Photo: Ralf Vorberg. Weser Estuary.

Wadden Sea Quality Status Report

Estuaries

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1. Introduction

Estuaries are 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; Schuchardt & Scholle, 2009 (QSR 2009)). Estuaries can be defined as tidally influenced transition zones between marine and riverine environments. However, especially in defining the down- and the upstream border several approaches exist. In the following we include the freshwater tidal reaches as upstream border and the so called "transitional waters" according to the Water Framework Directive (WFD) as downstream border.

According to the definition above, there are five estuaries in the Wadden Sea region: the Varde Å estuary in Denmark, the Eider, Elbe and Weser estuaries in Germany and the Ems estuary in Germany and The Netherlands (the Eider estuary has not been included into the Leeuwarden definition* despite the fact that it should be). 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) and on the other hand, estuaries themselves present a specific habitat, characterized by strong variability and dynamics of key factors, such as salinity, tidal range and turbidity. From an ecological point of view they are important, e.g., as migration routes or feeding-and nursery areas for a number of species. Additionally they are inhabited by various brackish-water or at least estuary-endemic species, thus being of special importance for nature conservation reasons. However, in contrast to the Wadden Sea estuaries are strongly altered by human activities (Reise, 2005; Schuchardt & Scholle, 2009 (QSR 2009), Figure 1).

* Estuaries include the parts of the rivers with a natural water exchange with the Wadden Sea. On the landward side, estuaries are delimited by the mean-brackish-water line. On the seaward side, the border is the average 10 ‰ isohaline at high water in the winter situation (Leeuwarden Declaration, CWSS 1994).

Figure 1. Harbour activities: A major driver of recent estuarine deepening measures. Left to right: Bremerhaven Terminal; The Elbe is the largest estuary in the Wadden Sea area and has a high frequency of human activites due to the ports of Hamburg; Recent harbour extension at Brake (Weser) (Photos: BioConsult).

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 forming the artificial upper tidal border and the outer part. This outer part is characterized by a funnel-like morphology with extended tidal flats, being part of the Wadden Sea. The Ems estuary differs from this general structure due to the Dollart, a brackish bay, and the Eider estuary due to the construction of a storm surge barrier and the Varde Å, where mixing of river and sea water normally takes place in the Ho Bugt seaward of the narrow river.

The estuaries vary considerably in size, length and river discharge (see Schuchardt et al., 1999). With the exception of Varde Å, the adjacent lowlands of all estuaries 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.

Two developments are currently discussed and still pending: further deepening of Elbe, Weser and Ems estuaries for shipping purposes and restoration for conservation purposes under the Habitat Directive (HD) and Water WFD. In the following this situation will be analyzed in greater detail.

2. Status and trends

2.1 Approach

Estuaries are not explicitly mentioned in the Common Package of the Trilateral Monitoring and Assessment Program. Thus, status and trends of the ecological situation in the inner estuaries in previous QSR contributions were described by using an approach based on a comparison with historical data. Four indicators have been described and evaluated: tidal range, extent of foreland area, oxygen depletion and heavy metal concentrations in sediments (Schuchardt et al., 1999, 2007).

Since the Habitat Directive (HD) and the Water Framework Directive (WFD) have been implemented, they call for regular monitoring, assessment, reporting and, if necessary, measures aiming to achieve a good ecological status or a good ecological potential.

As a consequence, extensive monitoring programs of habitats and species relevant for the directive have been established in the framework of the HD (for details see QSR 2009 and below; for monitoring and assessment according to the Bird Directive see reports Breeding birds and Migratory Birds).

In the frame of the WFD, all surface waters were classified according to a system of types of water bodies, ecological targets ("good ecological status", “good ecological potential” (if the water body is classified as heavily modified (HMWB)) and "good chemical status") and an extensive biological and chemical monitoring program was established for all surface waters including the estuaries. Good ecological status is mainly defined in terms of the quality of biological components and chemical characteristics, whereas hydrological characteristics and parameters like dissolved oxygen are used as “supporting parameters”. A set of procedures for assessing the ecological status for a given body of water has been developed and implemented. WFD differentiates five biological status classes: high, good, moderate, poor and bad. The biological elements for most of the types of water body considered include macrophytes, macroinvertebrates and fish. Measures

necessary to achieve the “good status” are (or should be) described in a River Basin Management Plan.

