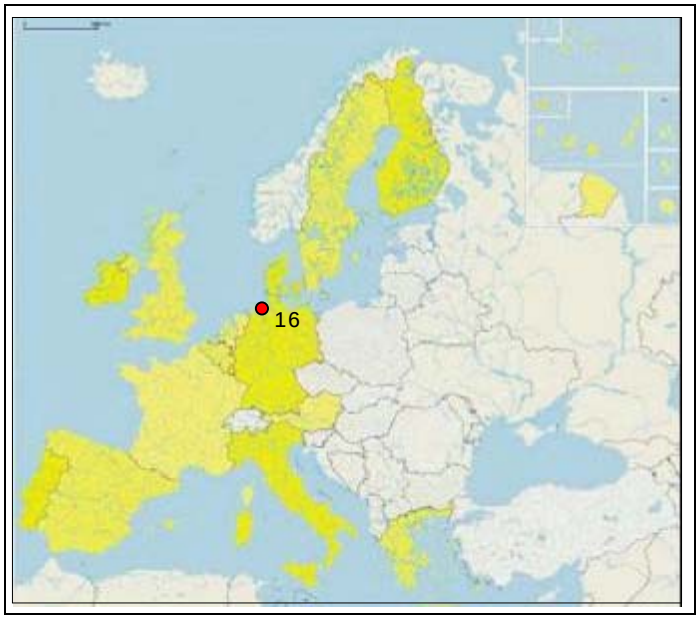
ELBE ESTUARY (GERMANY)



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1. GENERAL DESCRIPTION OF THE AREA

1.1 Physical process level

1.1.1 Classification

The Elbe Estuary is located at the Germany North Sea Coast (see Figure 1). In Hamburg, the river Elbe mouths into a 97-km-long estuary. It represents the border between Schleswig-Holstein on the northern coast and Lower Saxon on the southern coast of the Estuary.

The National Park Hamburgisches Wattenmeer with a surface measure of ca. 11,700 ha is situated in the estuary of the river Elbe. It exists as a National Park since 1990 and includes the islands Neuwerk, Scharhoern and Nigehoern.

The North Sea coastline of Germany is part of the low sandy shore bordering the eastern part of the North Sea between the French-Belgian border and the north of Denmark. The coastline is devoid of cliffs and has wide expanses of sand, marsh, and mud flats.

The classification conform the scoping study is:
3a. Tide-dominated sediment.
Plains. Atlantic & North Sea estuaries.

Fig. 1: Location of case area.

1.1.2 Geology

The mud flats between the Elbe estuary and the Netherlands border are believed to have been above sea level during Roman history and to have been inundated when the shoreline sank during the thirteenth century. The mud flats between the islands and the shore are exposed at very low tides and are crossed by innumerable channels varying in size from those cut by small creeks to those serving as the estuaries of the Elbe and Weser rivers. The mud and sand are constantly shifting.

1.1.3 Physical processes

Tide

The tide is semi-diurnal. Tidal ranges reach around 3 m in the mouth of the Elbe estuary. The tidal range for the whole Elbe Estuary is shown in Table. The tidal period is a-symmetrical, with a flood period that is shorter than the ebb period. This leads to a tendency to sedimentation in the area. In 1880 the tidal range measured around 1,9 m, which is irreversible increased due to canalization.

Table 1: Longterm tidal range of the Elbe [m].

Gauge	River-km	mean low tide	mean high tide	mean tidal range
Hamburg-Zollenspieker	598.2	4.87	7.43	2.56
Hamburg-St. Pauli	623.1	3.50	7.07	3.57
Stadersand	654.8	3.72	6.74	3.02
Glückstadt	674.3	3.75	6.56	2.81
Cuxhaven	724.0	3.54	6.52	2.98

Sea level rise

Figure 2 shows the sea level rise for the Elbe estuary. The rate of sea level rise in the last century has been about 2 mm/year which is similar to the world wide sea level rise. Predictions of future rates are about 6 mm/year.

