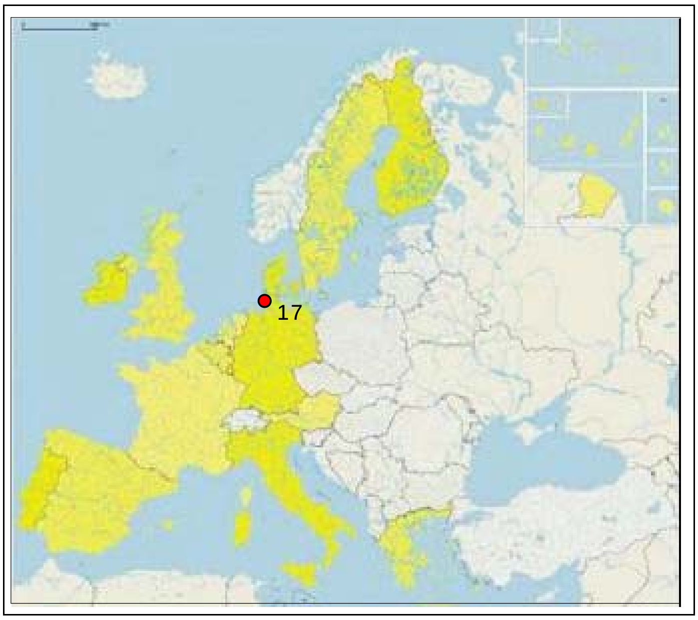
ISLE OF SYLT
ISLES SCHESLWIG-HOLSTEIN
(GERMANY)



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1. GENERAL DESCRIPTION OF THE AREA

1.1 Physical process level

1.1.1 Classification

Fig. 1: Location of case area.

The case area Sylt (Isles Schleswig-Holstein) is located at the Germany North Sea Coast (see map). The Schleswig-Holstein islands belong to the sandy barrier islands of the North Frisian chain of the German Wadden Sea coast. Sylt is the most northern of the islands, and will be handled as representative case study.

The coastal zone at Sylt exists of sandy dune cliffs with beaches in front of the dunes. The beaches act as wave breakers for the incoming waves from the North Sea. The west coast of Sylt has a length of 40 kilometres.

The North Frisian coast is a meso-tidal coast with barrier islands, the coastal classification conform the scoping study is:

3a. Tide-dominated sediment. Plains. Barrier dune islands

1.1.2 Geology

The Holocene marine transgression has inundated part of the North Sea to produce the submerged outlines of the mainland coast and estuaries, and initiate the accumulation of sandy barrier islands. In some cases these are built on or around residual foundations of glacial drift. The reworking of glacial drift deposits by waves and tidal currents generated sands, silts and clays. The sands were mainly deposited on the barrier islands while the finer sediments accumulated on the floor of the Wadden Sea and in the estuaries, relinquished particularly during slack water at high tides.

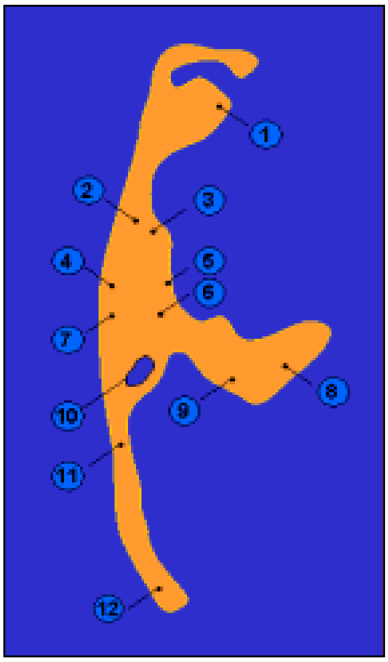
The barrier islands are formed by a complex interaction of waves, rip currents and tidal currents. Sand washed into the gaps between the barrier islands is shaped into tidal deltas by ebb and flood currents, with shoals partly emerging at low tide separated by diverging channels, on both the seaward and the landward side of each inlet. At low tide extensive sand flats with complex and variable bars, shoals, swales front the sandy beaches. (Gierloff-Emden, 1980).

The first two islands south of Denmark, Sylt and Amrum, consist of beaches and dunes built against a residual core of glacial drift deposits. On Sylt these deposits are exposed in cliffs up to 35 m high at Westerland. The moraines create the centre of the island. After the postglacial transgression of the North Sea the water began to erode the material and the northern and southern part of Sylt were sedimentated.

On the seaward side of the barrier islands, relatively high wave energy (dynamic beach) has built steep-profiled beaches of well-sorted medium to coarse sand (typical grain diameter 0,3 to 0,4 mm). Finer and muddier sand deposits form the near shore tidal flats and shoals.

1.1.3 Morphology

In Figure 3, the morphological development of the island Sylt is shown from 1793 to 1952. The northern and southern sand hooks are clearly visible. Furthermore the tidal gullies formed between the barrier islands can be seen in the map. Sylt is a long-stretched island with a wider centre that is connected to the mainland. The island has a length of 35 km and a width up to 13 km. The Hindenburg Dam connected Sylt to the mainland in 1928. The connection of Sylt to the mainland has caused increased sedimentation and salt marsh formation on either side of the Hinderburg Dam.