WFD and HD monitoring established in recent years have started to considerably increase the available information and data on estuaries. Assessments based on WFD and HD monitoring are performed every six years. Combined WFD and HD monitoring and assessment results form a good basis, also for an evaluation within the framework of the Trilateral Wadden Sea Plan (CWSS, 2010). However, since hydromorphology and dissolved oxygen have not yet been explicitly assessed within this framework, we refer here to our former apporach (see Schuchardt et al., 1999 and above).

2.2 Water Framework Directive (monitoring and assessment)

Within the WFD, the estuaries between the upper border of the salinity gradient and the mesohaline/polyhaline transition are defined as transitional waters. The tidal freshwater stretches are defined as (special) riverine water bodies. Being part of the Wadden Sea, coastal water bodies follow seawards of the transitional waters. In the transitional waters the biological quality elements, such as macrophytes, benthic invertebrate and fish fauna are monitored. Table 1 gives an overview of WFD assessment results for the Wadden Sea estuaries. Since methodologies were developed further over the years, differences between results of 2009 and 2015 rather reflect consequences of methodology implementation than real changes.

Table 1. Assessment of estuarine water bodies according to Water Framework Directive (Sources: Umweltkarten Niedersachsen; MELUR, 2015; pers. comm. Gaby Petri, NLWKN Oldenburg).

Assessment according to Water Framework Directive			Macrophytes		Invertebrates		Fish	
	name of waterbody (WK)	WK-ID	2009	2015	2009	2015	2009	2015
Ems	"Ems Wehr Herbrum bis Papenburg"	DE_RW_DENI_03003	?	5	?	5	?	5
	"Ems Papenburg bis Leer"	DE_RW_DENI_06037	?	4	?	5	?	5
	"TW Ems (Leer bis Dollart)"	DE_TW_T1_3000_01	?	3	?	4	?	3
	"TW Emsästuar" (seeward)	DE_TW_T1_3990_01	2	3	3	3	3	3
	"Eems-Dollart"	NL_TW_NL81_2	2	2	?	4	na	na
Weser	"Weser oberhalb Brake"	DE_NI_26035	4	4	4	3	3	4
	"TW Weser"	DE_TW_T1.4000.01	3	3	3	3	3	3
Elbe	"Elbe (West)"	DE_RW_DEHH_el_03	?	3	?	3	?	3
	"Hafen"	DE_RW_DEHH_el_02	?	na	?	3	?	3
	"Elbe (Ost)"	DE_RW_DEHH_el_01	5	3	?	3	?	3
	"TW Elbe"	DE_TW_DESH_T1.5000.01	4	3	3	3	3	3
Eider	"TW Eider"	DE_TW_DESH_T2.9500.01	?	2	na	na	?	2
Varde A	Varde A (lower part)		u	u	u	u	u	u

Ecological status/potential:	
1	high
2	good
3	moderate
4	poor
5	bad
na	not assessed
u	unknown
?	no data

Although it is too early for any long term trend assessments, trends in the ecological status of the water bodies already become obvious.

The WFD quality component “macrophytes” is assessed for Elbe and Eider following Stiller (2005) and for Ems and Weser according to Arens (2009). Stiller (2005) focuses on the quality of the reed beds (extension, zonation and vitality), whereas Arens (2009) takes additional parameters such as extension and quality of eelgrass beds on intertidal mudflats into account. Monitoring takes place once in a six-year reporting period.

The quality component "benthic invertebrates" is assessed by two approaches: M-AMBI (e.g., Borja et al., 2000) for the meso- and polyhaline reaches and AeTV/AeTV+ (Krieg 2005, Krieg & Bioconsult, 2013) for the oligohaline and freshwater sections in the estuaries of Ems, Weser and Elbe. The estuary of the Eider has not yet been evaluated. Relevant metrics are similar in both approaches: mostly species numbers, diversity and sensitivity of species via defined specific eco-values are assessed. The monitoring takes place once every year.

The quality component "fish" in the transitional and freshwater sections is assessed by FAT-TW/FAT-FW indices according to Scholle & Schuchardt (2012) and Bioconsult (2014). Relevant metrics are species composition and abundance of six selected species. The monitoring is carried out by stow net fishing in different estuarine salinity zones. The monitoring takes place twice a year (spring, autumn) at one- to three-year intervals (depending on the estuary).

