COASTLINE 2012-18
REPORTS

A fish-based index of biotic integrity – FAT-TW an assessment tool for transitional waters of the northern German tidal estuaries

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Coastline Reports

18 (2012)

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Bremen, 2012

ISSN 0928-2734
ISBN 978-3-939206-03-3

Imprint

Cover picture: Hamenkutter on the river Weser (Unterweser)
(Photo: Bastian Schuchardt)

Coastline Reports is published by:
EUCC – Die Küsten Union Deutschland e.V.
c/o Leibniz-Institut für Ostseeforschung Warnemünde
Seestr. 15,
18119 Rostock, Germany
eucc@eucc-d.de

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***Coastline Reports 18 (2012)**, ISSN 0928-2734, ISBN 978-3-939206-03-3*
S. 1–73

A fish-based index of biotic integrity – FAT-TW an assessment tool for transitional waters of the northern German tidal estuaries

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Abstract

The implementation of the EU Water Framework Directive (WFD) involves assessment of the fish fauna to determine the ecological status of transitional waters. Assessment in conformity with the WFD should take place at a qualitative (species community) and quantitative (abundance) level of analysis.

The FAT index developed in line with this background assesses the composition of the estuarine fish species community, taking into account ecological guilds. The parameter ‘abundance’ is evaluated via indicator species. The selected species (twaite shad, smelt, flounder, herring, striped seasnail, ruffe) each represent specific ways of life and habitat. Both, a change in the species community and a change in frequency of species may reflect impairments to the estuary as a habitat.

A historical reference represents a benchmark for the fish-based assessment of the ecological status in this context. The current ecological status is assessed via the similarity or dissimilarity to the reference community and classified in the relevant status class according to a 5-level system (high, good, moderate, poor, bad).

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1 Summary

General

The ecological status of transitional waters (De-type T1/T2) shall be assessed via the similarity or dissimilarity to the reference community and classified in the relevant status class according to a 5-level system (high, good, moderate, poor, bad). In Germany the type of water body designated as transitional waters encompasses the oligohaline to polyhaline zone of the estuaries of the Ems, Weser, Elbe and Eider Rivers.

The fish-based index developed for this type of water body in 2006 and further developed until 2010 (FAT-TW_de) comprises qualitative and quantitative metrics (species community, abundance of sensitive species) and thus meets the requirements of the WFD. A historical reference is the benchmark for determination of the ecological status in accordance with the Water Framework Directive.

Reference conditions

The fish reference community (species composition, frequency) for transitional waters (TW) was primarily derived from historical documents that date for the most part from the period from approximately 1870 to 1920, i.e. a period prior to or at the beginning of the first major river engineering measures. Since the estuaries were already subject to anthropogenic use at that time, the reference does not represent a pristine state, but can, nonetheless, be viewed as a (very) good ecological status with respect to fish fauna.

The reference frequency (abundance) was predominantly determined on the basis of existing historical and recent data according to the best of principle (WFD REFCOND 2.3 2000). To curb the influence of high variability (temporal, spatial), species-specific abundance classes derived from the available data were defined.

Species composition (4 metrics)

As part of the assessment procedure, the historical species community has been reliably reconstructed on the basis of the available data. The species spectrum was differentiated according to ecological guilds (diadromous species, estuarine residents, marine-juvenile, marine-seasonal), each of which has more or less specific requirements regarding its habitat, thus enabling an indication of certain impairments. The species composition of each of these guilds functions as a qualitative variable.

Abundance/age categories (6 metrics)

It is not possible to derive reference frequencies for all historically verified species. For this reason the quantitative analysis was restricted to 6 selected ‘types of indicator’. The indicator species, whose frequency is taken as a variable in each case, were selected according to various aspects: 1. sensitive to relevant impairment factors; 2. representatives of different habitats (benthic, demersal, pelagic, hard substrate, and soft substrate species); 3. important in terms of nature conservation (in particular Habitats Directive (1992) species, synergy with Natura 2000); 4. commercially important. All selected indicators are characteristic representatives of the estuarine fish community.

Assessment

The ecological status is determined as a deviation from the reference. This can be done for the species spectrum at the level of the respective ecological guilds as well as for the frequency at the level of abundance of the indicator species. The computer-aided assessment is carried out using a ‘database’ containing historical and species-specific characteristics (affiliation to user, habitat or reproduction

guilds, species-specific frequency, etc.). The final step is to allocate the results to an EQR (Ecological Quality Ratio) that takes on values between 0 and 1 according to a 5-level system with a corresponding status classification (ecological status 1 = very good, […] , 0 = poor).

Requirement of data collection

The FAT-TW index is calibrated to the anchor net catch method and therefore requires this method for its application. A major aspect in designing the monitoring procedure involves taking into account the high degree of spatial and temporal variability (e.g. salinity zones, seasonality, tidal phases) of the estuarine fish communities. A proposal for standardized execution of the monitoring (when, where, how long) and standardization of the data has been submitted.

Validation

Initial exemplary tests for validation of the FAT-TW index showed plausible results. Among other things, a comparison with expert judgements on the basis of hypothetical and real data records served the purpose of plausibilization. Hypothetical data records indicated that the ecological status classes were easily distinguishable from one another.

Outlook

Determination and specification of the class boundaries of the EQR for transitional waters, which currently still differ to a minor extent, are to be harmonized in the short term within the framework of the Dutch-German cooperation for the Ems transitional waters. Presumably the Dutch class boundaries will be used in the future (approximately as of the end of 2011). After the planned harmonization another evaluation of the FAT-TW index is envisaged in 2012 on the basis of the more extensive database that will be available by then.

Among other things, the class boundaries of the national EQR values for the specific types of water bodies will be reviewed within the scope of European intercalibration. Adaptation of the national boundaries may also be necessary at this stage for successful completion of the intercalibration (by the end of 2011/ beginning of 2012).

2 Purpose

The EU Water Framework Directive (WFD) creates a regulatory framework for protection of the inland surface waters, transitional waters, coastal waters and groundwater. The following goals apply to above-ground waters:

- implementation of a good ecological and chemical status by 2015
- implementation of a good ecological potential and good chemical status for significantly altered or artificial waters by 2015
- ban on any deterioration

In the case of artificial and significantly altered surface waters, they may be designated as significantly altered waters after meticulous examination of the improvement options. In such waters or water body sections in which a good ecological status cannot be restored at all, or at least not by commensurable means, and if certain uses, such as water power, shipping and flood protection, would be decisively impaired by the restoration, it is not necessary to achieve a good ecological status but a good ecological potential.

The directive defines a ‘good ecological status’ as a target that should be achieved by 2015 (in exceptional cases also by 2027). In view of this background, it is initially necessary to evaluate the current status of the waters and thus point out the need for action with respect to the objectives of the WFD. To be able to take this first step, it is necessary to develop suitable assessment methods for the quality components specified by the WFD.

Against this background, the purpose of this report is to develop a fish-based assessment tool that takes into account the specific requirements of the WFD for the type of waters designated 'North Sea transitional waters' (type T1/T2). The 'North Sea transitional waters' are characterized by the estuarine salinity gradient and the dynamic coincidence of limnetic and marine elements. Thus, this type of water body constitutes a habitat of a very particular nature with a specific fish fauna. This distinctive characteristic made it necessary to elaborate a specific assessment approach for the transitional waters with respect to fish fauna as a quality component.

The multimetric assessment procedure designed for this purpose encompasses the aspects of species diversity, abundance, and age structure of the fish fauna and at the same time makes use of a historic reference coenosis as an assessment benchmark.

BioConsult Schuchardt & Scholle GbR was commissioned to develop an appropriate fish-based assessment tool by the German federal states of Schleswig-Holstein and Lower Saxony in December 2004. The Elbe River Water Quality Board (Wassergütestelle Elbe, Hamburg) was responsible for coordination of the project, supported by a group of experts composed of representatives from the federal states of Schleswig-Holstein, Lower Saxony and Hamburg. In particular we have to thank Thomas Gaumert, Joachim Löffler (Hamburg), Matthias Brunke (Schleswig-Holstein), Michael Kämmereit and Lutz Meyer (Lower Saxony).

3 Methodology

3.1 Work steps

The multimetric assessment procedure, which encompasses the aspects of species diversity, abundance and age structure of the fish fauna and at the same time makes use of a historic reference coenosis as an assessment benchmark, is designed on the basis of the following work steps:

- Reconstruction of a historical reference as assessment benchmark
- Analysis of the natural variability of fish fauna by means of different statistical methods
- Examination of existing assessment proposals for transitional waters from neighbouring European countries
- Definition of metrics relevant for the assessment
- Definition of classification boundaries for determination of ecological status and/or ecological potential in a 5-level system in line with the Water Framework Directive
- Development of a computer-aided assessment tool
- Proposals for carrying out the WFD monitoring.

3.2 Database

Various historical papers on fish fauna in estuaries as well as a number of current data records are available for processing the project (section 4). The latter have been collected in tidal estuaries within the framework of various occasions in recent years (Elbe: ARGE Elbe (2004), Möller (1984, 1988), Weser: Voigt (2003), Eider: Hagge (2003), Ems: LFV Weser-Ems (2003)).

The historical papers form the basis for the reference. The current data records are primarily used to analyse the spatial and temporal variability of the fish communities. And, in addition to a limited number of quantitative data from historical works (Apstein 1894, Schräder 1941), they also form the basis for specifying reference frequencies for the aspect of 'abundance'.

All available current data records (with the exception of Arntz et al. 1992, Ems, near shore stow net catches) were collected using the same fishing method (anchor net catches), though in different seasons in some cases. Because of the identical data acquisition methodology, there is extensive qualitative and quantitative comparability of the various data records after standardization of the data to individuals*h^{-1}*80 m^{-2}. Later application of the assessment procedure therefore presupposes this catch method as the standard (supplementary information).

3.3 Statistics

Multivariate Analysis

Canonical Correspondence Analysis (CCA)

Evaluation methods that can structure information determined in the field make results more transparent and may be of significance for ecological questions. For this reason an evaluation by means of CCA (Canonical Correspondence Analysis) was conducted for the present study with the aim of obtaining indications of possible interrelationships between species abundances and study years and/or existing time gradients.

The direct gradient analysis (CCA) is an estimate of the extent to which certain environmental parameters explain the variation range of biological data. Combinations of environmental parameters (here: temporal and spatial parameters) are calculated. The analysis represents a multivariate form of regression in which the species-abundance data are modelled as a function of the given environmental parameters. The significance of the axes reflects the variance in the species figures (eigenvalue representation of the species in the diagram) while the variance of the station figures is shown as a parameter of secondary importance. The species-abundance data were log-transformed prior to the analysis.

For representation in the form of an ordination the CCA variables are depicted on the x and y axis in a linear model. The resulting aligned species values are shown as arrows. The longer an arrow belonging to a species is in the ordination, the greater the extent to which this species explains local and/or temporal differences.

The software package CANOCO 4.5 was used.

MDS/ANOSIM

Other multivariate statistics (MDS) were compiled using the "Primer 6" software package. The Bray-Curtis similarity served as the similarity measure. The quality of the MDS representation is indicated by the stress value (stress < 0.05: very good representation without possibility of misinterpretation; stress < 0.1: good ordination; stress < 0.2: potentially useful representation that, nevertheless, should be used with reservations; stress > 0.3: data points are almost randomly distributed in the representation).

ANOSIM tests the zero hypothesis that there is no difference between *a priori* defined groups (e.g. regions). In addition to the p value, an R value is determined in this process – it provides information on the difference between the groups ($R > 0.75$: the groups can be clearly differentiated; $R \approx 0.5$: good distinction of the groups, though with some concordance; $R < 0.25$: the groups can hardly be differentiated, Clarke & Warwick 1994).

Other evaluation methods

Correlation analyses were conducted in order to identify indications of systematic patterns in the spatial and temporal variability of the estuarine fish fauna. The Spearman rank correlation was used. The Spearman rank coefficient describes the degree of correlation between measured values (ranking of measured values). The analysis does not require any certain form of distribution of the data.

3.4 Definition of terms

3.4.1 Transitional waters

Estuaries characterized by longitudinal gradients of salinity and tidal range are allocated to a distinct type of water body in the WFD, i.e. transitional waters. According to the definition of the WFD REFCOND 2.4 (2000), transitional waters are surface water bodies near river mouths ("in the vicinity of a river mouth") that have a certain salt concentration or are characterized by a corresponding salt gradient ("partly saline in character") due to the proximity to coastal waters but are also extensively influenced by upstream water ("substantially influenced by freshwater flow"). The upstream boundary of transitional waters is formed by the 0.5 $^{o}/_{oo}$ isohaline, the lower boundary by the 30 $^{o}/_{oo}$ isohaline. Figure 1 shows the demarcation between the transitional waters and the North Sea for the Ems, Weser, Elbe and Eider rivers.

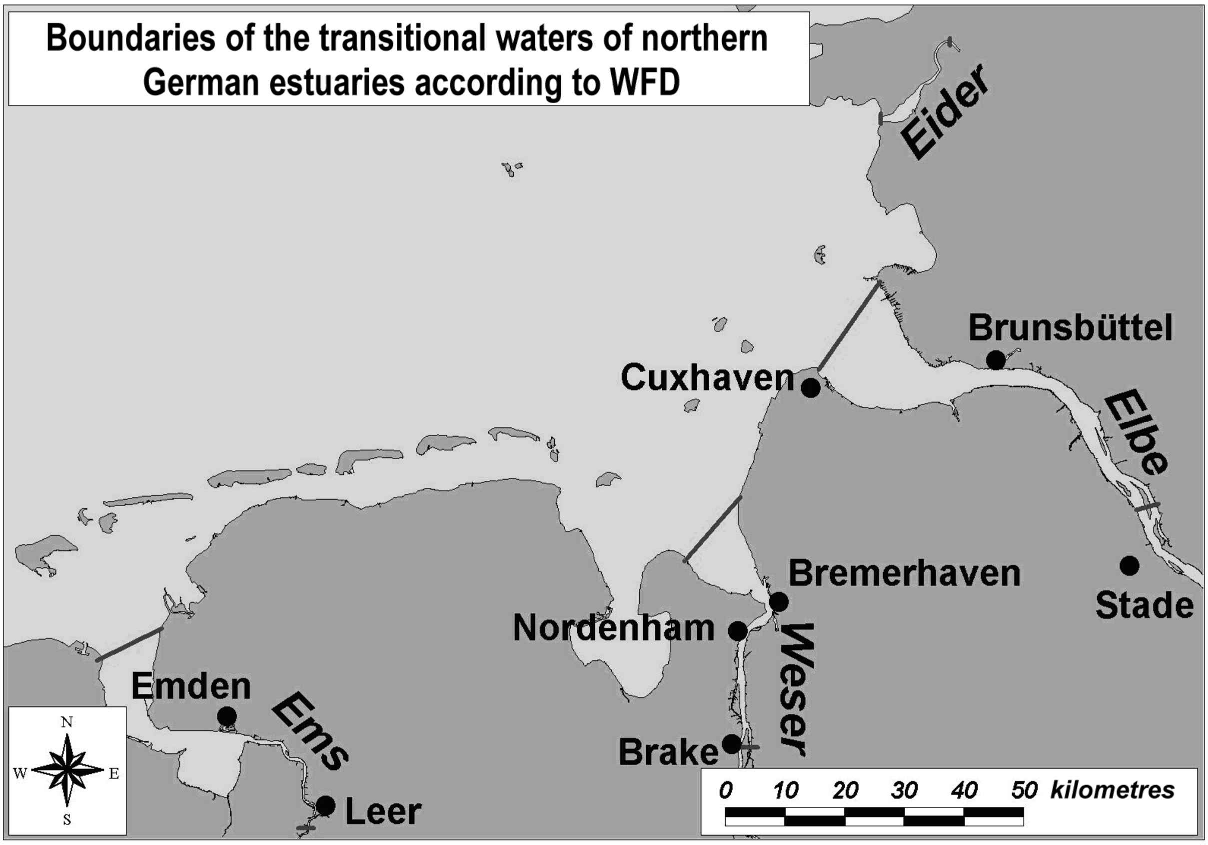


Figure 1: Demarcation of transitional waters type T1 (Ems, Weser, Elbe) and type T2 (Eider) in accordance with the Water Framework Directive (WFD 2000). [Legend: grey lines symbolize boundaries of the transitional waters of northern German estuaries; kilometres]

3.4.2 High ecological status

Achievement of the European protection goal is measured to a significant extent on the basis of biological-ecological criteria in addition to specific chemical and structural requirements. The water bodies have to be typified to have a basis for comparison of the present state with the respective reference state specified for each type. For this purpose the type-specific conditions of a high status, which exists in the absence of any disruptive anthropogenic influences, must be defined for the biological, physical-chemical and hydromorphological quality components on the basis of reference water bodies as far as possible.

