger sediment transport towards the salt marshes. A stronger accretion (counteracting the drowning tendencies) might be the result. Depending on which process dominates, the salt marshes will drown or balance sea level rise.

### 5.2.5 Salt marsh cliff erosion

Although salt marshes with a perennial halophytic vegetation cover are rather robust to hydrological changes (they even depend on a rising sea level, see 3.1.2, 3.5.3), the fronting pioneer zones are much more sensitive, especially to changes in storminess. An increase in wave-impact during storms will, under natural conditions, result in (an intensifying) salt marsh cliff erosion at the seaward edge of the salt marshes. If this process continues, the salt marshes might be eroded by (locally) up to 4 m/y until they finally disappear. However, as with flooding time and surface area of the intertidal flats, the working group stresses that large regional differences may prevail depending on the exposition of the salt marshes to incoming (storm) waves. In the Dutch and German sectors of the Wadden Sea cliff erosion is prevented or hindered by the construction of salt marsh works that dissipate the incoming wave (and current) energy (Table 5.1, Ch. 3.4).

### 5.2.6 Barrier retreat

A final parameter to characterize possible morphological consequences of hydrological changes along the outer North Sea coast is barrier retreat (i.e., the coastal strip from the dune crest to the foreshore). Under present conditions, a large range of morphological reactions to present sea level rise (from retreating to prograding) exists, depending on the sediment availability or, rather, the longshore drift. In general, barriers retreat in response to sea level rise. Thus, an increase in sea level rise and/or storminess will accelerate this trend. However, a number of barriers like Fanø, Rømø and Amrum, are rather stable or even prograde in a seaward direction. This is the result of a strong sediment input towards the beaches from the longshore drift. The working group estimates that under the "worst case" scenario the accretion

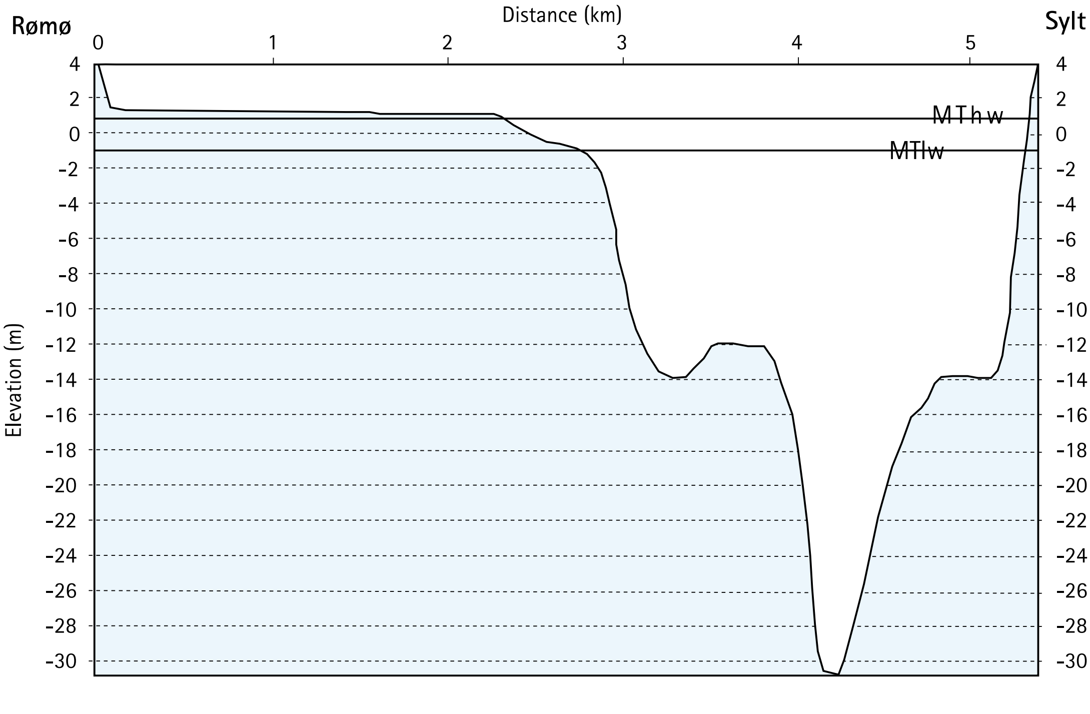



**Figure 5.2. Cross-sectional diagram of "Lister Tief" tidal inlet.**

might turn into erosion. In the Dutch and the German sector of the Wadden Sea, barrier retreat is mostly balanced by sand suppletion (Table 5.1, Ch. 3.1.3).

## 5.3 Biological consequences

A central factor in the assessment of the consequences for biological parameters are the foreseen morphological changes. As mentioned in 5.2, these will be only minor up to a 10 cm sub-scenario. With higher values for sea level rise and, consequently, morphological changes, most biological parameters are expected to respond, and often the response will be abrupt, indicating a break-down of interrelations formerly in a buffered balance. These "break points" will be reached at different sea rise levels in the different tidal basins (see Figure 5.1).

Another central factor is the sediment composition. It is generally assumed that sea level rise alone has no major influence on the sediment composition. Increase in storminess, however, will generally result in coarser sediments and increased turbidity. Because coarser sediment has, generally, a lower productivity, an increase in area with coarser sediment will lead to a general decrease in biomass input to the entire biological system. Mussel beds will be reduced with more storms. The decrease in biomass will become visible in a decrease in the number of migrating and breeding birds. Storms in (late) spring will have severe consequences for breeding birds.

Sea level rise and increased storminess are expected to have a clear effect on the following biological indicators:

- Benthic biomass;
- Birds;
- Fish;
- Seals;
- Salt marsh vegetation.

Other parameters will also be affected, but the CPSL working group does not have sufficient indications to allow a prediction.

### 5.3.1 Benthic biomass

Benthic biomass is expected to decrease slightly with a sea level rise up to 25 cm. Under the 50 cm scenario some decrease in total benthic biomass is foreseen, but not in a scale that could be termed "catastrophic". The interspecific distribution could well be affected, resulting in effects on the stocks of birds and fish feeding on special food sources. Increased storminess will reduce mussel beds, including the quite rich benthic fauna associated with these beds. Also the possibilities for restoring mussel beds will be reduced as a result of increasing storminess.

### 5.3.2 Birds

Feeding possibilities are central for the birds in the Wadden Sea. Possibilities are regulated by water depth and bottom substrate. Most bird species are specialized to a limited range in these two parameters and prefer to feed on emerged flats, where they select their specialty from the benthos. A shift in flooding time will affect the time available for feeding and a change of sediment composition affects the composition of food items available.

Birds, mainly waders, will also be affected at the lowest sub-scenario. But up to some 25 cm of sea level rise the effect will be difficult to isolate from general stock fluctuations, perhaps with the exception of small waders, which will have markedly less feeding time. Ducks and geese will not be affected to a measurable extent. With higher sea level, the number of waders will decrease, mainly due to increase in flooding time. An exception is the greenshank (and perhaps also the redshank), which may benefit from the expected increase in channel width, resulting in a larger area of channel slopes where the greenshank feeds.

A sea level rise of 50 cm in 50 years will result in a marked decrease in all waders, owing to an expected increase in flooding time, leaving less time for the birds to feed on the intertidal flats. Duck and geese stocks will also go down because salt marshes will be flooded more frequently, leaving less time for feeding.

Increased storminess will have an effect mainly on breeding birds. Oystercatchers and other bird species feeding on blue mussel will be affected, also when migrating. Birds breeding on low lying areas will be at higher risk (e.g. avocet, little tern), where a sequence of late spring floods can eradicate a whole colony and, in worst cases, the whole Wadden Sea breeding population.

### 5.3.3 Fish

Fish stocks in the Wadden Sea are not expected to be affected by sea level rises below 25 cm. Above this, the increase in flooding time could affect living conditions for flatfish hatchlings negatively, e.g. by reducing tidal pools and the surface relief. Fish migration could be impaired under the 50 cm sea level rise scenario, because the sluice opening periods will be shorter. But the anticipated increase in sluice capacity will (probably) balance the negative effects. Increased storminess could lead to increased loss of fish eggs and thereby affect breeding fish stocks.

### 5.3.4 Seals

Seals are not expected to respond to sea level rise in general. A decrease in fish stocks at higher sea levels due to a lack of suitable habitats for juvenile flatfish may affect seal population size. This effect could be (partially) compensated by the seals finding new foraging areas. At the highest sea level rise scenario also a shortage of haul-outs may affect the populations.

An increase in storminess will have a negative effect on the grey seal (breeds early, pups vulnerable to spring storms), whereas no effect is expected on the common seal.

### 5.3.5 Seagrass

The seagrass area will decrease with increased storminess because higher water turbidity leads to a decrease in light influx to the bottom. No effect is expected from sea level rise itself. It should be noted that the seagrass area has fluctuated strongly over the last century.

### 5.3.6 Salt marsh vegetation

Salt marsh plants are adapted to a harsh climate. The lack of shade requires resistance to extreme temperatures and they must tolerate high salt concentrations in the soil. Artificial drainage has changed the natural habitat of most salt marshes. Natural processes will eventually lead to less salty environments at some places, but not to the extent seen today.

The salt marsh vegetation will become more "typical" with a sea level rise above the 25 cm scenario and also with increased storminess. Both factors lead to more frequent and longer-lasting inundations with salt water, favoring the specialized, typical salt marsh plants. Moreover, the typical morphology of the salt marsh with meandering creeks and salt pans will be promoted, leading to increased variation in habitats within the salt marsh.

## 5.4 Socioeconomic consequences

### 5.4.1 Safety

Under the category safety the existing strategies to maintain present safety standards in coastal defense are categorized as follows:

- dikes;
- other hard constructions (revetment, groynes, stone walls);
- sand suppletion incl. complementary biotechnical measures in dunes, such as planting marram grass and installing brushwood fences;
- salt marsh works.

A comparison of the current relative expenditure for each of the four coastal defense categories is in Table 5.2. For all four strategies, the increase in intensity is expected to be insignificant for the lowest sea level scenario (10 cm in 50 years). Further, the expected changes do not increase linearly with sea level rise. It is suggested that, somewhere between 25 and 50 cm of sea level rise in the next 50 years, the costs to maintain present safety standards with traditional measures may start to rise more than proportionally.

For dikes (maintenance and strengthening) the expected increase in costs for the most realistic sea level scenario (25 cm in 50 years) is expected to be in the order of 5 to 15 % for the German Wadden Sea. In the Dutch and the Danish Wadden Sea the relative increase is estimated to be much higher. The main reason is that at present dikes are only maintained in these two countries, not strengthened as in Schleswig-Holstein and Niedersachsen. For the high sea level scenario (50 cm in 50 years) the costs to maintain present dike safety in the year 2050 may rise by up to 75 % (Germany) and even more in The Netherlands and Denmark. As an example, the present yearly ex-

| | Dikes | Other hard constructions | Sand nourishment | Salt marsh works |
|---|---|---|---|---|
| The Netherlands | 35 | 10 | 50 | 5 |
| Niedersachsen | 80 | 10 | 5 | 5 |
| Schleswig-Holstein | 50 | 10 | 15 | 25 |
| Denmark | 90 | 5 | 0 | 5 |

**Table 5.2: Current national relative expenditure (%) for four categories of coastal defense measures in the Wadden Sea.**

penditures on dikes in Schleswig-Holstein of about 24,0 million EURO may maximally increase to about 42,0 million EURO in the year 2050. This figure may still be about 15 % higher (i.e. 48.3 million EURO for Schleswig-Holstein) if storminess increases as well. Under this "worst-case" scenario the necessary costs to keep the present dike safety could double!