All estuarine water bodies have been classified as heavily modified water bodies (HMWB). This means that, according to WFD the natural (physical) conditions of the water bodies have been substantially altered (mainly for navigational purposes) and their utilization needs to be retained. Therefore, the environmental targets in HMWB are somewhat reduced compared to natural water bodies (ecological potential instead of good environmental status must be reached).

Most estuarine water bodies bodies were assigned to a moderate ecological potential (Table 1), whereas the ecological potential in the freshwater reaches tends to be "poor" or (for the Ems estuary) even "bad". The status class of the adjacent coastal waters is moderate or good (not presented here). Consequently, in order to fulfill the WFD requirements of a good ecological potential, measures need to be implemented accordingly.

2.3 Habitat Directive (monitoring and assessment)

Large parts of the estuaries are protected under the EC Habitat Directive as Special Areas of Conservation (SACs). The predominant portion of the Varde Å, Eider, Elbe, Weser and (most recently) the Ems estuaries belong to the Europe-wide Natura 2000 network of nature protection areas where conservation objectives have been defined. For an overview on the Natura 2000 areas in the estuaries see Schuchardt & Scholle (2009) (QSR 2009).

The HD Directive designates the types of habitat of community relevance to be protected or restored in its Annex I. Amongst others, the habitat type "estuaries" (1130) and, for the freshwater section, "riverside forests" are primarily of relevance (see Schuchardt & Scholle, 2009). Annex II of the HD Directive listed these species, for which core areas of their habitat must be protected. Twaite shad (*Alosa fallax*) and Elbe water dropwort (*Oenanthe conioides*, only Lower Elbe) are particularly relevant here. The latter is additionally listed in annex IV as species of exceptional community significance.

According to the HD requirements, relevant habitats and species within each SAC have to be mapped, monitored and assessed on a six year interval differentiating three classes of the conservation status: very good, good and unfavourable.

For the evaluation of the habitat type "estuaries" a bulk of different data on structures, populations and pressures is required (BLMP 2010), especially since the habitat type is a complex of different (sub-) types. Assessments are using data from different sources, including from HD- and WFD-monitoring. However, up to now the assessment is still more or less an expert judgement.

For evaluating the conservation status of twaite shad, data on population status, habitat quality and impairments are required. Since twaite shad is in the focus of the WFD as well, the WFD-monitoring provided most of the required population data (e.g., abundance of different age groups).

Table 2 gives the most actual overview on the results of the assessments according to the HD for the different estuaries, special areas of conservation (SACs) or functional groups of SACs for selected habitats and species (for references see Table 2).

Table 2. Assessment of conservation status of estuarine habitat types and species according to Habitat Directive.

Source	Special Area of Conservation (SAC)	EU-Code	functional space	no of functional space	1130 estuaries	1140 Mudflats and sandflats not covered by seawater at low tide	91E0 Alluvial forests with Alnus glutinosa and Fraxinus excelsior	91F0 hardwood riverside forests	1103 twaite shad (Alosa fallax)
Küfog 2014/ Autoren 2016	Ems (NI)	DE 2809-331	freshwater reach	4	-	-	B/ C	C/ E	C
	Unterems und Außenems (NI)	DE 2507-331	oligohaline reach	3	C	C	C	-	C
	Nationalpark Niedersächsisches Wattenmeer (NI) Unterems und Außenems (NI) Waddenzee (NL) Eems-Dollard (NL)	DE 2424-302 DE 2507-331 NL 1000-001 NL 2007-001	mesohaline reach	2	C	C	-	-	C
NLWKN & SBUV 2012	Weser zwischen Ochtummündung und Rekum (HB) Nebenarme der Weser mit Strohauser Plate und Juliusplate (NI)	DE 2817-370 DE 2516-331	freshwater reach	3	-	-	B/ C	-	C
	Nebenarme der Weser mit Strohauser Plate und Juliusplate (NI)	DE 2516-331	oligohaline reach	4	C	B	C	-	C
	Unterweser(NI) Weser bei Bremerhaven (HB)	DE 2316-331 DE 2417-370	oligohaline reach	2	C	C	C	-	C
	Nationalpark Niedersächsisches Wattenmeer (NI) Unterweser(NI)	DE 2306-301 DE 2316-331	meso-/polyhaline reach	1	B	B	-	-	C
Arbeits-gruppe Elbästuar 2011	Hamburger Unterelbe (HH) Borghorster Elblandschaft (HH) Zollenspieker/Kiebitzbrack (HH)	DE 2526-305 DE 2527-303 DE 2627-301	freshwater reach upstream port of Hamburg	1	-	-	A-B-C*/ B**	D*/B**	C*/ C**
	Mühlenberger Loch / Neßsand (HH) Rapfenschutzgebiet Hamburger Stromelbe (HH) Unterelbe (NI)	DE 2424-302 DE 2424-303 DE 2018-331	freshwater reach	3	B*/ C**/ C***	-	B-C*/ A**/ A-B***	B**	B*/ C**/ B-C***
	Unterelbe (NI) Schleswig-holsteinisches Elbästuar und angrenzende Flächen (SH)	DE 2018-331 DE 2323-392	oligohaline reach	4	C**/ C***	B**/ C***	B**/ A-B***	C**/ B***	C**/ B-C***
	Unterelbe (NI) Schleswig-holsteinisches Elbästuar und angrenzende Flächen (SH)	DE 2018-331 DE 2323-392	mesohaline reach	5	B**/ C***	B**/ C***	-	-	C**/ B-C***
	Unterelbe (NI) Schleswig-holsteinisches Elbästuar und angrenzende Flächen (SH)	DE 2018-331 DE 2323-392	polyhaline reach	6	C**/ C***	B**/ C***	-	-	C**/ B-C***
MELUR 2016	Untereider (SH)	DE 1719-391	freshwater to mesohaline reaches		B/ C	-	-	-	C
	Vadehavet med Ribe Å, Tved Å og Varde Å vest for Varde (DK)	DK 00AY176			u	u	u	u	u

