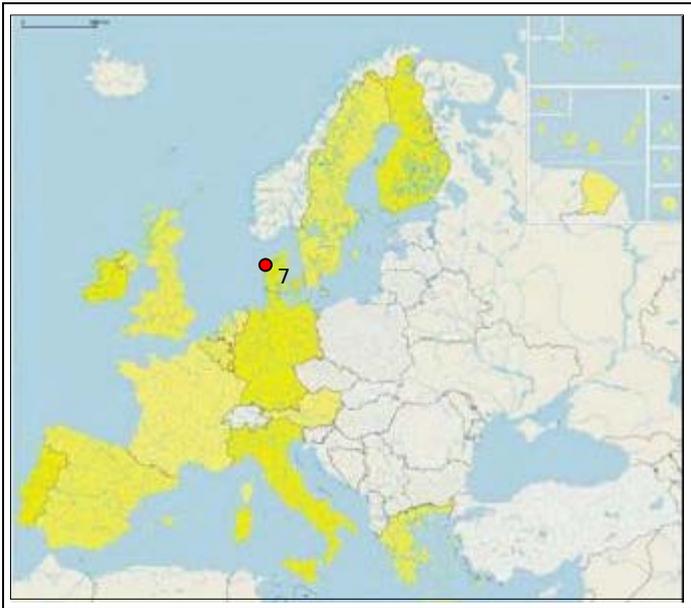


WESTERN COAST OF JUTLAND (DENMARK)



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1. GENERAL DESCRIPTION OF THE AREA

1.1 Physical process level

1.1.1 Classification

The Danish coastline is 7400 km long. There are three different types of coast in Denmark:

1. Tidal coast protected by sea dykes;
2. Highly exposed North Sea coast;
3. Less exposed coasts of Baltic Sea and Kattegat.

The Western coast of Jutland belongs to the highly exposed North Sea coast. The typical Danish coast facing the North Sea is a sandy beach, in front of dune ridges.

The west coast of Jutland is a shoreline of adjustment controlled by promontories and with embayments protected by offshore bars. It is typified as a highly exposed micro tidal sandy coast, according to the typology in the scoping study:

- 3a. Wave dominated sediment. Plains.
Dune coasts in micro-tidal zones.



Fig. 1: Location of case area.

1.1.2 Geology

During the Pleistocene glaciations, Denmark was an area of peripheral accumulation in contrast to Norway and Sweden, which mainly constituted an erosion area. The Scandinavian ice sheet did not cover the whole of Denmark during the Weichselien; its western margin stopped in northwestern and central Jutland. The surface of southwest Jutland is dominated by sediments of the Saalian glaciation, while deposits of the Weichselien glaciation form the surface layers in the northern and eastern Denmark. During the Saalian ice age, the ice sheet again reached Central Europe. Signs of another three glacial advances have been found in Denmark dating back to this period. The Saalian period left its mark on the landscape in West Jutland in the form of the so-called "hill islands" surrounded by melt water plains from the last ice age, the Weichselian period.

1.1.3 Morphology

Most of the coastal dunes are found on the West Coast of Jutland where they form a belt up to 10 km wide from Skallingen in the south to Skagen in the north. The North Sea coast of Denmark (The West Coast) is sandy and particularly vulnerable to erosion.

The main watershed of the peninsula lies towards the east coast; therefore elevated grounds are found on the east, while the western slope is gentle and consists of a low sandy plain of slight undulation. The North Sea coast (western) and Skagerrack coast (north-western) consist mainly of a sweeping line of dunes with wide lagoons behind them. The seaward banks of the lagoons are frequently broken in storms, and the narrow channels through them are constantly shifting. The interior is low. The Varde, Omme, Skjerne, Stor and Karup, sluggish and tortuous streams draining into the western lagoons, rise in and flow through marshes inland.

In Figure 2, three big fjords can be seen in the case area:

➤ **Ringkøbing Fjord- Hvide Sande**

The most southern bay is the Ringkøbing Fjord. It is Denmark's largest enclosed fjord with an outlet to the North Sea at the lock in Hvide Sande. The fjord is 40 km long and 10 km wide.

➤ **Nissum Fjord- Torsminde**

North of Ringkøbing fjord, the Nissum fjord is located with a surface of 70 km². It is a shallow fjord area with shoals and sandbanks and with intertidal zones and salt marshes with brackish lagoons, meadows and reedbeds. The fjord is connected with the North Sea by sluices at the small town of Torsminde.