The WFD employs a 5-level classification system to evaluate the ecological status. Table 1 designates the general WFD criteria for the classification of ecological quality while Table 2 indicates the fish-fauna WFD criteria.

Water bodies in which the values for the biological quality components show considerable changes and the biocoenoses differ significantly from those that are characteristic for the respective type of surface waters in the absence of disruptive influences (reference conditions) are classified as unsatisfactory or as poor.

Table 1: General WFD definition of terms for the ecological status of rivers, lakes, transitional waters and coastal waters (WFD REFCOND 2.3 2000)

	High status	Good status	Moderate status
General weir	The values for physical-chemical and hydromorphological quality components show no or very minor anthropogenic changes compared to the figures that are characteristic for the type of surface water in the absence of disruptive influences (reference conditions). The values for the biological quality components of the surface waters correspond to those that are characteristic for the type of surface water in the absence of disruptive influences, and they show no or only very minor deviations (reference conditions). The type-specific conditions and communities thus exist.	The values for the biological quality components of the type of surface waters show slight anthropogenic deviations, but differ only to a minor extent from the figures that are characteristic for the type of surface waters in the absence of disruptive influences (reference conditions).	The values for the biological quality components of the type of surface waters differ moderately from the figures that are characteristic for the type of surface waters in the absence of disruptive influences (reference conditions). The figures indicate moderate anthropogenic deviations and show significantly greater disturbances than in a good status.

Table 2: General WFD definitions of terms for the fish-fauna status of rivers, lakes, transitional waters and coastal waters (WFD REFCOND 2.3 2000)

	High status	Good status	Moderate status
Fish fauna	Composition and abundance of the species correspond completely or almost completely to the reference conditions. All type-specific species sensitive to disturbances are present. The age structures of the fish communities display hardly any signs of anthropogenic disturbances and do not indicate disturbances in the reproduction or development of any specific species.	Due to anthropogenic influences on the physical-chemical and hydromorphological quality components, the species composition and abundance deviate slightly from the type-specific communities. The age structures of the fish communities display signs of disturbances due to anthropogenic influences on the physical-chemical or hydromorphological quality components and in a few cases indicate disturbances in the reproduction or development of a specific species so that some age levels may be lacking.	Due to anthropogenic influences on the physical-chemical or hydromorphological quality components, the fish species composition and abuncance deviate moderately from the type-specific communities. The age structures of the fish communities display substantial signs of anthropogenic disturbances so that a moderate proportion of the type-specific species is lacking or very rare.

3.4.3 Definition of the reference period

As is clearly indicated in the previous section, a high ecological status in the 5-level assessment approach of the WFD is based on a reference situation in which no or very minor anthropogenic changes are noted for the physical-chemical and hydromorphological quality components for the respective type of waters. The values for the biological quality components of the water body should correspond to those that are characteristic for the particular surface water type in the absence of disruptive influences. Since there are no transitional waters in the North Sea that comply with this reference status, it makes sense to use a historical reference as the basis. For fish fauna as a quality component this is possible because historic data of relatively good quality exist due to the economic importance of this group as compared to other components like benthos.

We set the reference period at the end of the 19th century, i.e. a period prior to the beginning of the large-scale river engineering work that so significantly altered the estuaries in the following hundred years. In terms of water body structure the estuaries were influenced relatively little by direct measures during this period (BfG 1992, Schuchardt et al. 1993a,b). However, the dike lines had long been closed and thus large sections of the riverine meadows were separated from the water body (Kausch 1996).

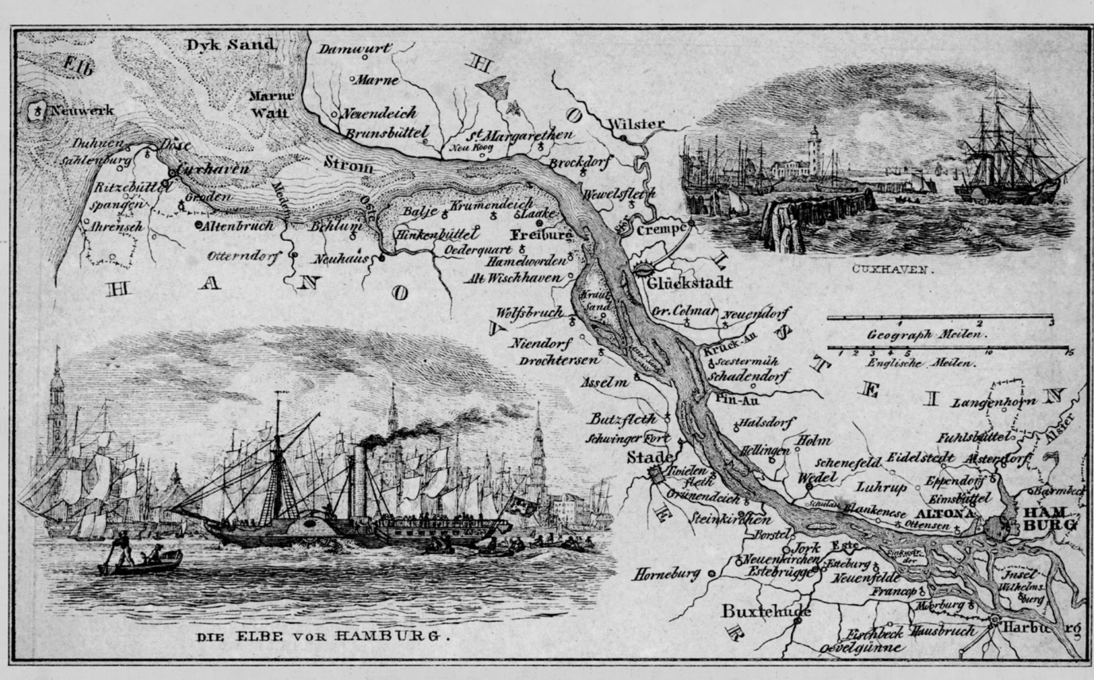


Figure 2: Map of the Lower Elbe. Published by "Hochlöbliche Schiffahrts- und Hafen-Deputation" in agreement with "löbliche Commerz-Deputation" in Hamburg (1837).

The water body morphology was characterized by a relatively shallow multi-channel system with many branches and sandbanks; the flow cross-sections were therefore relatively small (among others, Grabemann et al. 1999). The dike structures restricted the capacity of the estuaries for lateral enlargement, particularly in the inner estuaries. In large areas they cut off the link to the riverine meadows. However, the rivers themselves and the dike foreshore at that time can be designated as largely natural. The channels had not been fixed by river engineering measures and a dynamic shifting of the channels, plates and sands was possible. The current was not concentrated exclusively on an arm or channel, the overall flow speeds were significantly lower than today. The morphological processes in the inner estuaries, for example in the Weser estuary, were almost solely controlled by the tidal wave that still flowed unchanged into the river mouth with the greatly decreasing tidal range. Historically the tidal range was low to moderate in all estuaries; from the Outer to the Lower Weser, for example, it declined from approximately 2.7–3.3 m to < 0.4 m.

Direct human intervention in form of river engineering or dredging work virtually did not take place. The largely uninfluenced morphodynamics lead to a great species diversity based on a divers biotope structure: main channel, shallow-water zones, mud flats, reed zones, sand and gravel banks, riverine meadow woods, side arms and backwater. The interlinkage of the main channel with tributaries was morphologically very pronounced in some cases. This contributed to a great diversity of the estuarine habitats (Scholle & Schuchardt 1996) and in the reference period the estuaries still largely corresponded to a status defined nowadays as a model for nature conservation (Claus et al. 1994). Figure 2 provides an exemplary impression of the morphology of the Lower Elbe at the beginning of the 19th century.

4 The estuaries of northern Germany as transitional waters: characteristics and stressors

In the following the current abiotic conditional framework and impairments of the 4 northern German estuaries of the Ems, Weser, Elbe and Eider rivers are described against the background of the fish fauna assessment as a biological quality component. These estuaries form a habitat of a unique type that is predominantly characterized by its salt gradient and tidal range. They are subject to strong use pressures that have led to significant changes in structure and function of all estuarine water bodies, especially in the inner sections. Thus, the aquatic biotic communities are under pressure as well, particularly the fish fauna. The individual uses, such as

- shipping,
- coastal protection,
- storage of excavated material,
- removal of sand and gravel,
- agriculture,
- fishery
- and direct and diffuse input of substances,

had and still have a varyingly intensive impact on the estuaries (Schuchardt et al. 1999, Schuchardt & Scholle 2009, Essink et al. 2005).

While in some cases the water quality has improved in the river mouths in recent years (e.g. Schuchardt et al. 1989), the morphological deformation due to deepening of the shipping channels, was substantial in the past, and will be boosted further by the implementation of pending work (adaptation of Outer Weser / Lower Weser and Lower Elbe).

4.1 Morphology

The four estuaries differ considerably with respect to their morphology and size, and thus in terms of their hydrography, too. Some of the key variables are compiled in Table 3.

Ems: In the Ems estuary the kilometre measurement begins at Papenburg with km 0. Papenburg is located 13 km downstream of the Herbrum tidal weir. The Lower Ems meanders towards the Dollart and several river bifurcations exist. The estuary widens from < 100 m in the inner section to around 600 m near Pogum (km 35). There the Lower Ems reaches the Dollart which measures approximately 10 x 10 km and expands to the Outer Ems at about km 53 at the landmark called Knock. Km 90 is located near the island Borkum; the kilometre count ends at km 100 seaward from Borkum. The shipping channel upstream of Emden is about 4 m deep; downstream of Emden it is about 8 m deep and continues to deepen towards the sea. The transitional waters of the Ems stretch from Leer (Ems km 26) to a line between Eemshaven and Pilsum.

Weser: The kilometre count for the Weser estuary begins in Bremen about 4.6 km downstream of the Bremen-Hemelingen tidal weir with km 0. The trough-shaped, relatively narrow Lower Weser with its two remaining side arms extends down to km 65.5 at level with the mouth of the river Geeste in Bremerhaven. The width increases from approximately 300 m in the Bremen area to around 1,500 m near Bremerhaven. The target depth in the shipping channel is 9 m. From Bremerhaven seawards the Weser estuary expands in a funnel-shaped manner and includes extensive eulittoral areas. The section between km 65.5 and 120 is called the Outer Weser. Since the last deepening the target depth of the shipping channel there has been 14 m. The transitional waters of the Weser begin around Brake (Weser km 40) and end approximately at Weser km 84.

Elbe: In the Elbe, the largest of the estuaries, the kilometre count begins with km 0 at the point where the Elbe enters German territory in the federal state of Saxony. The upper tidal boundary is the Geesthacht weir at km 585.9. The relatively narrow (200 m) so-called tidal Elbe extends down to km

608. The river bifurcation area with the city of Hamburg follows in a seaward direction down to km 626. The two river arms, Norderelbe and Süderelbe or Köhlbrand, flow through this area. The Lower Elbe is located between km 626 and km 728 and expands in a funnel-shaped manner towards Brunsbüttel (km 700). Its width increases from approximately 500 m in Hamburg to about 2,000 m at Brunsbüttel. The Lower Elbe comprises several channels, one of which has been expanded to a shipping channel while the Elbe branches are subject to significant silting in some areas. In the branching areas the width may measure up to 6,000 m. Before the river adaptation to container shipping in 1999 the Lower Elbe shipping channel had a target depth of 13.5 m, which was realized only upstream of Brunsbüttel. There are eulittoral areas of varying size. The adjacent broad outer estuary between km 727.7 and 769.4 is called the Outer Elbe. The shipping channel there has very wide eulittoral fringe areas. Since the last adaptation to container shipping requirements in 1999 the shipping channel depth varies between 14.4 and 15.3 m. The transitional waters of the Elbe begin around Grauerort (Elbe km 660) and end at the sea boundary near Cuxhaven (Elbe km 727).

Eider: In the Eider the kilometre count starts at Rendsburg with km 0. The Upper Eider is completely separated from the Lower Eider by the Kiel Canal. The Nordfeld tidal weir is located at km 78. The tidal Eider extends between the tidal weir and the Eider dam at km 109.8. The Outer Eider begins off the storm-tide barrage. The Eider is the smallest of the estuaries with a length of approximately 30 km between the tidal boundary and the storm tide barrage. Upstream of Tönning (km 100) the estuary is very narrow and has nearly no eulittoral areas (< 200 m). Downstream of Tönning the eulittoral areas expand very significantly off the embankment of the Katinger Watt. Today the mud flats there have a maximum width of < 2,000 m. The 200–300 m wide channel of the Eider divides them into a northern and a southern part. The shipping channel depth ranges from 2 to 3 m below chart datum upstream and downstream of Tönning. Over approximately 7 km of eulittoral areas line the seaward Outer Eider with water depths between 3 and 8 m. The transitional waters of the Eider begin at about Nordfeld below the tidal weir and end at the sea boundary near Tönning.