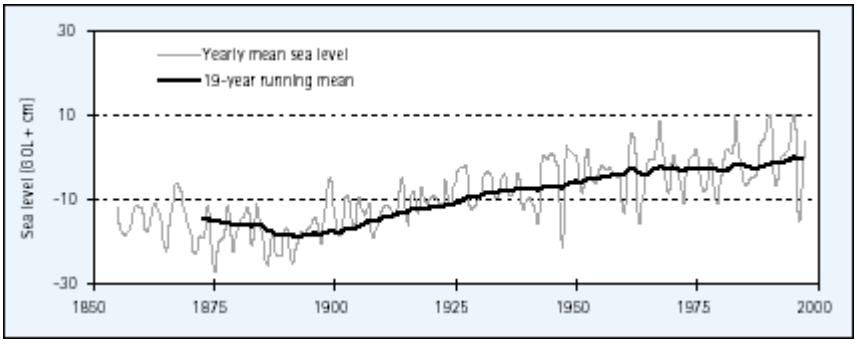

Fig. 2: Mean Sea Level at Cuxhaven.

Sediment sources

Sediment sources for the Elbe estuary are:

- Marine; tidal transport causes a net inflow into the Elbe estuary (sedimentation)
- Riverine; discharge from the river Elbe into the estuary

1.1.4 Erosion

The estuary has a tendency for sedimentation due to the asymmetrical tide. On a very small scale locations can be found with alternating erosion and sedimentation. This is mainly due to morphological adjustments to human induced changes (dredging, fixing the shipping route, canalisation, land reclamation).

In Figure 3, the morphological development of the Elbe Estuary is shown from 1992 to 1997 (the colors in the map indicate the change in depth in meters, i.e. erosion and sedimentation patterns, the coloured lines indicate the ERS at different points in time). The outer southern shore is mostly subjected to sedimentation. The northern coastline shows a constantly changing process of erosion and sedimentation.

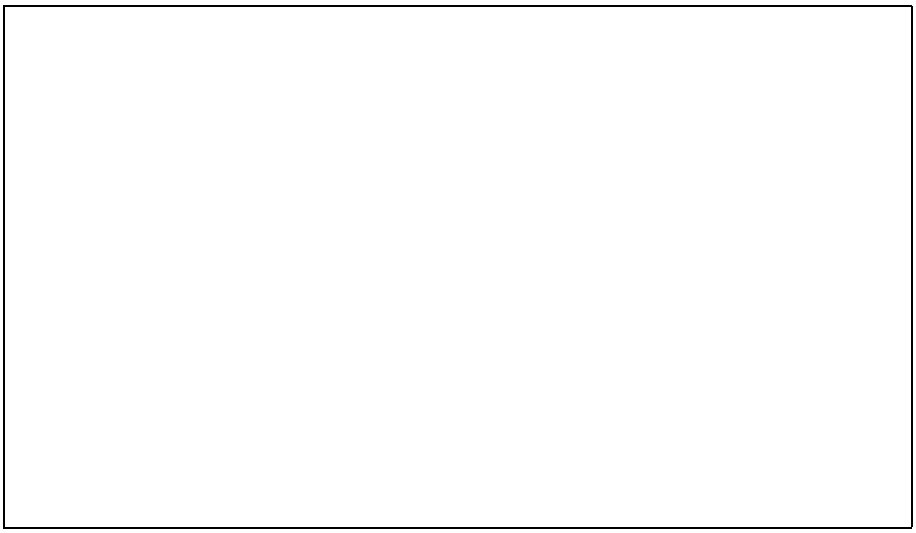

Fig. 3: Morphological changes in the elbe estuary.

During the last century, riparian forests, large marsh and semi-terrestrial areas bordering the rivers have been embanked for coastal protection and for agricultural purposes. The diking of freshwater/brackish marshes and reeds and the subsequent drainage for agricultural use has destroyed areas of major importance for breeding and migratory birds (see Table 2).

Table 2: Losses of aquatic habitats (% area) due to canalization in Elbe Estuary.

	Elbe 1896/1905 vs. 1981/82
tidal flats	brackish 21% freshwater 51 %
shallow water	brackish 63% freshwater 85 %

Cliff erosion (where human induced salt marsh development resulted in a steep slope between the marshes and the deep sea bed) is a severe problem (see Section 2.1).

Locally, the drifting of islands towards the navigation channel can result in a further shrinking of such Islands, this is the case for Scharhoern (see section 2.2).

The morphology of the Elbe estuaries has been adapted by humans in order to optimize their function as shipping routes. Their depths have been and still are continuously adjusted to the increasing size of vessels. The canalization has resulted in a loss of intertidal and shallow sub tidal areas (see Table 3) and in an irreversible increase of the tidal range.

Table 3: Losses of foreland (% area) in the Elbe estuary.