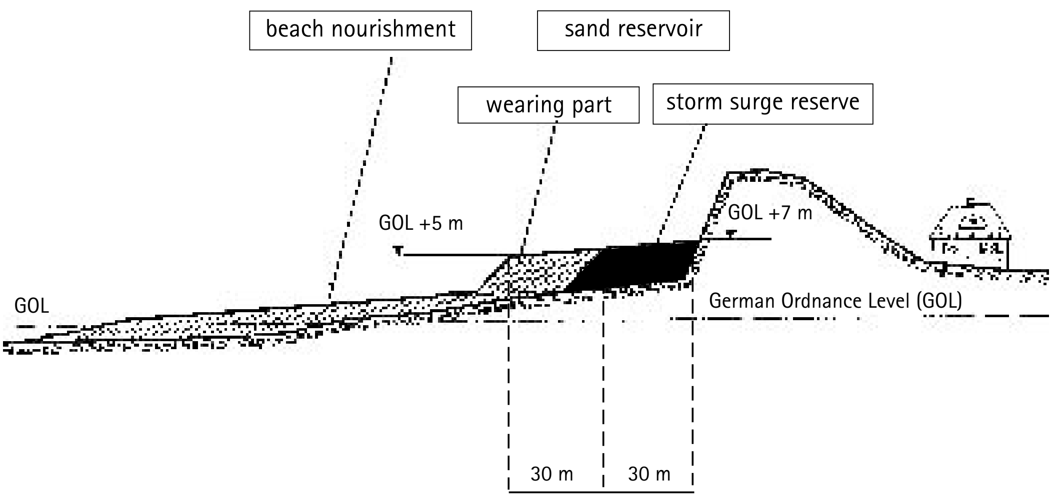
Under "other hard constructions" several measures like revetments, groynes and stone walls are combined. The crests of these constructions are situated near or only a few meters above present sea level. With rising sea level they will increasingly be exposed to tides and waves. Therefore, it is suggested that the costs may (relatively) increase more than the expenditures on dikes. As the present expenditures on these measures are normally much lower than on dikes, the absolute increase in costs will not be so high. However, under the BAU-scenario it may become necessary to build new or to strengthen existing hard constructions, which could raise the costs significantly.

One of the main measures to keep the coastline in its present position is the suppletion of sand on the beach or in the nearshore (Figure 5.3). According to present knowledge (the so-called Bruun rule) the upper nearshore and beach will increasingly erode with increasing sea level and, consequently, the coastline will retreat faster. Therefore, more sand is needed to maintain the coastline. At present, about 6 million $m^3$ of sand is suppleted each year along the total Dutch coastline (incl. the provinces of Holland and Zeeland). The volume of sand needed to stabilize the Dutch coastlines in the year 2050 might increase to more than 10 million $m^3$ for the "worst-case" scenario (50 cm of sea level rise in 50 years, combined with increasing storminess). For the most realistic sea level scenario (25 cm in 50 years) the estimated amount of sand needed would increase to about 8 million $m^3$.

Under the strategy "salt marsh works" the techniques to stabilize (and in some places create) salt marshes in the Wadden Sea are combined (Figure 5.4). One of the basic requirements for salt marshes to persist is a moderate sea level rise. Without sea level rise a vegetation succession towards fresh water biotopes would prevail. Hence, the expected increase in the intensity of salt marsh works under the different sea level scenarios is rather modest compared to the other strategies. One of the most destabilizing factors for salt marshes is wave attack along the outer edges (Ch. 3.4). As a result, cliffs may develop and the salt marsh may be eroded from its seaward side. An increase in storminess and, correspondingly, wave attack will thus result in much higher efforts to protect salt marshes. In Schleswig-Holstein the costs could rise from about 12 to 20 million EURO. For the most realistic sea level scenario on the other hand, the yearly costs in Schleswig-Holstein would rise by about 1 million EURO.

Some larger harbors, especially in the estuaries (e.g. Hamburg, Bremerhaven), have extensive out-of-dike areas. The efforts to maintain these areas will certainly increase with rising sea level. However, considering the huge investments in these areas, the working group expects that the

**Figure 5.3: Schematic presentation of sand nourishment on the isle of Sylt.**



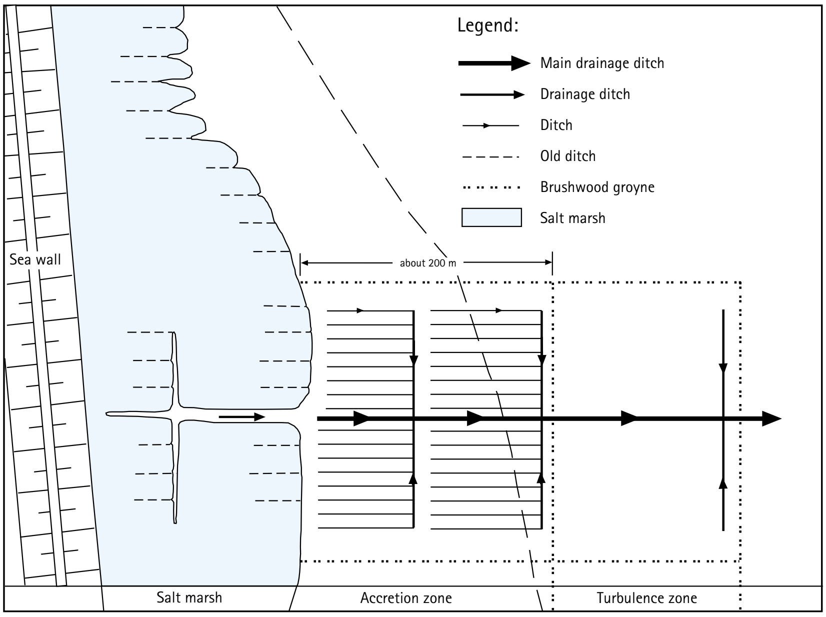



**Figure 5.4:**
**Schematic presentation of salt marsh works in Schleswig-Holstein.**

relative increase in costs will remain low. Furthermore, it is assumed that an increase in sea level rise is already anticipated in the planning schemes for these areas.

### 5.4.2 Fresh water run-off, harbors/ shipping, tourism, agriculture and salinity.

Although the working group concentrated on the effects of changes in sea level rise and storminess on coastal defense, it was decided to consider some other relevant aspects as well. Efforts to secure fresh water run-off from the hinterland and the functionality of harbors and shipping routes are often closely connected to coastal defense measures. Further, as stated in the terms of reference of the working group, tourism and agriculture are two significant uses in the Wadden Sea with direct interrelations with coastal defense and nature conservation.

To secure fresh water run-off into the North Sea or, rather, to prevent the coastal lowlands from drowning by rainwater (e.g. during storm floods) the following combination of measures is used:

(1) water storage basins behind the dikes;

(2) gates/sluices in the dikes;

(3) discharge channels through the salt marshes and tidal flats towards the tidal gullies.

Normally, the sluices are opened during ebb (tidal low water) and the fresh water, stored in the basins during flood, runs off through the channels towards the tidal gullies. However, at some places pumping stations already have to pump the water into the channels. With increasing sea level, the tidal low water level will probably rise as well. As a consequence, the water stored in the basins during flood may not be able to flow out naturally during ebb any longer. Moreover, the time during which discharge can take place will become shorter. Extra pumping stations, as well as, more and larger storage basins (and eventually dikes along the lower courses of some Danish rivers) may become necessary. In consequence, the efforts to secure fresh water run-off are estimated to increase by 50 to 200% for the highest sea level scenario (see box text on Lake IJssel in Chapter 6). An increase in storminess will probably result in more storm rainfall and, therewith, higher peak water discharges. Further, a more intense silting up of the discharge channels is expected under an increasing storminess. The efforts to secure fresh water run-off will increase correspondingly.

One further problem that is closely linked to fresh water run-off and sea level rise is increased salinity behind the dikes. Available data do not give indications about significant changes in salinity.

The navigability of the main shipping routes in the Wadden Sea is mainly secured by dredging. This artificial deepening of gullies has direct implications for the hydrology and morphology of the Wadden Sea. Vice versa, changes in the hydrology will influence tidal gullies morphometry and, therewith, dredging activities. It is expected that an increase in sea level rise will generally result in deeper channels and, consequently, in a (small) reduction of dredging efforts. In contrast, an increase in storminess may induce a stronger sedimentation in the channels and harbors. The efforts to maintain shipping channels and harbor access would increase correspondingly. Which of the two effects (deepening or sedimentation) would prevail under the "worst case" scenario cannot be predicted with present knowledge. The situation is even more complex in the estuaries. For example, salt and fresh water meet and mix here which strongly influences local sedimentation patterns. A shift in the position of this mixture zone resulting from sea level rise may have unknown implications for the navigability of the estuaries.

Two important uses/interests in the coastal zone that affect coastal defense and nature protection are tourism and agriculture. Tourism has become the most important source of income in many parts of the Wadden Sea region. The reaction of the public to sea level rise and increase in storminess is expected to be rather complex or even divergent. For example, an increase in storminess may result in an emotional negative attitude towards the Wadden Sea as an unsafe holiday region. Another example is mud flat walking that might be negatively affected if flooding time of the tidal flats increases. At the same time, however, increasing storminess may induce a new kind of active tourism during winter (watching and experiencing storm surges). Agriculture may, on a small scale, be influenced by an increase in sea level and/or storminess. If the present fresh water run-off is to be secured, extra arable land needs to be set aside for fresh water storage basins. Further, an increase in storminess (during summer) might result in more damages to the crops. In general, it is expected that, for the hydrologic scenarios, the effects on tourism and agriculture may be neglected. Other factors like atmospheric conditions (e.g. precipitation, hours of sunshine) or EU-policy will dominate the future development.

**Flatwalking in the Wadden Sea. (Photo: H. Marencic)**

# 6. BEP Options

## Best Environmental Practice (BEP) Options

### 6.1 Introduction

In the previous chapter 5 an analysis was made of, amongst others, the consequences of increasing sea level and storminess for present coastal defense practice, taking as a starting point that today's safety level would be maintained.

In this chapter several technical measures and practices are being evaluated with a view to their possible application in future coastal defense strategies. It concerns not only the „classical" measures covered in chapter 5, but also a large number of alternative measures, most of which are not being applied yet. The assessment was carried out by the working group with a view to having a broader array of measures and practices available for future choices, especially in the light of increasing sea level and storminess.

The measures and practices have been evaluated on the basis of two main criteria, namely their contribution to maintain safety and their impact on the environment. These criteria are called „Best Environmental Practice" (BEP) criteria.

The following BEP criteria were applied in the evaluation:

- safety: the contribution to coastal defense;
- Impact on habitats;
- Impact on natural dynamics.

All measures with a positive scoring for these criteria have been selected as Best Environmental Practice measures (BEPs). In some cases also a slightly negative scoring for the criteria impacts on natural dynamics and habitats was considered acceptable.

It is stressed that the selection of BEP measures has not taken into account aspects which are relevant for their feasibility. Because feasibility aspects will, in general, play a dominant role in the decision whether or not to apply the measure, the working group has also made a scoring for the following feasibility criteria:

- Technical: Technical possibility to carry out the measure, also considering the time it will take for the measure to become effective;
- Financial: Indication of costs;
- Legal: Agreement with current laws and rules;
- Public opinion: Acceptance by the public.
- Spatial: Applicability on a local or wider scale.

An evaluation of all individual measures, according to running number, is given in 6.2. A brief description of the measures is given in the box on the following page. The measures have been structured according to Sandy barrier coast (6.2.1), Tidal basins (6.2.2), Salt marshes (6.2.3) and Mainland (6.2.4). Brief descriptions of all measures are in the Box. An overview of the scoring of all measures is in Table 6.1.

In 6.3 the main conclusions of the evaluation and the selected Best Environmental Practice options are presented.