4.2 Tidal range

The tidal range is a parameter for the extent of deformation, particularly of the inner estuaries, due to adaptation of the shipping channel to increasing ship sizes and at the same time a variable that is characteristic of the living conditions for the biotic communities in the estuary. The change in the tidal range as a consequence of the various hydraulic engineering measures is documented for the individual estuaries (among others, Siefert & Jensen 1993, Grabemann et al. 1993, Busch et al. 1984, Siefert 1982, Wetzel 1987). Schuchardt (1995) supplies a comparison of the historical changes of the tidal range in the four estuaries that is used as a major reference here. The expansion measures not only encompass the widening and deepening of the actual shipping channel, but also its delimitation by training walls, groynes and backfilling of branches, thus concentrating the force of the current on the shipping channel. Similar measures had already been formulated and were implemented for the Lower Weser by Franzius (1895).

The four estuaries differ not only in size and discharge, but also in amplitude and longitudinal gradient of the tidal range (Table 3). In an unobstructed estuary the amplitude declines upstream depending on the morphology as a result of the energy dissipation of the incoming tidal wave. At present this is only the case in the transitional waters of the Eider estuary. The tidal range drops from 3.1 m at the Eider dam to 2.0 m at the Nordfeld tidal weir; however, this is influenced by the operation of the Eider dam (Wieland 1993).

In the Elbe, by contrast, it increases from 3.0 m in Cuxhaven to 3.5 m in Hamburg/St. Pauli. Only upstream of the Hamburg river bifurcation area and thus outside of the section developed for seagoing vessels does the tidal range drop to 2.4 m at the Geesthacht tidal weir.

Table 3: Key parameters for the inner estuaries of the Eider, Elbe, Weser and Ems.

Ems		**Eider**	
Catchment area up to tidal weir (km²)	13,000	Catchment area up to tidal weir (km²)	2,000
Length of inner estuary (km)	50	Length of inner estuary (km)	21 (30)
Mean discharge (m³/sec)	125	Mean discharge (m³/sec)	23
Mean tidal range Ems (m)		Mean tidal range Eider (m)	
Emden	3,2	Eider barrage outer gauge	3,1
Pogum	3,2	Tönning	2,6
Papenburg	3,1	Friedrichstadt	2,1
Herbrum weir	2,8	Nordfeld	2,0
Weser		**Elbe**	
Catchment area up to tidal weir (km²)	38,000	Catchment area up to tidal weir (km²)	135,000
Length of inner estuary (km)	70	Length of inner estuary (km)	120
Mean discharge (m³/sec)	323	Mean discharge (m³/sec)	725
Mean tidal range Weser (m)		Mean tidal range Elbe (m)	
Bremerhaven Doppelschleuse	3,7	Cuxhaven	3,0
Brake	3,8	Glückstadt	2,8
Bremen/Oslebshausen	4,0	Hamburg/St. Pauli	3,5
Bremen/Weserwehr	4,1	Geesthacht	2,4

The high tidal range of the Weser estuary in Bremerhaven (3.7 m) rises to 4.1 m at the Hemelingen Weser weir in Bremen, the highest tidal range on the German North Sea coast. The tidal range of the Ems estuary remains roughly the same (3.2 or 3.1 m) between Emden and Papenburg, i.e. in the section developed for seagoing vessels and it does not drop to 2.8 m before reaching the upper section at the Herbrum tidal weir (Schuchardt 1995).

In the Eider the tidal range at the Friedrichstadt water level gauge has fallen from approximately 2.4 m at the end of the last century to 2.1 m today. The reason for the changes was primarily construction of the Nordfeld tidal weir and the Vollerwiek Eider dam, which reduces the tidal wave today.

The tidal range has increased significantly in the three other estuaries (Table 3). This means substantial changes have taken place in the tidal activity in all four estuaries over the last 100 years (Schuchardt 1995).

4.3 Discharge

The discharge flowing into the estuaries influences the range of the brackish water and thus the location of the turbidity zone and is of key importance for the residence time of the water in the estuary. In general the headwater follows a typical annual cycle that depends on the precipitation in the catchment area and other parameters, such as snow melt, topography and the like.

The mean monthly discharges (MQ) of the various estuaries differ considerably depending on the different sizes of the catchment areas. The MQ ratios are: 1 (Eider): 5.4 (Ems) : 14 (Weser) : 31.5 (Elbe). They correlate to the varying sizes of the different estuaries (Table 1).

4.4 Salinity

The longitudinal and vertical gradients of salinity and their dynamics are the key parameters of the estuaries and of decisive importance for the biocoenoses (chapter 7).

On the one hand, the position of the brackish water zone is influenced by the tides, which have been massively changed in all estuaries (Schuchardt 1995). On the other hand, the discharge is especially important for the range and morphology of the brackish water zone. Due to the higher density of the salt water penetrating the estuary near the seabed, an upstream-pointing salt wedge forms a layer below the outflowing lighter freshwater.

Low summer and autumn discharges are characteristic of the Wadden Sea estuaries. In this process the upper sections of the brackish water zone may reach far into the inner estuary. Tides and headwater dynamics together lead to a very great longitudinal variability in salinity.

The range of the brackish water zone has presumably been shifted upstream due to the expansion of the estuaries (e.g. Riedel-Lorje et al. 1992, Bergemann 1995), though clear evidence is still lacking.

For the sake of simplicity salinity is classified with respect to biological aspects according to the Venice system (1959) used to classify transitional waters. A distinction is made here between the limnetic zone with a salinity of < 0.5, the oligohaline zone (0.5–5), the mesohaline zone (5–18) and the polyhaline zone (18–30). Since the borders and ranges of these zones in the estuaries are extremely variable, they can only be specified for certain headwater situations. The Venice system does not make any specifications in this regard. Very different criteria are stated for the definition of the upper brackish water boundary for low discharge situations (compilation in Riedel-Lorje et al. 1992). It appears meaningful to examine the biological impact of the range of the salinity zones, i.e. to ask whether the longitudinal spread of individual species is influenced by the (temporary) situations with low headwater discharge, the mean situation or the situations with high headwater discharge.

Ems: There is a relatively large amount of individual data compiled by IBL (1997). It is difficult to pinpoint and define salinity zones that correspond to the species diversity of the macrozoobenthos. The following approximate boundaries can be drawn: the transition of the limnetic zone to the oligohaline zone in the section between km 20 and 27 (Nüttermoor to Critzum), the transition to the mesohaline zone at around km 30 (Oldersum) and the transition to the polyhaline zone at about km 51 (Knock). Borkum (km 97) can be assumed as the point of transition to the euhaline zone.

Weser: The situation for a mean Weser headwater discharge is given by WBNL (1998) based on older data in relevant literature (Schuchardt et al. 1993b): limnetic zone (though salified anthropogenically) down to km 50, oligohaline zone down to km 65, mesohaline zone down to km 85 and polyhaline zone down to km 115. During low headwater discharge conditions, however, the upper brackish water boundary shifts substantially further down the Weser estuary.

Elbe: There has been an extensive debate regarding the definition of the salinity zones and their anthropogenic change in the Elbe estuary. While Caspers (1959) draws the end of the limnetic zone during low headwater discharge at km 670 (oligohaline zone then between km 670 und 695; mesohaline zone between km 695 und 705), Riedel-Lorje et al. (1992) describe the following situation during low headwater discharge: the limnetic zone ends at around km 650, the oligohaline zone is then situated between km 650 and 690, and the mesohaline zone is between km 690 and 720. During high headwater discharge the situation differs significantly. The oligohaline zone is then located between km 715 and 725. Data for mean headwater discharge conditions were not available.

Eider: For the Eider estuary only little data are available, compiled by Spratte (1992). According to him, the polyhaline zone extends from the sea to around km 107, i.e. somewhat upstream from the storm tide barrage. The section up to km 95 can be classified as mesohaline and the following section as oligohaline. The transition to the limnetic zone can hardly be pinpointed since it is changed substantially due to water management via the tidal barrage. These data correspond to those of Fock & Heydemann (1995) only to a limited extent. They point to the substantial seaward shift and changed division of the estuarine salinity gradient as a consequence of the construction of the Eider dam and the tide manipulation. The only 6–7 km wide mesohaline zone is completely shifted by the tide with a tideway of approximately 10 km. Measurements conducted by Ricklefs (1998) also show a lower size of the mesohaline zone than that given by Spratte (1992).

Once again, due to the longitudinal shift, a spatial definition of salinity zones can only provide a very rough indication of the conditions that influence the biotic characteristics at a defined place. In the end the ecologically relevant salinity can presumably be derived better from the species composition than vice versa.

4.5 Sediments

The sediment composition in the estuaries of Eider, Elbe, Weser and Ems primarily reflects their hydrodynamics and deformation. Sands of varying grain size dominate in the estuaries of the Weser and Elbe. The Ems and Eider are characterized by rather silty sediments.

Ems: A substantial increase of the fine-grain proportion in the sediments can be observed in the Lower Ems above Emden since the beginning of the 1980s so that the silt proportion in the Lower Ems is now 70–75% (IBL 1997). De Jonge (1988, 1995) has provided an overview for the Outer Ems. Medium and coarse sand dominates in the Outer Ems, with a very low percentage of fine-grain sand, while the fine-grain proportion may be higher locally in the eulittoral areas, especially near the shore. In the outer section of the estuary 87% of the sediments are composed of sand. The clay portion of 1.4% is very low because of the high energy input. In the middle section of the estuary the sand proportion is 67%, the silt proportion 33%, and the clay proportion 4.5%. This means the conditions in the sediment clearly reflect the declining energy input. In the Dollart the clay proportion increases from 5% in the central section to as much as 35% near the shore. The channels and the shipping channel generally display only a very low proportion of fine grain due to the high energy input. This does not apply to the Emden shipping channel and parts of the Lower Ems, where fine grain accumulates on the bottom of the water body in connection with the formation of the estuarine turbidity cloud (Spingat 1997).

Weser: The sediments on the bottom of the shipping channel in the Weser estuary are dominated by sand. In the side sections gravel/sandy sediments are only found locally. Fine-grain sediments can be found in isolated cases in the fringe areas of the shipping channel (BfG 1992) and are significantly widespread predominantly in groyne areas.

Elbe: The data on sediment characteristics in the Lower Elbe environmental impact study have been compiled and expanded (PGÖK 1997). They indicate that primarily non-stratified medium-sand is found in the shipping channel while fine sand dominates in the side sections. Coarse sand as well as older sediments (e.g. boulder clay) are found only in places. The same applies to silt.

Eider: Ricklefs (1998) describes the sedimentological situation in the Eider: the outer, very dynamic section of the Outer Eider is characterized by fine and medium sand. Upstream the grain size decreases both in the channels and in the eulittoral areas. Mixed mud and sand flats as well as mud flats dominate between the Eider barrage and Tönning. Above Tönning the sediments in the eulittoral zone are almost purely silt. This tendency is also reflected in the channels although the sediments there are somewhat coarser because of the greater hydraulic load. The turbidity zone, in which fine-grain material accumulates in the water column and on the bottom, is also important for the composition of the sediments. In the Eider the turbidity zone is essentially found between the barrage and Tönning.

4.6 Dumping

To maintain the approved water depths for the shipping channels of the estuaries and the Jade, maintenance dredging is necessary. The volumes dumped in the estuaries differ greatly (Table 4). If one compares these volumes to the length of the maintained shipping channel, the large volumes, particularly in the Ems, are striking. In the Weser the volumes declined very rapidly up to 1996, primarily as a result of hydraulic engineering measures to increase the transport capacity. They rose again substantially within the framework of the deepening to 14 m in 1999. The material is predominantly dumped in the estuary and is hardly stored on land nowadays. In 2001 significant quantities amounting to 0.06 million m^3 were dredged on a single occasion in the Eider.

Table 4: Quantities of dredged material dumped (in million m³) (according to data of the working group "Baggerei Küste" of the Federal Waterways and Shipping Administration supplemented by data from Baggerbüro Küste, WSA Bremerhaven in BioConsult 2003).

Year	Ems	Weser	Elbe
1995	9.2	1.5	11.7
1996	4	1	6.7
1997	5.3	1.9	11.9
1998	6.3	2.2	11.7
1999	6.9	5.8	7.1
2000	6.8	4.8	12
2001	6.3	4.7	9.9
2002	8.2	5.1	10.9
Mean/a	6.63	3.38	10.24

4.7 Water quality

Up to a few years ago the water quality in the estuaries led to ecological impairment, particularly in the Elbe and Weser. Summer oxygen deficits were primarily responsible for this. After expansion of the water treatment plants both at the estuary itself and in the upstream waters, however, there were significant improvements (among others, Schuchardt et al. 1985, Reincke 1995), though summer deficits still occur especially in the limnetic zone of the Elbe estuary. In the Ems, where extreme summer oxygen deficits have constantly recurred in recent years, the situation has deteriorated considerably. In 1994 the water quality between Herbrum and the Leda estuary (limnetic zone) was downgraded from class II to class III (heavily polluted) (Höpner 1996). In the water quality map for 2000 it was downgraded to class III/IV (extremely polluted) from the mouth of the Goldfischdever to north of the Leda estuary (NLÖ 2001). In the outer estuaries the oxygen supply in the water column can generally be designated as balanced.

4.8 Habitat losses

Settlement of the coastal region and its use have resulted in a large-scale and profound restructuring of the natural habitat that will be outlined on the basis of several indicators. Losses of some of the typical types of habitat in the estuaries have been relatively well documented for the last hundred years (ARGE Elbe 1984; Claus 1998, among others). It must be kept in mind here that the original extent of the riverine meadows was reduced to a great degree due to dike construction even around 1900 (Paluska 1992).

Shallow-water zones

Shallow-water zones are of outstanding significance for the materials cycle and also for the aquatic biotic community of the tidally influenced river because they have a substantially reduced current compared to the deeper sections and may therefore display different substrate conditions (ARGE Elbe 1984). Shallow-water zones (generally defined as areas with water depths less than 2 m) are important for primary plankton production, among other things. Due to the altered ratio between the depth receiving transmitted light and the total depth, the primary plankton production has often increased many times over shallow-water zones in relation to the deep shipping channel sections (Schuchardt & Schirmer 1991) so that the shallow-water zones may contribute significantly to a positive oxygen balance (ARGE Elbe 1984).

According to Claus (1998), the magnitude of the shallow-water zones diminished by 78% in the limnetic section of the Lower Weser and by 73% in the brackish section between 1887–93 and 1988. ARGE Elbe (1984) found a reduction of approximately 25% for the Lower Elbe.

Mud flats

The eulittoral zone is a characteristic estuarine habitat that may have developed into freshwater, brackish water, or coastal mud flats. It has a relatively low number of species but attains a high productivity. Although additional eulittoral areas form (predominantly at the expense of the shallow-water zones) by virtue of the increase in the tidal range that is caused by river development and is 60–90% due to the sinking of the low tide, numerous mud flat areas have been lost in the tidal estuaries in the past. The reason for this is construction work, such as bank reinforcement, the filling of backwater and branches, sand nourishment and the like. Overall, however, the reduction of mud flats is considerably less than for shallow-water zones.