➤ **Nissum Bay- Thyboron (channel).**

Nissum Bay is the largest of the three bays, it is connected to the North Sea with the Thyboron Channel.

1.1.4 Physical processes

Tide

The tidal range is 0,3 to 0,8 m. Tidal influence is very small at the western Jutland coast.

Storm events

A big storm occurred in November 1981 and eroded more than 10 m average and maximum of 30 m at some places along the west coast of Jutland.

Current

The Gulf Stream comes from the Wadden Sea and is directed northward at the western coast of Jutland.

Waves

For wind from a west to north-western direction, the fetch length stretches from the coast of England to the western coast of Jutland, causing very high waves. The average wave height



Fig. 2: West coast of Jylland.

is more than 2 meters with a wave period of 6 s. The maximum wave heights can reach 6 m with a period of 10 s. Wave lengths can vary from 350 to 1000 m (Aagaard, 1988 and 1989).

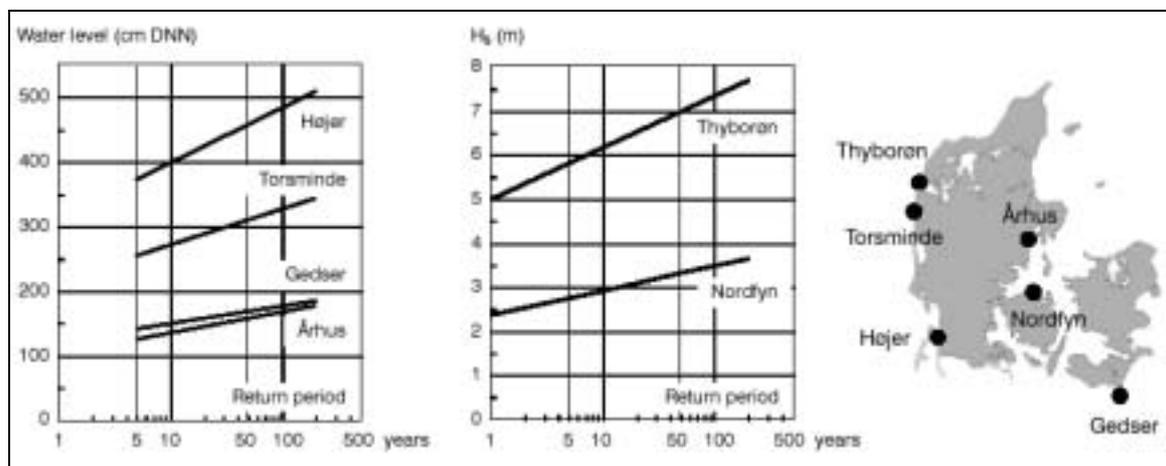


Fig. 3: Comparison water levels and wave heights at Danish coast.

1.1.5 Erosion

Average erosion of west coast is 3 to 4 meters per year, with a maximum of 11 m a year. The long shore transport and thus the erosion at the western coast of Jutland is mainly wave-induced. About 100 year ago, the dunes were stabilized by marram grass planting. At the same time, harbours and groin groups were built which resulted in serious downdrift erosion. The combined result of the stabilization of the dunes and the erosion was that in 1982, the dunes has disappeared or were weak along 50 km of the coast. The leeside erosion is man-induced. In Figure 4, the locations are shown where, due to the occurred erosion, the safety level was critical in 1982.

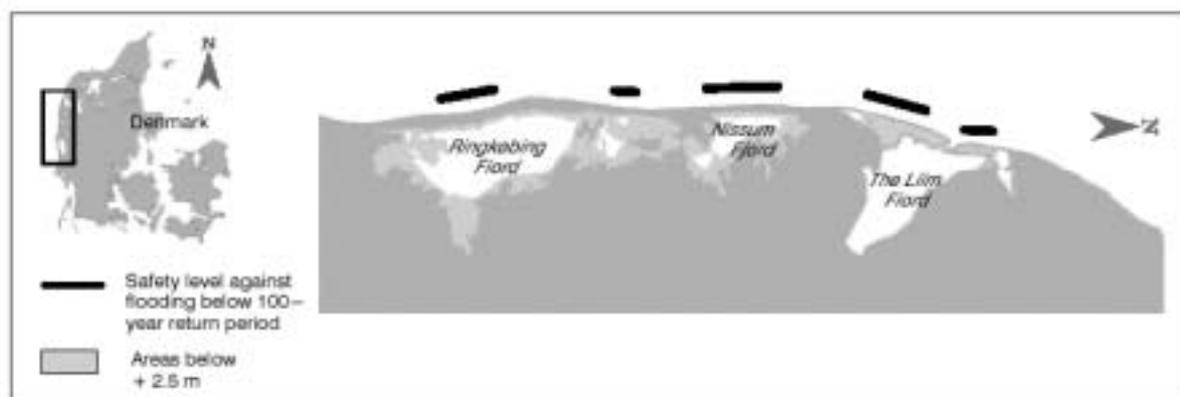


Fig. 4: Weak locations along the case area in 1982.