**Sandy barrier coast**

1. Artificial reefs: Reefs of hard constructions in the foreshore in order to reduce wave impact on the shore.
2. Beach drainage: Draining the beach by tubes and pumps in order to stimulate sedimentation of the beach.
3. Enhance dunes creation: The stimulation of sedimentation by marram grass and sand-trapping fences and thus accumulation of sand transported by the wind.
4. Dunes relocation: The building up of new dunes landward of the eroding old ones. In practice this will mean a gradual retreat of the dune front.
5. Natural dune dynamics: The transport of sand from the North Sea shore to the inner part of the barrier island where accumulation causes a gradual landward shift of part of the barrier island with rising sea level.
6. Overwash creation: Allowing water and sand transport across unprotected parts of barrier islands through wash-over channels. As with natural dune dynamics the transport of sand from the North Sea shore to the inner part of the barrier island and accumulation there causes a gradual landward shift of part of the barrier island with rising sea level.
7. Revetment building: Protecting the dunes against erosion by hard constructions.
8. Groynes: Constructions perpendicular to the coast into the foreshore. Comparable to revetment building.
9. Sand nourishment: Taking sand from outside the sand sharing system deeper water and pumping it on the beach or on the foreshore with the aim of stabilizing the beach.
10. Spatial planning: Spatial planning aiming, in the long term, at creating and maintaining buffer zones between land and sea where safety is not guaranteed under all circumstances.

**Tidal basins**

11. Dam building: Building dams between the mainland and the islands in order to stabilize tidal basins.
12. Dredging reduction: Reducing the dredging of shipping lanes.
13. Gullies damming: Diversion of tidal gully by 1) closing off the old gully with a sand dam and 2) dredging a new gully on another location in order to obviate hazardous gully meandering (e.g. gully approaching a dike foot).
14. Mussel bed reinstallation: Promoting the settling of mussels in order to stimulate accumulation of mud including protection of existing beds or potential locations for these beds:
15. Sea-grass bed reinstallation: Creating sea-grass meadows in places with low hydrodynamics in order to try to stimulate sedimentation.

**Salt marshes**

16. Revetments: Hard constructions protecting the salt marsh edges in order to prevent cliff erosion.
17. Creation marshes from dredged material: Deposition of dredged material on intertidal areas along the mainland or Wadden-sea side of the barrier island.
18. Outbanking of summer polders: Opening summer dikes in order to get a more frequent flooding of the area and higher sedimentation rates.
19. Groyne fields: Areas, sheltered by groynes, with reduced waves and in which accumulation of fine sediments is stimulated.
20. Artificial drainage: Digging ditches in the salt marsh in order to stimulate water run-off after the area has been flooded and vegetation growth in the lower parts of the salt marsh.
21. Grazing: Grazing by sheep and cattle with the aim of keeping a short vegetation and reducing the amount of flotsam.

**Dikes**

22. Revetments: Using hard material at the dike surface to protect the slope against damage by wave impact and currents.
23. Enforcement: Heightening and/or strengthening the dikes in order to maintain safety standards.
24. Second dike line: A dike, situated behind a primary sea wall, that serves to limit the area flooded after the primary sea wall breached.
25. Relocation of first dike line: Building a new dike landward of the old one.
26. Spatial planning: See running number 10.

**Mainland**

27. Pumping stations: Pumps for active discharge of fresh water from the inland to the to the sea.
28. Sluices: Constructions allowing passive discharge of fresh waters from the inland to the sea.
29. Storage basins: Inland basins for storing fresh water in periods when sea level is too high for the passive discharging the fresh water.

## 6.2 Evaluation

### 6.2.1 Sandy barrier coast

**Artificial Reefs (1).** Artificial reefs may be an option to reduce wave impact on the shore. Their contribution to safety is estimated as medium. Reefs form substrate and shelter for flora and fauna but they interfere with natural dynamics. The construction of artificial reefs is technically unproblematic and can be done at medium costs. They will be only locally applicable, and no substantial legal problems or public resistance are expected.

**Beach drainage (2).** Beach drainage is expected to have a medium contribution to safety and some impact on both the habitat (impact on the interstitial fauna) and natural dynamics. It is only locally applicable and considered very expensive. No substantial legal problems or public resistance are expected.

**Enhance dune creation (3).** Very locally it is possible to create new dune areas by catching wind driven sand. More often stimulation of dune growth will take place in the vicinity of existing eroding dunes. From the past there is already a lot of technical experience. On strong eroding beaches accumulated wind driven sand will be eroded by waves and currents. Dune creation will interfere with natural dynamics and existing habitats will be replaced by others. The public opinion is expected to react positively on the enlargement of dune areas.

**Dunes relocation (4).** This forms a cheap and technically practical way of sea defense but is only applicable if human interests in the dune area or the area behind it are low (no buildings, no infrastructure etc.).

**Natural dune dynamics (5).** By allowing natural dynamics, sandy areas lost by erosion will be replaced by sandy areas somewhere else. It is only applicable in uninhabited areas where safety is not at stake, but even then public resistance can be expected. On the long term natural dune dynamics contributes to the shifting of islands with rising sea level.

**Overwash creation (6).** This measure is locally applicable in uninhabited areas and provides, in the long run, a positive contribution to keeping areas above normal high water levels. It is also positive from a viewpoint of natural dynamics and may, on the long term, be beneficial because it stimulates island growth on the Wadden Sea side. Public resistance is expected if areas with vegetation are replaced by sandy areas.

**Revetment building (7).** This is an existing method of stopping retreat of the coast and guaranteeing safety. It is technically well feasible, accepted by the public but very unnatural. Erosion at the edges of the constructions make it necessary to extend the measures at those edges. Rising sea level will lead to an increase of finances needed.

**Groynes (8).** This method is comparable to revetment building.

**Sand nourishment (9).** Sand nourishment is, in general, a technically and financially feasible measure for coastal defense which has only slightly negative impacts on nature. It can be applied on a large scale.

**Spatial planning (10).** This is considered a good political instrument for a no regret policy. It is a useful tool by creating buffer zones where no building or rebuilding is allowed. This can work positively both from a financial point of view, as well as, for natural dynamics. The fear of loss of safety and the limitation of uses in buffer zones will lead to difficulties in public acceptance.

### 6.2.2 Tidal basins

**Dam building (11).** Although technically good applicable and positive for safety, this practice is considered negative for the environment, especially in a nature conservation area. From the public resistance is expected.

**Dredging reduction (12).** In estuaries the reduction of dredging in the channels will result in lower high water levels in the upstream parts. Reduction of dredging will also lead to a more natural development of the estuarine morphology. From legal and public opinion points of view this option is not regarded feasible.

**Gullies damming (13).** Very locally damming off gullies can prevent constructions or salt marshes to become unstable by gully erosion. It interferes however with natural dynamics. From Schleswig Holstein one example is known.

**Mussel bed reinstallation (14).** In general active reinstallation of biota is seen as gardening in a nature conservation area and therefore interfering with natural dynamics. Because these beds stimulate sedimentation and stabilization of the sediment they may diminish wave attack at the mainland shore. However during storm surges this effect is reduced to zero because of the large water depth. Favorable conditions for recovery of mussel beds can be achieved by limiting human exploitation of the area.

**Sea grass bed reinstallation (15).** Comparable to mussel bed reinstallation.

### 6.2.3 Salt marshes

Salt marshes can have both a nature protection and a coastal protection function (compare 3.4.2). The main functions in coastal defense are the reduction of wave energy input at the dike and the prevention of a scour hole and water flowing through the dike after a dike breach. Preservation of existing salt marshes can therefore be relevant from both perspectives.

**Revetments (16).** If there are big height differences between tidal area and salt marshes, the surface area of salt marshes can efficiently be protected by revetments. By preventing cliff erosion of the smaller salt marshes also the mainland shore behind them is safeguarded. Preventing erosion interferes with natural dynamics. In some countries there will be legal problems.

**Creation of marshes from dredged material (17).** Creation of new marsh lands may be positive from a safety point of view because an extra buffer is created between sea and land. Using dredged mud can make this option financially attractive. However, it interferes with natural dynamics and may only be applicable on a local scale.

**Outbanking of summer polders (18).** Outbanking of summer polders can compensate for the loss of salt marsh areas through cliff erosion or drowning caused by accelerating sea level rise and is therefore interesting from the point of view of nature protection. In the working group opinions differed strongly about the technical feasibility of this measure, ranging from very negative to very positive. In Germany the generally small summer polders have a function in sea defense. Outbanking would lead to higher expenses for guaranteeing safety. Here the feasibility is thought to be low. Public resistance may be expected if summer polders are private property. In these cases finances are needed for acquisition. Outbanking of summer polders in the inner parts of the estuaries may reduce storm surge levels because the storage capacity is augmented. However, in order to be effective, the surface area of the outbankment should be substantial compared to the total surface area of the inner estuary.

**Groyne fields (19).** The construction of groyne fields is an accepted, already existing measure, which is technically very good applicable. At the moment brushwood is frequently used to build the groynes. In future, with a rising sea level, hard material may become necessary. Up to a certain level of sea level rise the extra sedimentation will prevent salt marshes from drowning. Although the measure is positive for maintaining and extending the habitat salt marsh, it interferes with natural dynamics.

**Artificial drainage (20)** Artificial drainage of salt marshes may be positive for soil stabilization and resistance against erosion and, by this, enhances the vertical accretion of the salt marsh. It is technically good applicable. It interferes with natural dynamics.

**Grazing (21).** The opinions about the effectiveness of grazing in reducing the amount of flotsam and, therefore, the costs of coastal defense, differ (compare 3.4.2). Grazing with low to medium intensity causes diversification in vegetation which is interesting for biodiversity but may be regarded as undesirable from the point of view of interference with nature.

**Spatial planning in Schleswig-Holstein**

In the new master plan “Coastal Defense in Schleswig-Holstein” of 2001, ten strategic goals are formulated. Goal number three states: “Relocation or abandonment of sea walls is only possible as an exception”. Considering the protection of human lives, houses, economic assets and inhabited land against storm floods as the primary goals, the relocation or abandonment of primary sea walls may only be an alternative if,

- the existing safety standard is maintained, including (if present) a second dike line (see option 24; [Definition of a second dike (Schleswig-Holstein State Water Act): A dike, situated behind a primary sea wall, that serves to limit the area flooded after the primary sea wall has breached]).
- the people directly affected (i.e., the inhabitants of the protected lowland) agree, and
- coastal defense administration is kept free of extra costs.

Secondary sea walls that do not protect human lives have a lower safety standard. For these sea walls, relocation or abandonment may be appropriate if socio-economic arguments, especially the cost-benefit relation, supports this.

For some lowlands along the Baltic Sea coast of Schleswig-Holstein the relocation of sea walls is or was planned. However, the right of every individual on its property and on economic development (as defined under the German Basic Law), combined with the unwillingness of the affected people to move, has, until today, prevented such a measure

### 6.2.4 Dikes

**Revetments (22)**. Revetments are a classical and technically feasible method of preventing erosion of constructions. In areas with strong hydrodynamics revetments are necessary for the protection of the dikes. Revetments interfere with natural dynamics.

**Enforcement (23).** Dike enforcement is a classical technical solution, accepted by the public and applicable on a broad scale. It forms the guarantee for safety in future if alternatives are insufficient or not accepted. The costs for maintaining safety in this way will grow with a rising sea level. The separation between land and water will get stronger.

**Second dike line (24).** In the long run it may become cheaper to maintain the same safety standard by constructing a second dike line. A precondition is that there is no expensive infrastructure, either existing or planned, in the potential buffer zone between the two dike lines. Such a buffer zone with a low level of human exploitation may be positive from the nature protection point of view.

**Relocation of first dike line (25).** With rising sea level relocation of the dike may become cheaper compared to maintenance and enforcement of the dike. Legally this is not considered feasible. Also the public will be strongly against it. From a nature point of view it is a positive option because it means an extension of the Wadden Sea area.

**Spatial planning (26).** As in 10.

### 6.2.5 Mainland

**Pumping stations (27).** The use of pumps for the discharge of fresh water is regarded positive from both safety, technical feasibility and public opinion points of view. If high capacity has to be installed for incidental peak discharges this option becomes more expensive. Pumping stations accentuate the separation between the mainland and the sea. Fish traps should guarantee the migration of fish between fresh and salt water.

