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Estuaries

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1. Introduction

Varde Å estuary
(Photo: John Frikke)

1.1 Characterization of the Wadden Sea estuaries

Estuaries can be defined as tidally influenced transition zones between marine and riverine environments. However, several definitions in the scientific literature as well as in conventions and directives exist (see box below), especially in defining the down- and the upstream border. The definition within the framework of the Habitats Directive (HD) corresponds approximately to the WFD definition (estuaries are called "transitional waters" in the WFD). Especially the trilateral definition is excluding some areas at the downstream border compared to the WFD and HD definition.

Most definitions exclude the freshwater tidal reaches, although they form an integral part of the estuarine ecosystem (Fairbridge, 1980; Schuchardt *et al.,* 1993a).

However, in the present review the tidally influenced freshwater reaches are included. Laterally all areas up to the main dike or, where absent, the spring high tide water line are included.

According to the above definition, there are five estuaries in the Wadden Sea region: the Varde A estuary in Denmark and the Eider, Elbe, Weser and Ems estuaries in Germany. The Eider estuary has not been included in the Leeuwarden definition (Leeuwarden Declaration, 1994) due to the storm surge barrier. In terms of structure and function, however, it should be included.

On the one hand, these estuaries are of high relevance for the Wadden Sea ecosystem (input of nutrients and toxic substances, sediment dynamics, nursery and feeding area). On the other hand, the estuaries themselves are a specific habitat, characterized by strong variability and dynamics of key factors, such as salinity, tidal range, turbidity and others. From an ecological point of view they are important, *e.g.* for migration of a number of species, but additionally they are inhabited by various brackish-water and at least estuary-endemic species and are thus of special importance for nature protection reasons. However, in con-

Some definitions of an estuary:

Pritchard (1967): "..... and within which sea water is measurably diluted with freshwater derived from land drainage"

Fairbridge (1980): "... is defined as an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, ..."

Stade Declaration (1997): "....the estuaries in the trilateral cooperation are delimited on the landward side by the mean brackish water limit, and on the seaward side by the average 10 PSU isohaline at high water in the winter situation".

Water Framework Directive (WFD) (using the term "transitional waters" instead of estuaries): " bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows".

Habitat Directive (HD): "....the downstream part of a river valley, subject to the tide and extending from the limit of brackish water.....".

trast to the Wadden Sea the estuaries are strongly altered by human activities (Reise, 2005).

The estuaries under consideration are mesotidal coastal plain estuaries opening into the Wadden Sea. Morphologically, the river mouth can be divided into two sections: a river-like inner part (including the tidal freshwater, the oligohaline and parts of the mesohaline reaches) between a tidal weir and the outer part. This outer part is characterized by a funnel-like morphology with very extended tidal flats, being part of the Wadden Sea. The Ems estuary differs from this general structure due to the Dollard, a brackish bay, and the Eider Estuary due to the construction of a storm surge barrier and the Varde A, where mixing of river and sea water takes place normally in the Ho Bugt seaward of the narrow river. According to the above definition, this paper deals mainly with the inner parts of the estuaries.

The estuaries vary considerably in size, length and river discharge (see Schuchardt *et al.*, 1999).

Except the Varde A, in all estuaries the adjacent lowlands are protected by dikes against flooding, either from the sea or from the river, and they are of great economic importance for shipping, agriculture and industrial purposes and have been altered by human activities.

1.2 Trilateral Policy and Management

Estuaries are an integral part of the Wadden Sea and play an important role in its ecology as has been illustrated in the different Wadden Sea Quality Status reports (Schuchardt *et al.*, 1999; Essink *et al.*, 2005). Thus the estuaries of Varde A, Elbe, Weser, Ems and Eider have been included in the Trilateral Cooperation Area. However, the Eider estuary with its storm surge barrier has not been included in the chapter Estuaries (Trilateral Wadden Sea Plan, 1997). The following trilateral target regarding estuaries has been formulated:

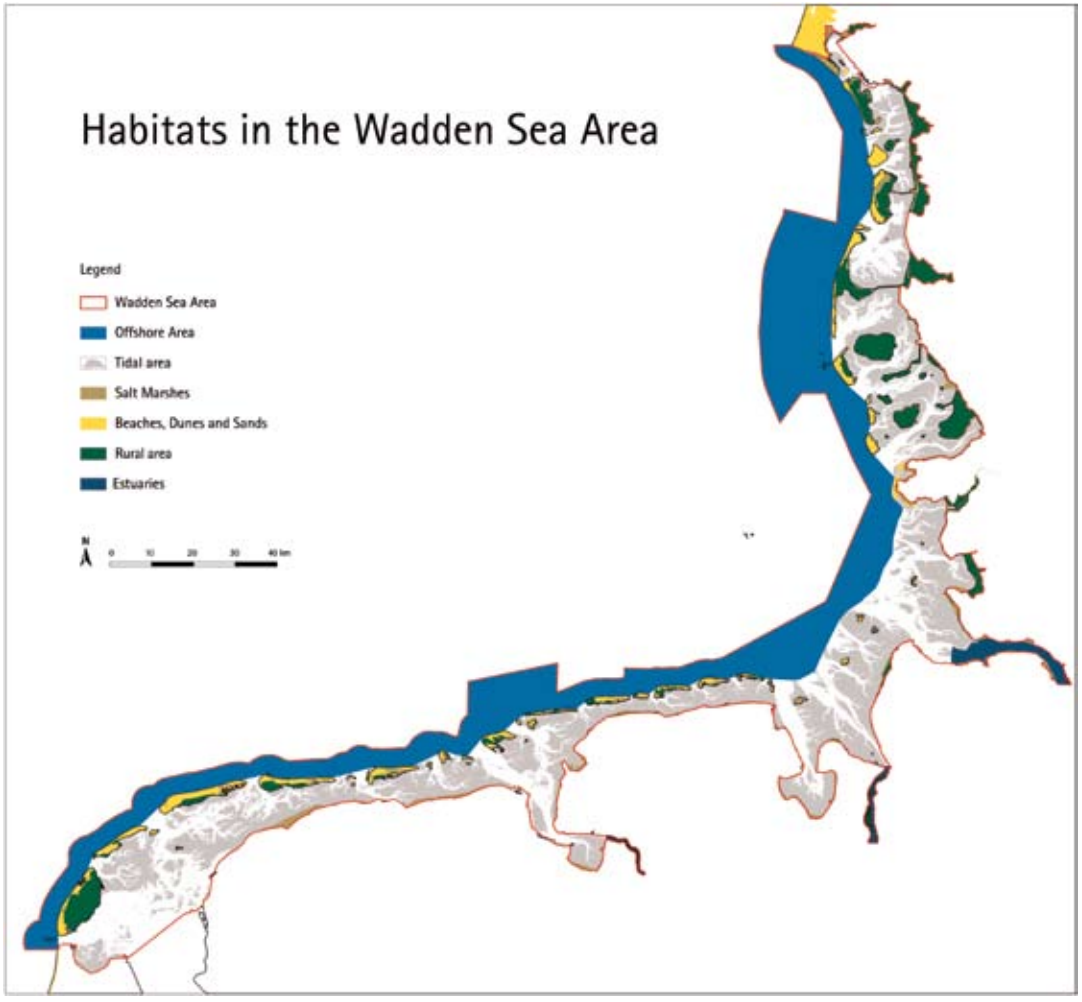

Figure 1: Wadden Sea Estuaries according to the Stade Declaration (1997) : Varde A, Elbe, Weser and Ems.

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

Concerning Trilateral Policy and monitoring, the Trilateral Wadden Sea Plan (TWSP 1997) stated that the relevant parts of the policies formulated for important elements of the Wadden Sea (*i.e.* water, salt and brackish marshes and the rural area) also apply to valuable parts of the estuaries. Additionally it has been formulated that:

- The extension, or major modification, of existing harbour and industrial facilities and new construction shall be carried out in such a way that the environmental impact is kept to a minimum and permanent, or long lasting, effects are avoided and, if this is not possible, compensated. In the Conservation Area, new, not yet approved plans for new construction, as well as for the extension or major modification of existing harbour and industrial facilities, are not allowed unless such is necessary for imperative reasons of overriding public interest and if no alternative can be found.
- The deepening of shipping lanes in the estuaries will be carried out in conjunction with an overall assessment of how to compensate and mitigate the measures.
- The impact of dumping dredged materials will be minimized. Criteria are, amongst others, appropriate dumping sites and/or dumping periods.
- Valuable parts of the estuaries will be protected and river banks will remain and be restored in their natural state, as far as possible.
- The transition zone between fresh and salt water should be as natural as possible.

The Policy Assessment Report (PAR) 2005, prepared for the Tenth Trilateral Governmental Conference (Schiermonnikoog Declaration, 2005), stated that the estuaries of Ems, Weser and Elbe fail to meet the target and that further effort will be necessary to implement the target. The PAR placed emphasis on reduction of natural transitions between fresh and salt water and recommended, amongst other things, a restoration of such gradients. The development of management plans for transitional waters, as required by the WFD, is seen as an opportunity in this respect by the PAR.

Estuaries are not explicitly mentioned in the Common Package of the Trilateral Monitoring and Assessment Program (TMAG, 1997). However, data on estuarine macrozoobenthos resulting from a regular monitoring programme of the Federal Institute of Hydrology (Essink *et al.*, 2005) can be regarded as part of the TMAG.

Currently, monitoring programmes within the scope of the Water Framework Directive (WFD) and the Habitat Directive are under development and include different quality components.

1.3 Findings of the QSR 2004

Based on the findings of the WFD Reports in 2005, which classify all transitional waters as "heavily modified water bodies", the QSR 2004 (Essink *et al.*, 2005) has concluded that most estuaries of the Wadden Sea still do not meet the target, mainly as a result of changes in hydrology, geomorphology and poor water quality.

Although a reduction of the inputs of nutrients and hazardous substances over the last decades has been noted, negative effects on the estuarine ecosystems have been assumed.

2. Ecological status and assessment

2.1 Method and data sources

Schuchardt *et al.* (1993) have evaluated long-term changes in the ecological situation of the inner estuaries of Eider, Elbe, Weser and Ems comparatively and based on a historical reference situation. The simple assessment approach makes use of a few selected indicators for the system. These describe central aspects of the biotope structure and ecosystem functions as well as directly indicate the anthropogenic influence. For pragmatic reasons, however, the data availability also had to be a key criterion. In a current paper, the only-slightly-altered assessment approach was applied again (Schuchardt *et al.*, 2007) so that even the changes in the past 20 years have been documented. These results are presented here in abridged form.

The parameters of tidal range, size of the dike foreland areas, oxygen concentration in the water and heavy metal contamination of the sediments were evaluated comparatively and based on a historical reference situation.

This heterogeneous parameter structure is a reflection of the demand to include both the water quality and the water body structure in the analysis. Biological components were not taken into account since the available database was too narrow. At present work is being carried out on monitoring programmes within the framework of implementation of the WFD, and consequently it will be possible to give consideration to biological components in future.

As far as possible, the comparison is based on quantitative data on the individual indicators, though in some cases only qualitative statements are possible. In this process the status quo situation of each single estuary is compared to a defined historical reference state and, furthermore, the status quo situations of the four estuaries are compared to each other.

2.2 Hydrological and morphological changes

Morphological alterations of rivers and estuaries have strongly affected virtually all estuaries under consideration except the Varde A: the main reasons were coastal protection and land reclamation on the one hand, and adaptation to increasing ship numbers and sizes on the other.

2.2.1 Indicator: Tidal range

The change in the tidal range represents an indicator for changes in water body morphology, particularly due to expansion measures and coastal protection. It is also relevant for changes in the size and characteristics of habitats like tidal flats. There are strong changes, especially in the innermost parts of the estuaries (Figure 2).