1. List.
2. Kampen.
3. Braderup.
4. Wenningstedt.
5. Munkmarsch.
6. Keitum.
7. Westerland.
8. Morsum.
9. Achsum.
10. Rantumer Becken.
11. Rantum.
12. Hörnum.

Fig. 2: Towns on Sylt island.

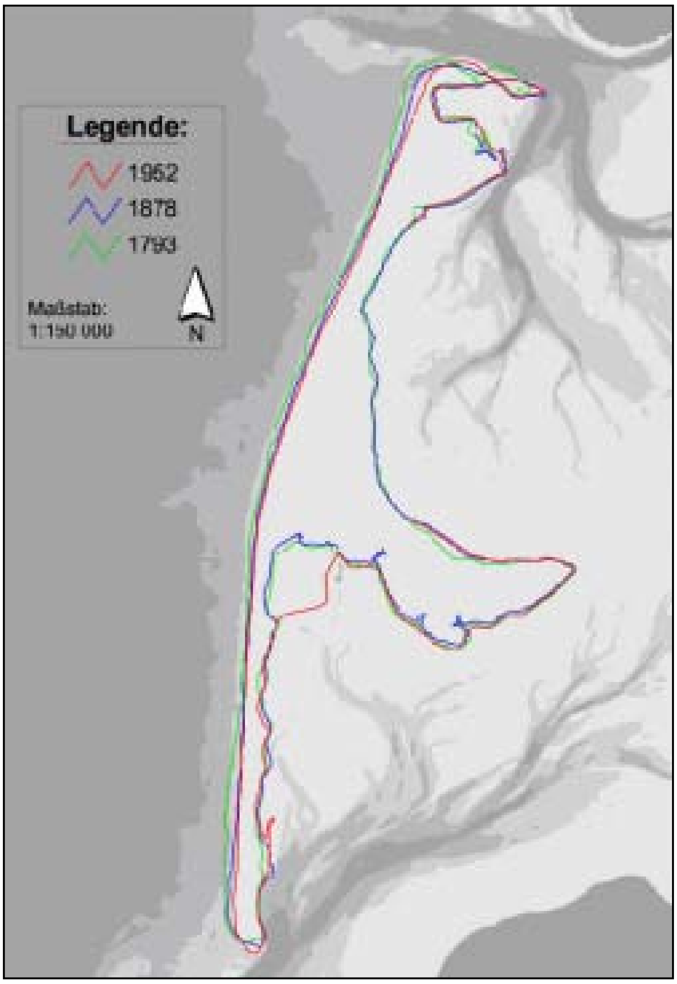


Fig. 3: Morphological changes isle ofSylt 1793-1952.

Between Kampen and Westerland the Rotes Kliff is located. Towards the south the height of the cliff decreases, in the north the cliff is bordered by high cliffs. The changes in the time frame 1793/1878 have been significantly larger than in the time frame 1878/1952 at the west coast of Sylt. Exceptions are the northern and southern spit, where the development has been equal over the entire time frame.

1.1.4 Physical processes

Tide

The tide is semi-diurnal. Tidal ranges reach around 2 m in the North Frisian region. Cross-shore transport through the gaps between barrier islands is mainly tide-induced.

Waves

At the North Frisian Islands, wave action is generated by the alternately south-westerly and north-westerly winds. Long shore transport along the coast is mainly wave-induced and therefore also alternates in direction. This can be seen at Sylt, the island grows northward as well as southward by spit prolongation in both directions.

Storm events

Occasional storm surges can cause substantial erosion to the described dune cliffs at Sylt and cause some reshaping of the intertidal morphology. The storm surges mainly come from the west, therefore the western coast of Sylt is highly attacked and affected by storm surges.

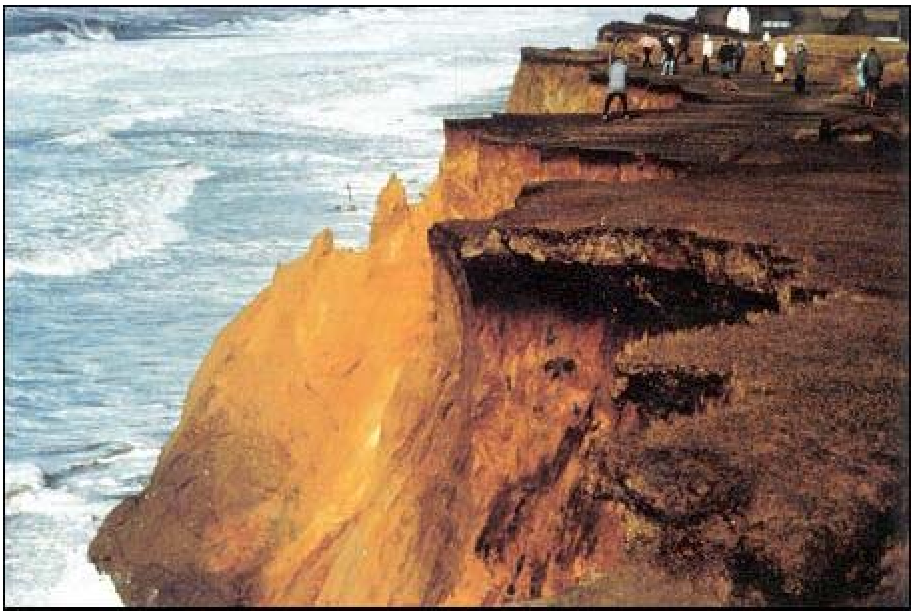


Fig. 4:Dune cliff erosion during a storm surge at Sylt.

