10. Estuaries

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The river mouth of the Varde Å, Denmark (Photo: J. Frikke).

10.1 Introduction

Estuaries can be defined as tide influenced transition zones between marine and riverine environments. According to the Wadden Sea Plan, the estuaries in the Wadden Sea Area are delimited on the landward side by the mean brackish water limit (salinity 0.5) and on the seaward side by the average salinity of 10 at high water in the winter situation. As in the 1999 QSR the freshwater tidal reaches were included in this review, as they form an integral part of the estuarine habitat. The EC-Water Framework Directive (WFD, 2000, Art. 2) also gives a broader definition of estuarine transition zones: 'Transitional waters are bodies of surface water in the vicinity of river mouths which are partly saline in character as result of their proximity to coastal waters but which are substantially influenced by freshwater flows'.

Target

Valuable parts of estuaries will be protected and the riverbanks will remain and, as far as possible, be restored in their natural state.

In the Wadden Sea, six estuaries can be described: Varde Å, Godel, Eider, Elbe, Weser and Ems; in the Dutch Wadden Sea, no tidal rivers have remained (Schuchardt *et al.*, 1999). The main features of these estuaries are shown in Table 10.1. The Godel is in fact a small river on the island Föhr. It is mentioned as an example for other smaller rivers within the coastal area along the Wadden Sea.

In the next paragraphs new information on the main developments in these estuaries, not documented in the 1999 QSR, will be presented.

10.2 Results of the 1999 QSR

There are only six estuaries in the Wadden Sea area (Ems, Weser, Elbe, Eider, Godel, Varde Å) so that there are only few larger natural transitions between fresh and salt water. The Varde Å and Godel estuaries have retained their natural character. The Ems, Weser and Elbe and their tributaries have been modified considerably by endikement and deepening. The anthropogenic impact on these estuaries is still increasing as a result of the current deepening of the Elbe and Weser and the construction of a storm surge barrier in the Ems. The 1999 QSR concluded that these estuaries are moving farther away from the Targets.

It was recommended to further detail the Target for estuaries taking into account the special character of each estuary and specifying the notion 'valuable parts', to evaluate the consequences of further anthropogenic impacts, to prepare an inventory of the most suitable sites for de-embankment and to improve the physical condition, such as restoration of gradients of salinity and tidal amplitude.

	Varde Å	Eider	Elbe	Weser	Ems
Drainage area above tidal weir (x 10^3 km^2)	1.1	2	135	38	13
Mean river discharge (m^3/s)	13	23	725	323	125
Mean tidal range at tidal weir (m)	1.3	2	2.4	4.1	2.8

Table 10.1: Main features of the five larger estuaries debouching into the Wadden Sea (Schuchardt *et al.*, 1999).

10.3 Hydrological and morphological changes

Since the beginning of the 20th century, the Elbe, Weser and Ems estuaries have been significantly altered due to deepening of shipping routes and coastal protection measures (Schuchardt *et al.*, 1999; Lozán and Kausch 1996). An analysis carried out within the Water Framework Directive in 2004, resulted in a classification of these transitional waters as 'Heavily Modified Water Bodies' because of significant changes of such aspects as width-depth ration, tidal amplitude, upper tidal limit, current velocity and of a reduction of tidal flats and brackish marsh habitats (EG-WWRL Bericht Ems, 2004; EG-WWRL Bericht Tideweser, 2005; EG-WWRL Bericht Tideelbe, 2004; EG-WWRL Bericht Eider, 2004).

10.3.1 Hydrological changes

Jensen *et al.* (2003) investigated the changes in mean high water (MHW) and mean low water (MLW) time series of the Ems, Weser and Elbe over the period 1936 to 1999. There has been a rise in MHW over time, which corresponds to the sea level rise in the North Sea and therefore has a natural cause. However, their results on MLW show a decreasing trend over time which deviates from results seen in the North Sea. The authors attribute this to the effects of enlargement measures in the rivers. A more detailed description is given below for each of the three estuaries.