Elbe 1896/1905 vs.1981/82
Northern Bank 52% Southern Bank 75%

1.2 Socio-economic aspects

1.2.1 Population rate

The average population rate in Schleswig Holstein is 170 persons/km^2. The population density around the Elbe estuary is lower (ca. 100 persons/km^2) at the outer estuary, in the middle part the population density is around 150 persons/km^2, while in the inner estuary, where Hamburg is located, the population density is of course very high (>250 persons/km^2).

1.2.2 Major functions of the coastal zone

- **Shipping / transport:** The port of Hamburg is the focal point for the trade concluded with Eastern and Northern Europe. It is situated on the banks of the Elbe. In 2000 more than 85 million tonnes of cargo was handled in the port of Hamburg, of which 45 million tonnes was container traffic. With this, Hamburg asserted its position as No. 9 in the rankings of world container ports and as no. 2 in Europe, and is still growing.

  The navigation channel is constantly adapted to the size of (overseas) vessels, travelling to and from the port of Hamburg. Furthermore, the Elbe estuary is the world's most frequented area for shipping to and from Scandinavia and the Baltic states (through the Kiel Canal).

- **Tourism and recreation:** The estuary area is important for recreation and tourism.
- **Fisheries and aquaculture:** The Elbe estuary has some importance for local shrimp fishery activities.
- **Nature conservation:** The seaward section of the estuary is part of the Wadden Sea National Parks. These are administred by the states of Scheswig-Holstein, Lower Saxon and Hamburg. The estuary is an important, though very sensitive and vulnerable ecosystem for seabirds. Furthermore it is a spawning ground for fish. The islands of Scharhoern and Nigehoern are major breeding colonies for migrating birds.

Fig. 4: Observation post on Island Scharhoern.

1.2.3 Land use

Most of the estuary consists of tidal flats and salt marshes. The island of Neuwerk is inhabited and lies just outside the mouth of the Elbe estuary Northwest of Cuxhaven in the middel of the The National Park Hamburgisches Wattenmeer.

The islands Scharhoern and Nigehoern are reserved for bird breeding, Scharhoern does have an observation post.

1.2.4 Assessment of capital at risk

The Elbe estuary reaches up to Hamburg. Hamburg is a large German city with over 1 million inhabitants. Hamburg houses the second largest port in Europe with high economic importance in the area. Along the coast of the estuary several smaller towns are present and some heavy industry. These locations are at high risk of flooding.

According to Bryant et al (1995), the coast of the Elbe estuary is at high risk.

2. PROBLEM DESCRIPTION

2.1 Eroding sites

The Elbe estuary has an overall tendency towards sedimentation. In two areas the morphological changes have significant erosion effects, as described below.

The island Scharhoern is one of the most important breeding island for terns and other seabirds in the whole region of the Wadden Sea. The development of dune vegetation has been artificially supported and added by installing bush fences to catch the drifting sand next to the island since 1926. In 1973 the island reached its largest extension covering more than 18 ha of the Scharhoern plate. Since then, it has been shrinking rapidly. Following the sedimentation transport affected by wind and sea, the island has drifted 1.4 km eastward during the last century and got closer to the deep fairway of the Elbe. The location of island Scharhoern is given in Figure 7.

Along the Schleswig-Holstein coast, salt marshes are under threat of erosion. With raising sea level (rates) the possibility that marshes drown increases. On some mainland salt marshes, present day accretion rates are more than 2.5 cm/yr. 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 increases the amounts of suspended material and 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. Figure 5 shows the locations of salt marshes in the mouth of the estuary.

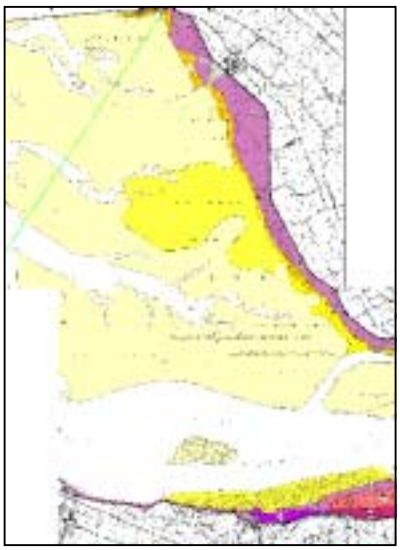

Fig. 5: Salt marshes along the coasts (in purple/dark grey (B/W).

Fig. 6: Salt marsh works.