Lower Eider

The tidal range in the Eider has risen from approx. 2.6 m at the Tönning gauge towards the end of the last century to 2.8 m today (not given in Figure 2). At Friedrichstadt the mean tidal range at present

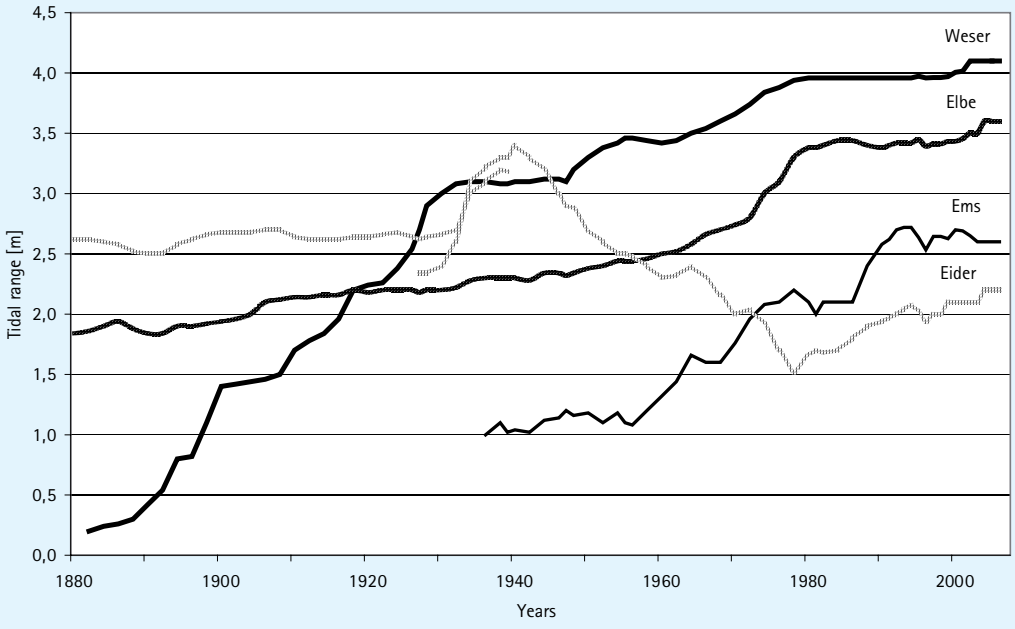

Figure 2: Changes in tidal range between 1880 and 2005 in the Eider (gauges Tönning and Friedrichstadt), Elbe (gauge Hamburg St. Pauli), Weser (gauge Bremen Oslebshausen) and Ems (gauge Herbrum) (5-year running mean) (from Schuchardt *et al.*, 2007).

is 2.3 m. In the meantime, however, changes to 3.4 m and 1.6 m have taken place: after the construction of the Nordfeld tidal weir (1936) a significant increase in the tidal range occurred for over 10 years since the mean low tidal water dropped considerably (Wieland, 1992). From 1944-1970, however, the tidal range fell from approx. 3.4 to 1.6 m as a consequence of the increased sand input from downstream. The current tidal range at the Friedrichstadt and Tönning gauges is the result of targeted flood reduction by means of the Vollerwiek storm surge barrier (Wieland, 1992) and therefore the relatively small change in the tidal range by a few decimetres, based on the situation around the turn of the century, is not an indicator for a slightly altered hydraulic (and ecological) situation.

Lower Elbe

In the Elbe, the tidal range at the Hamburg-St. Pauli gauge has risen from 1.9 to 3.6 m, *i.e.* by a factor of 1.9. The development over time shows a gradual but relatively continuous increase from around 1900 to about 1960 and then a significantly steeper rise until around 1980, *i.e.* during the deepening measures to -11, -12 and -13.5 m chart datum. The deepening to -14.5 m chart datum in 1999 led to a further, relatively small rise that was predominantly weaker than that forecast in the approval procedure (Strotmann, 2004). Among others, Hochfeld (2007) provides an up-to-date overview of the various expansion measures.

Lower Weser

The tidal range in the Lower Weser has risen from 0.2 to 4.1 m in Bremen in the past 130 years, *i.e.* by a factor of 20!. The increase in the tidal range was the steepest during the first three expansion measures between 1890 and 1930, which resulted in very substantial changes in the morphology of the Lower Weser (Busch *et al.,* 1984). After approximately 1930 the rise in the tidal range continued due to further expansion measures, but took place less rapidly. Compared to the first deepening measures, the last (and still the most recent) deepening of the Lower Weser from 1973-77 also led to a less steep rise. However, it was significantly more pronounced than was forecast within the framework of the planning approval procedure (Wetzel, 1987). Due to the deepening of the Outer Weser in 1999 to -14.0 m chart datum and further measures like the backfilling of harbour basins, the tidal range has increased further to a relatively minor extent. The rise predominantly corresponded to the figure forecast in the approval procedure (Lange, 2004).

Lower Ems

In the Ems, the tidal range in Papenburg has risen from approx. 1.4 m around the turn of the century to 3.1 m in the 1980s to 3.5 m today, *i.e.* by a factor of 2.5 (at the Herbrum tidal weir the rise is somewhat lower). The development over time differed from the Weser. As a consequence of smaller-scale measures (river cut-offs), the tidal range increased at Papenburg to approximately 1.7 m until around 1935. A considerable rise did not begin until 1955, after extensive maintenance dredging had commenced. This steep increase in the tidal range continued until 1975 and then stagnated in connection with reduced maintenance dredging (Arntz *et al.*, 1992). A second phase with a steep rise then became perceptible from 1985 to approximately 1995 and encompassed the deepening to 5.7 m and the adaptation to growing new vessel sizes in Papenburg. The tidal range is altered temporarily today due to the damming-up of the Lower Ems through corresponding control of the Gandersum storm surge barrier and weir when the water level is raised for the transfer of newly built vessels (de Jonge, 2007).

2.2.2 Indicator: Dike foreland areas

Foreland areas between the mean spring tide high water line and the winter dikes, frequently flooded, are of special ecological importance. This is not only reflected in the occurrence of specific types of biotope, but also in the large-scale designation as Habitats Directive protection areas or EU bird sanctuaries that has taken place in the meantime. The current use and characteristics of the foreland vary. The change in the foreland areas represents an indicator for a loss in habitat due in particular to coastal protection, agriculture, industrial and settlement development and expansion measures. It is also relevant for changes in the storm tide and suspended matter dynamics as well as the capacity for nutrient retention.

Lower Eider

Dike construction in the Eider lowlands began around 1500 and the dike line was not closed until the end of the 19th Century. Since then, the dike lines have changed very little. In sections, a growth in foreland areas as a result of pronounced sand input can be observed. A comparison of topographic maps from 1889 and 1977 shows that the foreland areas between Tönning and Nordfeld (tidal weir) have not changed significantly. The situation is different in the section downstream from Tönning. A great increase in foreland areas took place here at the expense of tidal flats, due to construction of the Eider barrage.