The differences of the MHW of the gauges Herbrum and Papenburg in the Ems do not show any significant changes. A slight rise of the MHW differences can be listed from the year 1964. Within the time span 1964-1997 some greater enlargement measures in the Lower Ems increasing the depth to 5.7 m (in 1984), to 6.8 m (1991/92) and to 7.3 m (in 1994) were carried out. The MLW differences of the gauges Herbrum and Papenburg decreased at the gauge Papenburg (approx. 34 cm) and at the gauge Herbrum (approx. 66 cm) between the years 1958 and 1962. The causes for that are attributed to the enlargement measures in 1984, 1991/92 and 1994.

The MHW differences of the gauges Bremen-Große Weserbrücke and Vegesack in the Weser show an increasing trend, the MLW differences a decreasing trend. In this time series, the greater enlargement measures can be seen (1921/28 enlargement of the outer Weser to approx. 10 m, 1969/71 enlargement of the outer Weser to approx. 12 m, 1973/78 enlargement of the lower Weser to approx. 9 m). A further enlargement of the Weser estuary is still at the planning stage (www.weseranpassung.de).

The MHW differences at the gauge St. Pauli (and with that the MHW in Hamburg) in the Elbe did not change significantly from about 1950 up to about 1964. In this period the shipping fairway was deepened to 11 m. From about 1964 up to 1978 (fairway enlargement to 12 m and then to 13.5 m) the MHW differences increased about 22 cm. After the end of the enlargement measure, the MHW differences did not change significantly up to 1999. The MLW differences at the gauge St. Pauli decreased uniformly from around 1960 (11 m enlargement) up to about 1974 (beginning of the 13.5 m-enlargement). After that an accelerated decrease occurred up to the end of the enlargement measure in 1978. During the 13.5 m-enlargement measure a lowering of MLW of 23 cm occurred, followed by a further lowering around about 24 cm up to 1999. This can be taken as a long-term hydrological effect. The differences between MHW and MLW at the gauge Bunthaus show a similar behavior as the differences at the gauge St. Pauli. The consequences of the enlargement measures are reflected in the time series. It is striking that the run of the differences at the gauge St. Pauli is more regular than at the gauge Bunthaus. The cause for this behavior is the higher river discharge influence and the lower influence of the tide at Bunthaus as compared to St. Pauli. A further enlargement of the Elbe estuary is still at the planning stage (www.zukunftelbe.de).

It has to be noted, that at present for the estuaries Ems and Elbe the differences between MLW in the estuary and MLW in the North Sea are nearly zero, whereas for the Weser estuary this difference has been zero since 1980. Further investigations are needed to clarify this.

In the Varde Å estuary there have not been major changes in the hydrological regime since many years.

10.3.2 Morphological changes

Since the 1999 QSR deepening of shipping routes has continued in the Elbe and Weser estuaries and further plans are being discussed for future enlargement measures. In the Ems, the construction of the storm surge barrier (Emssperrwerk) at Gandersum was started in 1998 and completed in 2002. The storm surge barrier is designed as a flood defense and to artificially maintain high water depth to allow passage of large cruise ships built at the Meyer shipyard at Papenburg. When the barrier is open, the profile of the river is unchanged, so there are no consequences for the geomorphology. Dutch-German measuring campaigns have not been able to demonstrate clear ecological effects due to closure of the barrier .

The siltation of the Bocht van Watum (Ems) has continued since 1999 (CSO, 2001). The gully might disappear in time, changing the system from a 2-gully system to a 1-gully system. There are no management objectives yet for this process in the Ems, as opposed to the Western Schelde estuary where the 2-gully system is preferred from the point of view of safety, shipping and ecology.