Assessment of conservation status:

A	favourable (excellent conservation)
B	favourable (good conservation)
C	unfavourable (average or reduced conservation)
B/ C	different categories within the area (example)
-	no conservation objective
u	no data
D	not significant
E	area for development

* Hamburg (HH)
** Lower Saxony (NI)
*** Schleswig-Holstein (SH)
Bremen (HB)
Netherlands (NL)
Denmark (DK)

The status of the habitat type “estuary” is mainly assessed as unfavourable in the inner parts of the Wadden Sea estuaries, reflecting the high anthropogenic pressure (Table 2). The status of twaite shad is assessed as unfavourable in all estuaries, although distinct differences between the estuaries exist: almost no reproduction takes place in the Ems estuary, due to bad water quality (oxygen deficit and high suspended sediment load), whereas reproduction in the Elbe estuary is quite successful. This example indicates that a simple comparison of the results of the assessments is only of limited explanatory value for an overall comparison of the ecological situation of the estuaries. For the consequences in the Wadden Sea Plan (WSP) (CWSS, 2010) framework see sections below.

Overall, Germany classified the state of preservation of the estuaries in accordance with the HD Directive as unfavourable vis-à-vis the EU Commission. This emphasizes the urgent need to take immediate coordinated action via integrated management plans to improve the ecological situation of estuaries.

2.4 Management plans

Management Plans (MP) have to be worked out for all Natura 2000 sites. This has been done for the estuaries of Elbe (Arbeitsgruppe Elbeästuar, 2011) and Weser (NLWKN & SUBV, 2012) as Integrated Management Plans (IMP), not only integrating several Natura 2000 sites but also harmonizing ecological and economic interests within the regions. For the Ems estuary the IMP is available as final draft (IBP Ems, 2016). IMPs call for specific measures necessary to achieve a good state of conservation for habitat types and/or species and serve as a guideline for national activities. The plans also seek to reach a negotiated agreement between all stakeholders regarding the preservation and consistent development of the ecological network Natura 2000. For a part of the Eider Estuary a MP is available (MELUR, 2014).

Parallel to the MPs according to habitat directive management plans as defined in Article 13 of the Water Framework Directive have been developed on a larger scale (for an entire catchment area) including the

estuaries in 2009 and in 2015 for the next reporting period 2016-21.

For the inner part of the Ems Estuary the so called Lower Ems Master Plan has been formally agreed upon. This plan aims to restore the heavily deteriorated hydrological and ecological systems and was triggered by an infringement procedure of the EU commission within the framework of the HD implementation.
Both, HD, as well as WFD formally require steps (measures) towards a good ecological status. However, according to WFD a good status/potential is to be achieved by a defined time, whereas within HD a time schedule is lacking.

Although achieving the targets is a long term process, the implementation of these directives has already triggered a lot of activities and processes on different scales.