Foreshore and salt marshes

The foreshore in front of the dike as a relict of the riverside and coastal lowlands that were very extensive prior to dike construction has been further reduced even after the early establishment of a closed dike line (Table 5). The very pronounced decline of dike foreland areas in the Elbe is exceptionally striking. This is primarily a consequence of the large-scale construction of dikes closer to the water after the storm tide in 1962. Contrary to the Lower Elbe, extensive dike construction closer to the water has not taken place on the Lower Weser in the recent past. The last significant diking measure closer to the water was the construction of the Luneplate dike south of Bremerhaven around 1920. Losses of foreshore habitats have occurred in recent years, particularly due to port construction projects.

Table 5: Reduction in size of foreshore areas in the inner northern German estuaries excluding the Eider (Claus 1998, Schuchardt 2003); Ems excluding Dollart; Elbe and Ems excluding upper tidal zone.

Estuary	Foreshore area around 1900 (ha)	Foreshore area around 1990 (ha)	Loss (%)
Elbe	21,431	7,904	63
Weser	7,061	6,160	13
Ems	1,712	1,081	37

4.9 Hydraulic engineering measures

In addition to dike construction, location of industry and agricultural use, hydraulic measures have significantly contributed to the substantial changes, especially in the inner estuaries.

Eider: The first major intervention was the diminution of the catchment area resulting from construction of the Kiel Canal (Wieland 1992a). The consequence was a reduction in the Elbe flow and increased sedimentation (Rhode 1965). As a result of construction of the tidal weir near Nordfeld (reason: storm tide protection and improvement of the drainage of the Eider lowlands), the river section above Nordfeld was transformed into a virtually stationary water body (Inner Eider) (Rhode 1965). As a consequence, the river cross-sections below Nordfeld were reduced by 90–95% (Rhode and Timon 1963).

The Vollerwiek storm tide barrage commenced operation, again for the professed purpose of storm tide protection and improvement of the water management conditions. In this connection the Eider estuary was closed by a 4.8 km long sea dike and a dike was constructed along the 1250 ha Katinger Watt. However, since the sand influx in the tidal Eider continued to increase (Harten 1979), the flood current has been reduced at the barrage since 1980 (Wieland 1992b).

Elbe: Up to the beginning of the last century the shipping channel of the relatively deep Lower Elbe had to be adapted to growing ship sizes by means of generally not very extensive dredging only in the Hamburg area (Schlüter 1989). In addition, river engineering work was carried out. Then, between 1922 and 1978, the Lower Elbe was deepened successively from 10 m to 13.5 m below chart datum within 4 expansion phases altogether in response to increasing ship sizes and the Geesthacht tidal weir. In 1999 the bottom of the Outer and Lower Elbe was deepened from 14.4 m to 15.3 m below chart datum as part of the adaptation to the needs of container shipping. A further adaptation is in preparation phase.

Weser: The first major expansion measure was the so-called “Weser correction”, in which the general morphology was significantly reshaped (Busch et al. 1984, Grabemann et al. 1993). The expansion principles developed by Franzius (1895) at the same time still apply today and were later also applied in the other river estuaries:

- expansion according to the funnel principle to strengthen the transport capacity of the tidal current,
- elimination of river bifurcations (backfilling of side arms), and
- hydraulic engineering measures to concentrate the force of the current (construction of groynes and training wall).

Extensive dredging work, backfilling of side arms and hydraulic engineering measures were performed (Busch et al. 1984). The 5-m expansion was followed by 5 additional expansion stages in the Lower Weser and one in the Outer Weser with only brief interruptions of a few years. In the 1980s a substantial groynework programme was carried out to reduce the large volumes resulting from maintenance dredging. Today, material is only relocated, i.e. inadequate depths are dredged and the material is dumped in areas with excessive depths or used for sand nourishment (Wetzel 1987). The 14-m deepening of the Outer Weser took place in 1999 (Rodiek & Steege 2001); another expansion is in preparation phase.

Ems: Between 1900 and 1928 the Herbrum weir was built and the greatly meandering Lower Ems between Herbrum and Leerort was shortened by 15% by means of several cut-offs, and groynes were constructed (Höpner 1994). Around 1950, relatively extensive maintenance dredging was started (Arntz et al. 1992) for the purpose of maintaining a shipping channel depth of 4.5 m below mean high water level between Leer and Papenburg and 5.5 m between Leerort and Emden. The dredged volumes increased considerably, especially at the beginning of the 1970s. After completion of the actual expansion of 1984/85 the dredged quantities dropped relatively little due to the still necessary maintenance dredging (Arntz et al. 1992). This was followed by several operations for deepening the shipping channel at short intervals. In contrast to the Weser and Elbe, the formulated objective of the expansion measures is not to create a sustainably deeper navigation channel for maritime shipping, but the current deepening measures are aimed at enabling single passages of new ships from Papenburg to the sea (Dette et al. 1994). In 2003 the Ems barrage near Gandersum went into operation with the aim of improving storm tide protection as well as enabling damming of the Lower Ems for transfer of new vessels with a large draught.

5 Preliminary work

5.1 Reconstruction of fish fauna reference community

The time towards the end of the 19th century, i.e. roughly the period between 1880 and 1900, has been defined as the reference point for a high ecological status in this report. In the following, the species diversity and typical abundance will be reconstructed for this period. A brief overview of the morphological and hydrographic situation during this reference period has already been provided above.

„*und finden sich unter und um Bremen allerhand arth guter Fische, alß Störe, Lachse, deren in Bremen zwischen den Ringmauern jährlich etliche tausend gefangen, gedorut und an fremde örther, ihres guten geschmacks und fettigkeit halber, defiederieret und hauffenweiß verführet werden: Lamprese, Neunaugen oder Pricken, Karpen, Barben, Hechte, Brässem, Rotaugen, Aland, Aele, Persich, Gründling, Forellen, Quappen, Butte, Schneppel, Stinte und in summa aller arth schmackhafte Rivier- und Seefische, hauffenweiß; jedoch dass zu Bremen fast sonderbahr ein jeglicher Monat im Jahr seine besondere Fische für andere zeuget, welches anderer örther nicht bald zu finden*“ (Freien Reichs- und fürnehmen An-See-Stadt Bremen 1780).

Within the scope of this report the reference community for transitional waters was primarily derived from historical work on the Elbe and Weser (only in part with reference to the Ems, Lohmeyer 1907) that predominantly date back to the period from around 1870 to 1920, i.e. prior to the first major hydraulic engineering measures. As the estuaries were already subject to anthropogenic uses at that time, the reference does not represent a pristine state, but nonetheless a (very) good ecological status with respect to the fish fauna in our view since the species diversity was very high and the major characteristic species of the estuaries, such as sturgeon (*Acipenser sturio*), houting (*Coregonus oxyrhynchus*), shad (*Alosa* spp.), salmon (*Salmo salar*), etc., were still caught in large quantities. According to Nolte (1976), the catch figures for houting around 1900, for example, were even higher than those for the salmon, which was also very common at that time.

For the period at the beginning of the 20th century Schuchardt et al. (1985) pointed to the decline that started in the Weser and became significant for most diadromous migratory fish species and lampreys by the mid-20th century. Similar declines were also documented in the Elbe (among others, Kühl 1976, Riedel-Lorje & Gaumert 1982, Möller 1988, Möller 1991, Costello et al. 2002). In particular the catch figures for sturgeon started to fall back at the end of the 19th century and then dropped very substantially in all estuaries of the North Sea coast after 1910, though the main fishing grounds for sturgeon shifted from the estuaries further into the Wadden Sea (among others, Lozán 1990, Lozán et al. 1996). At the same time the size of the landed sturgeons declined considerably. According to Ehrenbaum (1916), 97% of the sturgeons in 1898 were longer than 150 cm while after 1910 the proportion of this size category of the total catch dropped to only 12%.

The literature on which derivation of the reference coenosis was based encompasses early works on fish fauna, e.g. by Apstein (1894), von dem Borne (1883), Rübcke (1914), Bocherding (1889), Häpke (1876, 1880), Lohmeier (1907), Sterner (1916a–1916e, 1918a–1918e), Wiese (1918) and Schräder (1941). Furthermore, ‘more recent’ literature was also taken into consideration (Duncker & Ladiges 1960, Lozán et al. 1996, Meinken 1974, Nolte 1976, Möller 1984, Möller 1991, Peters et al. 1986, Scholle 1997, Scholle 2000, Schuchardt et al. 1985, Thiel 1995), which in turn contain compilations of historical fish fauna and/or fishery papers, such as the extensive work by Riedel-Lorje & Gaumert (1982), which comprises, among other things, an analysis of the fish stock of the Lower Elbe under the influence of river engineering work and sluice discharges. This database made it possible to reconstruct the original structure of the ichthyocoenosis of the tidal estuaries with a fairly good level of quality. In addition to the qualitative data available from the literature, references to the frequency of the fish were also taken into account so that rough frequency data can be provided for every fish species as far as possible.

5.1.1 Species diversity

Putting together a **reference species diversity** that is reliable poses no major problems as, from a qualitative point of view, the available information provides a comprehensive overview of the fish fauna at that time. On the basis of the available database for the tidal estuaries, more than 121 species (excluding present-day neozoans) are historically documented. The species can be divided into the six ecological guilds that were differentiated for estuaries by Elliot & Dewailly (1995) and represent in principle various 'user groups" of the estuary (Table 6). Along the estuarine salinity gradient, however, they differ in terms of quantitative and qualitative significance.

Table 6: Division of historical stock of fish species in the Elbe/Weser estuary into ecological guilds (type of community) (Elliot & Dewailly 1995, slightly modified).

Ecological guilds Type of community	Definition	Number of taxa in the estuaries at reference time
1. Freshwater species	Freshwater species that are characteristic in the limnetic section of the estuary but occur only occasionally in the brackish water zone. The limnetic-oligohaline section is used as the permanent habitat as a rule (reproductions, maturing, feeding grounds).	29
2. Diadromous migrant species	Migrant species (anadromous or catadromous) that use the estuary differently depending on species, seasonally as a transit section, for reproduction, or as maturing or feeding grounds.	13
3. Estuarine resident species	Genuine estuarine species that predominantly spend their entire lifecycle in the brackish water zone (meso-polyhaline).	19
4. Marine juvenile migrants	Marine species that migrate into the estuaries as juveniles (primarily meso-polyhaline) and use them predominantly as maturing grounds ('nursery').	12
5. Marine seasonal migrants	Marine species that regularly enter the estuary (primarily meso-euhaline) on a seasonal basis (refuge and feeding grounds)	9
6. Marine adventitious visitors	Marine species that occasionally occur in the estuary, predominantly visitor status.	39 +

Regarding the freshwater species, it cannot be clearly verified that this guild was also a typical element of the fauna in transitional waters. It can be assumed in any case, however, that most representatives of this guild were not among the characteristic components in the brackish water zone. According to available data, the **guild of freshwater species** encompasses around 29 species consisting, in turn, of various subguilds with specific ecological demands with regard to current as a factor (Table 7).

The species in the limnetic zone of the estuary that does not belong to transitional waters (type T1), however, were characteristic of the fish stocks. Only a few of these species were described as rare in the tidal estuary by Lohmeyer (1907), for example, brown trout (*Salmo trutta f. fario*), bullhead (*Cottus gobio*) and stone loach (*Barbatulus barbatulus*). Species like barbel (*Barbus barbus*), dace (*Leucisus leuciscus*), vimba bream (*Vimba vimba*) and burbot (*Lota lota*) as specialized rheotypical (typical of flowing waters) fish species that accounted for a large proportion of the total occurrence of individuals in the freshwater zone (Lohmeyer 1907, Riedel-Lorje & Gaumert 1982). The species were predominantly represented in sections with stronger currents and populated different subhabitats, such as the channel (e.g. barbel) or shallower overflowing sections having more structure (e.g. brown trout, river lamprey *Lampetra planeri*).

Table 7: Historical reference species diversity of the guild 'freshwater species' (type lim). Source: historical writings. With the exception of the ruffe, not relevant for the assessment of the transitional waters. Rheo = flowing waters species, indiff = indifferent to current, sg = slack water species, riverine meadow species. RL: Red List according to: a = Bless et. al 1998, b = Fricke et al. 1998, c = Gaumert & Kämmereit 1993, Schirmer 1991. Habitats Directive: II = Annex II – species of community interest, IV = Annex IV – species subject to strict protection requirements. Dem: demersal species, ben = benthic species, pel = pelagic species. Fs = prefer fine substrate, hs = prefer hard substrates. Classification of species-specific abundances according to Table 12 (category I = single specimens – category VI = very common).

Type	Freshwater species	RL	Habita t Directive	Guild	Habitat	Substrat	Trophy	Reproduction	historical species specific abundance class
rheo	Salmo truta f. fario	3 [a]		lim	dem	sand	invertivor/pisci	benthic	II
rheo	Lampetra planeri	2 [a]	II	lim	ben	fs	invertivor/veg	benthic	III
rheo	Barbus barbus	2 [a,b,c]		lim	dem	sand	invertivor	benthic	IV
rheo	Leuciscus cephalus			lim	pel	-	omni	Vegetation	V
rheo	Cottus gobio	2 [a]	II	lim	ben	hs	invertivor/pisci	brood care	II
rheo	Leuciscus leuciscus	3 [a]		lim	pel	-	invert/veg	benthic	V
rheo	Lota lota	2 [a,b]		lim	dem	hs	invertivor/pisci	pelagic	V
rheo	Aspius aspius	3 [a,b,c]	II	lim	pel	-	pisci/inver	benthic	V
rheo	Barbatulus barbatulus	3 [a]		lim	ben	indiff	invertivor	benthic	?
indiff	Leuciscus idus	3 [a,b]		lim	pel	-	invertivor	Vegetation	IV
indiff	Abramis brama			lim	pel	-	plank/inver	Vegetation	VI
indiff	Perca fluviatilis			lim	pel	-	pisci/inver/plank	Vegetation	VI
indiff	Gobio gobio			lim	dem	sand	invertivor	Vegetation	IV
indiff	Blicca bjoekna			lim	pel	-	plank/inver/veg	Vegetation	VI
indiff	Esox lucius	3 [a,b]		lim	dem	indiff	invertivor/pisci	Vegetation	IV
indiff	Gymnocephalus cernua			lim	dem	-	invertivor	Vegetation	V
indiff	Rutilus rutilus			lim	pel	-	plank/inver/veg	Vegetation	VI
indiff	Cobitis taenia	2 [a,b,c]	II	lim	ben	fs	invertivor/veg	Vegetation	III
indiff	Alburnus alburnus			lim	pel	-	invertivor/pisci	Vegetation	IV
indiff	Siluris glanis			lim	dem	fs	plank/inver/pisc	brood care	III
indiff	Vimba vimba	2 [a,b]		lim	pel	-	invertivor	benthic	VI
indiff	Abramis ballerus			lim	pel			benthic	III
indiff	Sander lucioperca			lim	dem	hs	invertivor/pisci	benthic	III
sg	Rhodeus sericeus/amarus	2 [a]	II	lim	ben	fs	plank/inver/veg	mussel	III
sg	Carassius carassius	3 [a,b,c]		lim	pel	-	omni	Vegetation	III
sg	Cyprinus carpio	2 [a]		lim	dem	indiff	omni	Vegetation	III
sg	Leucaspius delineatus	3 [a]		lim	pel	-	plank/inver/veg	Vegetation	III
sg	Scardinius erythrophthalmus			lim	pel	-	inver	Vegetation	IV
sg	Misgurnus fossilis	2 [a]	II	lim	ben	fs/veg	invertivor	Vegetation	IV
sg	Pungitius pungitius			lim	pel	-	invertivor	brood care	IV

A second group that was also significant in quantitative terms was made up of rather unspecialized fish species that are indifferent to current. They included a number of carp-like fish, such as ide (*Leuciscus idus*), bream (*Abramis brama*) and roach (*Rutilus rutilus*) as well as pike (*Esox lucius*) and ruffe (*Gymnocephalus cernua*). The ruffe was also of economic significance at the turn of the century. It came in second in the catch figures for the Elbe. According to Möller (1991), the species was primarily caught between the Este estuary and Freiburg, i.e. also in present-day transitional waters to a great extent. According to Sterner (1916a), the ruffe was even regarded as food of the people. Presumably the species was common to very common in the other estuaries as well (Schuchardt et al. 1995, Lozán et al. 1996), though the data on this according to Häpke (1876) are not definite. Apart from the ruffe, most of the 13 species indifferent to current occurred frequently to very frequently in the inner estuaries and primarily populated shore areas with little current and side arms (backwater, branches), but in some cases apparently also channel areas exposed to current, such as the spined loach (*Cobitis taenia*), which, however, was less common.