Between 1970 and 2000 there was an increase in the concentration of suspended matter in the middle of the southern part of the Ems estuary close to Delfzijl (Merckelbach and Eysink, 2001). It is unknown if this is caused by the dredging activities. The 1999 QSR reports a yearly average of 9.4 million m^3 of sediment dredged from harbors and shipping channels in the Ems estuary over 1989-1997. As Dutch dredging did not change much (about 4 million m^3/yr; data Rijkswaterstaat) and German dredging in 2002 amounted to about 7 million m^3 (Mulder, 2004), present dredging effort is estimated at 9–10 million m^3 annually. Although some of this sediment was actually removed from the system, the majority was dumped elsewhere in the estuary. There is continual dredging, primarily for maintenance purposes. The effects of this on the estuarine system with regard to coastal protection and ecology are unclear. Local effects have been studied (BfG, 2001). In the 'Emder Fahrwasser' continuous dredging takes place. The material (1/3 sand, 2/3 mud) is relocated at disposal sites in the outer estuary ('Dukegat'). The described effects include local and short-term raised turbidity, and incorporation of mud in originally sandy sediments. Regarding biota there is partly reduced biomass or species numbers and a shift in species composition, the latter being caused by changes in sediment composition. In the upper Ems estuary (upstream of Gandersum) dredging is carried out only for maintenance purposes on a case-by-case basis for single cruise ship transfers. The dredged material is disposed on land.

10.4 Ecological structure

A characterization of estuarine habitats, abiotic structures and flora and fauna was given by Schuchardt *et al.* (1999). Recent information on the importance of estuaries for fish is compiled in chapter 8.6 by addressing diadromous fish (pelagic and demersal); for the Ems-Dollard estuary, results of a migratory fish survey are presented .

The WFD Reports 2005 have also pointed out that the Ems, Weser and Eider estuaries are still influenced by high loads of nutrients and contaminants mainly from diffuse sources upstream.

Macrozoobenthos communities have been monitored for all German estuaries by the Federal Institute of Hydrology (BfG, Koblenz) since 1995, and is used as an indicator for the evaluation of environmental conditions. Samples are usually collected once a year in the fall season. In the Ems, Weser and Elbe estuaries six stations are monitored, while in the Jade embayment five stations are investigated, as are three stations in the Eider estuary. At each station six replicates were usually collected using a van-Veen grab (0.1 m^2) and a dredge haul was taken (Nehring and Leuchs, 1999).

In Figure 10.1 numbers of macrobenthos species are presented for different estuaries and their salinity zones for the years 1999–2002. Within each of the German estuaries, with the exception of the Elbe, there is a trend of higher species numbers being present in the polyhaline part (more seaward), and lower numbers in the oligohaline part (towards the river). In the Elbe estuary, lower species numbers were found in the polyhaline part which could be explained by higher contamination of sediments. The low species numbers in the oligo- and mesohaline parts of the Ems are probably due to occurrence of fluid mud. The species numbers in the Eider estuary are not fully comparable to those of other estuaries due to a lower number of samples.

Among the macrobenthos, also Red List species were found in these estuaries, *viz.* the hydroid *Sertularia cupressina*, the anemones *Metridium senile* and *Urticina felina,* the polychaetes *Ophelia rathkei, Boccardiella ligerica* and *Nereimyra punctata*, the crustaceans *Corophium lacustre*, *Eurydice pulchra, Idotea linaris* and *Palaemon longirostris*, the bivalve *Petricola pholadiformis*, and the gastropod *Crepidula fornicata*. The occurrence of these species indicates the presence of suitable biotopes, although no information is available about the spatial extent of these.

In the Varde Å estuary, several decades of intensive fertilization and drainage of salt marshes and meadows did cause habitat loss and impoverishment of biodiversity. In 1998, a restoration project was started which aimed at less intensive agriculture, resulting in a reduction of nutrient and pesticide leaching into the aquatic environment and an improvement of the biological values of the meadows and wetlands in the estuary. The aim of this project is mediated by compensation to the land owners and users of any loss of income. The expected result is a better compliance to the restoration obligations in the Birds and Habitats Directives.