A more pertinent threat to salt marshes (compared to drowning) is cliff erosion. Former practice of artificial salt marsh creation and subsequent reclamation resulted in a steep slope

(large water depths in front of the marshes). These marshes were thus situated in exposed areas, susceptible to high-energy processes like strong currents and waves (i.e. to erosion). Without protective measures a large part of these salt marshes would probably erode and finally disintegrate. This problem of cliff erosion will intensify if the input of energy by waves and tides into the Wadden Sea increases and also as a possible result of sea level rise.

2.2 Impacts

The loss of island Scharhoern has major effects for migratory birds, especially terns. Also the loss of salt marshes impacts the ecosystem.

The salt marshes in front of the dikes have a significant influence on the wave energy attacking the dikes. Because of the small depths above the salt marshes the wave will break and dissipate energy before reaching the dikes. Loss of saltmarshes will increase the attack on the dikes. This will have effects on the safety levels of the area, protected by the dikes.

3. SOLUTIONS / MEASURES

3.1 Policy options

In the master plan "Coastal Defence in Schleswig-Holstein" of 2001, ten strategic goals are formulated. Goal number three states: "Relocation or abandonment of seawalls 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 defence 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.

Since the above-mentioned criteria are not met for the Elbe estuary, the policy option along the coastline of the estuary is hold the line.

3.2 Strategy

On the islands in the Lower Saxon legislative area, a long-term evaluation programme is implemented, concerning sustainable protection concepts in areas with structural erosion. In the future, regional management plans of the foreland areas will integrate demands of coastal defence and nature conservation.

Coastal defence (coastal protection and coastal flood defence) is regulated in the Schleswig-Holstein State Water Act and the Master Plan Coastal Defence (the technical and financial concept). In principle coastal defence devolves on the persons who profit. However, flood defence is in the interest of the general public. Depending on the measures (and the aims), the responsibility is in the hands of state administration, or municipal administration or local water boards.

The legal basis for coastal defence in Lower Saxon is the Niedersachsen Dike Act. It contains regulations for design, maintenance, supervision and usage of dikes, forelands, dunes and other coastal defence structures, as well as regulations for responsibilities of the authorities and the water boards. Main objective of the Dike Act is protection of man, settlements, facilities (public, industrial and infrastructure) and agricultural areas against flooding.

3.3 Technical measures

3.3.1 Historic measures

The old philosophy of executing coastal defence (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 defence 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 defence. However, this attitude changed into trying to use more natural techniques and material, e.g. sand nourishment, to combat coastal retreat. In 1995 a common salt marsh management plan was established by coastal defence and environmental authorities that aims at an ecologically sound protection and management of salt marshes, salt marshes being both an important (natural) coastal defence structure as an ecologically sensitive and valuable habitat.

During the last century, large areas of marsh, riparian forest and semi terrestial areas, have been cut off from the water by means of dikes and embankments (approx. 52% of the northern bank and approx. 75% of the southern bank during the time period 1896 to 1982). The diking of these freshwater/brackish marshes and reeds, but also the subsequent drainage for agricultural use, has destroyed large areas of high importance for breeding and migrating birds. With these measures large natural retention areas were lost for the storage of water masses during storm surges.