A third group of the freshwater guild comprises species typical of slack waters. They primarily include so-called riverine meadow species (e.g. bitterling – *Rhodeus amarus*; weatherfish – *Misgurnus fossilis*). These species were evidently present in the Lower Weser and occurred with a high frequency locally (Lozán et al. 1996). The population focal points were backwater and old branches with little current. All freshwater species used the limnetic-oligohaline section as a permanent habitat that thus assumed all ecological functions as reproduction, maturing and feeding grounds. A prerequisite for this was the structural diversity of the water bodies with shallow and deep areas, areas exposed to current and those with little current as well as the presence of side arms. The habitat diversity enabled a high species diversity and a successful search for spawning grounds as well as good recruitment and thus significant autochthonous fish stocks, also in terms of economic aspects.

The **guild of diadromous species** encompasses a number of economically extremely important species. A total of 11 (12) diadromous species (the historical occurrence or frequency of the listed thin-lipped grey mullet (*Liza ramada*) is questionable) are documented as occurring in the estuaries and the adjoining tributaries (Table 8) while Häpke (1876) describes for the Weser estuary that, for instance, smelt (*Osmerus eperlanus*) did not occur in the Lesum or in the Hamme-Wümme system. He attributed this to the higher humin content of the water, especially in the Hamme. This guild also includes the eel (*Anguilla anguilla*), a catadromous species that spawns in the sea and migrates to the rivers as larva or young fish to mature. The estuary serves as a transit section for the eel, both upstream and downstream, and also as a habitat (maturing and feeding grounds). The other species of this guild were anadromous migrant fish spawning in freshwater, including salmon (*Salmo salar*) and brown trout (*Salmo trutta*). Particularly the salmon was highly abundant in the Weser and in the Elbe until around the mid-19th century to the beginning of the 20th century (among others, Meinken 1974, Möller 1988, Möller 1991). Especially the sturgeons (*Acipenser sturio*) climbing into the estuaries were significant until around 1900. Even this large species, up to 20 specimens of which were caught in the Weser in one year (1877), not only remained in the main rivers, but apparently also migrated into the lower reaches of the tributaries (Häpke 1880, Bocherding 1889, Brumund-Rüther 1994). A similar situation applies to the Elbe – according to Thiel (1994), significant sturgeon spawning grounds originally existed in the lower reaches of the Oste as well. All diadromous species, including shad (*Alosa alosa, A. fallax*), houting (*Coregonus oxyrhynchus*) and the smelt (*Osmerus eperlanus*), seasonally occurred frequently to very frequently (Lozán et al. 1996, Schuchardt et al. 1985) with the exception of the sea lamprey (*Petromyzon marinus*), which in historical terms did not belong to the taxa having high numbers of individuals according to Bocherding (1889) and Häpke (1876). According to Sterner (1916d), approximately 500 million young smelt were caught annually by means of eel traps.

Table 8: Historical reference species spectrum of the guild 'diadromous species' (subtypes: transit species-dia, estuarine-dia/aes the last four lines from below). Source: historical writings. Rheo = flower waters species, indiff = indifferent to current, sg = slack water species, riverine meadow species. **-** = no classification. RL: Red List according to: a = Bless et. al 1998, b = Fricke et al. 1998, c = Gaumert & Kämmereit 1993, Schirmer 1991. Habitats Directive: II = Annex II species of community interest, IV = Annex IV species to be stringently protected. Dem: demersal species, ben = benthic species, pel = pelagic species. Fs = prefer fine substrate, hs = prefer hard substrates. Classification of species-specific abundances according to Table 12 (category I = single specimens – category VI = very common).

Type	Diadromous species (transit, estuarine)	RL	Habita t Directive	Guild	Habitat	Substrat	Trophy	Reproduction	historical species specific abundance class
indiff	Anguilla anguilla	3 [a,b]		dia	ben	fs	plank/pisci/inver	not in estuary	V
-	Liza ramada			dia	pel	-	invertivor/pisci/det	pelagic	?
-	Mullus surmuletus			dia	pel	-	invertivor/pisci/det	pelagic	?
indiff	Gasterosteus aculeatus			dia	pel	-	invertivor/pisci	not in estuary	V
rheo	Lampetra fluviatilis	2 [a,b]	II	dia	ben	fs	piscivor	not in estuary	V
rheo	Salmo salar	1 [a,b]	II	dia	pel	-	invertivor/pisci	not in estuary	V
rheo	Alosa alosa	1 [a,b,c]	II	dia	pel	-	pisci	+/-not in estuary	IV
rheo	Salmo trutta	2 [a,b]		dia	pel	-	invertivor/pisci	not in estuary	IV
rheo	Petromyzon marinus	2 [a,b]	II	dia	ben	fs	piscivor	not in estuary	III
rheo	Alosa fallax	2 [a,b,c]	II	dia/aes	pel	-	plank/pisci	pelagic	V
rheo	Osmerus eperlanus			dia/aes	pel	-	invertivor/pisci	benthic	VI
rheo	Acipenser sturio	0 [a,b,c]	II, IV	dia/aes	dem	sand	invertivor/pisci	benthic	IV
rheo	Coregonus oxyrhynchus	0 [a,b]	II, IV	aes/dia	pel	-	piscivor/inver	benthic	IV

As far as the importance of the estuary is concerned, the anadromous species can be divided into two 'user groups': 1. those that reproduce in the upper reaches of flowing waters and 2. those that reproduce in the estuary. With respect to water body structure the Weser estuary and the lower reaches of the tributaries were of less importance for the former group, i.e. for salmon, brown trout, shad (*A. alosa*) as well as for the lamprey (*P. marinus, Lampetra fluviatilis*), among others, because the tide-influenced sections primarily acted as a transit section for reaching the spawning grounds located inland significantly further upstream. The estuarine conditions regarding unhindered passability and with respect to good water quality, which may also have a barrier effect, were important for these species. Greater importance from an ecological point of view is attached to the second group of anadromous species that also came to the tidal estuary for reproduction and possibly used it as maturing grounds, including the sturgeon, the twaite shad (*A. fallax*) and the smelt, perhaps the houting (Scheffel 1994) as well. It is assumed that all species indicated here migrated to spawning grounds in the oligohaline zone (in part in the limnetic section, too) and possibly also in the upper mesohaline section.

The **guild of estuarine species**, i.e. those that predominantly spend their entire lifecycle in the estuaries, was represented by about 19 species (Table 9).

With the exception of the flounder (*Platichthys flesus*) most of the estuarine species were of minor commercial importance. Flounder in addition to smelt, for instance, accounted for the largest share of the total commercial catch in the Elbe in 1918 (Sterner 1918a–e). A similar result is mentioned by Möller (1991) for the whole period 1891–1920. Substantial declines in flounder shares were then recorded in the period from 1960 to 1986, presumably, among other things, because of the high fishery use pressure, on the one hand, and later also due to diminishing demand (Schuchardt et al. 1985). At a very early stage Schnackenbeck (1926) pointed out the damaging effect, especially of trawling, on young stocks of flounder since large quantities of undersize fish were caught using such equipment. According to Möller (1991) and Möller & Diekwisch (1992), it is unclear to what extent the flounder also migrates or migrated to the inner estuary for reproduction. Diekwisch (1987) presumes that in addition to its main spawning grounds in the 'southern North Sea' the flounder also uses at least saltier areas of the tidal Elbe as spawning grounds. No historical data on this are available. According to SFB (1994), however, the presence of very young flounder larvae in Mühlenberger Loch, for example, may be attributable to behavioural mechanisms with which the larvae use the tidal current for speedy upstream transport. The authors do not give any indication of spawning grounds in sections of the tidal Elbe itself. On the basis of fish fauna investigations in the Lower Weser, Scheffel (1989), too, presumes that the flounder larvae from the coastal region can cover large distances upstream in a few days. The author verified the presence of 5 mm long flounder (i.e. only a few days old) in the Bremen section of the Weser. The estuaries and in particular the side channels were exceptionally important as maturing grounds in view of the juvenile flounder. Most of the estuarine species were probably restricted mainly to the seaward portion of the estuary and were caught in the mesohaline and polyhaline zone of the estuaries. In most cases these species are documented as bycatch and their commercial importance was limited to their function as animal feed. Lohmeyer (1907) described most of the estuarine species as frequent, with the exception of the 15-spined stickleback (*Spinachia spinachia*) and the butterfish (*Pholis gunellus*), both of which were evidently not frequent historically or were rarely documented in catches. The striped sea snail (*Liparis liparis*) presumably occurred frequently to very frequently in the Ems-Dollart as well as in the Elbe and Weser estuary. Lohmeyer (1907) describes that the species was caught together with the sand goby (*Gobius minutus – Potamoschistus minutus*) in "*nearly all nets*" and served together with the latter as chicken and duck feed. There are no records on the development of the stocks of the species, but it can be assumed that the river engineering measures or the resulting maintenance work led to impairments of the stocks. The estuaries acted as major spawning, maturing and feeding grounds for the species.

Table 9: Historical reference species diversity of the guild 'estuarine species'. Source: historical writings. K.E. = no classification. RL: Red List according to: a = Bless et. al 1998, b = Fricke et al. 1998, c = Gaumert & Kämmereit 1993, Schirmer 1991. Habitats Directive: II = Annex II – species of community interest, IV = Annex IV - species to be protected stringently. Dem: demersal species, ben = benthic species, pel = pelagic species. Fs = prefer fine substrate, hs = prefer hard substrates. Classification of species-specific abundances according to Table 12 (category I = single specimens – category VI = very common).

Estuarine resident species	RL	Habita t Directive	Guild	Habitat	Substrat	Trophy	Reproduction	historical species specific abundance class
Platichthys flesus			aes/dia	ben	fs	invertivor/pisci	pelagic	V
Liparis liparis	3 [b]		aes	ben	indiff	invertivor/pisci	Vegetation	IV
Nerophis ophidion			aes	dem	fs/veg	invertivor/pisci	brood care	II
Nerophis lumbriciformes			aes	ben	hs/veg	invertivor/pisci	brood care	II
Zoarces viviparus			aes	ben	indiff	invertivor	brood care	IV
Pholis gunellus			aes	ben	indiff,veg	invertivor	brood care	IV
Potamoschistus pictus	R [b]		aes	ben	sand	invertivor	nest	III
Raniceps raninus			aes	dem	hs	invertivor	nest	?
Aphia minuta			aes	pel	-	piscivor	benthic	II
Syngnathus acus	3 [b]		aes	ben	indiff	invertivor/pisci	benthic	IV
Syngnathus typhle	3 [b]		aes	dem	indiff/veg	invertivor/pisci	nest	II
Ammodytes tobianus			aes	ben	sand	plank	benthic	IV
Syngnathus rostellatus			aes	ben	sand, veg	invertivor	nest	IV
Potamoschistus minutus			aes	ben	sand	invertivor	benthic	V
Gobius niger			aes	ben	ws/veg	invertivor	benthic	?
Myoxochephalus scorpius			aes	ben	fs	invertivor/pisci	brood care	III
Spinachia spinachia	3 [b]		aes	pel	-	piscivor	benthic	II
Agonus cataphractus			aes	ben	fs	invertivor	Vegetation	V
Potamoschistus microps			aes	ben	sand	invertivor	benthic	V

Table 10: Historical reference species diversity of the guild 'marine juvenile' and 'marine-seasonal'. Source: historical writings. K.E. = no classification. RL: Red List according to: a = Bless et al. 1998, b = Fricke et al. 1998, c = Gaumert & Kämmereit 1993, Schirmer 1991. Habitats Directive: II = Annex II – species of community interest, IV = Annex IV – species to be protected stringently. Dem: demersal species, ben = benthic species, pel = pelagic species. Fs = prefer fine substrate, hs = prefer hard substrates. Classification of species-specific abundances according to Table 12 (category I = single specimens – category VI = very common).

marine juvenile migrants		Habita t Directive	Guild	Habitat	Substrat	Trophy	Reproduction	historical species specific abundance class
Gadus morhua			mar-juv	dem	fs	invertivor/pisci	pelagic	IV
Trisopterus luscus			mar-juv	dem	indiff	invertivor/pisci	benthic	III
Scophthalmus rhombus			mar-juv	ben	fs	invertivor/pisci	benthic	II
Clupea harengus			mar-juv	pel	-	invertivor/pisci	benthic	V
Limanda limanda			mar-juv	ben	sand	invertivor/pisci	benthic	V
Pollachius pollachius			mar-juv	dem	hs	pisci	pelagic	II
Trigla lucerna			mar-juv	dem	fs	invertivor/pisci	benthic	II
Pleuronectes platessa			mar-juv	ben	fs	invertivor	pelagic	IV
Solea solea			mar-juv	ben	fs	invertivor	pelagic	IV
Psetta maxima			mar-juv	ben	fs	piscivor	pelagic	II
Merlangius merlangius			mar-juv	dem	indiff	invertivor/pisci	benthic	V
Dicentrarchus labrax			mar-juv	dem	indiff	invertivor/pisci	pelagic	I
marine seasonal migrants		Habita t Directive	Guild	Habitat	Substrat	Trophy	Reproduction	historical species specific abundance class
Chelon labrosus			mar-saison	ben	hs/veg	pisci/invert/Det	pelagic	II
Liza aurata			mar-saison	ben	indiff	pisci	pelagic	?
Ciliata mustela			mar-saison	ben	indiff	pisci	pelagic	IV
Dasyatis pastinaca	3[b]		mar-saison	ben	fs	invertivor/pisci	viviparous	I
Eutrigla gurnardus			mar-saison	ben	sand	invertivor/pisci	pelagic	II
Belone belone			mar-saison	pel	-	invertivor/pisci	Vegetation	IV
Engraulis encrasicolus			mar-saison	pel	-	planktivor	pelagic	II
Cyclopterus lumpus	R[2]		mar-saison	ben	hs	invertivor/pisci	pelagic	II
Sprattus sprattus			mar-saison	pel	-	planktivor	pelagic	V

The oligohaline zone of the estuaries was of minor importance for the marine guilds (marine-juvenile, marine-seasonal, marine species). This does not apply to juvenile herring (*Clupeus harengus*) and juvenile sprat (*Sprattus sprattus*), for which there are indications of seasonal occurrence in the oligohaline sections. The outer transitional waters, by contrast, were very important for marine fish species, particularly for the **guild of marine juveniles**, which was represented by approximately 12 species in the mesohaline zone of the estuaries (Table 10).