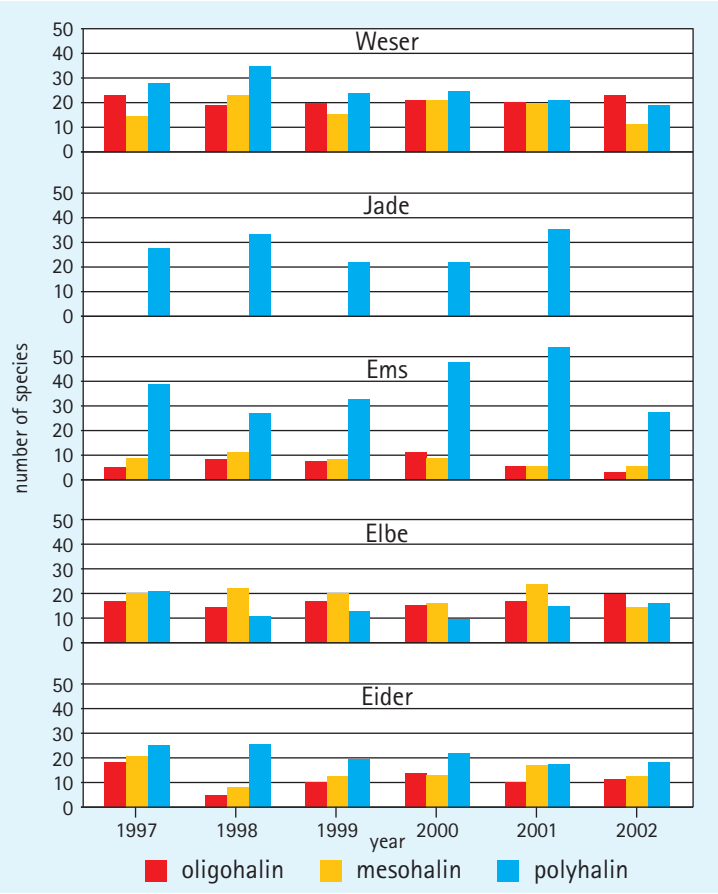

Figure 10.1: Development of macrozoobenthos species numbers (1997–2002) in the estuaries of the rivers Eider, Elbe, Ems and Weser and in the Jade embayment at three stations (source: BfG, Koblenz).

10.5 Target evaluation

Although the target is not specific as to the 'valuable parts' of estuaries to be protected and restored, the available information shows that most estuaries of the Wadden Sea still do not meet the target, mainly as a result of significant changes in hydrology, geomorphology and of poor water quality.

10.6 Conclusions

The Ems, Weser and Elbe estuaries and their tributaries have been modified considerably by endikement, deepening, harbor construction and other human use which resulted in significant changes in width-depth ratio, tidal amplitude, upper tidal limit, current velocity and in an reduction of tidal flats and brackish marsh habitats.

In the first analysis and characterization of transitional waters within the WFD Reports 2005 (WFD, Article 5) all transitional waters were classified as 'Heavily Modified Water Bodies' because of significant morphological changes and corresponding negative effects on biological components. It was also concluded that the 'Good Ecological Potential' of these waters will probably not be reached by 2015 mainly due to the still high input of nutrients and hazardous substances. Although the loads have decreased over recent decades (see chapter 4) a negative effect on the estuaries' ecosystem is assumed. Further measures are necessary to reduce these significant loads.

The lower number of macrozoobenthos species in the Elbe estuary as compared to the Weser and Ems estuary is probably caused by a higher degree of pollution. However, several new species (neozoons) were found in the German estuaries for the first time indicating ecological space within the estuarine benthos communities. Occurrence of 'Red List' species was also observed which may indicate the presence of suitable biotopes; further information is necessary concerning the spatial extent of these biotopes.

In the Varde Å estuary, a project is ongoing since 1998 aimed at restoration of natural values of estuarine habitats through reduction of agricultural practice in salt marshes and meadows.

10.7 Recommendations

A number of recommendations from the 1999 QSR are still valid. In addition, the WFD Reports 2005

have to be taken into account. The following recommendations pertain to the Wadden Sea estuaries:

- Integration of the tidal freshwater reaches into the definition for estuaries according to the typology of the Water Framework Directive.
- Existing ecological targets for estuaries must be specified, taking into account the individuality of each estuary.
- Monitoring of ecological long-term changes, other than water quality and macrozoobenthos in the estuaries, is necessary.
- Active restoration of estuarine habitats (especially shallow areas and foreland) is necessary in all estuaries under consideration. Problems linked to the artificial increase of the tidal range have to be given special attention.
- Consequences of further deepening, barriers and harbor extension should be evaluated very carefully, taking into account the historical deterioration of the estuaries.
- Further improvement of water quality is necessary, especially for the Elbe.

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