1.1.5 Erosion

At the southern part of Sylt, the net long shore transport is directed southward and at the northern part of Sylt, the net long shore transport is directed northward (see Figure 5). In total around 1,0 Million m^3 of sediment is lost every year from the western coast of Sylt. The coast is eroding along the entire western coast. The island loses the majority of this sand through storm tides.

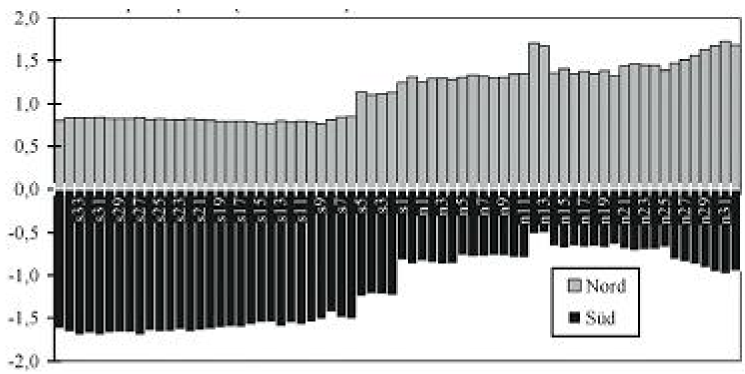


Fig. 5:Sediment transport along Sylt coast (Milion m^3).

The erosion at the western coast of Sylt is structural as well as acute:

Structural erosion

The island's base rises gradually from the foreshore, where a sandy reef is located. Shore and reef together function as a transportation mean. Waves and tides continuously erode and move away material from the sandy shore and foreshore area, causing structural erosion.

Acute erosion

The dune cliffs are only affected in irregular intervals during storm surges. This is an acute form of erosion, the dune cliffs are being eroded further and further every year.

1.2 Socio-economic aspects

1.2.1 Population rate

About 21.000 persons live on the island of Sylt, which has a surface of 99 km^2. This results in a population rate of 212 persons/km^2.

1.2.2 Major functions of the coastal zone

The vulnerable island Sylt has a multi-functional socio-economic character (e.g. tourism) and is covered by a mixture of natural and cultural territories. Besides high level standards in living and recreation facilities, Sylt provides unique aspects of a biotope. The two main towns are Westerland, a popular seaside resort, and Kampen. The major functions on the island are:

- **Nature conservation:** In 1985, the region was designated as national park in recognition of the high ecological significance of the Wadden Sea. It serves, for example, as a place to feed and rest for migratory birds and is an important nursery for many fish and crustaceans.
- **Tourism and recreation:** The island Sylt also provides many recreational opportunities. The long west coast with its sandy beaches attracts many tourists and has considerable economic importance not only for the island but also for the federal state.
- **Fisheries and aquacultures**
- **Urbanisation (safety of people and investments)**

1.2.3 Land use

Except in it's cultivated and inhabited western tip, the island Sylt is covered by dunes and heath land. The main functions at the coastal area are recreation and nature development.

1.2.4 Assessment of capital at risk

According to Bryant [1995], the coast of Sylt is at moderate to high risk.

High risk: city or major port or > 150 persons/km2 or >150 m road/km2 or > 10 m pipeline/km2
Moderate risk: 150 < persons/km2 > 75 and 150 < m road/km2 > 100 and 10 < m pipeline/km2 > 0
Low risk: persons/km2 < 75 and m road/km2 < 100 and no pipelines

For Sylt, the average population rate is 212 persons/km^2. The population and economic values are highest and mainly concentrated in the main towns Westerland, Wenningstadt and Kampen in the central part of the island (see also Figure 2), for these towns the risk is high. For the rest of the island, the northern and southern spit, the risk can be considered as moderate, though the recreational values are high in the entire coastal zone of Sylt.

2. PROBLEM DESCRIPTION

2.1 Eroding sites

The entire coast of Sylt has been severely eroding since a long time, accumulation of sand is not seen at any part of the coast. The high erosion rates are mainly caused by heavy storm surges from the west, these affect the westerly-orientated coast of Sylt a lot. After 1950 in Westerland-Kampen (north of Westerland) the erosion rate is getting higher compared to the Westerland-Rantum (south of Westerland) area. The average annual retreat at the west coast from 1870 to 1950 has been 0.9 m / year but has increased during the past 35 years. The erosion is advancing faster these days because of rising sea levels and warmer, stormier winters. The expected erosion for now is ca. 1,5 m / year up to ca. 15 m / year in the very south of Sylt.