2.5 Hydromorphology

Morphological alterations of rivers and estuaries have strongly affected all estuaries under consideration, except the Varde Å: the main reasons were coastal protection and land reclamation on the one hand, and adaptation to increasing ship numbers and sizes on the other (Schuchardt et al., 2007). The change in the tidal range represents an indicator for changes in water body morphology, particularly due to the above mentioned human interventions. It is also relevant for changes in the size and characteristics of habitats, such as tidal flats (Figure 2, right). Strong changes, particularly in the innermost parts of the estuaries (Schuchardt et al., 2007) are evident between the beginning and the end of the 19th century.

The tidal range in the Eider has risen from approx. 2.4 m at the Tönning gauge towards the end of the 19th century to 2.7 m today, mainly as a result of water level management using the storm surge barrier. In the Elbe, the tidal range at the Hamburg-St. Pauli gauge has risen by a factor of 1.9 from 1.9 to 3.6 m. The tidal range in the Lower Weser has risen by a factor of 20, from 0.2 to 4.1 m in Bremen in the past 130 years. In the Ems the tidal range in Papenburg has risen by a factor of 2.5 from approx. 1.4 m around the turn of the century to 3.1 m in the 1980s to 3.5 m today (at the Herbrum tidal weir the rise is somewhat lower).

The increase of tidal range indicates a bulk of changes in the hydromorphological system: increase in current velocities, concentration of high velocities to the main channel, siltation of side channels, increase of tidal flat area, and decrease of shallow water areas. In the estuaries of Ems and Elbe, the relation of ebb to flood currents has changed considerably resulting in an increase of upstream transport of sediments (silty in the Ems, sandy in the Elbe) (Schuchardt et al., 2007). This leads to problems associated with increasing amounts of dredging material (Ems and Elbe) and a strong reduction of dissolved oxygen in the Ems Estuary (see below). Data analysis from tributaries, comparing the historic and recent situation, revealed that the artificial increase of the tidal range seem to have an impact on the composition of benthic invertebrates (Bioconsult, 2015).

Figure 2. Left: Small restoration measure of estuarine embankment (Weser); Right: Tidal flats: a highly productive habitat (photos: BioConsult).

2.6 Dissolved oxygen

The dissolved oxygen concentration in the water column in summer represents an important 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 shortage situations going significantly beyond those expected in natural estuarine conditions have been documented for the inner estuaries (Flügge et al., 1989).

The oxygen situation in the estuaries is described in more detail in Schuchardt & Scholle (2009). An improvement compared with the 1980s has been reported for the Eider and Weser estuaries, although weak oxygen deficits may still occur.

While some improvement of the oxygen concentrations in the Lower Elbe compared with the 1980ies has been reported (Arge Elbe, 2004), the situation in the upper most part is still critical. An increase in secondary pollution in the Lower Elbe from upstream 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 strong oxygen deficit situations in spring and summer may still occur (BfG, 2015).

In the Ems Estuary the situation is worse. Relatively high oxygen concentrations in the Lower Ems have been measured before the mid-1980s. Then the system started to shift resulting in extremely worse oxygen conditions today. 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 approx. 6 to less than 2 mg/l in the past 20 years. Schöl et al. (2007) also 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 of less than 4 mg/l have occurred to an increasing degree and even concentration below 1 mg/l have been measured. The situation up to 2011 is described in IBL (2013). 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; Talke et al., 2009) have been identified as primary causes. Due to the very poor water quality, species diversity and abundance in the inner Lower Ems have declined dramatically (e.g., Bioconsult 2007b).

2.7 Recent developments

Since the 2009 QSR (Schuchardt & Scholle 2009) the main developments identified are:

- **Cooling water**: 10 years ago several additional mainly coal-fired power plants have been under planning leading to increasing heat-input to the estuary and additional loss of fish. Due to several changes of the political and economic boundary condition the situation has partly shifted: only two new power plants have been built (Hamburg-Moorburg at the Elbe and Eemshaven at the outer Ems) and existing nuclear power plants have been decommissioned (Esenham Weser; Stade and Brokdorf Elbe). This has led to a reduced ecological impact on the estuaries (see report Energy);
- **Further deepening**: Further deepening due to increasing vessel size has been planned for more than 15 years for the estuaries of Elbe and Weser (inner and outer parts) and Ems (outer part). The formal approval has been given for Elbe and Weser but national judicial review is still pending due to open questions mainly concerning HD and WFD and a special European Court of Justice judgement the Federal Administrative Court has asked for. This aspect shows that legal requirements mainly resulting from HD and WFD give some support to nature conservation aspects;
- **Coastal Defense**: For compensating secular sea-level rise, the following options are currently planned or already under construction: better consideration of wave run-up and climate change (see below) and raising and strengthening of dikes and storm surge defense structures. Loss of foreland habitats takes place locally and has to be compensated for;
- **Port Expansion**: The past years have been characterized by dynamic economic development in the estuaries. Further port expansion took place or is currently planned, leading to further loss of habitats (e.g., Cuxhaven, Bremerhaven, Brake, Emden) and requires partly extensive compensation measures.
- **Maintenance Dredging**: Partly as a result of previous deepening in the outer and inner estuaries, the necessary maintaining dredging activities have correspondingly increased during the last decade (see report extraction and dredging);
- **Nature Protection**: Large areas in the estuaries have been secured for conservation purposes within the framework of the Natura 2000 network (see QSR 2009 and above). 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 (Figure 2, left);
- **Integrated Management**: Concerning Integrated Management in recent years, major steps have been made forward. Integrated Management Plans in the framework of the HD have been published for the estuaries of Elbe and Weser; a final draft is available for the Ems estuary. Management Plans in the framework of WFD have also been published; however, a better linkage between both seems to be reasonable;
- **Climate Change Adaptation**: During the last years a bulk of research on climate change impact and necessary adaptation measures has been performed mainly in the Elbe and Weser estuaries (Schuchardt & Wittig, 2012). An accelerated increase of mean sea level has been identified as a main pressure. Consequently, the anticipated increase has been taken into account during the recent dike strengthening. However, an overall strategy taking further aspects, such as consequences for the ecological situation in the estuaries into account still needs to be developed (see reports on climate change and climate ecology).

3. Assessment

Since the previous QSR 2009, the Trilateral Wadden Sea Plan has been developed further (CWSS, 2010) and the trilateral targets concerning the estuaries have been extended from two to four (see below). Targets are focusing on protection and restoration of valuable parts (habitats and tidal dynamics) on the one hand and functions (migration routes; breeding areas) on the other. However, concerning Trilateral Policy and monitoring, additional aims such as reduction of existing and planned impacts due to infrastructure projects, power plants, sediment relocation and good water quality and natural salinity gradients are formulated. In addition, a reduction of vulnerability to climate change is formulated as an aim of the trilateral policy.

The Trilateral Wadden Sea Plan (CWSS, 2010) also states now that the relevant parts of the policies formulated for important elements of the Wadden Sea, e.g., the water, sediment and tidal flats, salt and brackish marshes, the rural area, birds and fish, apply to valuable parts of estuaries as well.

Below, the results of the WFD and HD assessments and other information will be used for evaluating the targets of the Wadden Sea Plan and compiling the level of implementation of measures and corresponding activities to reach these targets.

3.1 Target: Protection of valuable parts of the estuaries

By virtue of the designation of large sections of the foreland and water areas of the estuaries as HD sites or EU bird sanctuaries (Figure 3), the target can be viewed as extensively achieved (Schuchardt & Scholle, 2009 (QSR 2009)).

3.2 Target: Maintaining and where possible restoring natural habitats and tidal dynamics typical of estuaries

The status of natural habitats as well as tidal dynamics has been strongly altered in all of the estuaries due to anthropogenic activities (see Table 2). The status of the natural habitat type “estuaries” has been assessed as “unfavourable” according to HD. During the past years, measures aiming to restore natural habitats, e.g., opening of summer dikes have been implemented. However, this has been done almost exclusively within the framework of compensating additional losses by venue of infrastructure projects (for a compilation of measures see Saathoff et al., 2013) and thus can only partly be understood as estuarine habitat restoration sensu strictu.

In recent years Integrated Management Plans were developed for the estuaries of Elbe, Weser and Ems (master plan, see above). In these plans, mainly developed within the framework of Natura 2000, measures required towards achieving the good status for habitats and species have been outlined. Measures for restoring foreland habitats are covered for most parts, whereas measures targeting aquatic habitats due to a lack of possibilities and ideas are covered to a lesser extent.