Table 11: Historical reference species diversity of the guild 'marine visitors'. Source: historical writings. K.E. = no classification. RL: Red List according to: a = Bless et. al 1998, b = Fricke et al. 1998, c = Gaumert & Kämmereit 1993, Schirmer 1991. Habitats Directive: II = Annex II – species of community interest, IV = Annex IV – species to be protected stringently. Dem: demersal species, ben = benthic species, pel = pelagic species. Fs = prefer fine substrate, hs = prefer hard substrates. Classification of species-specific abundances according to Table 12 (category I = single specimens – category VI = very common.

marine migrants occasional		Habita t Directive	Guild	Habitat	Substrat	Trophy	Reproduction	historical species specific abundance class
Hippoglossius platessoides		mar	mar	ben	fs	invertovor/pisci	pelagic	?
Ctenolabrus rupestris			mar	dem	hs/veg	invertivor	pelagic	II
Squalus acanthias	3 [b]		mar	ben	fs	invertivor/pisci	viviparous	I
Mustelus asterias	R [b]		mar	dem	indiff	invertivor/pisci	viviparous	III
Callionymus lyra			mar	ben	fs	invertivor	pelagic	I
Raja batis			mar	dem	sand	invertivor	nest	I
Ammodytes lanceolatus			mar	ben	s	plank/pisci	benthic	I
Entelurus aequoreus	R [b]		mar	dem	indiff	?	viviparous	II
Trachinus draco	1 [b]		mar	ben	fs	invertivor/pisci	pelagic	II
Hippoglossus hippoglossus			mar	ben	fs	invertivor/pisci	pelagic	II
Zeus faber	2 [b]		mar	pel	hs/veg	invertivor/pisci	pelagic	I
Trachinus vipera			mar	ben	fs	invertivor/pisci	pelagic	I
Scyliorhinus caniculus			mar	dem	fs	invertivor/pisci	nest	II
Crystallogobius linearis			mar	pel	-	veg	brood care	I
Arnoglossus laterna			mar	ben	fs	invertivor/pisci	benthic	I
Molva molva			mar	dem	hs	invertivor/pisci	benthic	II
Microstomus kitt			mar	ben	fs	invertivor	pelagisch	II
Potamoschistus lozani			mar	ben	sand	invertivor	benthisch	III
Scomber scombrus			mar	pel	-	invertivor/pisci	pelagic	I
Conger conger			mar	ben	fs	invertivor/pisci	pelagic	II
Gaidropsarus mediterranus			mar	ben	hs	invertivor/pisci	pelagic	I
Raja clavata	3 [b]		mar	dem	sand	invertivor	nest	?
Raja fullonica			mar	dem	sand	invertivor	nest	I
Ammodytes marinus			mar	ben	sand	plan/invertivor/pisci	benthic	I
Melogrammus aeglefinus			mar	dem	indiff	invertivor/pisci	benthic	II
Taurulus bubalis			mar	ben	hs	invertivor/pisci	Vegetation	II
Merluccius merlucius			mar	dem	indiff	invertivor/pisci	benthic	I
Aspitriglia cuculus			mar	ben	fs	invertivor/pisci	benthic	I
Pollachius virens			mar	dem	hs	invertivor/pisci	pelagic	I
Lophius piscatorius			mar	ben	indiff	pisci	nest	I
Anarhichas lupus			mar	dem	hs	invertivor	benthic	I
Raja radiata			mar	dem	sand	invertivor	nest	I
Trachurus trachurus			mar	dem	hs	invertivor/pisci	pelagic	I
Mullus surmuletus			mar	ben	hs	invertivor	pelagic	II
Rhinonemus cimbrius			mar	ben	fs	invertivor	pelagic	II
Glyptocephalus cynoglossus			mar	ben	fs	invertivor/pisci	benthic	II
Phynorhombus norvegicus			mar	ben	fs	invertivor/pisci	benthic	II
Trisopterus minutus			mar	dem	hs	invertivor/pisci	benthic	I
Buglossidium luteum			mar	ben	sand	invertivor	pelagic	II

From a quantitative point of view emphasis must be placed on juvenile herring, plaice (*Platessa platessa*), dab (*Limanda limanda*) and Atlantic cod (*Gadus morhua*), among others, in this group, large numbers of which entered the estuaries as juveniles. Häpke (1876), for instance, describes that herring were caught "*in substantial quantities sometimes*". Lohmeyer (1907), too, states that herring regularly migrated "*in considerable numbers*" to the outer estuaries (Ems-Dollart, Elbe, Weser) even for spawning every spring. The herring juveniles remained in the outer estuary throughout the year "*where they are then caught in large quantities in every net*".

The estuaries had similar importance for the **guild of marine-seasonal fish**, which were represented by 8 species altogether (Table 10). Such species as the five-bearded rockling (*Ciliata mustela*) and the sprat (*Sprattus sprattus*), which presumably occurred somewhat less frequently as compared to the herring, e.g. in the Weser estuary (Häpke 1876), were extremely numerous in the outer estuaries. For the species of the ecological guilds mentioned here the outer estuaries acted primarily as major maturing grounds and as feeding grounds. The special function of the estuaries with respect to the ecological functions for juvenile species is emphasized by Elliot et al. (1990), among others.

The largest proportion of marine species belongs to the group of fish that occur only sporadically in the estuary. Around 39 species (incl. questionable taxa) from the guild of marine visitors have been documented (The oligohaline zone of the estuaries was of minor importance for the marine guilds (marine-juvenile, marine-seasonal, marine species). This does not apply to juvenile herring (Clupeus *harengus)* and juvenile sprat (Sprattus *sprattus),* for which there are indications of seasonal occurrence in the oligohaline sections. The outer transitional waters, by contrast, were very important for marine fish species, particularly for the **guild of marine juveniles,** which was represented by approximately 12 species in the mesohaline zone of the estuaries (Table 10).

Table 11). With few exceptions one can assume that the species entered the outer estuary only occasionally and in small numbers. It is assumed that the estuary has no special ecological functions for the representatives of this guild.

5.1.2 Frequencies

In contrast to the species diversity, there are only very limited reliable quantitative data with regard to the **historical abundance** of the species. However, there are a large number of frequency descriptions (on a massive scale, common, etc.) some of which have already been mentioned in previous sections. To be able to use these descriptive frequency estimates for the WFD assessment procedure, the verbal data were divided into 6 categories and allocated to numeric values (= '*species-specific frequency values*') (Table 12). It must be kept in mind here that descriptive terms such as 'frequent' or 'in isolated cases' may stand for different abundances depending on the species. For this reason we use the term 'species-specific frequency values'. Use of such a variable in the reference or in the assessment procedure for the actual status requires allocation of actual catch data to these categories. A major source for defining the reference frequencies for selected species is the work by Apstein (1894), who quantitatively evaluated stow net catches in the tidal Elbe with regard to scientific aspects. This applies with restrictions also to Schräder (1941; stow net catches in 1929).

Table 7 to The oligohaline zone of the estuaries was of minor importance for the marine guilds (marine-juvenile, marine-seasonal, marine species). This does not apply to juvenile herring (Clupeus *harengus)* and juvenile sprat (Sprattus *sprattus),* for which there are indications of seasonal occurrence in the oligohaline sections. The outer transitional waters, by contrast, were very important for marine fish species, particularly for the **guild of marine juveniles,** which was represented by approximately 12 species in the mesohaline zone of the estuaries (Table 10).

Table 11 contains the inventory of species as well as the respective frequency category for the species. It becomes evident that the predominant portion of the fish was frequent. It must be pointed out in this connection that, it was not possible at all, or only to a limited extent, to determine the section and seasonal time of the estuary on which the descriptive frequency data are based. As a rule, they are presumably summary estimates that included the entire tidal estuary.

However, it can be assumed that the frequencies varied very much depending on species, both spatially and temporally, and only a small proportion of the species was constantly found in the entire transitional waters with similar frequency. The probability was high for some of the estuarine-resident species (sand goby, flounder) and diadromous-estuarine species like smelt or also twaite shad since they were present as adults from the polyhaline to the limnetic-oligohaline zone in the spring/early summer and were then found as juveniles in the transitional waters later in the year.

Table 12: 'Translation' of the historical data into 6 frequency categories and allocation to frequency values.

Historical description	Category – verbal	Category – numeric (species-specific frequency value)
"on a massive scale"	very frequent – on a massive scale	VI
"common everywhere, numerous specimens"	frequent – very frequent	V
"frequent occurrence, significant"	moderately frequent – frequent	IV
"occurring quite frequently everywhere"	rare – average	III
"occasional"	very rare – rare	II
"in isolated cases"	in isolated cases – very rare	I

5. 2 Analysis of variability and causal factors

High variability of many abiotic and biotic parameters on different spatial and time scales is a characteristic of the coastal waters (e.g. Niesel & Günther 1999) and a major requirement of the central stability feature, resilience (Grimm 1999). In the estuaries this variability is reinforced by the changeability of the discharge with its consequences for the salinity gradient and position of the turbidity cloud, among other things (Grabemann et al. 1995, Grabemann & Krause 1998).

On the one hand, this abiotic conditional framework that is very variable over space and time and, on the other hand, species-specific behavioural patterns (e.g. feeding behaviour, reproduction behaviour) result in an equally pronounced variability of the key figures of aquatic communities. This also applies to the fish fauna of an estuary whose variability in terms of number of species and frequencies manifests itself on different spatial and time scales (Thiel & Potter 2001). The following factors must be viewed as significant in this connection:

- **spatial:** primarily salinity zones, structural water body habitat features, reproduction, occurrence of food organisms;
- **temporal:** primarily low and high tide, seasonality, interannual population fluctuations, reproduction, occurrence of food organisms.

In view of the WFD assessment special consideration has to be given to 'variability of the fish community' with respect to two aspects:

1. in the determination and definition of the category boundaries of the reference frequencies;
2. for the requirement regarding spatial and temporal catch intensity when applying the assessment procedure.

The variability of the fish fauna on spatial and temporal scales is depicted exemplarily on the basis of current stow net fishing data from the Weser (Voigt 2003) and Elbe (ARGE Elbe 2004) in the following. The analyses are conducted using different statistical methods (multivariate analysis: canonical correspondence analysis (CCA), Spearman rank correlation analysis, significance tests). All data were standardized prior to the analyses to individuals$*h^{-1}*80\ m^{-2}$ (section 5) and have been log-transformed for some analyses.

First of all, the significance of the factors influencing variability is depicted by a gradient analysis on the basis of the Elbe data (catch data: different salinity zones, seasons as well as high-tide and low-tide catches). Temporal (short-term/long-term) and spatial factors are inputted in the analysis. Figure 3 illustrates the importance of these factors. The influence of 'abiotic' factors is shown in the ordination diagram on the basis of the fish fauna data. The (relative) importance of the respective factors is depicted by the length of the gradient arrows. Figure 3 shows clearly that salinity and season are extremely crucial. On the spatial scale the aspect of 'salinity' is illustrated by the gradient arrows 'oligo-meso', 'meso' and 'polyhaline' that are positioned along the first axis of the ordination diagram. The opposite direction of the various 'salinity arrows' shows that the fish community of the polyhaline and oligo-mesohaline zone differs considerably. The aspect of seasonality is of similar importance: both corresponding arrows (autumn, spring), which are positioned on the second main axis of the ordination, also contribute significantly to the structuring of the data record.

Furthermore, the result shows that, in addition to the aspects of salinity and seasonality, interannual differences and diurnal factors (tidal phase) also contribute to structuring the fish communities. Relatively speaking, however, the significance of these aspects is less compared to the former factors, as is indicated by the considerably shorter gradient arrows in some cases. With regard to the factor of 'tidal phase' the diametrically opposite arrows (high tide / low tide) indicate that differences exist between low and high tide catches. In comparison, however, the importance of this variability scale is less than that resulting from the salinity gradient and a seasonal gradient. The first two main axes only moderately explain the cumulative percentage variance of species data at 33.7%. The species-environment relation, on the other hand, is very well explained by the first two main axes at 75.1%. The Monte Carlo permutation test indicates a significant relation between species and the abiotic factors taken into account here (p value < 0.01, Table 13).

A description of the species that contribute to these differences is provided for 3 species on the basis of Elbe-data from 2000–2004. They include the flounder (*Plathichthys flesus*, guild: estuarine-resident), whose abundance in the autumn catches was substantially higher than in the spring catches and which is additionally expected in higher abundances in the polyhaline zone. This pattern was noted with a certain interannual variability in each year of study. Figure 4 shows the result of the analysis. The isolines mark the increasing frequencies along the salinity gradient and also the relation of high flounder numbers to the autumn catches. The correlations are statistically significant (t-Test, $p < 0.01$).