The central part of Sylt at Kampen and Westerland has always been severely protected in the past and still is (because of the high economic values) by hard coastal protection measures. Because of the high erosion rates at the northern and southern spit and the reasonably stable situation (because of the heavy protections) at the central part, the coastal line is forming more and more into an arch shape. If the coastline would not have been fixed by hard structures, the island would have wandered towards the east.

For the next fifty years, a model was set up to calculate the expected erosion in this time frame through extrapolation. The result of these calculations can be seen in Figure 6. The List area (northern spit), Kliffende at Kampen, Wenningstedt at Westerland and Rantum-Hornum area (southern spit) are affected the most in the next fifty years according to these computations. These are therefore the most concerned areas to take care of in the future.

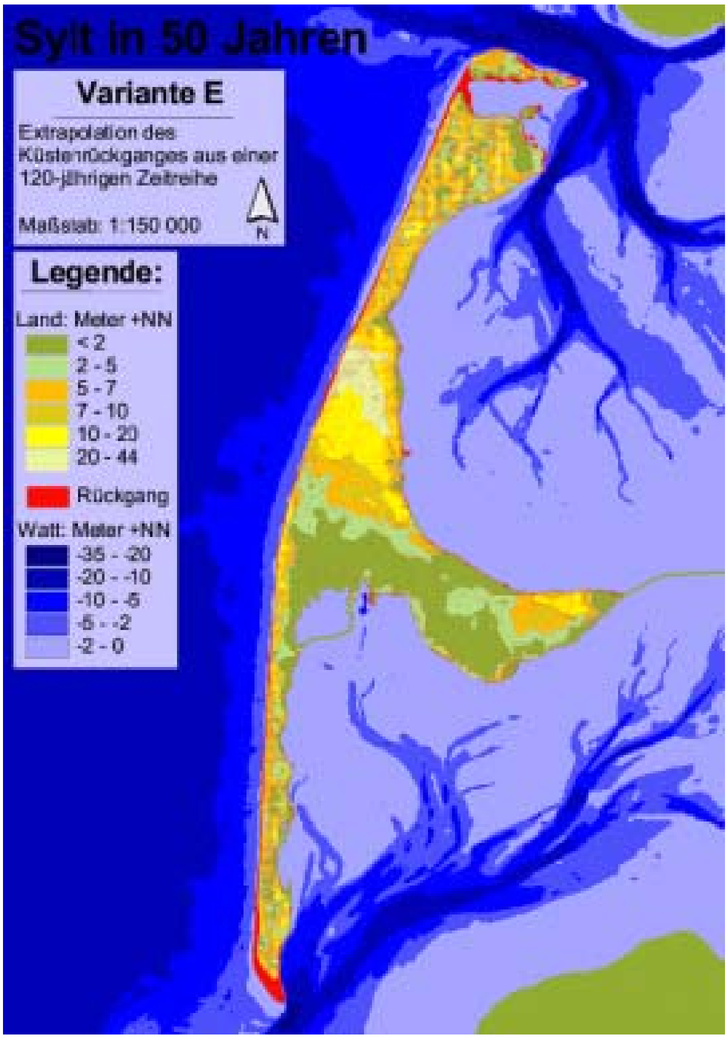


Fig. 6: Calculated erosion for the next fifty years.

Over 1 million m^3 of sediment is lost every year; 800,000 m^3 / year is lost towards the north and 400,000 m^3 / year is lost towards the south.

2.2 Impacts

The long west coast with its sandy beaches attracts many tourists and has considerable economic importance not only for the island but also for the federal state. The erosion threatens these values. Furthermore, buildings and built-up areas are threatened by flooding if the coastal protection system is damaged.

3. SOLUTIONS/MEASURES

3.1 Policy options

The current policy line at Sylt is "hold the line". As people and capital values of the coastal region are concentrated in coastal cities and seaside resorts in Germany, recently debates at institutional levels have focused on whether a "protect-selected-areas strategy" might be adequate for adaptation to climate change on the long run. However, to bring about such a principle policy change (compared to "hold-the-line" strategy) extensive discussion will be necessary. To stimulate this discussion three localities in Schleswig-Holstein have been selected to test the option of "Managed retreat" in coastal segments that lack dense economic use.

3.2 Strategy

The old philosophy of executing coastal defense (building sea walls) in order to reclaim fertile land already ceased in the early fifties. The last sea wall aiming at this purpose was constructed in Schleswig-Holstein in 1954 (Friedrich-Wilhelm-Lübke-Koog). Afterwards, the policy for coastal defense turned into achieving the same level of security for all state dikes (i.e. each sea wall has the same probability of breaching). The sixties, seventies and early eighties were characterized by a strong belief in engineering (hard) solutions for coastal defense. However, this attitude changed into trying to use more natural techniques and material, e.g. sand nourishment, to combat coastal retreat.

Fig. 7: Beach nourishment operations at Kampen, Sylt.