Lower Elbe

Between 1896 and1905 and 1981 and 1982, the area of the foreland marshes decreased by approximately 52% on the northern bank of the Lower Elbe between Altona and Brunsbüttel and by approximately 75% (an average of about 66%) on the southern bank between Elbbrücken and Cuxhaven (Arge Elbe, 2004). The main reason for this was the extensive construction of dikes closer to the water after the severe storm tide in 1962. Storm surge barriers were also constructed on all tributaries in this context, in connection with relocation of the dike line closer to the water in most cases. This construction of dikes closer to the water after 1962 not only resulted in elimination of the tidal influence in large sections of the foreland areas with their ditch and tidal inlet systems, but also in various branches (the best known example is Haseldorfer Binnenelbe). At present, large-scale dike realignment is the subject of discussion within the framework of the "Tidal Elbe Concept" (Hochfeld, 2007).

Lower Weser

Between 1887 and 1975, the area between the winter dikes decreased from 133 to 78 km^2, while the loss in foreland area amounted to about 50% (Schuchardt *et al.*, 1993). The reason for the losses was shortening of the dike line, separation and backfilling of side arms, industrial locations and, in the 1970s, shifting of dike lines in connection with the construction of barrages on tributaries. The rise in the mean high tidal water, by contrast, did not contribute to a further decline in reed areas, as was determined for the period from 1950 to 2002 (Steege *et al.*, 2005). Currently, foreland areas are used for extension of the Brake port. At Luneplate near Bremerhaven, on the other hand, a polder that can be controlled for the tide is to be opened behind the winter dike as part of compensation measures. Opening of summer dikes and development of tidal polders have taken place at several places, others are in the preparation phase.

Lower Ems

A distinction regarding the loss of foreland areas can be made between two sections in the Lower Ems. While the foreland area has hardly been altered in the section downstream from Papenburg, considerable losses have occurred upstream from Papenburg due to dike construction in 1966. The foreland area (in front of the winter dike, *i.e.* including summer polders) has been reduced by about 70%. Based on the total foreland area, this means a decline of approximately 33% (Schuchardt *et al.*, 1993). Recently use has been made of smaller areas due to the construction of the Ems barrage, among other things. A current assessment within the framework of the Interreg project HARBASINS by Herrling and Niemeyer (2007) showed an approximately 20% loss of supratidal habitats for the section between Papenburg and Pogum in the period from 1898 to 2005.

2.3 Water quality

2.3.1 Indicator: Oxygen concentration

The oxygen concentration in the water in summer represents an indicator for pollution with oxygen-consuming substances and eutrophication, primarily by virtue of direct and diffuse discharges, relocation of dredged material and especially changes in the water morphology. It is a key ecological factor that is decisive for the structure of the biocoenosis. Oxygen deficit situations going significantly beyond those expected in natural form have been documented for the inner estuaries (Flügge *et al.*, 1989).

Lower Eider

Oxygen saturation in the Lower Eider of 55-90% in the summer has been documented for the 1960s (Kühl and Mann, 1971). After expansion of the treatment plant in the town of Tönning, saturation below 70% has hardly occurred from the 1980s to the present (however, this is deduced from limited data, since only individual measurements are available; data: LANU Kiel).

Lower Elbe

The oxygen concentrations in the Lower Elbe have been very well documented since the 1950s (www.arge-elbe.de) (Figure 3). The oxygen concentrations in the upper section of the Lower Elbe may be greatly reduced in summer. In the 1980s, concentrations of less than 3 and even below 1 mg/l were measured over long periods of time. Since the 1990s, concentrations of less than 3 mg/l have been significantly reduced both spatially and temporally (Arge Elbe, 2004). A major environmental relief factor was the reduced primary pollution due to expansion of the treatment plants in Hamburg and, after reunification, in the Upper and Middle Elbe. The reduced toxic inhibition of primary plankton production in the Middle Elbe and the resulting increase in secondary pollution in the Lower Elbe, as well as other measures like backfilling of Mühlenberger Loch and, though this is controversial, further deepening of the Lower Elbe, had polluting impacts (see Arge Elbe, 2004; Neumann, 2004; Kerner, 2007). At present it appears possible that the oxygen concentrations will worsen again.