Estimates of the net sediment transport along the coastline range from of 500,000 to 1,000,000 m³/yr.



1.2 Socio-economic aspects

1.2.1 Population rate

The population rate at the western coast of Jutland is not high. No large concentrations of people and economic investments are present along the coastal stretch of the western coast. The average population density is about 50 persons/km².

1.2.2 Major functions of the coastal zone

- **Urbanisation (protection of life and investments):** The main function of the beaches and dunes is protection of the hinterland.
- **Agriculture:** About two third of the land is used for agricultural production, i.e. arable land. The land use in the case study area is very similar to the rest of Denmark, i.e. intensive cash crop and roughage production.
- **Tourism and recreation:** Valuable recreational areas (beaches) are available at the western coast of Denmark, however there are plenty of beaches available in Denmark. This puts the value of the beaches with regard to recreation into perspective.
- **Nature reservation:** Ringkobing Fjord on the coast of West Jutland is a shallow brackish lagoon separated from the North Sea by a narrow sand-barrier. The lagoon includes Denmark's biggest river delta. Until drainage in the 1960s, Ringkobing Fjord was one of the most important habitats for migrating and breeding waterbirds in that part of the world. Ringkobing fjord is a Ramsar site. Furthermore, Nisum fjord is a wildlife reserve.
- **Fisheries and aquaculture:** In Hvide Sande, which has the fifth largest fishing port in Denmark, fishing is the main occupation and the harbour is always a place of many exiting experiences.

1.2.3 Land use

About two third of the land is used for agricultural production, i.e. arable land. The land use in the case study area is very similar to the rest of Denmark, i.e. intensive cash crop and roughage production. The agricultural land has been decreasing slightly over the past 50 years, due to expansion of urban areas. In the future, afforestation and demand for restoration of natural ecosystems will be the main pressures on agricultural land use.

1.2.4 Assessment of capital at risk

According to Bryant et al (1995), the West coast of Jutland is at high risk. Where does West Jutland fit in; 1,2 or 3??



-
- High: city or major port or > 150 persons/km² or >150 m road/km² or > 10 m pipeline/km²
 - Moderate: $150 < \text{persons/km}^2 < 75$ and $150 < \text{m road/km}^2 < 100$ and $10 < \text{m pipeline/km}^2 < 0$
 - Low: persons/km² < 75 and m road/km² < 100 and no pipelines

A lot of small villages are located at the coastal strip of the west coast. Furthermore, the area represents a high recreational and environmental function. The risk is considered to be high.

2. PROBLEM DESCRIPTION

2.1 Eroding sites

➤ Hvide Sand- Ringkøbing Fjord

Flooding became increasingly a nuisance in the town of Ringkøbing and to farmers in the past. Therefore and for the wish to have a navigable channel to the North Sea, in 1910 the natural outlet for water near Nymindegab was closed and a new one was excavated through the barrier of Hvide Sande. Erosion increased the width of this artificial channel to 230 m in only a few years which had consequently to be closed. But the new excavated channel near the old natural outlet at Nymindegab was too shallow for fishing vessels. In 1931 the old channel was re-opened but had consequently to be controlled by sluices (including a ship lock). The entrance is poorly protected by two jetties. To prevent sediment filling up the entrance, another jetty was constructed. But the construction of jetties caused increased erosion through vortices of the beach south of Hvide Sande, in particular at Årgab. However, the barrier has to be preserved because of the protection of the town of Ringkøbing and the population along the fjord.

➤ Torsminde- Nisum Fjord

The jetties, built to prevent the entrance channel to Nisum Fjord to fill up, causes serious erosion at the adjacent coasts. There is a net southward long shore transport. North of the port entrance accretion against the groins occurs and south of the port entrance erosion takes place. No structures have been built at this site, to combat the erosion nourishments are carried out. During the period 1978-1988 an average coastline retreat of 6.7 m/year was measured.