**Sluices (28).** Sluices are positive for safety, technically good applicable and accepted by the public. With rising sea level the sluice capacity has to be enlarged in order to maintain the same discharge capacity. As with pumping stations technical measures should guarantee the migration of fish between fresh and salt water.

**Storage basins (29).** By applying this option investments for pumping stations and sluices can be reduced because of lower necessary peak discharge capacities. It guarantees the storage of fresh water after high precipitation. Depending on the design of the basins, they can have positive functions for nature.

#### Enclosure Dike

In 1932 the Enclosure dike was built, separating the “Zuiderzee” from the Wadden Sea. Since then fresh water from the newly formed Lake IJssel had to be discharged into the Wadden Sea through sluices in the Enclosure Dike. 70% of the water in Lake IJssel comes from the river Rhine. Because of bottom subsidence the expected accelerating sea level rise and growing river discharges, the discharge capacity for water through sluices in the Enclosure Dike has to be doubled from 5500 $m^3/s$ to 11000 $m^3/s$. Already in the last 25 years it became more and more problematic to keep the water level of the Lake IJssel at the normal level. In 1998 the water level of Lake IJssel rose up to 1 meter above the normal level. The possibility of combining the extension of discharge capacity with a more gradual transition from fresh to salt water by creating a brackish water zone, is included in the research program investigating options for the doubling of the discharge capacity.

**Table 6.1:**
**Relative scoring of coastal defense practices for feasibility and Best Environmental Practice (BEP) criteria.**

| Environment | Measure | Feasibility | | | | | BEP Aspects | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Technical | Financial | Legal | Public opinion | Spatial | Impact on Habitat | | Impact on natural dynamics | Safety | |
| **Sandy barrier coasts** | | | | | | | | | | | |
| 1 | Artificial reefs | 4 | 3 | 3 | 3 | 1 | 2 | | 2 | 3 | |
| 2 | Beach drainage | 4 | 1 | 3 | 3 | 1 | 2 | | 3 | 3 | |
| 3 | Dunes creation | 4 | 4 | 3 | 4 | 2 | 3 | Replace one habitat by another | 2 | 4 | |
| 4 | Dunes relocation | 4 | 4 | 3 | 2 | 2 | 3 | | 3 | 4 | Relocation=retreat |
| 5 | Allowing wind driven sand transport | 4 | 5 | 3 | 2 | 2 | 4 | | 5 | 2 | Possibly positive on a long time scale and strongly dependent on locality |
| 6 | Overwash creation | 4 | 4 | 2 | 2 | 2 | 4 | Loss of fresh water species | 4 | 2 | On a very long run |
| 7 | Revetment building | 4 | 3 | 2 | 3 | 3 | 2 | | 2 | 4 | |
| 8 | Groynes | 4 | 3 | 3 | 3 | 3 | 3 | | 2 | 3 | |
| 9 | Sand nourishments | 4 | 4 | 4 | 3 | 4 | 3 | | 2 | 4 | Extraction from outside the sandsharing system |
| 10 | Spatial planning (create buffer zones) | 4 | 3 | 3 | 2 | 4 | 3 | | 4 | 4 | |
| **Tidal basins** | | | | | | | | | | | |
| 11 | Dam building | 4 | 2 | 2 | 2 | 3 | 2 | | 2 | 4 | |
| 12 | Dredging reduction | 4 | 4 | 1 | 1 | 1 | 4 | | 4 | 3 | In estuaries |
| 13 | Gullies damming | 3 | 3 | 2 | 3 | 1 | 3 | | 3 | 3 | One positive example from SH |
| 14 | Reinstallation and protection of mussel beds | 4 | 3 | 3 | 3 | 3 | 4 | | 2 Reinstall<br>4 Protect | 2 | In the long run |
| 15 | Sea-grass beds reinstallation | 3 | 2 | 3 | 3 | 2 | 4 | | 3 | 2 | In the long run |
| **Salt marshes** | | | | | | | | | | | |
| 16 | Revetments | 4 | 3 | 2 | 3 | 2 | 3 | | 2 | 4 | |
| 17 | Creation from dredged materials | 3 | 3 | 3 | 3 | 2 | 3 | | 2 | 4 | |
| 18 | Outbanking of summer polders | 4 | 2 | 3 | 2 | 2 | 5 | | 4 | 1 | Site specific in estuaries |
| 19 | (Brushwood) groynes | 4 | 3 | 4 | 4 | 4 | 3 | | 2 | 3 | |
| 20 | Artificial drainage | 4 | 3 | 3 | 3 | 4 | 3 | | 2 | 3 | |
| 21 | Grazing | 4 | 4 | 3 | 3 | 4 | 3 | | 2 | 3 | Reducing flotsam |
| **Dikes** | | | | | | | | | | | |
| 22 | Revetments | 4 | 3 | 4 | 4 | 4 | 2 | | 2 | 4 | |
| 23 | Enforcement | 4 | 2 | 4 | 4 | 4 | 3 | | 3 | 5 | |
| 24 | Second dike line | 4 | 2 | 3 | 3 | 4 | 4 | | 3 | 5 | |
| 25 | Relocation of first dike line | 4 | 1 | 1 | 1 | 2 | 4 | | 4 | 2 | |
| 26 | Spatial planning | 4 | 4 | 3 | 2 | 4 | 3 | | 4 | 4 | In the long run |
| **Mainland** | | | | | | | | | | | |
| 27 | Pumping stations | 4 | 2 | 3 | 4 | 3 | 3 | | 3 | 4 | |
| 28 | Sluices | 4 | 2 | 3 | 4 | 3 | 3 | | 3 | 4 | |
| 29 | Storage basins | 4 | 3 | 3 | 3 | 2 | 3 | | 3 | 4 | |

**Legend**

| | | |
|---|---|---|
| Technical: | 1 (almost impossible) ........ | 5 (very practical) |
| Financial: | 1 (very expensive) ........ | 5 (very cheap) |
| Legal: | 1 (very problematic) ........ | 5 (unproblematic) |
| Public opinion: | 1 (very negative) ........ | 5 (very positive) |
| Spatial: | 1 (site specific) ........ | 5 (everywhere) |
| Impact on habitat: | 1 (large scale destruction of typical Wadden Sea habitats) ........ | 5 (large scale creation of typical Wadden Sea habitats) |
| Impact on natural dynamics: | 1 (large scale reduction of natural dynamics) ........ | 5 (large scale increase of natural dynamics) |
| Safety: | 1 (low contribution) ........ | 5 (substantial contribution) |

## 6.3 Conclusions

### 6.3.1 Sandy Barrier Coast

Sand nourishment (9) is in general a good practice for coastal defense with slightly negative impacts on nature. It can be applied on a large scale. In addition to the classical methods of coastal defense many of the other suggested practices for the sandy barrier coast may prevent erosion, stimulate accumulation of sand or enhance safety on a local scale. This holds for artificial reefs (1), beach drainage (2), overwash creation (6) and dune creation (3) or dune relocation (4). In general, these measures are more or less neutral for nature. Allowing natural dune dynamics (5) and overwash creation (6) on the uninhabited parts of the islands is positive from a viewpoint of natural dynamics and may be beneficial on the long term because island growth at the Wadden Sea side is stimulated. In this way disappearing ecotypes at the North Sea side of the islands are recreated at the Wadden Sea side.

Spatial planning (10) is a useful tool through which buffer zones are created in which no building or rebuilding is allowed. In these areas safety must no longer be guaranteed. This can work out in a positive way both from a financial and a nature protection point of view The fear of loss of safety and the limitation of human activities in buffer zones will lead to difficulties in public acceptance.

The measures selected as BEP for the sandy coast are artificial reefs, beach drainage, dunes creation, relocation and allowing natural dune dynamics, overwash restoration, sand nourishment and spatial planning aiming at creating buffer zones.

### 6.3.2 Tidal basins

The selection of BEP measures for the tidal basins depends, first of all, on the political choices that have been made for the area under consideration. One extreme is not accepting any change in the character of the tidal basins and the other extreme is accepting all changes as a consequence of changed hydrodynamics. In addition, it must be realized that, on the scale of whole tidal basins, preventing changes in morphology induced by accelerating sea level rise is an impossible job. On a local scale, however, safeguarding intertidal areas from drowning can be done by (re)-installing mussel beds (14) or seagrass beds (15). Locally erosion and damage of constructions or loss of salt marsh area can be prevented by damming gullies (13). Schleswig-Holstein has an example of a successful application of this technique. Where human activities have morphological consequences comparable to those of sea level rise, the reduction of such activities will cause less changes and a postponement of the moment that changes in the system will become distinguishable from natural variability. This holds for mining causing bottom subsidence and sand and shell extraction.

In the estuaries both sea level rise and dredging works cause an easier penetration of the tidal wave and storm surges. A reduction of dredging (12) will diminish this effect leading tot a reduction in costs of maintaining safety along the inner parts of the estuaries. On the other hand this will give problems for navigation between the North Sea and the harbors. This makes this option not feasible from a legal and public point of view. However, in the long term, stimulating the increase of harbor capacity along the more outer deep water parts of the estuaries instead of the inner parts might be a preferred option.

The measures selected as BEP for the tidal area are reinstalling mussel beds and seagrass beds, gullies damming and dredging reduction.

### 6.3.3 Salt marshes

Outbanking of summer polders (18) can compensate the loss of salt marsh area caused by cliff erosion or drowning as a result of accelerating sea level rise and is, therefore, a good option from the point of view of nature protection. However, in Niedersachsen, where summer polders are important for coastal defense, outbanking will lead to higher expenses for guaranteeing safety. Here, the feasibility is therefore considered low. The outbanking of summer polders along the inner parts of the estuaries will cause a reduction of storm surge levels because the inundation area and, therewith, the storage capacity is increased. The surface of the outbanked area should, however, be substantial compared to the total surface area of the inner estuary.

Applying the already existing method of groyne fields (19) will safeguard salt marsh areas when sea level rise accelerates. If applied, it is clear that a choice has been made for safeguarding the habitat at the cost of natural dynamics. It is an already existing measure which is technically very good applicable. At the moment brushwood is frequently used to build the groynes. In future, with a higher sea level, hard materials may become necessary. The extra sedimentation prevents marsh lands from drowning, also, up to a certain level, with an accelerating sea level rise. Although it may be positive for certain habitats, it interferes with natural dynamics.

Artificial drainage (20) and low intensity grazing (21) stimulate root and swath growth and, consequently, the stability of the salt marsh. There are different opinions about the effectiveness of grazing in reducing the amount of flotsam at the dikes and thus reducing the costs of coastal protection (compare 3.4.2.). From a nature protection point of view both measures cause interference with natural dynamics. Grazing with low to intermediate intensity can, however, result in a more diverse vegetation which is interesting for biodiversity. Here political choices have to be made about the desired kind of nature: natural dynamics versus a high biodiversity. This choice does not necessarily have to be the same for the different countries.

The measures selected as BEP for the creation and maintenance of salt marshes are brushwood groynes and outbanking of summer polders in estuaries.

### 6.3.4 Dikes

Maintenance and enforcement of existing dikes (23) and revetments (22) is the classical, technically feasible starting point for guaranteeing safety. If alternatives are insufficient or not accepted, the continuation of this kind of protection seems logic. The separation of land and water will, however, become stronger. The question is whether, on the long term, this will still be the cheapest method. One possibility is, for instance, to create a second dike line (24) parallel to the first one with a buffer zone in between. In the long run this may become attractive from a financial point of view, provided no large infrastructural investments take place in the potential buffer zone. From a nature protection point of view such a buffer zone with low human exploitation must be regarded as positive.

Relocation of the first dike line (25) with rising sea level may be cheaper than guaranteeing safety forever and everywhere. Legally this option is, however, not considered feasible. Also public opinion will be strongly against it. From a nature perspective it is positive because it would mean an extension of the Wadden Sea.