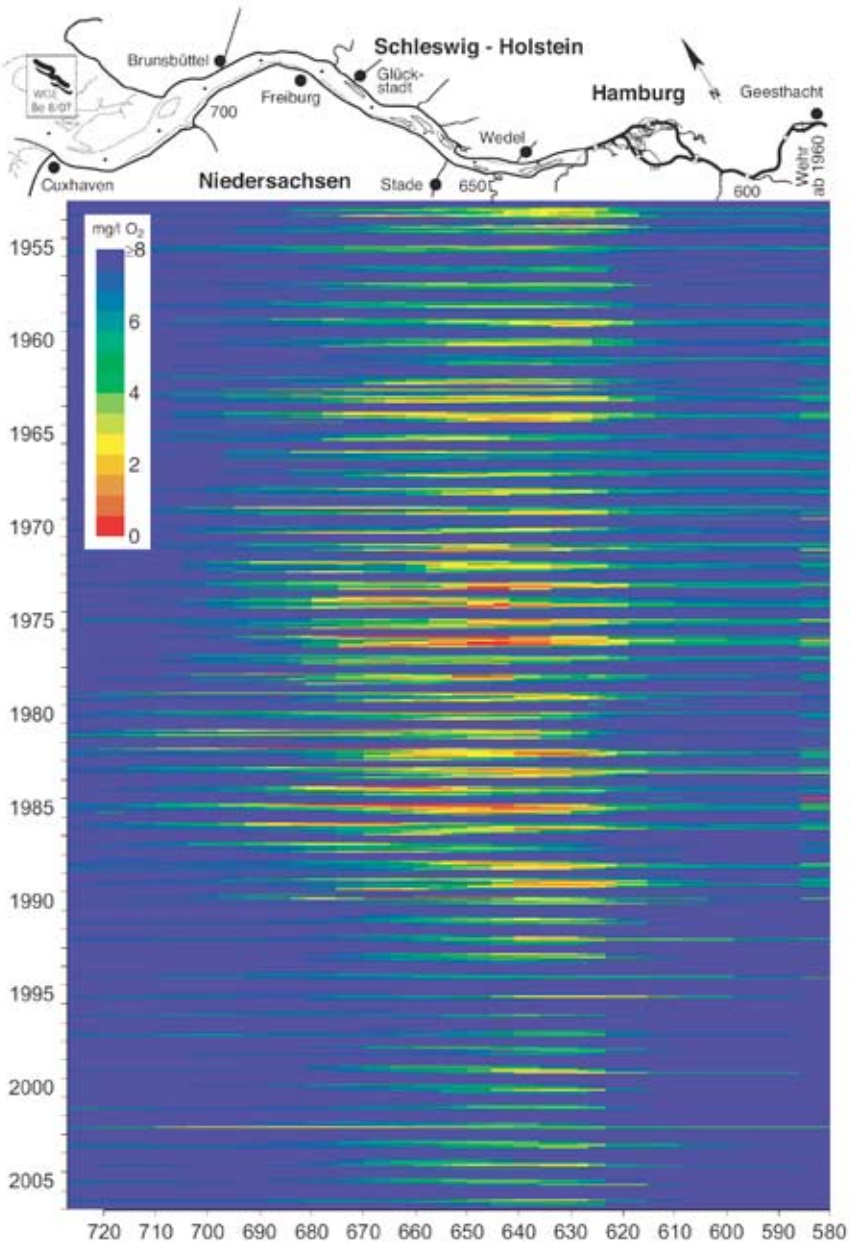

Figure 3:
Spatio-temporal plot of the oxygen concentration in the Elbe estuary between Geesthacht (tidal weir) and Cuxhaven. Source: Wassergütestelle Elbe.

Lower Weser

In the Lower Weser, too, extensive oxygen deficit situations, with concentrations below 2 mg/l, were documented before about 1985. Since 1985 (expansion of the Bremen treatment plant), the shortage situations have reduced substantially and this did not change significantly in the 1990s and thereafter (Grabemann *et al.*, 2005); oxygen concentrations below 4 mg/l hardly occur.

Lower Ems

The oxygen concentrations in the Lower Ems have changed substantially since the mid 1980s. This change is well documented by virtue of the fact that a comprehensive measurement network has been set up (Figure 4). Engel (2007) shows both the significant spatial and temporal extent of the oxygen deficiencies in summer in the Leer region and the intensification of the deficiencies: the minimum values have dropped from about 6 to less than 2 mg/l in the past 20 years. Schöl *et al.* (2007), too, show for the Papenburg, Leerort and Terborg measuring stations that the oxygen situation in the Ems estuary has worsened considerably. Since the mid 1990s, oxygen concentrations less than 4 mg/l have occurred to an increasing degree and even concentrations below 1 mg/l are

measured. The primary causes identified for this are the extreme increase in suspended matter concentrations, particularly as a consequence of the pronounced deepening of the Inner Ems for ship transfer (resulting in strong tidal pumping) and the intensive relocation of dredged material (Schöl *et al.*, 2007; de Jonge, 2007). Because of the very poor water quality, the biocoenosis (for smelt as an example, see Bioconsult 2007) in the inner Lower Ems has declined dramatically.

2.3.2 Indicator: Heavy metals

Heavy metal pollution of the sediments represents an indicator of the pollutant input into the water body, primarily due to direct and diffuse discharges. Increased concentrations with respect to the geochemical background occur in all water bodies. In the estuaries, concentrations that decline downstream are characteristic and essentially reflect the product of mixing more heavily polluted riverine and less polluted marine sediments.

The summary of the heavy metal concentrations from the 1980s (Schuchardt *et al.*, 1993) shows considerable differences for the various estuaries and the individual heavy metals in the degree to which the natural background values are exceeded. In the Lower Eider the excess was a factor of 2-3, in the Lower Elbe a factor of 3-30, in the Lower Weser a factor of 8-40 and in the Lower Ems a factor of 2-3.

Since around the end of the 1980s, a significant reduction in heavy metal pollution has taken place both in suspended matter and (to a lesser extent) in sediments, especially in the Elbe and Weser but also in the Ems, as a result of increased efforts

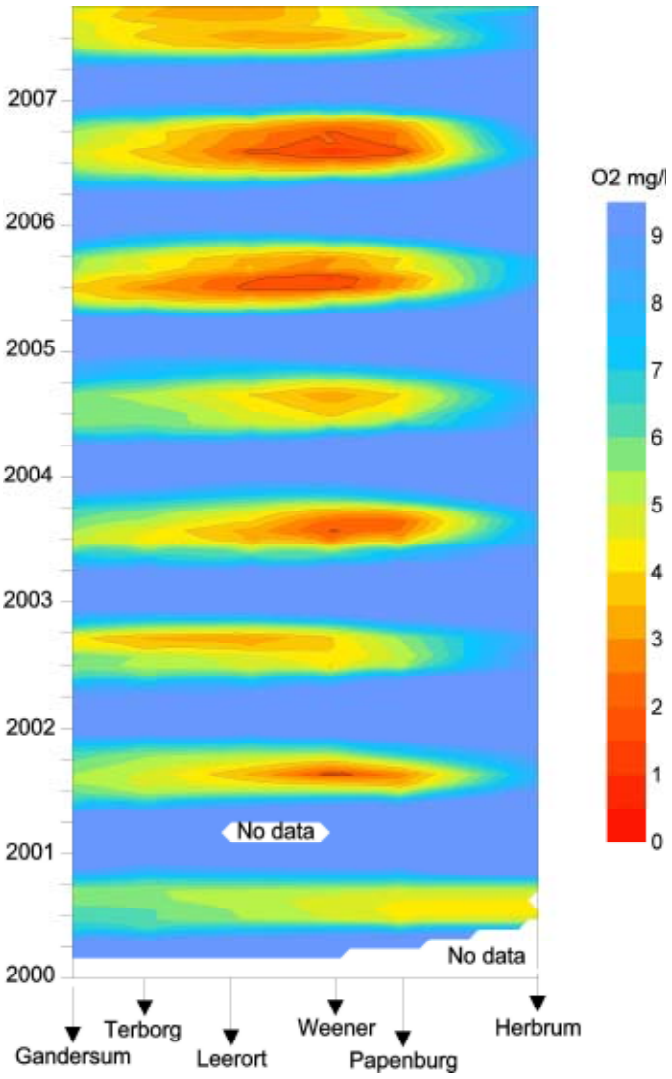

Figure 4: Spatio-temporal plot of the oxygen concentration in the Ems estuary between Herbrum (tidal weir, km -12.7, and Gandersum, km 35. Papenburg is located at km 0). (Source: data NLWKN; HARBASINS project).

in water protection (Bakker *et al.,* 2005; see also Report No. 5 in the QSR 2009). The reduction in the Elbe was more pronounced than in the Weser, primarily as a consequence of reunification. This also led to a substantial reduction in heavy metal depositions in the North Sea, in some cases to a factor of about 3 (Bakker *et al.,* 2005).