In 1995 a common salt marsh management plan was established by coastal defense and environmental authorities that aims at an ecologically sound protection and management of salt marshes, salt marshes being both an important (natural) coastal defense structure and an ecologically sensitive and valuable habitat. In the future, the coastal defense policy will probably increasingly include risk analyses for single flood units (risk being defined here as the product of he probability of dike breaching and the damage potential in he flood unit). Furthermore attention will be paid to public participation and the integration of other interests in coastal defense policy (integrated coastal defense management).

As a result of the storm surges of the past years, the managing state agency in Husum has developed the project ‘Coastal protection on Sylt’, in which the solution offered by the latest developments and technologies (e.g. solid constructions: every kind of bank revetment, groins) and sand nourishment were examined. It turned out, that continuously repeated sand nourishments are an appropriate solution from the technical, economical and environmental point of view. The sand nourishments consist of backfill material and a 60 m wide artificial dune in front of the erosion line, that functions as a stockpile of sand. In the case of extremely severe storm surges, this recession depot will be eroded. The artificial dune has to be restored in certain time periods with new material, which is excavated by automatic trailing suction dredgers out of an area, which is located 7 – 10 km in front of the island’s west coast with an average water depth of 14 m. No impact on the island is expected from this sand borrowing.

Fig. 8: Examples of hard measures at the western coast of Sylt: tetrapod dune foot revetment at Hörnum and geotextile revetment at Kliffende, Kampen.

3.3 Technical measures

3.3.1 Historic measures

The historic (hard) measures at the Sylt coast are shown in Figure 9A.

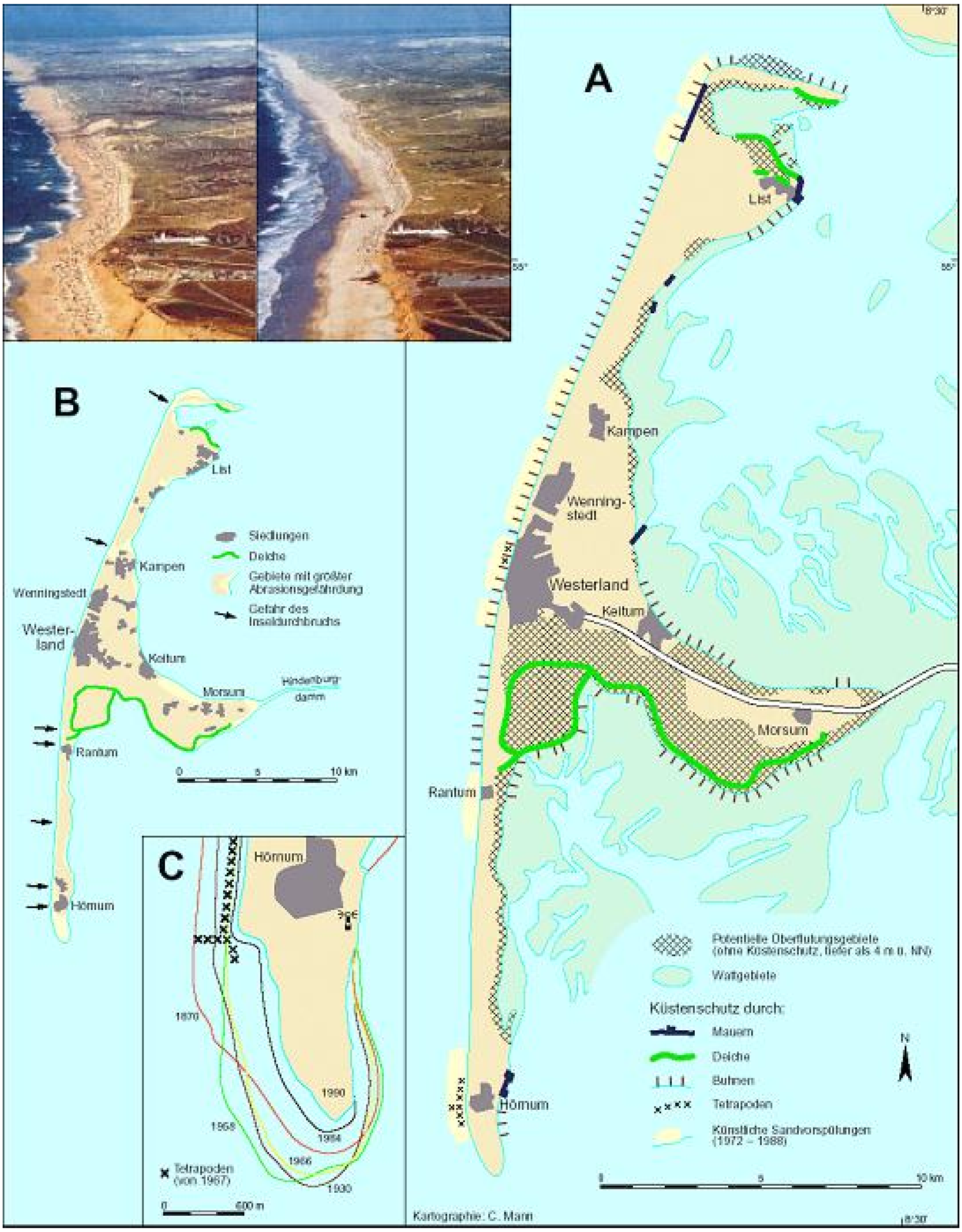


Fig. 9: Coastal protection works at the western coastline of Sylt.