With appropriate spatial planning (26) in the zone landward of the dikes it can be guaranteed that alternative options for guaranteeing safety will not be lost. In general this means that economic developments in areas directly bordering the Wadden Sea are limited.

The measures selected as BEP for dikes are creating different dike lines, dike relocation in estuaries and spatial planning aiming at preserving the possibility to use stretches of land along the coast for future coastal defense.

### 6.3.5 Mainland

An alternative for creating expensive extra pumping stations (27) or higher sluice capacity (28) for the discharge of increasing amounts of fresh water, is creating storage basins (29) on land. This is positive from a safety, technical feasibility and public opinion point of view. Dependent on the design of the basins they can also have functions for nature. This measure must therefore be regarded as BEP.

# 7. Conclusions and Recommendations

## 7.1 Introduction

The CPSL has investigated possible impacts of three sea level rise scenarios:

- Scenario 1 reflects a continuation of current sea level rise of about 10 cm/50 years;
- Scenario 2, the intermediate and most realistic scenario, assumes a sea level rise of 25 cm/ 50 years;
- Scenario 3, the worst case scenario assumes a sea level rise of 50 cm/50 years.

For all scenarios also the additional effects of an increase in storminess have been evaluated.

The analysis was done under the assumption of a continuation of current coastal defense practices (Business As Usual, BAU), taking as the main starting point that current safety standards are maintained. The main conclusions with regard to the anticipated impacts on several physical, biological and socioeconomic parameters are given in 7.2. In general, the intensity of impacts on the elaborated physical, biological and socioeconomic parameters is expected to show a strong regional and temporal variability.

As a second step the CPSL has investigated a large number of alternative measures which may alleviate and reduce the impact of enhanced sea level rise and storminess and which also take into account the environmental impact. Those options that were regarded as both positive from a coastal defense point of view and acceptable or even positive from a nature protection perspective (Best Environmental Practice [BEP] measures), either on a local or on a larger scale, have been listed in 7.2.5 below.

It should be stressed that all measures, both BAU and BEP, needed to counteract the negative effects of sea level rise and increase in storminess, are actually combating symptoms and not the causes.

It should finally be underlined that the assessment of the CPSL is based upon best available knowledge and best expert judgement and that little hard facts are available.

## 7.2 Conclusions

### 7.2.1 General conclusions

1. The Wadden Sea system shows a high natural variability. Consequently changes caused by accelerated sea level rise and increased storminess will not easily be distinguishable from natural variability.

2. The Wadden Sea system has a high resilience to changes and will, up to intermediate increases in sea level (25 cm/50 years), which is the most realistic scenario, be able to compensate the increased levels. Within this most realistic scenario costs for coastal defense will be higher than today. Also changes in the ecosystem are expected but these will not be substantial.

3. When sea level rises beyond intermediate levels and storminess increases, there will probably be a point between the intermediate and the worst-case scenarios at which the capacity of the system to balance the changes will be exhausted (breakpoint) and after which significant changes in the system can be expected. These will be changes in the morphology, which will influence biological parameters. The most notable change will be a reduction in the size of the intertidal area. Consequently the Wadden Sea tidal basins may start to evolve into the direction of tidal lagoons.

The reduction of intertidal area will cause a reduction in population sizes of some bird species. Also the costs for coastal defense will increase substantially after the breakpoint has been passed. A more detailed description of the changes is given in Sections 7.2.2 to 7.2.4.

4. In the long term, the application of current and future coastal defense measures may alleviate impacts of sea level rise and storminess but will not be able to prevent such impacts, certainly not under the worst case scenario. Policies will therefore have to adapt to the anticipated changes by starting, as soon as possible, to develop long term interdisciplinary policies for coastal defense, nature protection and economic development in the coastal area.

5. There is a lack of qualified data to assess possible effects of sea level rise and increase in storminess.

### 7.2.2 The Tidal Area

Up till an intermediate sea level rise (25 cm/50 years) it is likely that no significant changes will occur in the Tidal Area, at least not such which will be clearly distinguishable from natural variability. Beyond the breakpoint, which may substantially differ between individual tidal basins, significant changes can be expected. The main changes will be:

- A reduction of the intertidal area (because of higher sea level);
- An Increase of flooding time (because of larger water depths);
- A deepening of the channels (because of higher tidal currents);
- An increase of salt marsh edge erosion (because of higher wave impact);
- A decrease in accretion of sediment (because sea level rise will outbalance sedimentation capability).

These physical changes will have the following impacts on biological parameters:

- A reduction of benthic biomass (because of increase in dynamics);
- A decrease of intertidal mussel beds (because of increasing storminess);
- A reduction in population size of bird species (breeding birds mainly because of a reduction of breeding area; migratory birds mainly because of a reduction of feeding time);
- A reduction of the fish nursery function (reduction or disappearance of suitable habitats);
- A reduction of the seal population size (unfavorable haul-out conditions due to storms);
- A decrease in seagrass coverage (decrease of intertidal area, increase of turbulence);
- An increase in the diversity of typical salt marsh flora (mainly in the higher salt marshes because of a higher inundation frequency and inundation time).

### 7.2.3 The barrier islands

For the barrier islands the changes will have a more linear character because this system reacts more directly to the changes.

The main impacts of increasing sea level rise and increasing storminess will be:

- An increase of barrier retreat (or a reduction of accretion);
- For bird species breeding on beaches and in primary dunes decreasing population sizes are expected, mainly because of increasing storminess.

### 7.2.4 Socioeconomic impacts

An increase in sea level rise and storminess will have considerable impacts on coastal defense. Because of the breakpoint between the middle and worst-case scenarios (see 7.2.1) the efforts to keep today's safety level will increase in a more than linear way and, under the worst case scenario, efforts may double. More in particular it is expected that, under the worst-case scenario,

- it will be necessary to strengthen dikes and other hard constructions (because of increase in water level and wave energy);
- an increase in sand suppletion will be necessary to combat barrier retreat;
- a strong increase in efforts to maintain salt marshes is needed because of the higher wave energy;
- dredging efforts might become less because of higher water levels, but this reduction may (partly) be nullified by increased efforts due to increased sedimentation as a result of increasing wave energy and a higher sediment-transport capacity;
- increased efforts are needed to discharge fresh water (pumping, sluices, storage basins), because, due to higher water levels in the Wadden Sea, there will be less possibilities for sluicing out fresh water. The situation may be aggravated by more an more irregular precipitation

On the basis of available information no significant impact on salinity in areas behind the dike is expected.

The CPSL furthermore anticipates that changes in tourism and agriculture will be influenced much more by other factors, such as EU policies and development of income.

### 7.2.5 Best Environmental Practice

On the basis of the criteria "Impact on natural dynamics", "Impact on habitat" and "Contribution to coastal defense" a number of practices was selected. These so-called "Best Environmental Practice" measures are listed below in alphabetical order and are described in more detail in Chapter 6.

It is stressed that there may be considerable legal, financial and/or public perception drawbacks to some of these practices. These aspects will have to play an important role in the assessment of the feasibility of the measures as proposed in Recommendation 2.

Generally, it must be concluded that, in the long term, the application of these measures may alleviate impacts of sea level rise and storminess, but will not be able to prevent such impacts, certainly not under the worst case scenario.

**Sandy barrier islands**

Artificial reefs
Beach drainage
Dike relocation
Dunes relocation.
Overwash.
Spatial planning, aiming at creating buffer zones where no building is allowed.
Wider application of sand nourishments.
Natural dune dynamics.

**Tidal basins**

Brushwood groynes
Dredging reduction
Gullies damming
Reinstalling mussel beds

**Salt marshes**

Outbanking of summer polders in estuaries

**Dikes**

Building/strengthening of 2nd dike line
Dike relocation in estuaries

**Mainland**

Creation of fresh water storage basins
Spatial planning, aiming at creating buffer zones where no building is allowed.

## 7.3 Recommendations

**1. Policies**

Under the currently most realistic scenario (25 cm in 50 years) it is expected that the system will be able to adapt. There will be increasing costs for coastal defense as well as effects on the ecosystem, but the latter will not be substantial.

However, there is also a chance that the worst-case scenario will become reality. Under the worst-case scenario substantial physical, biological and socioeconomic impacts are expected and it is, therefore, recommended to start developing or to further develop, as soon as possible, long-term interdisciplinary policies for coastal defense , nature protection and economic development in the coastal area, in order to anticipate on impacts caused by increased sea level and storminess. Such policies may, amongst others, include spatial planning in the coastal zone aiming at the creation of buffer zones, the initiation of coastal defense measures which will start to become effective in the long-term and reducing or phasing out activities which enhance the effects of sea level rise.

Obtaining a long term reliability for coastal protection planning into action requires a further harmonization of coastal protection and nature conservation interests. A suitable way is the implementation of regional management plans developed in participation with the various interested parties. In such management plans the question should be addressed whether to introduce more flexibility in the coastal zone in order to reduce the growing costs for coastal defense. The question should be answered which functions of the coast need to be safeguarded at what costs. Another question is where dynamic processes can be reintroduced without losing safety.

**2. Best Environmental Practice**

In addition, or as an alternative to regular coastal defense measures, it is recommended to seriously investigate the feasibility of the Best Environmental Practice options listed in 7.2.5, within a long-term perspective and taking account of the different sea level rise scenarios, to combat negative effects of enhanced sea level rise and storminess.

**3. Public perception**

It is recommended to develop a communication strategy with the aim of starting a discussion with the general public about possible future impacts of increased sea level rise and the introduction of measures.

**4. Methodology and research**

Because all partners in the CPSL apply different methodologies for assessing possible impacts of enhanced sea level rise and storminess, it is necessary to start a process of improving the level of the qualitative assessment. It is in this respect recommended to start a research project in which a detailed sediment budget study is carried out, encompassing all natural and man induced inputs and outputs of sediment and other material (sand, mud, shells) and factors affecting transport processes. It is furthermore recommended to start a study into the links between geomorphological and biological changes.

**5. Monitoring**

It is recommended to evaluate the parameters of Trilateral Monitoring and Assessment Program (TMAP) for their suitability to assess impacts of climate change, on the basis of the outcome of targeted research mentioned under "4".

**6. Other BEP options**

It is recommended to continue to survey the literature for possible additional BEP options.

# Annex 1: CPSL Terms of Reference

## Responsibility

The Working Group acts under the responsibility of the Trilateral Working Group (TWG)

## Composition

The Group will consist of representatives of the responsible administrations (coastal protection and nature protection) and/or members of the scientific community, to be nominated by the countries. There is a maximum of two members per country/federal state, not including the Chairperson.

The secretarial work will be carried out by the Common Wadden Sea secretariat.

## Tasks

The tasks of the Working Group can be divided into three parts.

### 1. Definitions and administrative structures

Before starting the work on the issues listed under '2', a common understanding of technical terms must be developed.

Taking into consideration the national differences in coastal protection, it will also be necessary to produce an overview of current national policies and administrative structures relevant for coastal protection.

### 2. Development of a common knowledge basis

In the past ten years, our knowledge of fundamental geomorphological processes has increased considerably. The Working Group will, as a first step, collect relevant information and work towards a common understanding of facts concerning, in particular:

2.1 The overall sediment budget of the Wadden Sea ecosystem and its subsystems (barrier islands, salt marshes, tidal inlets, estuaries, tidal gullies, tidal flats);

2.2 Changes in storminess and tidal water levels;

2.3 The relevance of the volume of the tidal basin for sedimentation processes;

2.4 The relevance of changes of inundation area (for example through outbankment of summer polders) for sedimentation and/or of wave energy, as well as other factors (i.e. tourism, agriculture, nature protection, biodiversity);

2.5 Possible effects of fixing of (parts of) the islands under different sea level rise scenarios;

2.6 Changes in sediment composition in relation to changes of inundation area (amongst others as a result of the past straightening of the coastline and changes in wave energy);

2.7 Relevance of biogenic structures (mussel beds, seagrass beds, sabellaria reefs, shells) for sediment stability, reduction of current velocities and wave energy;

2.8 Relevance a reduction of wave energy through salt marshes and summer polders for the protection of sea walls;

2.9 Best environmental practices for coastal protection under different hydrological scenarios;

The results will be submitted to the Trilateral Working Group (TWG) by the end of 1999.