2.4 Long-term assessment

The results of the assessment of the recent ecological situation (1985; Schuchardt *et al.*, 1993b and 2005; Schuchardt *et al.*, 2007) related to a historical reference situation (about 1880) are compiled in Table 1.

The resulting comparison of the ecological situation in the 4 estuaries over the last 20 years clearly indicates that the problem areas identified by us towards the end of the 1980s (compared to a historical reference situation) have fundamentally remained the same, but different developments have taken place for the individual indicators in the various estuaries.

The morphological deformation of the Elbe and Weser estuaries because of their use as major waterways continued and continues even now due to further expansion measures. As a result, the tidal range has increased, though to a relatively weaker extent. This also applies, but to a significantly greater degree, for the Ems estuary as a consequence of several deepening measures. In addition to the impacts on the habitats of the tidal flats and shallow-water zones, the rise in the tidal flow oriented sediment transport above the turbidity zone (Sohrmann, 2006; de Jonge, 2007) is of particular significance. Higher maintenance expenditures and increased turbidity may be the consequences, giving rise to considerations regarding extensive counter-measures parallel to further expansion planning (among others Hochfeld, 2007). For individual aspects such as restoration of flood space, such measures are based on concepts developed by environmental organizations (Claus, 1998).

The enlargement of foreland areas in the estuaries has altered only to a relatively small extent in the past 20 years. The primary reason for this is the absence of further large-scale construction of dikes closer to the water, as took place in particular on the Elbe in the 1970s. However, there are further losses, especially due to port expansion work and industrial location and additional measures are planned. This contrasts to local ecological upgrading by opening summer dikes, for example. Large-scale provision of protective status to the foreland areas, the increasing necessity of flood space and simultaneous growth of foreland areas (also against the background of climate change, Schuchardt and Schirmer, 2005) will presumably require increased action in future, such as opening of summer dikes and dike realignment.

The efforts for greater water quality protection in the past decades also manifest themselves in the inner estuaries. As a result of expansion of the treatment facilities, oxygen-consuming processes have been reduced. Environmental relief is also perceptible for the Weser and, to a lesser degree, for the Elbe, too, where the deficiency was very pronounced in the past years. A significant change in the water quality (indicator: oxygen) in the past 20 years is evident for the Ems estuary. The acute need for remediation is considerably greater here than in the Lower Elbe.

As far as heavy metals as an indicator of the water quality are concerned, an improvement in the pollution situation overall is noted by virtue of the increased efforts for water quality protection.

About 1985	**Eider**	**Elbe**	**Weser**	**Ems**
Morphology / cross-sections	very strong	strong	very strong	moderate
Loss of foreland	none	very strong	strong	moderate
Deficiency of dissolved oxygen	small	very strong	strong	moderate
Heavy metals in sediments	moderate	very strong	very strong	strong
About 2005	**Eider**	**Elbe**	**Weser**	**Ems**
Tidal range	very strong	strong	very strong	moderate
Loss of foreland	none	very strong	strong	moderate
Deficiency of dissolved oxygen	small	**strong**	**moderate**	**very strong**
Heavy metals in sediments	moderate	**strong**	**moderate**	**moderate**

Table 1: Evaluation of the ecological status of the estuaries for about 1985 (above) and 2005 (below) related to a historical reference situation (about 1880) (Schuchardt *et al.,* 1993b and 2007). Categories of change: none, small, moderate, strong, very strong. Changes in status between 1985 and 2005 in bold.

3. Nature protection status

While the outer estuaries as parts of the Wadden Sea have been subject to special protection as a national park for about 20 years already, large-scale designation of the inner estuaries as protected areas, particularly within the framework of the European network Natura 2000, has taken place in conjunction with implementation of the Habitats Directive in recent years. This development encompasses the nature reserves of the EU Birds Directive of 1979 and the protection areas of the Habitats Directive (HD) that were stipulated in a two-stage procedure after a national and EU-wide assessment. The paramount goal of Natura 2000 is to preserve biodiversity in Europe.

3.1 Habitat types of Annex I of the Habitats Directive (selection)

In Annex I, the Habitats Directive designates the types of habitat of Community relevance that are to be protected or restored through implementation of the directive. Primarily the following habitat types are relevant in the estuaries:

1130 Estuaries: The estuaries habitat type encompasses large areas in the inner and middle estuary sections (see below). They include both water body habitats like sublittoral and eulittoral as well as the bordering reeds with varying characteristics that are closely linked via tidal inlets. The limnetic sections can be included.

1330 Atlantic salt meadows: This habitat type is characteristic of the shore sections of the outer estuaries to the extent they are not partially separated from the tidal dynamics through summer polders. Because of the outer boundary of the estuaries according to the Leeuwarden definition, this type of habitat is predominantly located seaward.

91E0 *Riverside forests with *Alnus glutinosa* and *Fraxinus excelsior* and 91F0 hardwood forests: These types of habitat occur in the estuaries only in the form of very small residual stocks. Because of the inner boundary of the estuaries according to the Leeuwarden definition, the potential area of distribution of these habitat types is primarily upstream.

3.2 Species of Annex II of the Habitats Directive

Annex II of the Habitats Directive designates the species of exceptional community significance that are to be protected or restored through implementation of the directive. In addition to migrating fish species, particularly twaite shad (*Alosa fallax*), houting (*Coregonus oxyrhynchus*) and Elbe water dropwort (*Oenanthe conioides*; only Lower Elbe) are relevant in the estuaries.

3.3 Birds Directive

The majority of the HD areas of the estuaries are also EU bird sanctuaries so that management coordinated between the goals of the two directives is necessary. The avifauna of the estuaries is extraordinarily numerous with a wide diversity of species and is composed of bird communities of the open water areas, tidal flats, salt meadows and open greenland areas, reeds, shrub fringes and riverside forests. The estuaries are of great importance for breeding birds as well as for migratory and wintering birds. Numerous species (especially ducks and geese) occur here regularly in stocks of international significance.

3.4 Natura 2000 areas in the estuaries – an outline

An overview on the Natura 2000 areas in the estuaries is presented in Table 2. The predominant portion of the Eider, Elbe and Weser estuaries now belongs to the Europe-wide Natura 2000 network of nature protection areas. The Lower and sections of the Outer Ems are (still) a potential HD area since lawsuits against such designation are pending.