Nevertheless, the plans are a major step forward towards meeting the target. It is becoming increasingly obvious, that achieving the good status is a really long term process, especially in the Ems Estuary due to the

very specific situation and the strong linkage to restoring tidal dynamics (see above).
The second part of the target, aiming on the restoration of tidal dynamics typical of estuaries, is very difficult to achieve. The existing alterations (see above for tidal range as an example) are mainly reflecting the deepening due to shipping purposes. As long as further deepening is on the agenda at least for Elbe, Weser and Ems, measures to restore tidal dynamics are very challenging. However, the recent master plan for the inner Ems Estuary as well as concepts for the Elbe Estuary include steps aiming also on a restoration of tidal dynamics (partly motivated by increasing dredging costs due to an increase of tidal pumping and thus maintenance dredging).

However, regarding this target there is still significant need for action.

Figure 3. Estuarine natural habitats in a shallow side-arm (Weser) (photo: BioConsult).

3.4 Target: Maintaining and as far as possible restoring the river banks in their natural state

Estuarine river banks have become reinforced especially in the innermost (riverine) stretches of the estuaries during the last decades (more than 60 % of the banks in the innermost part of the Weser Estuary). There are examples for the restoration of short stretches of stony river banks (Figure 2), mostly within the framework of compensation measures. However, willingness for a critical evaluation of possibilities for any restoration has increased within the responsible authorities.

A stronger use of sand replenishment (using sandy material derived from maintenance dredging) instead of

stony embankments for maintenance of the banks might be appropriate.

However, concerning this target there is still significant need for action.

3.5 Target: Maintaining and where possible restoring the function as migration route and breeding area for fish and birds

As migration routes between the marine and freshwater environment, estuaries are of immense importance for migrating fish and for some agile benthic invertebrate species. This function is partly restricted in the estuaries under consideration, due to tidal weirs at the upstream border of the tides. Despite their equipment with fish ladders, upstream migration is restricted depending on size and construction details of these fish passes (additional restriction for downstream migration takes place if a hydroelectric power station is installed). In the Elbe estuary a new and very large sized fish ladder has been constructed some years ago, as a compensation measure for a new coal-fired power station in Hamburg. Results of ongoing monitoring indicate a good efficiency (Hufgard et al., 2013). However, in other estuaries a continual improvement of the construction might be necessary. Biological consistency of the entire river systems including the estuaries is a main focal point of the implementation of the WFD and progress can be expected (e.g., FGG Ems, 2015).

Additional restriction of the function as migration route results from dissolved oxygen depletion in the Ems (Bioconsult 2012) and, to a lesser degree, in the Elbe estuary (Trautenhahn & Gessner, 2012).

The importance of estuarine habitats for breeding birds is still high, as reflected e.g., in the Natura 2000 assessments (see report breeding birds) even though negative trends of several species are documented. The Integrated Management Plans (see above) may contribute to a positive development in the future.

3.6 Outlook

Within HD and WFD, several goals have been set for the estuaries under consideration. They are more detailed than the targets for estuaries in the Trilateral Wadden Sea Plan 2010 (CWSS, 2010).

The comparison of the TWSP and WFD goals (Bioconsult, 2007a) has provided strong evidence, that some of the goals of WFD and HD should be implemented into the TWSP targets for estuaries. This might result in somewhat more specific targets for the estuaries and could improve the guidance for estuarine future development. In addition, the extensive monitoring within the framework of HD and WFD can give significant support for ecological evaluation of the Wadden Sea region in the framework of the QSR. Overall, a stronger linkage between TWSP and HD and WFD, both relatively strong instruments for nature conservation, might strengthen the trilateral policy concerning the estuaries.

4. Recommendations

The following recommendations given in previous QSRs have been partly fulfilled:

- *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 several biological compartments has been started (see above);
- *Long-term strategies for adaptation to climate change should be developed for the estuaries*: during the last years a bulk of research on climate change impact and necessary adaptation measures has been performed mainly in the Elbe and Weser estuaries and adaptation has been started (strengthening of the dikes). However, an overall strategy taking further aspects like the consequences for the ecological situation in the estuaries into account is still missing;
- *Several new coal-fired power stations are planned in estuaries. Both removal and return of the cooling water must be evaluated critically according to cumulative aspects*: the number of planned power stations has been strongly reduced; with respect to WFD and HD the impact of newly built station Moorburg in Hamburg has been evaluated critically including cumulative aspects and permission was subject to a court decision.