### 3. Development of proposals for common coastal protection strategies

Pending the decisions of the TWG the Working Group will, as a second step, draft proposals for future integrated policies regarding the above mentioned issues, on the basis of the commonly agreed facts Specific attention should be given to safety and nature protection aspects. However, other interests in the coastal zone that affect coastal and nature protection (e.g. tourism, agriculture) should be considered in an adequate way.

# Annex 2: CPSL Members

**Mr. Frank Steyaert (Chairman)**
Rijkswaterstaat Directie Noord-Nederland
Postbus 2301
NL - 8901 JH Leeuwarden
Phone +31 (0)58 2344 404
Fax +31 (0)58 2344 332
F.Steyaert@dnn.rws.minvenw.nl

**Mr. Albert Oost (until Feb. 2001)**
RIKZ
Postbus 207
NL – 9750 AE Haren
Phone +31(0)50 5331331
Fax +31 (0)505 340 772
a.p.oost@rikz.rws.minvenw.nl

**Mr. Jaap de Vlas (until April 1999)**
Min. Landbouw Natuurbeheer en Visserij
Direction Noord
Postbus 30032
NL – 9700 RM Groningen
Phone +31 (0)505 99 23 27
Fax +31 (0)505 99 23 99
J.d.Vlas@lnvn.agro.nl

**Mr. Wim Wiersinga (as of Feb. 2001)**
IKC
Postbus 30
NL 6700 AA Wageningen
Phone +31(0) 3174 74943
Fax +31(0) 3174 27561
w.a.wiersinga@eclnv.agro.nl

**Ms Anne Rebsdorf (until August 2000)**
Kystinspektoratet
Danish Coastal Authority
Postbox 100
DK 7620 Lemvig
Phone +45 99 63 63 63
Fax +45 99 63 63 99
ki@kyst.dk

**Mr. Jørgen Nicolaisen (until Dec. 2000)**
Sønderjyllands Amt
Jomfrustien 2
DK 6270 Tønder
Phone +45 74 33 50 94
Fax +45 74 72 05 66
Joergen_Nicolaisen@SJA.dk

**Mr. Thorsten Piontkowitz (as of May 2000)**
Kystdirektoratet
Danish Coastal Authority
Højbovej 1
DK 7620 Lemvig
Phone +45 99 63 63 63
Fax +45 99 63 63 99
ki@kyst.dk
www.kyst.dk

**Mr. Aksel Voigt (as of Dec. 2000)**
Sønderjyllands Amt
Skelbaekvej 2
DK 6200 Aabenraa
Phone +45 74 33 55 58
Fax +45 74 33 51 52
avo@sja.dk

**Ms Dagmar Fischer (until Dec. 2000)**
Bundesministerium für Ernährung, Landwirtschaft und Forsten (BMELF)
Referat 524
Postfach 14 02 70
D – 53107 Bonn
Phone: +49 (0)228 529 3568
Fax: +49 (0)228 529 4262 / 3477
Bn3568@bml.bund400.de

**Mr. Jacobus Hofstede**
Ministerium für ländliche Räume, Landesplanung Landwirtschaft und Tourismus des Landes Schleswig-Holstein
Postfach 7129
D 24171 Kiel
Phone +49 (0)431 988 4984
Fax +49 (0)431 988 5172
Jacobus.hofstede@mrl.landsh.de

**Mr. Hubert Farke**
Nationalparkverwaltung Niedersächsisches Wattenmeer
Virchowstr. 1
D 26382 Wilhelmshaven
Phone +49 (0)4421 911 281
Fax +49 (0)4421 911 280
hubert.farke@br-we-whv.niedersachsen.de

**Mr. Frank Thorenz (as of Dec. 1999)**
Nds. Landesbetrieb für Wasserwirtschaft u. Küstenschutz, Betriebstelle Norden .
Postfach 102
D 26491 Norden
Phone +49 (0)4931-947 152
Fax +49 (0)4931 –947125
Frank.Thorenz@nlwk-nor.niedersachsen.de

**Mr. Hans Kunz (until Dec.1999)**
Niedersächsisches Landesamt für Ökologie
Forschungsstelle Küste (NLÖ-FSK)
An der Mühle 5
D 26548 Norderney
Phone +49 (0)4932 916 101
Fax +49 (0)4932 1394
Kunz.CRS@t-online.de

**Mr. Folkert de Jong (Secretary)**
Common Wadden Sea Secretariat
Virchowstr.1
D 26382 Wilhelmshaven
Phone +49(0)4421 910813
Fax +49(0)4421 910830
dejong@cwss.whv.net
http://cwss.www.de

# Annex 3: Technical Terms

**Accretion**
The accumulation of mineral material in a particular locality or environment, e.g. tidal muds in a shallow coastal sea.

**Amphidromic point**
The area around which the tidal wave is turning and therefore without any tidal difference itself.

**Barrier island (Barrier)**
An elongated sand or shingle bank, either with or without dunes, which lies parallel to the coastline and is not submerged by the tide.

**Best Environmental Practice (BEP)**
The application of the most appropriate combination of measures, eliminating or minimizing environmental impact.

**Biogenic structure**
A structure that is created by living organisms, either animal or plant.

**Bottom subsidence (Subsidence)**
The setting of the bottom by
1. gravitational forces following accumulation of material,
2. the extraction of mineral deposits, e.g. salt or coal subsidence,
3. large-scale structural readjustment of the Earth's surface, as in basin down warping or rift valley formation.

**Coastal protection**
The protection of coasts against loss of land by marine erosive forces (tidal and wind waves).
(see also Coastal Defense and Flood Defense)

**Coastal defense**
The protection of coastal lowlands against flooding by the sea, to a certain limit.

**Coastline**
The line forming the boundary between the land and the water.

**Damming**
The building sea walls for the protection of coastal lowlands against flooding by storm surges.

**Design water level**
Storm water level with a certain frequency of occurrence (return interval, e.g. 100 year) that is taken as a design criterion to establish/calculate the necessary dike height.

**Dredging works**
Works carried out in order to maintain the function of shipping channels or to maintain a certain water flow in a channel or belt.

**Ecosystem**
A functioning, interacting system composed of one or more living organisms and their effective environment, in a biological, chemical and physical sense. It is applicable at any scale (Fosberg 1963)
Natural functional unit of organism, as well as, natural and artificial abiotic compartments which are interconnected concerning the exchange of energy, substances and information. (Ref. Glossary Stade Declaration)

**Embankment**
The activity by which a former flood-prone area becomes protection against flooding.

**Erosion**
The processes of wearing away the land surface by the mechanical action of the debris which is being transported by the various agents of erosion.

**Eulittoral (eulitoral)**
The zone between high and low spring tide marks

**Eustatic sea level change**
Change in sea level not considering changes in bottom level (see also sea level rise).

**Flood defense**
The protection of lowlands against flooding.

**Geostrophic wind**
The wind blowing parallel to isobars and representing the first-order approximation of the real wind. It is a measure for the driving force of the air pressure gradient on the real wind. Other factors, e.g. friction an centrifugal forces, are neglected.

**Greenhouse effect**
The ability of the atmosphere to allow shortwave radiation to reach the Earth's surface whereas outgoing long-wave radiation is absorbed and reradiated by water vapor, droplets, carbon dioxide and other radiative gases.

**Intertidal flats (tidal flats)**
That part of a tidal coastal landscape that is situated between the mean low and mean high tidal water level. Consequently, the area is submerged at high tide and emerged at low tide.

**Inundation area**
The area exposed to flooding without protective measures (damming).

**Littoral sand transport**
Nearshore parallel transport of sand by waves.

**Low water level (low tidal water level)**
The water level reached at low tide.

**Mean Sea Level**
The average level of the surface of the sea, determined by averaging recorded tidal levels over a one-year interval.

**Mean Tidal Range (MTR)**
The difference between the level of the surface of the sea at high tide and low tide, determined by averaging all high and low tidal water levels recorded over a one-year interval.

**Mud flat**
Tidal flat composed mainly of muds.

**Natural dynamics of the coastal zone**
The principle by which all natural (biological, chemical and physical) processes in the coastal zone be allowed, i.e. no human interference.

**Nourishment**
The activity of artificially replenishing the sandy coast

**Outer delta (ebb-tidal delta)**
An accumulative structure formed by the deposition of material transported into the area by ebb-tidal currents. As soon as the ebb currents leave the tidal inlet the bulk of the load is deposited as a result of decreasing current velocities.

**Salt marshes**
A coastal ecosystem, composed of marine sediments, occupied by salt tolerant and/or salt resistant vegetation, that is regularly inundated by salt water.

**Sand balance**
The net amount of material carried into or out of a specific area over a certain time interval. It is often established by the comparison of high resolution topographic maps for different epochs.

**Sand flat**
Tidal flat composed mainly of sand.

**Sand sharing system**
Coastal systems and tidal basins within which sand is relocated and between which sand is exchanged without a net lost of sand.

**Sea level rise (change)**
The long-term (secular) rise (change) of mean sea level. Different processes, e.g. eustatic, isostatic, etc. may be responsible for this change.

**Sea level rise scenario**
A scenario for future sea level rise. It is a hypothetical series of possible future sea levels that is constructed to evaluate causal correlations.

**Secular sea level rise**
See "Sea level Rise"

**Sediment budget**
The amount of material that is redistributed in a specific area over a certain time interval. The gross amount is the turnover volume, the net amount the sand balance.

**Sediment importing system**
Area with a net accumulation of sediments.

**Storm flood**
High water caused by a storm.

**Storm surge**
The elevation of the sea water level resulting from meteorological forcing (wind) on the water surface in shallow coastal seas

**Storminess**
The force, duration and frequency of storms, characterized by significant state variables.

**Sublitoral = (Sublittoral)**
That part of a tidal coastal ecosystem that is permanently water covered (subtidal area).

**Summer polder**
Former salt marsh which is now protected by a low dike (summer dike) against flooding by high tides during summer.

**Tidal basin**
That part of a coastal sea that is drained by one unitary channel network. Its perimeter is marked by tidal drainage divides, terrestrial environments and/or artificial constructions like sea walls.

**Tidal channel**
A channel in a tidal system that functions to transport tidal water masses.

**Tidal current**
The movement of sea water in response to the rise and fall of the tide.

**Tidal flats**
See intertidal flats

**Tidal inlet**
A large tidal channel that is often situated between two barrier islands through which the tidal waters may enter or leave a tidal basin during flood- or ebb-tide.

**Tidal prism**
The amount of water between high water and low water, excluding any freshwater flow.

**Tidal range**
The difference between consecutive low tide and high tide.

**Tidal system**
(Behind barrier islands) System of (a tidal inlet) tidal channels and tidal flats between two tidal drainage divides, ranging from the dike to approximately the 20 m depth line.

**Tidal volume**
The sum of the amounts of water that a flood-tide carries into, and an ebb-tide carries out of, a tidal basin.

**Tidal wave**
The oscillation, generated by the gravitational attractions on the earth's surface of the moon and the sun and the magnitude, in proportion to the planetary pull, the local water depth and the distance from the amphidromic point (see also wind wave)

**Tide**
The regular rise and fall of water level in the world's oceans, resulting from the gravitational attraction that is exerted upon the earth by the sun and the moon.

**Water shed (tidal divide)**
Hypothetical line connecting the highest points of the upper tidal flats, separating neighboring tidal basins. It is the first to fall dry on the ebbing tide.

**Wave climate**
The average wave conditions at a specific place over a lengthy period of time (> 30 years), including absolute extremes, means and frequencies of given departures from these means.

**Wind climate**
The average wind conditions at a specific place over a lengthy period of time (> 30 years), including absolute extremes, means and frequencies of given departures from these means.