➤ Thyborøn channel- Nisum Bay

Thyborøn channel is located on the West coast of Jutland, Denmark. The channel was formed naturally during a severe storm in 1862 when waves broke through the coastal sand dunes and the narrow barrier beaches, which separated the North Sea from the Limfjord. In the years after the opening of the channel, the neighbouring coasts experienced substantial erosion, which threatened the town of Thyborøn.

The Danish Coastal Authority (DCA) has followed the evolution of the coastal zone and the inlet closely for many years. Massive protection works, groins and dikes, have been constructed, and over the past 10 years the structures have been supplemented by comprehensive nourishment of the beaches.



Fig. 5: Thyborøn channel entrance.

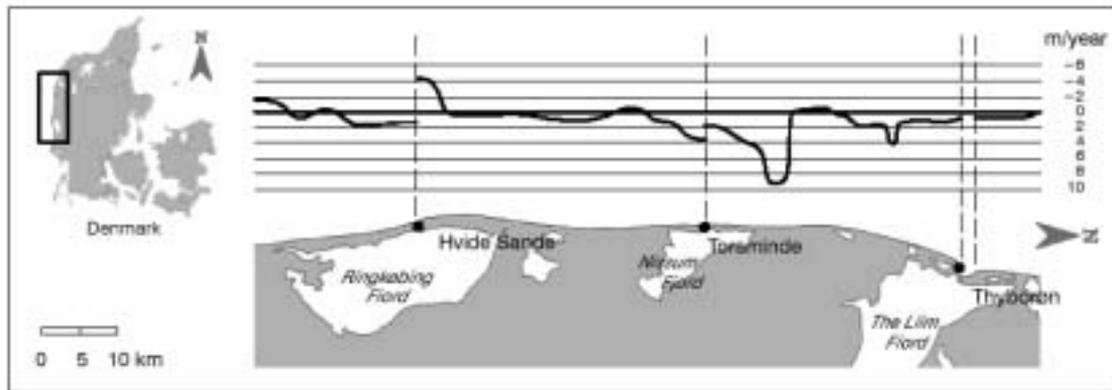


Fig. 6: Yearly erosion rates at western coast of Jutland in 1982.

2.2 Impacts

Besides the loss of valuable recreational areas, the high erosion rates had the effect of significantly reducing the protection against flooding provided by the dunes. Recreational beaches are threatened, however the amount of available beaches is large in Denmark, so this is not considered to be a problem. The main function that should be maintained is protection of the hinterland against flooding.

3. SOLUTIONS/MEASURES

3.1 Policy options

In Denmark, there is no basal coastline defined by law. There are no national rules for safety assessment of dikes and dunes. The actual policy for safety assessment and erosion control policy are established as an agreement between local authorities and the government based on Danish Coastal Authority recommendations. The main reason for the lack of national regulations is that, apart from the land protected by two major dikes in the tidal region, the danger to human life is small and only land is damaged by erosion and flooding.

The costs of coastal protection on the North Sea are shared between the government and the local authorities.

Very high rates of leeside erosion caused by harbour breakwaters and large groin groups were present at the western coast of Jutland. Therefore in 1982, it was decided to implement a coastal protection scheme. The headlines of this policy were:

- To re-establish a safety level against flooding to a 100-year return period minimum
- To stop the erosion where towns are situated close to the beach
- To reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years.

The policy line is a combination of hold the line, do nothing, managed realignment and limited intervention depending on the location, the functions at the location and the current and future state of the coastal protection at the location.

3.2 Strategy



Fig. 7: Nourishment, revetment and breakwaters.

To re-establish the safety against flooding to a 100-year return period, the dunes were reinforced and new dunes were built (soft measures). However, in many cases it was not possible to reach the safety level required because there was not enough land between the beach and the houses or the road to build a sufficient dune volume. In this case, hard measures were taken in the form of revetments.

To stop or slow down the general erosion of the coastal profile, the following approach was used in 1982:

- On highly exposed stretches where erosion should be stopped, low detached breakwaters were used in combination with nourishment. One reason for the use of breakwaters was that for historical reasons, local politicians trusted in hard structures like groins and breakwaters. Another reason was the high price of the nourishment sand.

- Nourishment was applied but on a small scale. The main reason for this was that the principle of beach nourishment was new to the politicians. It was difficult to convince the politicians that “the erosion of the nourishment sand during storms is part of the plan”. This meant that volumes were small and unit costs were high which was one reason for stabilizing the nourishment by means of detached breakwaters.