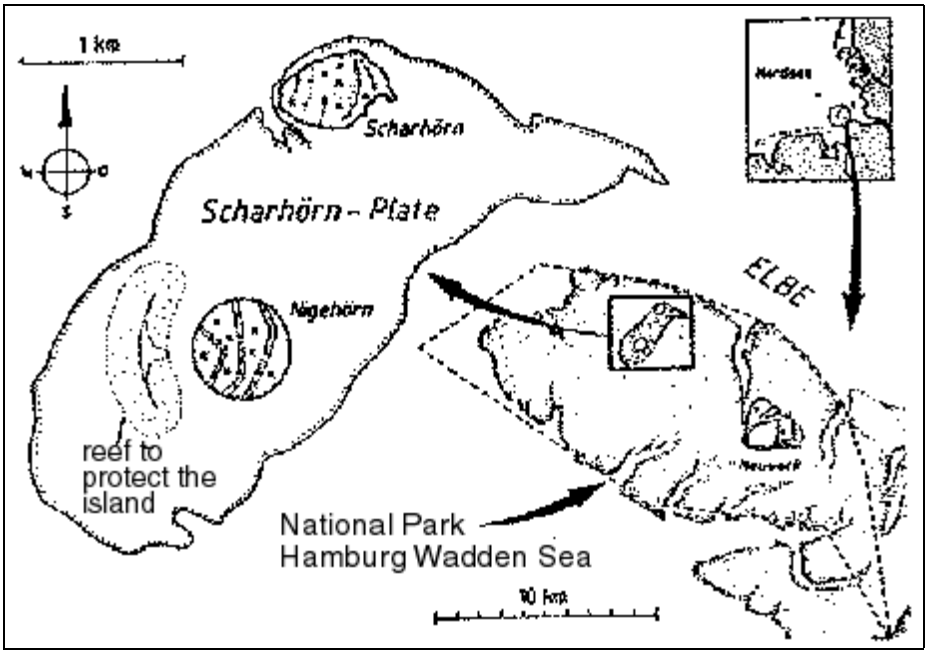

Fig. 7: Islands Scharhoern and Nigehoern.

To compensate for possible loss of the breeding sanctuary Scharhoern, the environmental authority of Hamburg decided in 1989 to establish a new dune island. The artificial island Nigehoern was created by sand nourishment 1.5 km away in the southwest of Scharhoern, but still situated on the Scharhoern reef. The activities started in June 1989. Using a 2.5 km long pipeline, 1.3 mill. m^3 sediment was pumped up the Scharhoern-plate within a time span of 5 weeks. When sculpturing the topography of the surface, the typical look of a low dune island in the estuary of the river Elbe was imitated: the initial form was a circle covering about 30 ha. This was supported by concentric bush fences at the periphery, a double circle of bush fences at the edge and also three parallel bush-fence lines in the center of the island. The latter ones were built to promote the development of primary dunes. The mean height of the new island was 4.25 m above sealevel, reaching 5.2 m on the top of the

dunes. In late summer of 1991 a kidney shaped reef was created in the northwest of the island to protect it from strong sea erosion (waves wash against the reef). To minimize eolic sediment drift on the island, high activities in sowing and planting dune vegetation (mainly Elymus arenarius, Ammophila arenaria and Agropyron junceum) have taken place.

3.3.2 Type

Dikes protect the majority of the Elbe estuary coast. In front of these dikes, especially on the northern coast, large flats of salt marshes exist. The salt marshes are being protected with several means:

Revetments

Hard constructions protecting the salt marsh edges in order to prevent cliff erosion.

Creating marshes by dumping dredged material

Deposition of dredged material on intertidal areas along the mainland or Wadden-sea side of the barrier island.

Outbanking of summer polders

Opening summer dikes in order to get a more frequent flooding of the area and higher sedimentation rates.

Groyne fields

Creating areas with reduced waves in which accumulation of fine sediments is stimulated.

Artificial drainage

Digging ditches in the salt marsh in order to stimulate water run-off after the area has been flooded and consequently vegetation growth in the lower parts of the salt marsh.

Grazing

Grazing by sheep and cattle with the aim of keeping vegetation low and reducing the amount of flotsam.

Lately, the last two measures are less frequently used: In Schleswig-Holstein the area with intensive grazing of sheep has decreased from 95% in 1989 to 45% in 1995. In accordance with the Schleswig-Holstein salt marsh management plan artificial drainage in ungrazed salt marshes within the Schleswig-Holstein National Park has been stopped. Also in the Niedersachsen National Park there has been a progressive reduction of grazing. Presently 60% of the salt marshes are unused, 24% are extensively used and 16% are heavily grazed. Here also artificial drainage has been reduced considerably.

3.3.3 Costs

The organization and administration of (public) coastal defence in Germany is in the responsibility of the respective states. However, as coastal defence has national consequences, capital measures are co-financed by the federal government with 70% of total eligible costs (the other 30% are matched by the states). The maintenance of existing state coastal defence structures, on the other hand, is financed 100% by the state. Municipalities and/or local water boards that are responsible for coastal defence measures in their area normally have to contribute between 5 and 20% to the costs. The rest is financed by state (and federal) government. Finally, a small but increasing financial contribution to coastal defence comes from the European Union.

Table 4: Current national relative expenditure (%) for four categories of coastal defence measures in the Wadden Sea.

	Dikes	Other hard constructions	Sand nourishment	Salt marsh works
Lower Saxon	80	10	5	5
Schleswig-Holstein	50	10	15	25

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

The attempt to establish a bird-protecting-island (Nigehoern) with natural features has been succesful. In the area of the bush fences the vegetation of white dunes has developed successively, in the edge of the island vegetation of drift line communities appeared as well as of salt marshes.