- *Revetment / seawall* at List
- *Rif enhancement* at Kampen, 1990

A section of the beach at the west coast of the island Sylt near Kampen, which was particularly endangered by coastal erosion, was protected by means of an artificial longshore bar in 1990. Three years later a significant improvement in the coastal structure can be recognized. A high and wide longshore bar has developed and leeward, the beach has widened as well.

- *Geotextile revetment* at Kampen/Kliffende
- *Seawall* at Westerland, 1907-1954

For the protection, seawalls of a total length of 3 km along the coast were constructed between 1907 and 1954, but erosion in front of the construction and lee-erosion at the edges appeared.

- *Tetrapod dune revetment* at Westerland
- *Groins* from List to Rantum

Wooden groins in 1865, concrete in 1913, iron in 1927

- *Tetrapod barriers* at Hornum 1967

The tetrapods were built in cross (jetty) and long shore direction (dune foot revetment), south of the cross shore tetrapods the erosion increased due to lee-erosion of the tetrapods.

In Figure 9B the most probable flooding points are shown in the case of a 1 m sea level rise. In Figure 9C, the effect of the tetrapod groin on the downdrift beach at Hornum is shown. The inserted pictures show the erosion of the dune cliffs at Sylt.

3.3.2 Type

Artificial beach nourishment

Different types of nourishment take place at Sylt:

1. Soft protection of seawalls and revetments against local scour through toe nourishments.
2. Strengthening of dunes and beaches in order to keep shorelines at their 1992 positions introduced as a legal instrument at island of Sylt along 30 km of dunes and cliff adding up to 22M m^3 from 1983 to 1996.
3. Compensation of lee-erosion caused by coastal structures at Sylt, with an effective length of 2.5 km. Total fill volume so far 2M m^3 from 1995 to 1997.

These types of projects are carried out in the framework of legal coastal protection by coastal authorities. In addition, local communities take initiatives to improve their beaches for recreational purposes. Type *2* above was a result of a changing policy over time from no protection measures to manmade interference and the favouring of beach nourishment instead of continuous maintenance of hard structures (seawalls and revetments). This policy was introduced into the legal framework for Sylt in the early 1990's.

For the protection of the Westerland seawall on Sylt three unusual design types were developed (Dette and Gärtner 1987) including:

1. a successful spit-type fill which extended seawards more than 350 m from the seawall;
2. a less successful, linear, one-km long fill to 3 m above MHW;
3. the combination of both previous designs called a "girland-type" fill with satisfying results.

3.3.3 Technical details

Details on the nourishment up until 1996 are shown in the following tables for the northern part of Sylt, the central part (at Westerland) and the southern part of Sylt. The data was taken from the study “Beach nourishment projects, practices, and objectives”.

Table 1: Northern part of Sylt.

Year	Length [m]	Volume [10^3 m^3]	Fill density [m^3 / m^1]	d50 native borrow [mm]	fill type	purpose/ problem	borrow site	supporting measures
1985	4,805	1,975	410	0.29 0.50	High berm	Recession prevention	Off-shore	-
1990	1,900	990	520	0.29 0.40	Lower berm	Recession prevention	-"-	-
1987	520	300	580	0.29 0.54	Spit	Housing protection	-"-	Geo-tex-tile barrier
1996	1,150	240	210	0.29 0.51	Bar	Support sand bag bar	-"-	Artificial bar

Table 2: Westerland.

Year	Length [m]	Volume [10^3 m^3]	Fill density [m^3 / m^1]	d50 native borrow [mm]	fill type	purpose/ problem	borrow site	supporting measures
1972	900	1,000	1,100	0.35 0.441)	Spit	Raising the beach berm	Terrestrial	-
1978	1,690	1,000	590	0.35 0.441)	Linear fill	-"-	-"-	-
1984	1,390	1,030	740	0.35 0.35	Girland	-"-	Off-shore	-
1990	1,490	1,200	805	0.35 0.35	Girland	-"-	-"-	-
1996	2,140	745	350	0.35 0.50	Flat spit	-"-	-"-	-

Table 3: Southern part of Sylt.

Year	Length [m]	Volume [10^3 m^3]	Fill density [m^3 / m^1]	d50 native borrow [mm]	fill type	purpose/ problem	borrow site	supporting measures
1984	1,840	320	175	0.38 0.29	Berm	Recession prevention	Off-shore	-
1987	2,880	1,440	500	0.38 0.42	Berm	-"-	-"-	-
1996	2,940	400	135	0.38 0.51	Berm	-"-	-"-	-

1)30 % losses of fines (D_{50} < 0.20 mm) during dumping (not included in fill volume list)
2)n/a = not available

3.3.4 Costs

Other data on nourishments on Sylt, less extensive but indicating more nourishments than the previously mentioned study (and thus more complete apparently), are given in the "Generalplan Kustenschutz 2001". These data are shown in Figure 7 in combination with the following table, and are used for an indication of the costs. The total costs for 29.35 Million m^3 of nourished sand is 114,581 Million Euros.