Since 1982, the engineering solutions have changed from a hard to a soft approach. There is a number of reasons for this development of which the most important are:

- A growing awareness among the general public and among politicians of environmental issues.
- The problems which required hard solutions have been solved.
- The budgets have been raised dramatically rendering soft solutions more competitive. Because of the small volumes and the lack of experience of the Danish contractors regarding pumping of sand directly on shore on the North Sea coast, the mobilization costs were quite high and consequently, the unit costs were high. With increasing volumes and experience, a better approach for nourishing the different parts of the profile has been developed. Today, three methods are used. The methods are pumping onshore through a submerged steel pipe, pumping over the bow and dumping from split barges.

3.3 Technical measures

3.3.1 Historic measures

A hundred years ago the first coastal protection works at the western coast of Jutland were executed. Protection types include:

- Groins
- Breakwaters
- Revetments
- Reinforcement present dunes
- Nourishments



Fig. 8: Revetment at western coast of Jutland.

3.3.2 Type

The coastal protection scheme in 1982 included the following technical measures:

Detached breakwaters

Aim of the breakwaters is to reduce the nourishment volume needed.

Nourishments

The nourishments are applied to stop the coastline from receding any further, however the erosion is not stopped with nourishments.

Revetment

In cases where it was not possible to reach the safety level required with nourishments, because there was not enough land between the beach and the houses or the road to build a sufficient dune volume, revetments were applied.

3.3.3 Technical details and costs

Figure 6 shows the development in the use of structures and beach nourishment for the period, including costs. For the revetment the number of kilometers is shown, for the detached breakwaters the number of breakwaters built are shown and for the nourishment the volume (Mm^3) of sediment is shown.

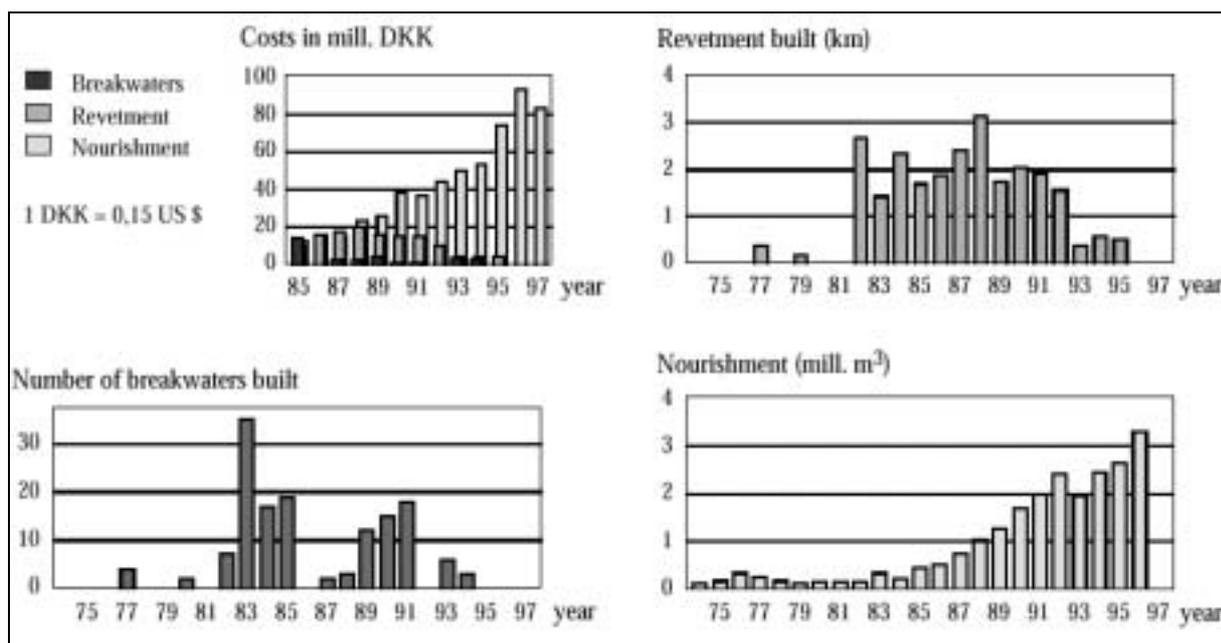


Fig. 9: Development of construction types and costs in time.

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

4.1.1 Total effect

Figure 10 shows the coastline retreat rate in 1998 for the southern part of the North Sea coast. The very high erosion rates are no longer a fact. We do not have absolute zero erosion but the erosion has been stopped where it is important for the dune safety and on average, the coastal erosion rate is 0.1 m/year. The safety level of the dunes has been reestablished to a level of at least 100 years, which was the goal in 1982.