Estuary	Total area (km^2)	Area HD (km^2)	Area HD (%)	Area BD (km^2)	Area BD (%)	Area protected (%)
Ems	228	171	75	124	54	75
Weser	250	230	92	193	77	94
Elbe	471	461	98	299	63	98
Eider	32	26	82	26	82	82

Table 2: Compilation of areas protected according to Natura 2000 in the estuaries Eider, Elbe, Weser and Ems. Area: transitional waters according to WFD; HD: area protected according to the Habitats Directive; BD: area protected according to the Birds Directive. Large parts are protected according to both, HD and BD.

Germany classified the state of preservation of the estuaries in accordance with the HD Directive as unfavourable vis-à-vis the EU Commission. This means there is already today an urgent need to take action coordinated via integrated management plans in order to improve the ecological situation.

Currently integrated management plans according to the HD are under development. More or less in parallel, Water Framework Directive (WFD) management plans are under development. These should be coupled to each other to a greater extent. This also applies to the necessary monitoring.

The river of Varde Å runs into Ho Bugt (Ho Bay) at the most northerly part of the Wadden Sea and this area is unique. It is the only major waterway to the Wadden Sea which has not been altered through straightening or the construction of dikes or locks in the estuary. On account of the original occurrence of a wide range of distinctive bird species and nature types, it has been designated as an EU Bird Protection Area, EU Habitats Directive site and a Ramsar site. However, the wide area of meadowland was used for a very intensive form of agriculture for more than two decades since the beginning of the 1970s. This practice had unfortunate consequences for the water quality of the river Varde Å and the Wadden Sea, and also significantly depleted the conditions for the flora and fauna in the estuary.

Thus a project was established in the years 1998-2002, to secure the area as a dynamic part of the Wadden Sea with its natural flora and fauna, including breeding and resting birds, to reduce the leaching of nutrients into the aquatic environment, and to ensure compensation of the owners or users of the land for any loss of income and to give them a high level of influence. The area covered by the project consists of 2,800 hectares of particularly vulnerable agricultural land, of which about 2,500 hectares is made up of salt marshes and meadows under the provisions of the Danish Nature Protection Act.

The overriding intention of the project is that the agricultural use of the meadows should be extensified through subsidised schemes for environmentally friendly methods. This has been achieved by raising the quality and levels of the groundwater, by stopping the use of fertilisers and pesticides, and by placing special conditions on hay harvesting and grazing.

Individual land owners participate voluntarily in the project, which is conducted on the basis of twenty-year operating agreements. The project is based on more than 400 contracts with more than 250 land owners, and covers an area of almost 2,400 hectares.

The effects of the project are positive and flora and fauna is reacting to the new situation. However, the changes in the conservation status of the area have not been as effective and fast as expected. This is mainly caused by the farmer's choice of traditional cutting and moving of grass instead of choosing practices that involves grazing with cattle (Frikke, 2009).

4. Other brackish waters

Restoration of transition zones between marine and freshwater environments is one of the policy aims for the cooperation area (Policy Assessment Report, Schiermonnikoog Declaration, 2005). Diking and land reclamation all along the coast of the Wadden Sea have eliminated the broad natural transitional zone with creeks, swamps and marshes where freshwater draining from land and seawater mixed and created a chain of brackish water habitats between the big open estuaries. The concentration of drainage systems to form a few sluices ("Siele") with a combination of gates and powerful pumps created small, isolated brackish water environments with very unstable conditions. Little and/or irregular freshwater flow, depending on intermittent pumping, is the main reason for the very poor ecological quality of these biotopes, as stated by Michaelis *et al.* (1992). Most of these show hardly any salinity gradient, but a sharp salinity break. One overview is presented by de Jonge and de Jong (2002). Essink *et al.* (2005) gave an overview on other types of brackish waters such as small tidal creeks in the salt marshes of the Wadden Sea islands with some freshwater input or polders with special water management.

However, there is another type of "estuary", which has not received special attention with respect to its estuarine function: the tributaries of the estuaries of Elbe, Weser and Ems discharging to poly-, meso- or oligohaline reaches (Table 3). Some of these are open to the tide and brackish water environments are present (storm surge barriers), others are dammed up with sluices. These "estuaries", not considered as estuaries with respect to Natura 2000, should be analysed with respect to their ecological functions in more detail.

As mentioned above, restoration of transition zones between marine and freshwater environments and measures to improve the connectivity for migrating species is one of the policy aims for the cooperation area. In the Dutch as well as in the German Wadden Sea, restoration of salinity gradients in small sites has started; further measures are planned (for The Netherlands, see Kroes and Monden (2005). For Lower Saxony, a study on the possibilities for increasing migration between coastal and freshwater is in preparation (Bioconsult, 2009).

Table 3: Tributaries entering the transitional waters of the estuaries Eider, Elbe, Weser and Ems.

Estuary	Tributary	Mouth at km	Salinity at the mouth	Connectivity
Eider	Treene	61	?	sluice
Elbe	Pinnau	660	oligohaline	storm surge barrier
	Krückau	664	oligohaline	storm surge barrier
	Stör	678	oligohaline	storm surge barrier
	Oste	707	mesohaline	storm surge barrier
	Medem	712	polyhaline	drainage sluice
Weser	Drepte	49,5	oligohaline	drainage sluice
	Lune	51	oligohaline	drainage sluice
	Geeste	66	mesohaline	storm surge barrier
Ems	Leda	14	oligohaline	tidal barrier

5. Recent developments and perspectives

The past years have been characterized by dynamic economic development in the estuaries. Further deepening measures and port expansion have taken place, contributing to a further increase in the tidal range, among other things. Parallel to that, however, large areas have been secured for conservation purposes within the framework of the Natura 2000 network. At the same time, a number of improvements have been carried out, primarily in the foreland areas, as part of compensation measures for construction projects (though delayed implementation has been noted for the Lower Elbe – WWF, 2007).

For the near future, too, one can assume that other projects having impacts on the ecological situation will be implemented, of which the most important are the following:

- Ems estuary: closing of the Gandersum storm surge barrier in order to the transfer of ships from the Papenburg shipyard to Emden also in summer; deepening of the outer estuary in The Netherlands as well as in Germany resulting, for instance, in increasing dredging activities; discharge of salt water from cavern construction to the inner estuary; construction of coal-fired power plants in Dörpen, Emden and Eemshaven; raising of dikes and storm surge defence structures. At present, possible remediation concepts for the Lower Ems are the subject of discussion.
- Weser estuary: extension of Brake harbour; deepening of the outer and inner Weser estuary, resulting in increasing dredging activities (Bremen to the open sea; ongoing approval procedure), among other things; raising of dikes and storm surge defence structures.
- Elbe estuary: deepening of the lower and outer Elbe, resulting in increasing dredging activities (Hamburg – Cuxhaven; ongoing approval procedure), among other things; raising of dikes and storm surge defence structures; filling of harbour basins in Hamburg; construction of up to five coal-fired power plants in Hamburg, Stade and Brunsbüttel.