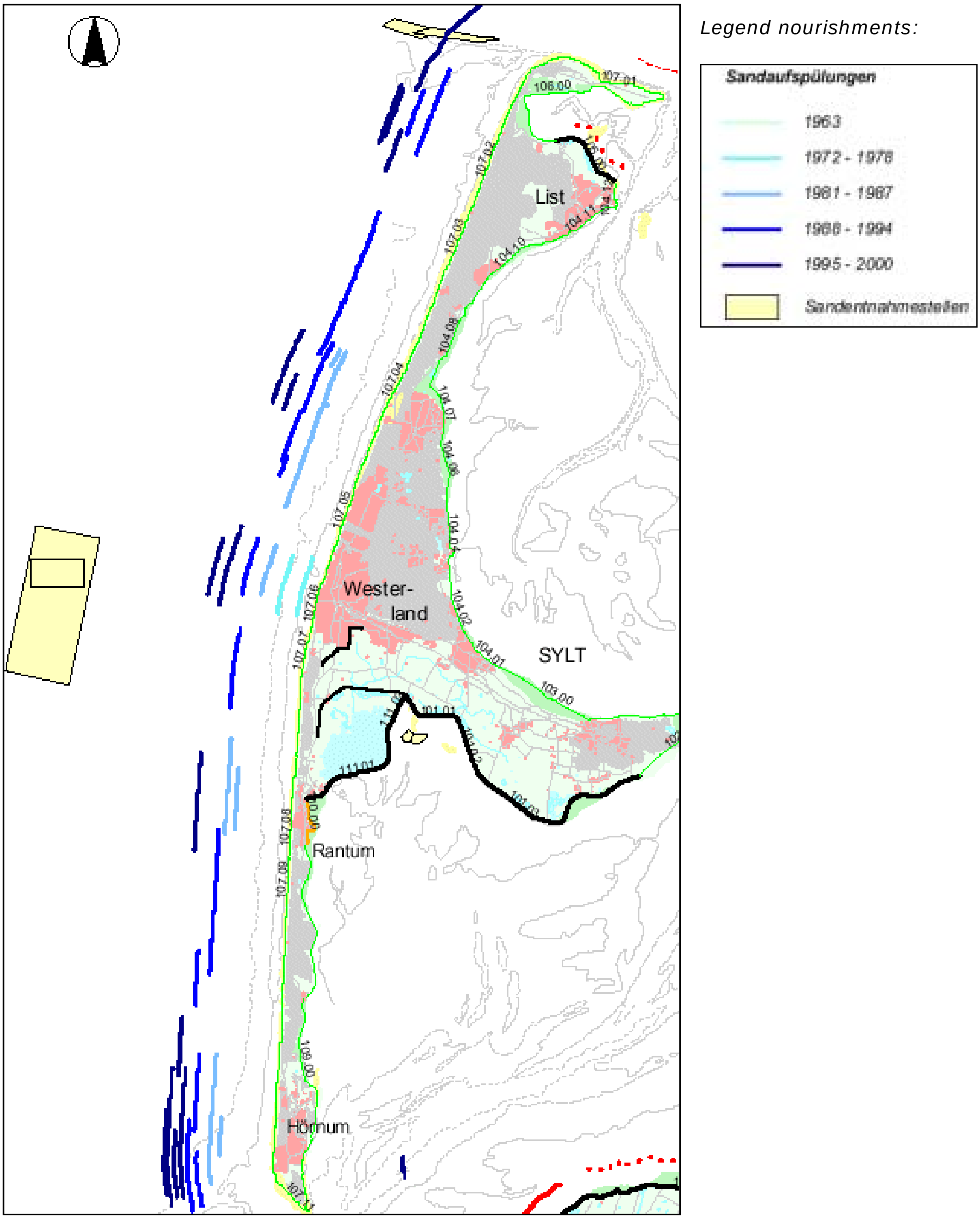


Fig. 10: Sand nourishments at Sylt [Generalplan Kustenschutz 2001].

Nourishments along sections of Sylt coast, from south to north [Generalplan Kustenschutz 2001]:

Profil	47s - 40s	39s	37s	35s	33s	31s	29s	27s	25s	23s	21s	19s	17s	15s	13s	11s	9s	7s	5s	3s	1s	1n	3n	5n	7n	9n	11n	13n	15n	17n	19n	21n	23n	25n	27n	29n	31n	33n	35n	Menge Mio. m^3	Kosten Mio. Euro
1972																					■	■																		1.00	3.119
1978																					■	■																		1.00	2.659
1983				■	■																																			0.64	1.636
1984														■	■	■					■	■																		1.39	3.732
1985																								■	■	■	■	■												1.97	7.363
1986				■	■	■	■																																	1.60	3.937
1987														■	■	■												■												1.74	6.647
1988																		■	■	■															■	■	■	■		2.21	6.238
1989										■	■	■	■	■																										1.97	5.266
1990			■	■																	■	■		■	■		■	■												3.47	11.811
1991					■	■	■																			■														2.02	7.874
1992																												■	■	■	■	■	■							2.08	9.766
1993			■	■	■				■	■	■																								■	■	■			2.21	10.379
1994				■	■	■	■																											■				■	■	1.54	8.743
1996														■	■	■	■				■	■				■	■													1.38	6.340
1997				■	■		■	■	■																															0.72	3.988
1999			■	■	■	■	■																												■	■	■			0.71	4.755
2000				■	■																■	■						■	■						■	■				1.70	9.970
Summe																																								**29,35**	**114,581**