4.1.2 Detached breakwaters

The effect of using low detached breakwaters has been studied (Lastrup and Toxvig Madsen, 1994). The results were based on 10 years of monitoring of a group of breakwaters. The purpose of the study was to confirm the design theory which had been used and which was based on theoretical computations. The paper confirmed that the use of breakwaters in this group had reduced the need for nourishment landward of the breakwaters by 50%.

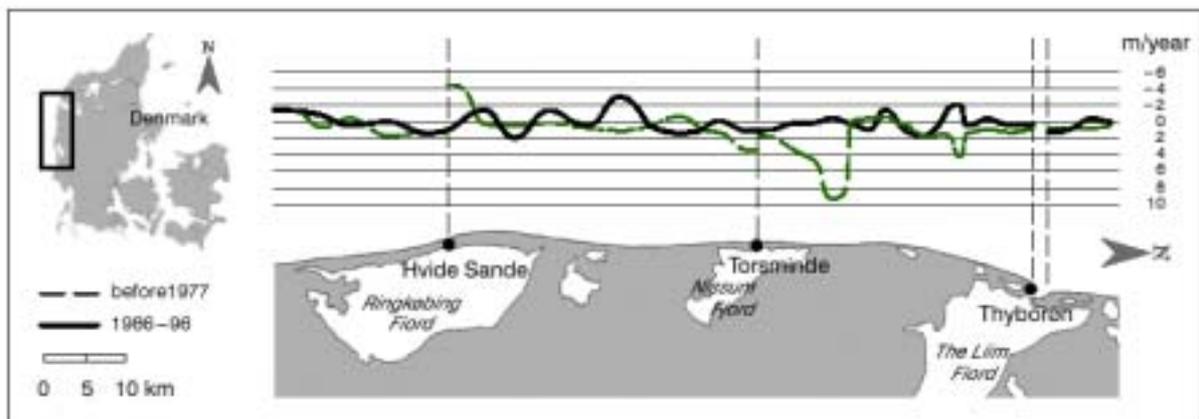


Fig. 10: Effect of coastal protection scheme on erosion.

4.1.3 Nourishments

Some effects of the nourishment have now been evaluated. In this chapter, some of the aspects concerning a steepening of the coastal profile, positioning of the nourishment sand in the profile and the effect of using coarse sand will be discussed.

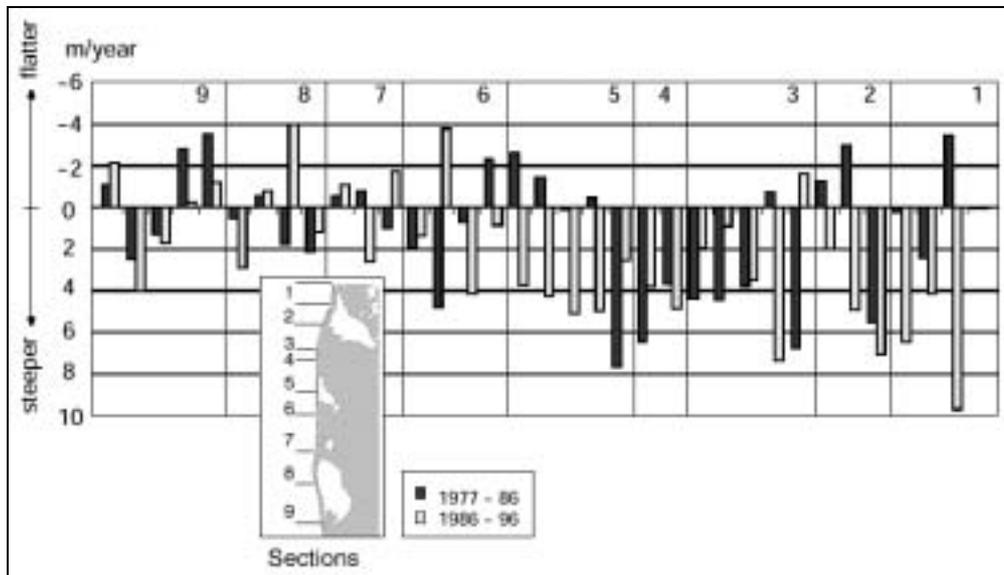


Fig. 11: Difference between retreat rates seaward and landward of -6 m.