**Wind wave**
A deformation of a water surface in the form of an oscillatory movement which manifests itself by an alternating fall and rise of that surface. The oscillation is generated by the wind pressure on the water surface and the wave magnitude is in proportion to the speed of the wind, its duration and the length of fetch.

# Annex 4: Relevant Running Projects

### 1. Evaluation study of the coastal lowlands in Schleswig-Holstein

Area: coastal lowlands of Schleswig-Holstein
Project period: 1997 - 2000
Contact: Prof. Dr. H. Sterr, FTZ Westküste der CAU Kiel, Hafentörn, D- 25761 Büsum, Tel.: +49 431 8802944, e-mail: sterr@geographie.uni-kiel.de
Contents: this projects aims at establishing the damage potential for the coastal lowlands using a GIS and a digital terrain mode
2. MERK - micro scale evaluation of the risks in coastal lowlands.
Area: four coastal flood units in Schleswig-Holstein.
Project period: 01.01.2000 - 31.12.2002.
Contact: Prof. Dr. H. Sterr (see address project 1).
Contents: this project focusses on establishing a common method to evaluate the (future) risk of coastal flooding on a micro scale using GIS and DTM.

### 3. Programs to optimize the long-term stability of the Wadden Sea

Area: Wadden Sea of Schleswig-Holstein
Project period: 1998 - 2001
Contact: P. Witez, Landesamt für Natur und Umwelt des Landes Schleswig-Holstein, Hamburger Chaussee 25, D-24220 Flintbek, Tel.: +49 4347 704461, e-mail: pwitez@lanu.landsh.de
Contents: This projects aims at the prediction of morphological changes in the Wadden Sea for different hydrographic scenarios using digital terrain models. Further, methods to counteract possible negative developments are described and evaluated.

### 4. Regeneration of sediment source areas for beach nourishments

Area: German North Sea
Project period: 1999 - 2002
Contact: Dr. Figge, Bundesamt für Seeschiffahrt und Hydrographie, Postfach 301220, D-20305 Hamburg, Tel.: +49 40 31903240.
Contents: This project deals with the establishment and the analysis of the long-term development (hydro-, morpho- and ecological) of sediment source areas for beach nourishments.

### 5. PRODEICH - probabilistic design of sea walls

Area: German North and Baltic Sea coasts.
Project period: 01.02.2000 - 01.01.2002.
Contact: Prof. Dr.-INg. Hocine Oumeraci, Leichtweiß-Inst. TU Braunschweig, Beethovenstr. 51a, D-38106 Braunschweig, Germany, Tel.: +49 531-391 3930, e-mail: h.oumeraci@tu-bs.de.
Contents: this project aims at establishing probabilistic design criteria for sea walls as well as increasing the knowledge about the probability of failure of coastal flood defence systems under given hydrographic scenarios.

### 6. NOURTEC (Innovative nourishment techniques evaluation)

Type of project: co-sponsored by EU-MAST II (MAS2-CT93-0049)
Co-ordinator and partners: RWS-RIKZ (National Institute for Coastal and Marine Management, The Netherlands), CRS (Coastal Research Station, Germany), DCA (Danish Coastal Authority, Denmark) and UU (University of Utrecht, The Netherlands)
Area: Terschelling (The Netherlands), Torsminde (Danmark) and Nordeney (Germany)
Project period: 1993-1996
Contact: dr. R. Spanhoff, RWS RIKZ, Kortenaerkade 1, P.O. Box 20907, 2500 EX, The Hague,
Tel: +31 70 114230,
e-mail: R.Spanhoff@rikz.rws.minvenw.nl.
Contents: Description and explanation of three experimental nourishments (complete or partly on the shoreface). Conclusions on the feasibility and effectiveness of shoreface nourishments. Design recommendations for shoreface nourishments in different coastal environments. The development of a database for future model tests.

### 7. RIACON (Risk analysis of coastal nourishment techniques)

Type of project: co-sponsored by EU-MAST II (MAS2-CT94-0084
Co-ordinator: RWS-RIKZ (National Institute for Coastal and Marine Management, The Netherlands)
Area: Terschelling (The Netherlands), Torsminde (Danmark), De Haan (Belgium), Costa Daurada

(Spain) and Nordeney (Germany).
Project period: 1994-1997
Contact: dr. K. Essink, RWS RIKZ, Kerklaan 30, P.O. Box 207, 9750 AE, Haren, tel: +31 50 533 1373, e-mail: K.Essink@rikz.rws.minvenw.nl.
Contents: Evaluation of the risk of shoreface nourishments and offshore subaqueous sand extraction for the marine zoobenthic community of the foreshore.

### 8. NWO-ALW Outer Delta Dynamics project

Type of project: NWO (National Science Foundation) sponsored acandemic research program.
Participants: Utrecht University, Delft University, Netherland Insitute for Sea Research (NIOZ), and support from RWS-RIKZ (National Institute for Coastal and Marine Management, The Netherlands) and WL|Delft Hydraulics.
Area: Tidal inlets in the Wadden Sea.
Project period: 2000-2004
Contact: dr. H.E. de Swart, Institute for Marine and Atmospheric Research (IMAU), Utrecht University,
P.O. Box 80005 Utrecht, The Netherlands, e-mail: H.E.deSwart@phys.uu.nl
Contents: The aim of this programme is to gain more fundamental knowledge about the dynamics of the outer deltas by addressing the following questions:
1. what is the role of outer deltas in the sand balance of the coastal zone;
2. what is the morphodynamic relationship between the outer delta and the inner basin;
3. how to model and understand the cyclic channel-shoal behaviour and related sediment bypassing over the outer delta.

### 9. Delft Cluster Research program: theme Coasts and Rivers.

Type of project:: NWO (National Science Foundation) sponsored acandemic research program.
Participants: Delft University, WL|Delft Hydraulics, TNO-NITG, Alkyon and RWS-RIKZ (National Institute for Coastal and Marine Management, The Netherlands).
Area: Tidal basins in the Netherlands
Project period: 2000-
Contact: Delft Cluster, Postbus 69, 2600 AB Delft, Tel: +31 15-2693793,
Contents: To identify and further develop data, knowledge and models regarding the medium and long-term morphological evolution of coast-basin interaction based on the coastal cascade concept. The Delft Cluster Theme 3-Project Coasts focuses on the morphological interaction between the coast and tidal/estuarine basins.

### Ongoing research

Sediment transport and morphological development in a barrier/lagoon system: This project focuses on the Skalling barrier spit with the following key issues:
Offshore: The role of flocculation in possible fluff layer formation during calm weather situations in the North Sea. Resuspension during storm of fluffy material and its import to the Wadden Sea.
Coastal zone: Understanding the 3-D nature of the bar system, morphological evolution in both cross-shore and longshore directions. Sediment transport in the surf zone. Exchange of sediment between the surf zone and offshore. Eolian transport processes and resulting morphology on beach face and in dunes. Hydrodynamics and sediment budget of wash-over fans.
Inlets: Examining when and how episodic transport takes place. Import/export balancing of suspended matter. Bedform migration with time.
Tidal flats and salt marsh areas: Tidal flat dynamics and their role as temporal storages for fine grained material. Resuspension effects of biological activity. Salt marsh development with time and its connection to sea-level variations. Drainage pattern evolution and effects on salt marsh growth. Retention of fine grained material, nutrients and heavy minerals on salt marshes.
Barrier evolution: Surface sediments and their stratigraphic relations. Morphological evolution from cores and shallow seismic.

INTERMUD. EU MAST III project
The Morphological Development of Intertidal Mudflats
The objectives of the project are: To investigate the characteristics of intertidal mudflats in NW Europe in order to establish a classification which reflects the morphological effect of variations in such parameters as: tidal range and phase, wave climate, sediment physical and biological properties, biological communication structure etc. This will propose a series of conceptual models of mudflat development. To carry out experiments on a number of type-mudflats, using harmonized methods, to quantify the processor, and their interactions, their ranges and time scales of variation. To formalize the relationships in statistical descriptions, and test the validity of the concepts by computer modeling, using the experimental field data. To provide a basis of understanding, which can be used in management of mudflats, in order to maintain ecological health, particularly under changing climatic, sea level, and anthropogenic pressures.

DECO (Danish Research Councils Danish Environmental Monitoring of Coastal Waters) The objectives of the project are: The project encompasses two major objectives. The first being the development and validation of the spectral fingerprint technique, and the set-up of a spectral library of key parameters for the Danish coastal waters. This goal will involve the integration of sea truth measurements, remote observations, statistical analysis, and modeling, leading to a unique data library pertaining specifically to the Danish marine environment. The second major objective of this program is the application of the spectral fingerprint information to specific problems and processes relevant to research and monitoring questions. The specific questions to be addressed include: Distinction between different phytoplankton pigment and determination of their concentration. Determination of suspended sediment concentrations and size distribution Sediment resuspension and transport in coastal waters Classification of different bottom types in shallow waters including vegetation and mussel beds.

Within RWS RIKZ (National Institute for Coastal and Marine Management, The Netherlands) several research projects address aspects of the subjects mentioned in the CPSL Final Report. The subjects include: subsidence due to ongoing and possible future mining projects, the future sediment budget of the Wadden Sea, including the effects of sea-level rise, improved nourishment techniques, and more.

# Annex 5: Literature


Asmus, R, Gätje, C. & de Jonge, V.N., 1994. Mikrophytobenthos - empfindliche Oberflächenhaut des Wattbodens. In: Warnsignale aus dem Wattenmeer. Lozan, J.IL., Rachor, E., Reise, K., v. Westernhagen, H. & Lenz, W. (Hrsg.). Blackwell, Berlin: S.75-81

Asmus, R. & Asmus, H., 1998. Bedeutung der Organismengemeinschaften für den bentho-pelagischen Stoffaustausch im Sylt-Romo Wattenmeer. In: Gätje, C. & Reise, K. (Hrsg.) Ökosystem Wattenmeer - Austausch-, Transport- und Stoffumwandlungsprozesse. Springer-Verlag, Berlin, Heidelberg: S. 257-302.

Austen, L. & Witte, G., 1997. Comparison of the erodibility of oxic and anoxic sediments in the East Frisian Wadden Sea. Berichte - Forschungszentrum Terramare 2: S 75-76.

Austen, L., 1997. Temporal and spatial variations of biodeposits - a preliminary investigation of the role of faecal pellets in the Sylt-Romo tidal area. Helgoländer Meeresunters. 51: S 281-294.

Bayerl, K., Austen, L., Köster, R., Pejrup, M. & Witte, G., 1998. Dynamik der Sedimente im Lister Tidebecken. In: Gätje, C. & Reise, K. (Hrsg.). Ökosystem Wattenmeer - Austausch-, Transport- und Stoffumwandlungsprozesse. Springer-Verlag, Berlin, Heidelberg: S. 127-159.

Bijl, W., 1996. Looking for observational signs of changing storminess. EU-Project WASA, report RIKZ/OS-96.157x. Den Haag, Niederlande: 56 p.

Bijl, W., 1997. Impact of a wind climate change on the surge in the southern North Sea. Climate Research, 8: 45-59.

Bruun, P., 1962. Sea level rise as a cause of shore erosion. Journal of the Waterways and Harbour Division. Proc. ASCE, 88: 117-130.

Bunje, J., 1997. Salt marshes in the National Park "Niedersächsisches Wattenmeer". Status, Management, Aims and Results. Wadden Sea Newsletter 1997-1: 16-19

Cadée, G.C., 1976. Sediment reworking by Arenicola marina on tidal flats in the Dutch Wadden Sea. Netherlands Journal of Sea Research, 10: 440 – 460.

De Boer, P.L., 1981. Mechanical effects of microorganisms on intertidal bedform migration. Sedimentology, 28: 129 – 132.

Dean, R.G., 1988. Sediment interaction at modified coastal inlets: processes and policies. Lecture Notes on Coastal and Estuarine Studies, 29: 412-439.