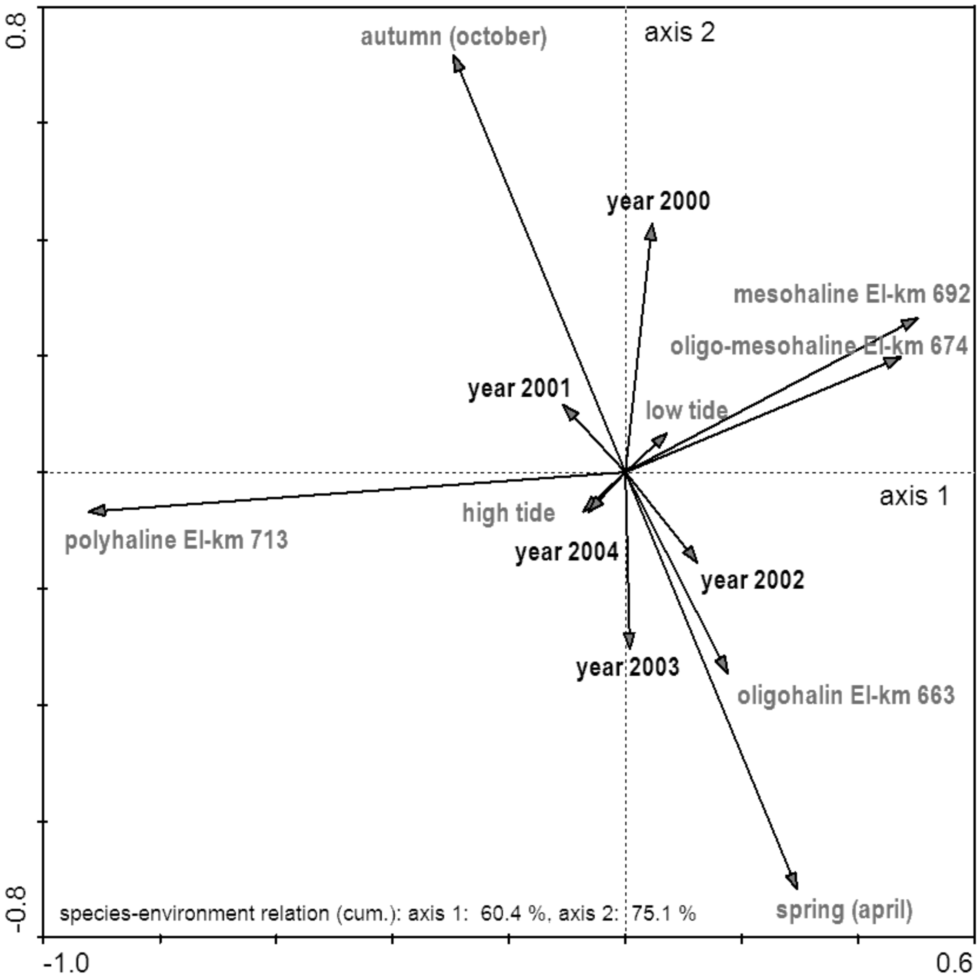


Figure 3: Ordination diagram of the canonical correspondence analysis (CCA), database: anchor net fishing catches (ARGE Elbe 2004). The (relative) importance of the respective factors is depicted by the length of the gradient arrows. Statistics in Table 13.

Table 13: Results of CCA. Explanatory values of the ordination axes with respect to the variance of the catch data. Results of the Monte Carlo tests.

**** Summary ****					
Axes	1	2	3	4	Total inertia
Eigenvalues :	0.289	0.070	0.057	0.030	1065,0
Species-environment correlations :	0.938	0.750	0.649	0.700	
Cumulative percentage variance					
of species data :	27.1	33.7	39.0	41.9	
of species-environment relation:	60.4	75.1	87.0	93.4	
Sum of all eigenvalues					1065,0
Sum of all canonical eigenvalues					0.478
**** Summary of Monte Carlo test ****					
Test of significance of first canonical axis: eigenvalue = 0.289					
F-ratio = 24.919					
P-value = 0.0020					
Test of significance of all canonical axes : Trace = 0.478					
F-ratio = 6.062					
P-value = 0.0020					

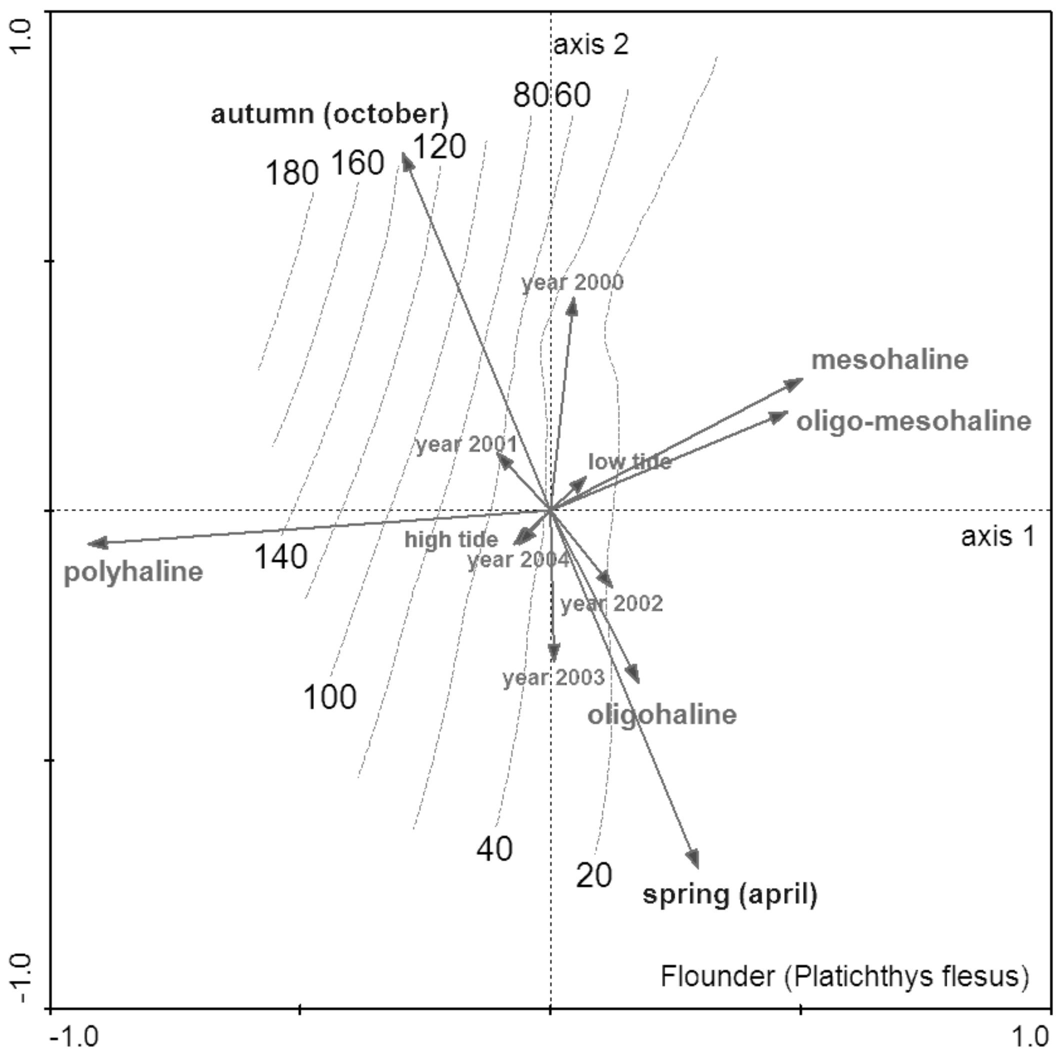


Figure 4: Ordination diagram of CCA on the basis of anchor net fishing data from the Elbe 2000–2004 (ARGE Elbe 2004). The graph shows the abundance distribution of the flounder against the background of temporal and spatial factors. Dotted lines are isolines that mark the increasing frequencies along the salinity gradient and also the relation of high flounder numbers to the autumn catches. The (relative) importance of the respective factors is depicted by the length of the gradient arrows. Statistics in Table 13.

Figure 5 shows the result for the herring (*Clupea harengus*, guild: marine-juvenile), another typical species of the transitional waters. As far as the frequency distribution of this species is concerned, there is a clear relation of higher abundances in areas with higher salt concentrations. This species is significantly more frequent in the meso-polyhaline zone (t-test, $p < 0.01$) than in the oligohaline section of the transitional waters. Herring do occur in areas of lower salt concentration, but not regularly and in rather low abundance. A pronounced seasonally caused variability of frequencies in comparison to spring and autumn has not been determined for this species. There was a tendency to higher catch figures in spring, but these differences were not significant (t-test, $p > 0.1$). A similar spatial distribution was also ascertained historically and Duncker & Ladiges (1960) describe that herring occurred in the Elbe up to around Glückstadt.

Figure 6 shows for the anadromous twaite shad pronounced seasonal occurrence patterns that differ depending on the age group. Adults are expected in larger numbers solely in spring (April, May) while juvenile twaite shad were predominantly present in the anchor net catches in late summer or autumn.

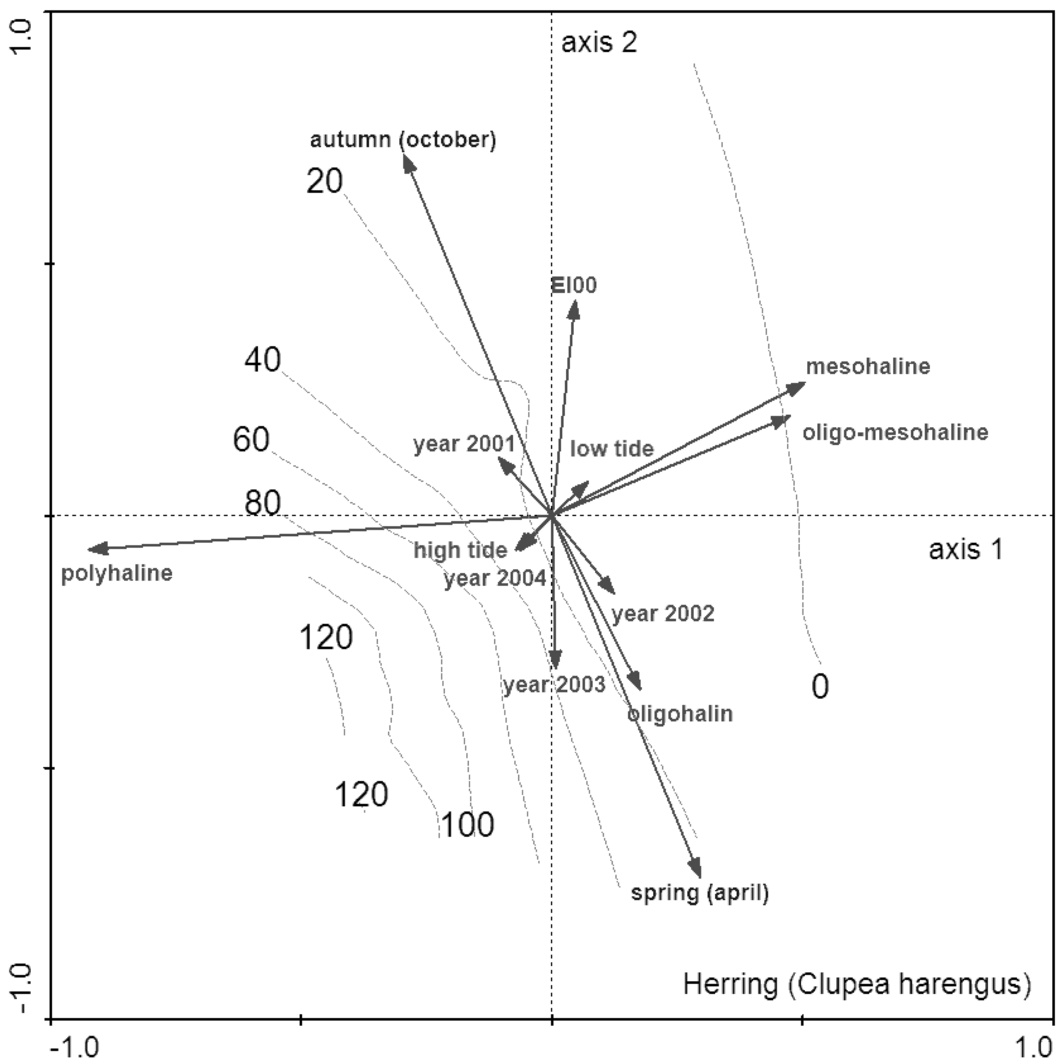


Figure 5: Ordination diagram of CCA on the basis of anchor net fishing data from the Elbe 2000–2004 (ARGE Elbe 2004). The graph shows the abundance distribution of the herring against the background of temporal and spatial factors. Dotted lines are isolines that mark the increasing frequencies along the salinity gradient and also the relation of high herring numbers to the autumn catches. The (relative) importance of the respective factors is depicted by the length of the gradient arrows. Statistics in Table 13.

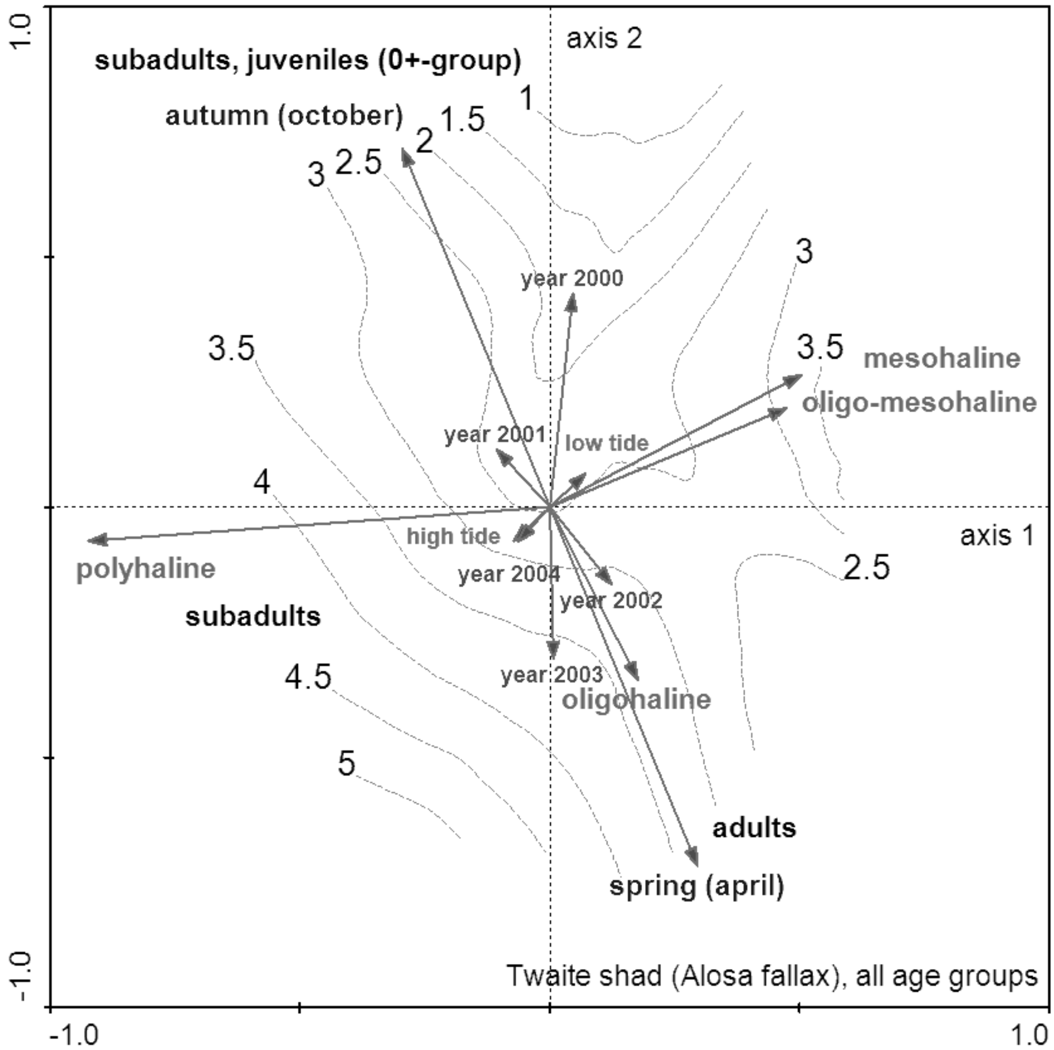


Figure 6: Ordination diagram of CCA on the basis of anchor net fishing data from the Elbe 2000–2004 (ARGE Elbe 2004). The graph shows the abundance distribution of the twaite shad against the background of temporal and spatial factors. Dotted lines are isolines that mark the increasing frequencies along the salinity gradient and also the relation of high twaite shad numbers to the autumn catches. The (relative) importance of the respective factors is depicted by the length of the gradient arrows. Statistics in Table 13.