4.1 Monitoring and research

Estuaries are not explicitly mentioned in the Common Package of the Trilateral Monitoring and Assessment Program (TMAG, 1997). However, during the last years monitoring programmes within the scope of WFD and HD have been developed and implemented including different quality components (see above). This is a major step forward regarding the necessary data basis for any target evaluation also within the framework of TMAG.

However, some additional recommendations can be given:

- To some extent an integration of the monitoring programmes of HD and WFD has been done. However, some further steps will be necessary (e.g., integration of parameters like age structure required for the HD assessment into the WFD monitoring for fish). A critical cross sectional analysis on this item would be useful;
- The extent of measures necessary for reaching the targets in WFD and HD is still unknown and needs to be addressed. Research on this issue is recommended.

4.2 Management

The following recommendations must be repeated and replenished also in the recent report; however, some positive developments can be stated:

- *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*: still needs to be determined;
- *The downstream borders of the estuary definition according to Stade declaration, WFD and HD should be harmonized*: partly takes place
- *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*: first measures have been applied. This has been included as target in TWSP (CWSS, 2010);
- *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*: due to the legal requirements of HD and more recently WFD the evaluations are carried out more cautiously;
- *Further improvement of water quality is necessary especially for the Elbe and Ems estuaries*: situation in the Ems estuary has worsened and an improvement is really urgent. Situation in the Elbe estuary shows no clear trend of improvement;
- *Further active restoration of smooth gradients of salinity and tidal amplitude in small creeks along the Wadden Sea coast and the estuaries is important*: first measures have been taken place and more are

currently being developed;
- *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*: a cross sectional analysis would be useful;
- *Reduction of tidal pumping is necessary especially for the Ems, but also for the Elbe estuary*: a (very long term) master plan for the Lower Ems is in the process of implementation; for the Elbe estuary discussion has recently started;
- *With respect to the restoration of estuarine habitats and salinity gradients also the tributaries of the estuaries should be taken into consideration* (e.g., Geeste river): first measures within the framework of WFD and for compensation purposes have been performed.

5. Summary

Estuaries are tidal river mouths with a free water exchange with the sea. They are characterized by tidal brackish and freshwater areas forming the transition zone between rivers and high-salinity tidal waters. There are five such estuaries in the Wadden Sea Area, namely the Varde Å (DK), the Eider, the Elbe and the Weser (D), and the Ems (D, NL).

These estuaries are of high relevance for the Wadden Sea ecosystem and themselves present a specific habitat, characterized by strong variability and dynamics of key factors, such as salinity, tidal range, turbidity and others.

The estuaries of the rivers Elbe, Weser and Ems constitute the seaward access routes to the major German and Dutch sea ports and are among the most industrialized regions of the Wadden Sea Area. The industrial development along the estuaries including the deepening of channels and the embankment of river banks has resulted in significant alterations in morphology, hydrography (including tidal amplitude), flora and fauna, and, e.g., the loss of brackish and freshwater marshes. This development is still ongoing, although the recent legal framework (HD, WFD) is leading to some restrictions and improvements.

During the past 20 years loads of nutrients and several contaminants have been reduced and large sections of the foreland and water areas of the estuaries have been designated as Natura 2000 sites, thus creating the basic conditions for sound ecological management. However, water quality should be improved further and restoration of brackish marshes and meadows as well as tidal forests and marshes in the freshwater tidal part has so far not been achieved.

Such efforts will be hampered by a tendency to further increase the draught of the vessels heading for the ports along the Ems, the Weser and the Elbe, requiring further deepening of the channels. Taking all aspects into account, the estuaries constitute the part of the Wadden Sea with the worst ecological condition.
Since the Habitat Directive and the Water Framework Directive have been implemented, they call for regular monitoring, assessment, reporting and if necessary, measures aiming on a good ecological status/ potential. As a consequence, extensive monitoring on habitats and species relevant for the directives has been established increasing the available information and data on the estuaries considerably.

Within HD and WFD several goals have been set for the estuaries under consideration. Especially the WFD goals are more detailed than the targets for estuaries in the Trilateral Wadden Sea Plan and might serve as a basis for defining the TWSP targets for estuaries in more detail as well.

This might not only improve the guidance for estuarine future development but the extensive monitoring within the framework of HD and WFD can also give significant support for ecological evaluation of the Wadden Sea region within the framework of the QSR. Overall, a stronger linkage between TWSP and HD and WFD, both strong instruments for nature conservation, might strengthen the trilateral policy concerning the

estuaries.

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