Within the framework of implementation of the WFD and the HD, measures for improvement of the ecological situation are necessary in all German estuaries. They have to be specified in management plans and documented through a monitoring procedure. Another long-term aspect that will also have consequences for the ecological situation in the estuaries in future is climate change. Here it is important to develop a precautionary and long-term adaptation strategy (Schuchardt and Schirmer, 2007).

6. Evaluation of objectives

The objective focuses on giving protective status to valuable areas and regenerating river banks. By virtue of the designation of large sections of the foreland and water areas of the estuaries as HD sites or EU bird sanctuaries, the first part of the objective can be viewed as extensively achieved. For the second aspect, too, *i.e.* regeneration of disturbed bank and foreland areas, several steps have been taken towards meeting the target. Action such as the opening of summer dikes, *etc.*, has been taken primarily within the framework of compensation measures. However, there is still significant need for action here (see also WFD and HD).

Concerning trilateral policy and monitoring, the Trilateral Wadden Sea Plan (1997) states that the relevant parts of the policies formulated for important elements of the Wadden Sea (*i.e.* water, salt and brackish marshes and the rural area) apply also to valuable parts of the estuaries. However, this has not yet been detailed, as already recommended in QSR 1999 (Schuchardt *et al.*, 1999).

In the Wadden Sea Plan (1997), some additional policy aims have been formulated for the estuaries (see 16.1.2). In short:

1 Avoiding and reducing impact due to new construction.
2 Deepening of shipping lanes in the estuaries in conjunction with compensation and mitigation.
3 Minimizing the impact of dumping dredged materials.
4 Protecting valuable sections; restoring river banks (see objective).
5 Naturalization of the transition zones between fresh and salt water.

Regarding (1): Nowadays construction projects, such as port expansion or building of new structures, power stations, *etc.*, take place almost exclusively outside the national parks and HD sites so that direct impact on the cooperation area is avoided. However, further indirect impacts, such as due to heat input, can be expected. The political goal has therefore been achieved in part.

Regarding (2): Avoidance and compensation measures are now an integral element of all approval procedures for further deepening measures in the shipping lanes. However, the type and scope of the measures, as well as the justification for their necessity, remain controversial in most cases. The political goal has thus been achieved in part.

Regarding (3) and (4): Dumping of dredged material is regulated with respect to quantity, pollution and biological effects and an attempt is made to reduce the impacts by means of appropriate dumping site management. However, the amounts of dredged material in the estuaries of the Elbe, Weser and Ems have further increased considerably due to the deepening measures, so that these efforts are impeded in part. The political goal has therefore been achieved only to a very restricted degree.

Regarding (5): In the past years, transition zones have been improved in specific cases thanks to measures taken in the cooperation area. At present, further action on sluices is pending within the framework of implementation of the WFD. Thus there is progress in achieving this political goal and further improvements can be expected by virtue of the WFD.

Overall, it is evident that in some cases there continues to be acute need for action in spite of a number of improvements in the ecological situation. In our view this is primarily due to measures for reduction of the oxygen deficiency and tidal pumping in the Ems and Elbe, projects to secure and restore side arms with their shallow-water zones as well as the restoration of typical estuary habitats in the foreland of all estuaries.

This and other need for action, the further increasing economic significance of the estuaries because of globalization, the implementation of EU directives (WFD, HD) and the required adaptation to climate change make it necessary to coordinate further measures with each other in the form of integrated management plans and at the same time give appropriate consideration to long-term consequences of current activities.

7. Recommendations

The recommendations given in QSR 1999 (Schuchardt *et al.*, 1999) have been repeated for the most part in the 2004 QSR (Essink *et al.* 2005) and most of them are still valid (see below). However, some of the recommendations have been partly fullfilled:

- Existing ecological targets for estuaries in the TWSP must be detailed, taking into account the individuality of each estuary.

This has been (partly) done in the framework of WFD and HD; however, more intensive integration of both directives is necessary.

- Monitoring of ecological long-term changes other than water quality and macrozoobenthos in the estuaries is necessary.

Within the framework of WFD and HD, monitoring of fish fauna in the transitional waters has been started some years ago, according to the design outlined in Scholle and Schuchardt (2009).

Although some of the previous recommendations have been partly fullfilled in the meantime (see above), the following must be repeated and replenished also in the recent report:

- A compilation and integrated analysis of the existing ecological data for the estuaries are lacking.
- The tidal freshwater reaches should be integrated into the Stade Declaration definition of an estuary. The Lower Eider should be included in the estuary definition.
- The downstream borders of the estuary definition according to Stade Declaration, WFD and HD should be harmonized.
- 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. However, first measures have been taken.
- Consequences of further impact due to further deepening, barriers and harbour extension should be evaluated very carefully, taking into account the historical deterioration of the estuaries and the uniqueness of each estuary.
- Further improvement of water quality is necessary, especially for the Elbe and Ems estuaries. However, the situation in the Ems estuary has worsened and improvement is really urgent.
- Further active restoration of smooth gradients of salinity and tidal amplitude in small creeks along the Wadden Sea coast and the estuaries is important. However, first measures have been taken and further are under planning.

Some additional recommendations can be given:

- The management plans currently being developed within the framework of implementation of the WFD and HD should be coupled to each other to a greater extent. This also applies to the necessary monitoring (see chapter 16.3.4).
- Reduction of tidal pumping is necessary, especially for the Ems, but also for the Elbe estuary. Discussions on this with regard to both estuaries have begun (16.2.3 and Report No. 3.7 on dredging and dumping).
- Several new coal-fired power stations are also planned in estuaries. Both removal and return of the cooling water must be evaluated critically according to cumulative aspects.
- With respect to the restoration of estuarine habitats and salinity gradients the tributaries of the estuaries should also be taken into consideration (*e.g.*, Geeste river) (see section 16.4).
- Long-term strategies for adaptation to climate change should be developed for the estuaries.

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