The retreat rates shown in Figure 7 have been calculated for the profile section from -6 to +4 m. For nourishment we only use a volume equivalent to the erosion on this part of the profile. As it could be expected, this policy leads to a steepening of the profiles. Figure 8 shows a number of bars each representing a number of profiles on a part of the coast. The length of the bars represents the difference between erosion velocity of the profile seaward of -6 m and landward of -6 m. This difference represents the steepening of the profiles. Before 1986, the steepening took place on parts of the coast where groin groups had been built (sections 3,4 and 5 in Figure 8). After 1986, the steepening mainly took place where the nourishment projects were carried out (sections 1-5 in Figure 11).

In 1993 - 1996, the European Union MAST project Nourtec was carried out with participation from the Netherlands, Germany and Denmark. In the Danish case, a nourishment project on the long shore bar and a project on the beach were studied (Lastrup and Madsen, 1996).

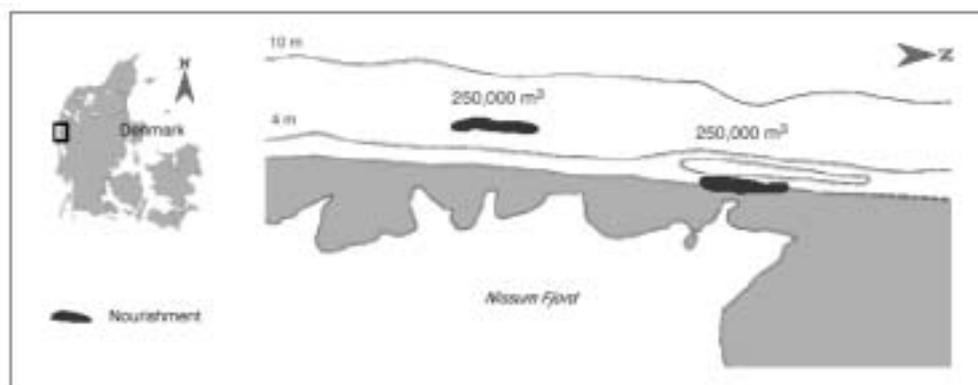


Fig. 12: The nourishment location plan at Nissum Fjord.

The main results are:

- In the first year, the beach nourishment gives the better stabilization of the beach.
- At the end of the period, the shoreface nourishment is the better option for the stabilization of the beach.
- The shoreface nourishment is more stable than the beach nourishment. The main reason is that the shoreface nourishment sand was coarse, $d_{50} = 0.57$ mm. The effect of the beach nourishment is that of a feeder berm and the effect of the shoreface nourishment is that of a breaker berm. The effect of the shoreface nourishment on the outer part of the profile is that of a feeder berm. The conclusion was that the profile should be nourished by dumping sand on the bar. This is also cheaper than placing the sand on the beach. There was nearly no migration of sand from the bar to the beach so for the inner part of the profile it was recommended to place the sand on the beach. Figure 10 shows the principles of positioning the sand in the profile that we are going to implement in the future. Part of the nourishment on the beach is used as a buffer to prevent erosion of the dunes during storms.

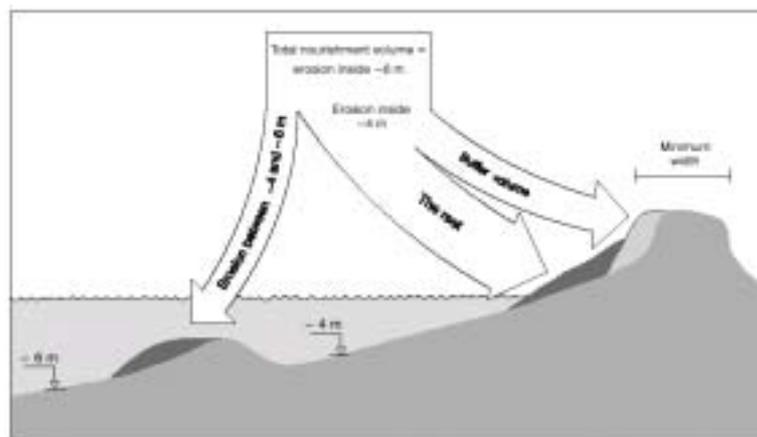


Fig. 13: Shore face and beach nourishment.

The relationship between the d_{50} and the effectiveness of the sand was studied. For that purpose, nine projects involving annual nourishment during the period 1986–96 were evaluated. The length of the project stretches is 3-5 km and the volume per meter is 10-50 m^3 . The principle used for the study is shown in Figure 11. We know the 1986 and the 1996 profile. However, the effect of the nourishment is the shaded area between the 1996 profile and the autonomous 1996 profile (the profile without nourishment). The autonomous 1996 profile was calculated with three different methods.