4.2 Effects related to socio-economic aspects

Nature development on the island Nigehoern succeeds. Already in the first spring after preparing the island, Nigehoern was colonized by breeding sea birds. From 1990 it was the preferred breeding area for little terns (Sterna albifrons) and kentish plovers (Charadrius alexandrinus), followed by arctic tern (Sterna paradisaea) and common tern (Sterna hirundo). In 1996 the whole colony of sandwich tern (Sterna sandvicensis) had moved to Nigehoern. Furthermore the new island had developed into an important resting area for the little tern (Sterna albifrons) and to an important moulting place for the barnacle goose (Branta leucopsis).

Furthermore, the flooding area of the Elbe estuary is sufficiently protected in the current situation. Foreshore erosion could threaten this safety bur for now this threat does not seem to be very big.

4.3 Effects in neighbouring regions

The Elbe estuary lies in the Wadden Sea. The Wadden Sea is a system that stretches from the Netherlands to Denmark. A lot of research into the area is being executed in a larger context between the governments of The Netherlands, Germany and Denmark.

4.4 Relation with ICZM

In both Schleswig-Holstein as Lower Saxon the coastal defence is currently regulated in policy. In Schleswig-Holstein this is done through the Schleswig-Holstein State Water Act and the Master Plan Coastal Defence. In Lower Saxon the legal basis is in the Niedersachsen Dike Act. They contain both regulations for design, maintenance, supervision and usage of dikes, forelands, dunes and other coastal defence structures and responsibilities of the authorities and the water boards.

In future, the coastal defence policy will probably increasingly include risk analyses for single flood units (risk being defined here as the product of the probability of dike breaching and the damage potential in the flood unit). Further, more attention will be paid to public participation and the integration of other interests in coastal defence policy (integrated coastal defence management).

4.5 Conclusions

Effectiveness

The Elbe estuary has an overall tendency for sedimentation instead of erosion. This is mainly caused by an a-symmetrical tidal period. Locally erosion of marshes and islands threathens important habitats and/or coastal defences (dikes).

A major success was reached when the artificial island Nigehoern was colonized by migrating birds in the first year after it was built. This island has more or less taken over the role of the rapidly shrinking island Scharhoern. The loss of the tidal marsh island Scharhoern was compensated.

The salt marshes are being protected with several means, with an overall change to soft measurements since the 1970s. The effect is difficult to assess, as the marshes also have a natural capacity to compensate the effects of sea level rise and thus accrete and rise in level.

Gaps in information

As no real problems due to erosion have been observed up until now in the Elbe Estuary, no specific information could be found on impacts or issues concerning threat to life and property. Further more the most useful information describes the whole of the German North Sea coast with little specifics on the Elbe Estuary.

5. REFERENCES

Common Wadden Sea Secretariat (CWSS) (2001). *Coastal Protection and Sea Level Rise (Final Report),* Trilateral Working Group on Coastal Protection and Sea Level Rise (CPSL), Wilhelmshaven, Germany, ISSN 0946-896X.

Internet:

http://www.dfd.dlr.de/projects/TIDE/morphodynamic.html

http://www.rivernet.org/elbe/

http://cwss.www.de/TMAP/WSE7/WSE7text.html

http://www.encyclopedia.com/html/E/Elbe.asp

http://www.tdctrade.com/shippers/14/01port/port05.htm

http://www.hydromod.de/projects/OPCOM/CM_de.html

http://www.netcoast.nl/projects/netcoast/info/download/wcc_apen2.doc

http://www.coastalguide.org

Figures

Fig.1: http://www.icm.noaa.gov/country/germany.html
Fig 2: http://www.dfd.dlr.de/projects/TIDE/morphodynamic.html

Fig.3: see Literature references.
Fig.4: http://www.neuwerk-insel.de/index1.html
Fig.5: http://www.cux.wsd-nord.de/
Fig.6: see Literature references.

Fig7: http://www.coastalguide.org

Tables:

Table 1: http://cwss.www.de/TMAP/WSE7/WSE7text.html
Table 2: http://cwss.www.de/TMAP/WSE7/WSE7text.html
Table 3: Michael Bergemann, Arbeitsgemeinschaft für die Reinhaltung der Elbe (ARGE ELBE), Hamburg.
Table 4: see Literature references.