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

4.1.1 Effects historic hard measures

The hard structures to stop erosion did not stop the erosion and failed on the long run. The erosion did not stop. Some negative effects are caused by the hard structures, for example:

- The tetrapod groin at Hornum is protecting the coast north of the groin. However, downstream of the tetrapod cross-shore groin, the erosion is increased by the presence of the groin.

- The seawall at Westerland failed on the long run, a lot of damage to the seawall occurred. The seawall needs to be protected at the toe by nourishments to prevent the seawall from collapsing. Furthermore, the seawall causes lee-side erosion downstream of the seawall.

4.1.2 Effects nourishments

The nourishments do not stop the erosion but stop the coastline from receding. Depending on the circumstances and beach fill types the nourishments have to be repeated with a certain interval. The performance of the nourishment is shown by means of the percentage of the fill density that is still present after the period of time that is shown in the same column.

The nourishments are not repeated at a regular interval, the interval varies from three to nine years. After five years 15 % of the initial beach fill is present for the 1985 nourishment, while after two years 50 % of the initial beach fill is present for the 1990 nourishment. The total volume for the nourishments decreases through the years, while the intervals increase.

Table 4: Northern part of Sylt.

Year	Volume [10^3 m^3]	Fill density [m^3 / m^1]	fill type	performance life time
1985	1,975	410	High berm	15%/ 5 yrs
1990	990	520	Lower berm	50%/ 2 yrs
1987	300	580	Spit	n/a
1996	240	210	Bar	n/a

Table 5: Westerland.

Year	Volume [10^3 m^3]	Fill density [m^3 / m^1]	fill type	performance life time
1972	1,000	1,100	Spit	25%/ 6 yrs
1978	1,000	590	Linear fill	17%/ 6 yrs
1984	1,030	740	Girland	33%/ 6 yrs
1990	1,200	805	Girland	50%/ 3 yrs
1996	745	350	Flat spit	n/a[2]

The nourishments are repeated every 6 years. After six years 20-30 % of the initial beach fill is still present. The linear fill shows a lower result (17 % after six years) than the girland and spit fill type. The total volume for the nourishment is reasonably constant.

Table 6: Southern part.

Year	Volume [10^3 m^3]	Fill density [m^3 / m^1]	fill type	performance life time
1984	320	175	Berm	10%/ 3 yrs
1987	1,440	500	Berm	25%/ 3 yrs
1996	400	135	Berm	n/a

The nourishments are not repeated at a regular interval, the first nourishment took place in 1984. The intervals are three years and nine years. However, the second time the nourishment volume was also a lot higher than the first time. After three years 10 % of the beach fill remained for the 1984 nourishment and 25 % remained for the 1987 nourishment.

4.1.3 Conclusions

The nourishments at Westerland started in 1972 and have been executed at a regular basis since that time. The nourishments at the southern and northern spits of Sylt started in 1984 and are not executed on a regular basis yet. Furthermore at Westerland the beach nourishments are more effective; the performance is better. This is probably caused by a better protection through the present hard coastal protection measures. In general the performance of the beach nourishments at Sylt is considered to be satisfactory.

Fig. 11: The situation in 1978 before the second stockpile nourishment at Westerland, Sylt.

Fig. 12: Situation in 1978 just after the second stockpile nourishment at Westerland, Sylt.

Fig. 13: Situation in 1979, one year after the nourishment, at Westerland, Sylt.

4.2 Effects related to socio-economic aspects

The nourishments improve the recreational values at Sylt by creating wide sandy beaches. Furthermore, the protection of human lives and investments are secured by protecting the dunes with beaches in front of it.

4.3 Effects in neighbouring regions

The island's protection does not have influence on neighbouring regions, the taken measures locally can have influences on the downstream coastline as was described before.

4.4 Relation with ICZM

In order to improve our understanding on the correlation between man and natural environment, and to develop ICZM as an integrative tool to be applied to natural and civilized coastal systems on regional and local scales, the case study Sylt was designed from seven different disciplines: geology, coastal and water engineering, ecology, geography, economy, psychology, and sociology. In this way all aspects are taken into account in the planning process for Sylt.

4.5 Conclusions

Effectiveness

The hard measures turned out not always to be effective in stopping the erosion. Though the central part of Sylt is reasonably stable, partly because of the hard measures taken there, the hard measures on the long run will fail. Nourishments are now needed to protect these hard coastal constructions. Furthermore, the nourishments are effective in stopping the coastline from receding. The performance of the nourishments is satisfactory. At Westerland, the nourishments have to be repeated every six years.

Possible undesirable effects

No undesirable effects of the beach nourishments were observed. The hard measures however do have undesirable lee effects.

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