The effect of the nourishment is the shaded area in Figure 14. The nourishment volume is known so the effectiveness is the effect divided by the volume. In this case, it is greater than one. The effectiveness can also be defined as the ratio between erosion velocities in native and borrow material. Since the renourishment factor (James, 1975) is the ratio of erosion velocity in borrow material to native material, this is the inverse of the effectiveness.

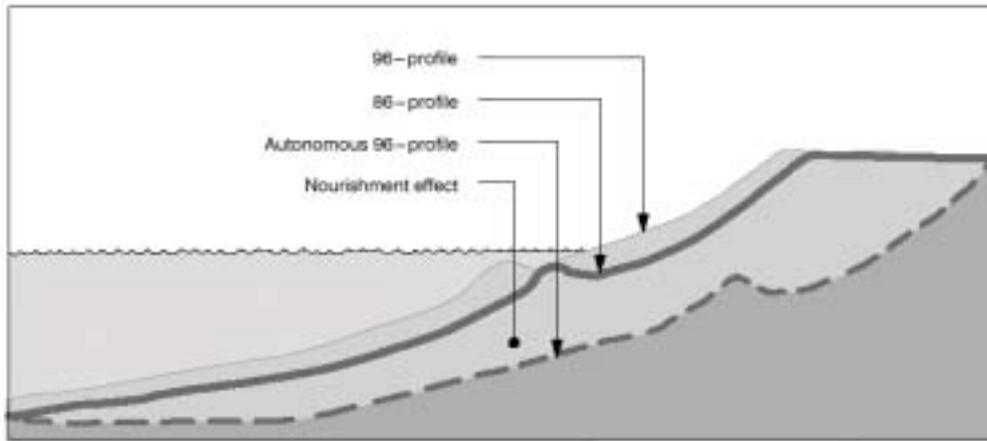


Fig. 14: Effectiveness of a nourishment.

4.2 Effects related to socio-economic aspects

The main effect related to socio-economic aspects is the fact that the safety level of the dunes has been re-established to a level of at least 100 years. This was the goal in 1982, this goal was reached with the taken measures. Another additional positive socio-economic effect is that the beaches are recovered, and can be used for recreational purposes again.

4.3 Effects in neighbouring regions

Outside the studied region of the case area, no effects were observed of the measures taken in the case area.

4.4 Relation with ICZM

The Kystinspektoratet and the Vandkvalitetsinstituttet did an environmental assessment along the central part of the Danish North Sea coast, how the gaining of sand and the nourishment affect the bottom-fauna. The conclusion is, that in the areas of sandgaining, the fauna re-establishes within one year and in the nourished areas within 2-3 years. However, the re-established individuals after one year are smaller in size.

4.5 Conclusions

Effectiveness

Erosion control with a combination of nourishment and low detached breakwaters has reduced the retreat rate to average zero for the depth range from -6 m to +4 m. The policy of only nourishing this part of the profile has resulted in a steepening. The safety against flooding has been raised to a return period of more than 100 years by building new dunes and by protecting the dune foot with a revetment.

Based on monitoring of nine nourishment projects with a total volume of 10 M m³ for a period of 11 years, guidelines for positioning of nourishment sand in the profile and for the use of coarse sand in nourishment projects have been developed. Better quality information about the native and borrow sand characteristics is needed.



Possible undesirable effects

The coastal protection scheme of 1982 did not bring about clear undesirable effects in general. Locally some leeside erosion probably occurs downstream of the detached breakwaters and revetments.



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Figures:

Figure 1: <http://www.icm.noaa.gov/country/denmark.html>

Figure 2: ??????????

Figure 3: Evaluation of the Effect of 20 Years of Nourishment

Figure 4: Evaluation of the Effect of 20 Years of Nourishment

Figure 5: <http://www.dhi.dk/dhiproj/Country/Denmark/thyboron/Main.htm>

Figure 6: Evaluation of the Effect of 20 Years of Nourishment

Figure 7: Evaluation of the Effect of 20 Years of Nourishment

Figure 8: Evaluation of the Effect of 20 Years of Nourishment

Figure 9: Evaluation of the Effect of 20 Years of Nourishment

Figure 10: Evaluation of the Effect of 20 Years of Nourishment



Figure 11: Evaluation of the Effect of 20 Years of Nourishment
Figure 12: Evaluation of the Effect of 20 Years of Nourishment
Figure 13: Evaluation of the Effect of 20 Years of Nourishment
Figure 14: Evaluation of the Effect of 20 Years of Nourishment