Dijkema, K.S., 1992. Sea level rise and management of salt marshes. WSNL, 92/2: 7-10.

Dijkema, K.S., Bossinade, J.H., Bouwsema, P. & de Glopper, R.J., 1990. Salt marshes in the Netherlands Wadden Sea: rising high-tide levels and accretion enhancement. In: Beukema, J.J., Wolff, W.J. & Brouns, J.J.W.M. (Eds.). Expected Effects of Climatic Change on Marine Coastal Ecosystems. Kluwer, Dordrecht: 173 – 188.

Doing, H., 1983. Geomorphology and Soil of Dunes. In: Wolff, W.J. (Ed.). Ecology of the Wadden Sea,Bd. 3. Balkema, Rotterdam: 9/12-9/26.

Ehlers, J., 1988. The morphodynamics of the Wadden Sea. Balkema, Rotterdam: 397 p.

Ellenberg, H., 1982. Vegetation Mitteleuropas mit den Alpen in ökologischer Sicht. Eugen Ulmer, Stuttgart.

Erchinger, H.F., Coldewey, H.-G., Frank, U., Manzenrieder, H., Meyer, C., Schulze, M. & Steinke W., 1994. Verbundbericht zum KFKI-Forschungsvorhaben "Erosionsfestigkeit von Hellern". KFKI, Kiel: 119 p. (unpublished)

Erchinger, H.F., Coldewey, H.G. und Meyer, C, 1996: Interdisziplinäre Erforschung des Deichvorlandes im Forschungsvorhaben "Erosionsfestigkeit von Hellern". Die Küste Heft 58

Führböter A. & Dette, H.-H., 1992. Strandvorspülungen vor der Westküste von Sylt. Die Küste, H. 53: 51-126.

Gast, R., Köster, R. & Runte, K.-H., 1984. Die Wattsedimente in der nördlichen und mittleren Meldorfer Bucht. Untersuchungen zur Frage der Sedimentverteilung und der Schlicksedimentation. Die Küste 40: 165-257.

Gerlach, A., Brüning, T. & Brüning, K., 1999. Untersuchung zur Zusammensetzung und Herkunft von Getreibsel ("Teek") an der niedersächsischen Küste. Universität Oldenburg.

Haven, D.S. & Morales-Alamo, R., 1972. Biodeposition as a factor in sedimentation of fine suspended solids in estuaries. Geol. Soc. Mein. 133: 121-130.

Heuers, J., Jaklin, S., Zühlke, R., Dittmann, S., Günther, C.-P., Hildenbrandt, H. & Grimm, V., 1998. A model on the distribution and abundance of the tube-building polychaete Lanice conchilega in the intertidal of the Wadden Sea. Verhandlungen der Gesellschaft für Ökologie, Bd 28: 207-215.

Hofstede, J.L.A., 1991. Sea level rise in the Inner German Bight (Germany) since AD 600 and it's implications upon tidal flats geomorhology. In: Brückner, H. & Radtke, U. (Eds..): Von der Nordsee bis zum Indischen Ozean. Franz Steiner Verlag, Stuttgart: 11-27.

Hofstede, J.L.A., 1996. Saltmarsh management for coastal defence in Schleswig-Holstein, Germany. In: Proceedings of the 31st MAFF Conference of River and Coastal Eng.: 6.2.1 - 6.2.9.

Hofstede, J.L.A.,1999. Process-response analysis for Hörnum tidal inlet in the German sector of the Wadden Sea. Journal of Quaternary International, 60: 107-117.

Hofstede, J.L.A. und Schirmacher, R., 1996: Vorlandmanagement in Schleswig-Holstein. Die Küste, 58: 61-74.

Hoozemans, F.M.J., 1989. Het windklimaat ter hoogte van de Nederlandse kust over de periode 1907 - 1980. Nota: GWAO 89.010

IPCC, 1995. Climate Change 1995, the science of climate change. Publ. for the IPCC, Cambridge Univ. Press.

Jelgersma, S. & Tooley, M.T., 1993. Sea level changes during the recent geological past. In: State of the art report "Sea level rise and their consequences for hydrology and water management", prepared for the international Workshop SEACHANGE ´93. RIKZ, Den Haag: 9-41.

Jensen, J, H.-E. Mügge & Schönfeld, W., 1990. Development of water level changes in the German Bight - an analysis based on single value time series. Proc. 22nd ICCE Delft, Netherlands.

Jensen, J., Hofstede, J.L.A., Kunz, H., De Ronde, J.G., Heinen, P.F. & Siefert, W., 1993. Long term water level observations and variations. In: Hillen, R. & H.J. Verhagen (Eds.). Coastlines of the southern North Sea. ASCE, New York: 65-84.

Louters, T. & Gerritsen, F., 1994. The riddle of the sands. A tidal system's answer to a rising sea level. Report RIKZ-94.040. RIKZ, Den Haag. Pp.69.

Mai, S., Daemrich, K.-F., Zimmermann, C., 1998. Wellentransmission an Sommerdeichen. Wasser und Boden, H. 11

Neuhaus, R. & Petersen J., 1999. Dunes. In: De Jong, F., Bakker, J.F., van Berkel, C.J.M., Dankers, N.M.J.A., Dahl, K., Gätje, C., Marencic, H. & Potel, P. (Ed.)., 1999 Wadden Sea Quality Status Report. Wadden Sea Ecosystem No. 9. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Quality Status Report Group. Wilhelmshaven.

Niemeyer, H.D., 1986. Ausbreitung und Dämpfung des Seegangs im See- und Wattengebiet von Norderney. Jahresbericht 1985 der Forschungsstelle Küste, 37: 49-95.

Niemeyer, H. D., Kaiser, R., 1999. Hydrodynamische Wirksamkeit von Lahnungen, Hellern und Sommerdeichen. Schlußbericht zum KFKI-Forschungsvorhaben "Bemessung auf Seegang".

Obert, B., 1995. Entwicklung einer neuangesiedelten Miesmuschelbank des Brutfalls 1991 im Norderneyer Watt. Ber. Forschungsstelle Küste 40: 71-76.

Oost, A.P. & Dijkema, K.S., 1993. Effecten van bodemdaling door gaswinning in de Waddenzee. IBN Rapport 025.

Oost, A.P., 1995a. Dynamics and sedimentary development of the Dutch Wadden Sea with emphasis on the Frisian inlet. Geologica Ultraiectina, Mededelingen van de Faculteit Aardwetenschappen Universiteit Utrecht, 455 p.

Oost, A.P., 1995b. The influence of biodeposits of the blue mussel Mytilus edulis on fine-grained sedimentation in the temperate-climate Dutch Wadden Sea. Geologica Ultraiectina, 126: 359 - 400.

Paterson, D.M., Yallop, M.L. & George, C., 1994. Spatial variability in sediment erodibility on the island of Texel. In: Krumbein, W.E., Paterson, D.M. & Stal, L.J. (Eds.) Biostabilization of Sediments. BISVerlag - Oldenburg: S. 107-120.

Reise, K., 1998. Coastal change in a tidal backbarrier basin of the northern Wadden Sea: are tidal flats fading away? Senckenbergiana marit. 29: 121-127.

Schmidt, H., 1997. 120 Jahre geostrophischer Wind in der Deutschen Bucht. Deutsche IDNDR-Reihe, 7: 20-23.

Siefert, W., 1984. North Sea tide and storm surge investigation. Proc., 19nd ICCE, ASCE, New York: 1749-1764.

Stal, L. J., 1994. Microbial mats: Ecophysiological interactions related to biogenic sediment stabilization. In: Krumbein, W.E., Paterson, D.M. & Stal. L.J. (Eds.) Biostabilization of Sediments. BIS-Verlag Oldenburg: 41-53.

Stengel & Zielke, 1994. Der Einfluß eines Meeresspiegelanstiegs auf Gezeiten und Sturmfluten in der Deutschen Bucht. Die Küste, H. 56: 93-117.

Striegnitz, M., 1999. Verbesserung des Verfahrensmanagements zum Interessensausgleich zwischen Küstenschutz und Naturschutz. 39. BWK Fortbildungslehrgang Küstenschutz - Analyse, Probleme, Lösungen, Papenburg 28. und 29.06.1999

Stock, M., 1997. Salt marsh management in the National Park "Schleswig-Holsteinisches Wattenmeer. Wadden Sea Newsletter 1997-1: 11 - 15.

Stock, M., Schrey, E., Kellermann, A., Gätje, C., Eskildsen, K., Feige, M., Fischer, G., Hartmann, F., Knoke, V., Möller, A., Ruth, M., Thiessen, A. & Vorberg, R., 1996: Ökosystemforschung Wattenmeer Synthesebericht: Grundlagen für einen Nationalparkplan. Schriftenreihe des Nationalparks Schleswig-Holsteinisches Wattenmeer, Heft 8, pp. 784.

Storch, H. von, 1997. Auswirkungen von Klimaänderungen auf Sturmentwicklung und Extremwasserstände in der Nordsee. Deutsche IDN-DR-Reihe, 7: 3-11.

Streif, H., 1989. Barrier islands, tidal flats, and coastal marshes resulting from a relative rise in sea level in East Frisia on the German North Sea coast. Proc. KNGMG Symp. "Coastal Lowlands, Geology and Geotechnology". Kluwer Acad. Publ., Dordrecht: 213-223.

Thiel, H., Grossmann, M. & Spychala, H., 1984. Quantitative Erhebungen über die Makrofauna in einem Testfeld im Büsumer Watt und Abschätzung ihrer Auswirkungen auf den Sedimentverband. Die Küste 40: 260-314.

Töppe, A., 1993. Zur Analyse des Meeresspiegelanstieges aus langjährigen Wasserstandsaufzeichnungen an der Deutschen Nordseeküste. Mitt. des Leichtweiß-Instituts der TU Braunschweig, H. 20: 132 p.

Zielke, W., Hoyme, H. & Kück, F., 1997. Auswirkungen von Klimaänderungen auf die Wasserstände und Windverhältnisse an der deutschen Nordseeküste, Teilgebiet: Auswirkungen veränderter Windverhältnisse auf die Wasserstände. Abschlußbericht des ISER der TU Hannover zum BMBF-Projekt Nr.: 03F0141A: 39 p. (unpublished).

Zimmermann, C., von Liebermann, N. & Mai, S., 1999. Machbarkeitsstudie zur Ermittlung des für den Küstenschutz erforderlichen Vorlandprofils. Gutachten im Auftrag des MLR Schleswig-Holstein, Kiel, 38 p. (unpublished)

# Issues of the Publication Series „Wadden Sea Ecosystem“

No. 1: Breeding Birds in the Wadden Sea 1991. 1994.
No. 2: Migratory Waterbirds in the Wadden Sea1992/93. 1994.
No. 3: Guidelines for Monitoring of Breeding Birds in the Wadden Sea (in Dutch, German, Danish). 1995.
No. 4: Breeding Birds on Census Arteas 1990 until 1994. Status of Shorelark, Twite and Snow Bunting in the Wadden Sea. 1997.
No. 5: Migratory Waterbirds in the Wadden Sea 1993/94. 1996.
No. 6: Trilateral Monitoring and Assessment Program. TMAP Expert Workshops 1995/96. 1996.
No. 7: Assessment of the Wadden Sea Ecosystem. 1997.
No. 8: Monitoring Breeding Success of Coastal Birds. Monitoring Pollutants in Coastal Bird Eggs in the Wadden Sea. 1998.
No. 9: Wadden Sea Quality Status Report 1999. 1999.
No. 10: Breeding Birds in the Wadden Sea in 1996. 2000.
No. 11: Contaminants in Bird Eggs in the Wadden Sea. Spatial and Temporal Trends 1999 - 2000. 2001.
No. 12: Lancewad. Landscape and Cultural Heritage in the Wadden Sea Region. 2001
No. 13: Final Report of the Trilateral Working Group on Coastal Protection and Sea Level Rise. 2001.