Correlation Analysis

The results of a correlation analysis conducted on the basis of the Elbe data record of 2000–2004 shows the scales of variability for the most frequent fish again in summary form (Table 14). The cells marked in colour indicate significantly higher (blue) or significantly lower (red) abundances for the respective fish species based on the respective scale of analysis. It is evident, without going into species-specific detail, that predominantly seasonal and, as expected, also spatial (salinity) aspects strongly influence the abundances of the fish. On the basis of this data record, the interannual differences are less important.

Table 14: Correlation analysis (Spearman's rank) of the ARGE Elbe (2004) data 2000–2004 (selection of most frequent/ selected species). *O. eperlanus, A. fallax* no differentiation of age groups.

	temporal – interannual					temp.–seasonal		spatial – salinity zones			
	2000	2001	2002	2003	2004	FJ	HE	PS	GS	BB	ME
p < 0,05 signifcant								oligo-haline	oli-mesoh.	mesoh.	poly-halin
correlation-coeff.	0.060	0.125	0.043	-0.027	-0.200	-0.069	0.069	0.180	-0.075	-0.410	0.305
Osmerus erperlanus/ no. of samples	40	40	40	40	40	40	40	40	40	40	40
significance	0.358	0.222	0.395	0.434	0.108	0.335	0.335	0.133	0.323	**0.004**	**0.028**
	-0.248	-0.017	-0.105	0.193	0.176	-0.026	0.026	-0.595	-0.305	0.224	0.677
Clupea harengus	40	40	40	40	40	40	40	40	40	40	40
	0.061	0.460	0.260	0.117	0.138	0.436	0.436	**0.000**	**0.028**	0.082	**0.000**
	-0.007	-0.057	-0.110	0.182	-0.007	-0.265	0.265	-0.329	-0.329	-0.059	0.717
Syngnathus rostellatus	40	40	40	40	40	40	40	40	40	40	40
	0.483	0.364	0.249	0.131	0.483	**0.049**	**0.049**	**0.019**	**0.019**	0.358	**0.000**
	0.032	-0.184	-0.173	0.043	0.282	-0.286	0.286	0.365	0.335	-0.045	-0.655
Gymnocephalus cernuus	40	40	40	40	40	40	40	40	40	40	40
	0.421	0.128	0.143	0.395	**0.039**	**0.037**	**0.037**	**0.010**	**0.017**	0.391	**0.000**
	0.325	-0.130	-0.244	0.000	0.049	-0.308	0.308	-0.265	-0.375	-0.020	0.660
Platichthys flesus	40	40	40	40	40	40	40	40	40	40	40
	0.020	0.212	0.065	0.500	0.383	**0.027**	**0.027**	**0.049**	**0.009**	0.451	**0.000**
	-0.174	0.223	0.008	-0.142	0.084	0.858	-0.858	-0.151	0.118	0.169	-0.136
Gasterosteus aculeatus	40	40	40	40	40	40	40	40	40	40	40
	0.141	0.083	0.480	0.192	0.302	**0.000**	**0.000**	0.176	0.234	0.149	0.202
	0.023	-0.097	-0.156	0.131	0.099	-0.241	0.241	-0.517	-0.247	0.003	0.761
Sprattus sprattus	40	40	40	40	40	40	40	40	40	40	40
	0.445	0.277	0.168	0.211	0.271	0.067	0.067	**0.000**	0.063	0.494	**0.000**
	-0.500	0.080	0.122	0.216	0.082	-0.302	0.302	-0.184	-0.367	0.139	0.412
Pomatoschistus minutus	40	40	40	40	40	40	40	40	40	40	40
	0.001	0.313	0.226	0.091	0.307	**0.029**	**0.029**	0.128	**0.010**	0.196	**0.004**
	0.297	0.124	-0.190	-0.080	-0.150	0.182	-0.182	-0.281	-0.262	-0.028	0.571
Pomatoschistus microps	40	40	40	40	40	40	40	40	40	40	40
	0.031	0.224	0.120	0.312	0.177	0.131	0.131	**0.040**	0.051	0.432	**0.000**
	-0.081	0.032	-0.011	0.097	-0.038	0.169	-0.169	-0.063	-0.168	0.120	0.110
Alosa fallax	40	40	40	40	40	40	40	40	40	40	40
	0.309	0.421	0.474	0.275	0.408	0.149	0.149	0.351	0.151	0.230	0.250
	0.188	0.188	-0.188	-0.188	0.000	-0.098	0.098	-0.218	-0.218	-0.218	0.653
Liparis liparis	40	40	40	40	40	40	40	40	40	40	40
	0.122	0.122	0.122	0.122	0.500	0.274	0.274	0.089	0.089	0.089	**0.000**

A comparison of the salinity zones with regard to species abundance illustrates the respective importance of these zones for the frequency of the species due to the predominant differences (Table 15). Particularly the mesohaline and polyhaline zones show considerable differences from the oligohaline and the transition between oligohaline and mesohaline zones (here Glückstadt) with regard to the species abundance of characteristic fish species in each case.

Table 15: Difference in catch figures on various scales for selected species (Water Quality Office for the Elbe (ARGE Elbe 2004). * = significant differences, $p < 0.1$; ** = $p < 0.05$ (H-Test, Kruskal-Wallis). *O. eperlanus, A. fallax* no differentiation of age groups.

Species	Mean value/ entire water body 2000 –2004 (Ind.*h^{-1}*80 m^{-2})	Standard deviation	Interannual 2000 – 2004	Seasonal Spring/autumn	Salinity zone Oligo-, meso- & polyhaline
Alosa fallax	7.9	3.8	p = 0.96	p < 0.05**	p = 0.6
Clupea harengus	94.4	70.5	p = 0.35	p = 0.86	P < 0.05**
Gymnocephalus cernuus	67.7	37.7	p = 0.33	p = 0.07*	p < 0.05**
Liparis Liparis	4.6	5	p = 0.35	p = 0.5	p < 0.05**
Osmerus eperlanus	2.639	964	p = 0.74	p = 0.66	p = 0.07*
Platichthys flesus	39.4	20.6	p = 0.21	p = 0.05*	p < 0.05**

Thus, the variability can be characterized as follows:

- interannual differences (species abundance) are evident, but statistically significant only in a few cases. ***Note:*** This is due to the high variability of catch figures within a year that is also caused by spatial factors (in this case primarily salinity zones). Because of the little catch data, it is not possible to make interannual comparisons for the salinity zones. To this extent, the results of the variance analyses carried out on an exemplary basis here are reliable only to a restricted degree and thus merely serve as an orientation.
- Seasonal differences (spring/autumn) are significant for some species.
- Weekly recorded abundances also display differences in some cases (not shown here).
- Spatial differences along the salinity gradient are significant for many species.

Natural and anthropogenic variability

The described variability not only encompasses the natural variability, but also contains an ‘anthropogenic’ component. That is, the change in natural variability due to anthropogenic measures that either alter the abiotic parameters that are important for the structure of the fish communities or directly influence species. These may include hydraulic engineering measures and the related changes in the current regime or other habitat conditions, or also direct impacts, such as due to increased vessel traffic (wake and swell).

The complex consisting of natural and anthropogenic variability must be differentiated only to a limited extent within the framework of monitoring. A high natural variability is a characteristic system feature of the estuary and a key requirement of the central stability feature, resilience. Resilience refers to the property of a system of returning to the reference status or, more accurately, the reference dynamics after an external impulse triggering a change (Grimm 1999).

A large number of factors contribute to the natural variability of the structure and distribution of fish communities (among others, temperature, discharge, sediment composition, feeding pressure, basic diet, long-term cycles in the population dynamics of individual species, migration of new species). These can never be completely recorded within the framework of monitoring studies.

To be able to distinguish the impact of possible stressors from the natural variability, the scales of variability have to be defined and the sampling design geared to determining this variability (at the "right" level). A key problem here, apart from the effort and expenditure required, is to operationalize the natural variability in such a way that it can be used as a benchmark. The 'measurement' and thus the operationalization of the variability as well essentially depend on the spatial and temporal scale examined, which must be specified according to a possible impact signal.

6 Design of the assessment procedure

The purpose of this report is to develop a fish-based assessment procedure for the water body type 'transitional waters – North Sea' (type T1/T2) that meets the specific requirements of the WFD. The water body type 'transitional waters – North Sea' is characterized by the estuarine salinity gradient and the dynamic convergence of limnetic and marine elements. It therefore forms a habitat of its own that has a specific fish fauna. This peculiar characteristic made it necessary to have a specific assessment approach for transitional waters with respect to fish fauna as a quality component. Adoption of the procedure developed by Dußling et al. (2004) for inland waters, for example, is not meaningful and thus not feasible.

Based on the preliminary work in the previous section and taking into account available assessment proposals from neighbouring European countries (chapter 6.1), we feel it is necessary to draft a multimetric assessment procedure that encompasses the aspects of species diversity, abundance and age structure of the fish fauna and at the same time refers to the historical reference coenosis as an assessment benchmark.

One of the prerequisites was to make the assessment tool or assessment process transparent and comprehensible, i.e. as 'simple' as possible. In the selection of the metrics, therefore, we focused on avoiding possible redundancies or double assessments. The 11 qualitative and quantitative metrics selected altogether reproduce through their combination the ecological status of the transitional waters via the fish fauna in accordance with the WFD and derive indications of possible stressors or stressor complexes.

6.1 Overview of assessment procedures of neighbouring European countries

The metrics were selected while also taking into account available assessment proposals from neighbouring European countries. All member states have developed national fish-based methods for transitional waters. The following shows the references:

Table 16 shows for orientation purposes an overview of the assessment parameters used in the national methods. It is evident that the metrics viewed as relevant differ at the national level more or less significantly. There is extensive accordance with regard to the selection of qualitative metrics that regard to 'species composition', which are primarily differentiated according to specific guilds and take into account the species number.

A substantial difference exists concerning the parameter abundance. Some approaches (UK, E, B) use, for example, relative abundance while other approaches (F, NL, GER) take absolute abundance as the basis for the assessment in some cases. The parameter "fish health" is exclusively taken into account by E_Basque while NL and GER exclusively give consideration to the parameter "age structure" for selected species (*O. eperlanus, A. fallax*). The selection of the metrics also reflects the different data acquisition methods.

Table 16: Metrics used by the fish-based assessment tools for transitional waters. UK = United Kingdom, B = Belgium, E = Spain, F = France, NL = Netherlands, GER = Germany (status: 2010); (***Note:*** Portugal is missing, Cabral et al. in Press)

	UK	E_Asturias	E_Basque	F	B	NL	GER
Species Richness	+	+	+		+		
(pollution) indicator species (nr)	+	+					
(pollution) indicator species (%)			+				
Introduced species (nr)			+				
Fish health (% affected)			+				
Flatfish (%)			+				
Smelt individuals (%)					+		
Trophic composition (% omnivorous)			+		+		
Trophic composition (% piscivorous)	+	+	+		+		
Resident species (nr)	+	+	+			+	+
Resident species (%)			+				
Diadromous species (nr)						+	+
Marine juv. species (nr)	+	+				+	+
Marine juv. species (%)					+		
Marine seasonal species (nr)	+	+				+	+
Species relative abundance	+	+					
Nr. taxa = 90% of abundance	+	+					
Functional guild composition	+	+					
Benthic invert. feeding (nr species)	+	+					
Feeding guild composition	+	+					
Abun. diadrom. species, pelagic (twaite shad, smelt incl. age groups)						+	+
Abundance diadromus species				+			
Abundance resident species, benthic (flounder)						+	+
Abundance resident species, bernthic (striped seesnail)							+
Abundance resident species, benthic (eelpout)						+	to be discussed
Abundance benthc species				+			
Abundance marine juvenile species, pelagic (e.g. herring, total*)				+*		+	
Abundance marine juvenile species, benthic (plaice)						+	to be discussed
Abundance ruffe, demersal, euryhaline species						+	+
Total density (abundance)				+			

All assessment approaches encompass the aspects of species diversity and frequencies required by the WFD. Some include further variables, such as illness rates of certain species (Jager & Kranenbarg 2004), or give consideration to indicator species (Borja et al. 2004: pollution indicators – Spain). Furthermore, Spain-Basque (Borja et al. 2004, Uriate & Borja, 2009) view crustaceans (Decapoda) as a variable relevant for transitional waters. Rare or threatened species as well as neozoans are taken into account by Great Britain. In addition to the ecological species guilds ('user types') that are applied in all procedures, Coates et al. (2007) for example, also include trophy guilds (e.g. number and proportion of fish- and invertebrate-eating species) in the assessment.

The information shown in Table 16 is based mainly on the following publications: Jager & Kranenbarg 2004, Bioconsult 2006, Breine et al. 2007, Coates et al. 2007, Uriarte & Borja 2009, Delpeche et al. 2010, Cabral et al. in press.

So far as possible, we have applied these procedures (mostly preliminary while working on FAT-TW) on an exemplary basis and, as far as feasible, with Weser or Elbe data to test possible applicability of the approaches for the northern German estuaries. In this connection, however, several basic conditions have to be kept in mind that make 'direct' application of one of the approaches appear impractical:

- The work on the assessment proposals had in some cases not been completed while the assessment approach FAT-TW was being prepared. The British proposal by Coates et al. (2004, 2007), for instance, was modified since the first approach in 2004. The available Belgium assessment proposals by Goethals et al. (2002) have also been revised (Breine et al. 2007, 2010).
- Especially in Great Britain various types of transitional waters to which the metrics of the UK approach are specifically geared have to be assessed. The Belgian approach has been defined in terms of variables and they limit values on a 'Schelde-specific' (oligohaline section only) basis and cannot be applied without modification.
- The individual metrics are primarily assessed by defining categories. This does not correspond to the approach preferred here of carrying out the assessment through a comparison with the historical reference status.
- With the exception of the Netherlands, the assessment proposals are usually based on qualitative and/or semi-quantitative data capture methods (various net fishing methods, shore catches, Table 17). The northern German estuaries, by contrast, are evaluated on the basis of quantitative stow net catches. This has consequences for selection of the metrics, particularly with regard to the aspect of abundance.

Table 17: Overview of the national fishing gear in transitional waters.

Member states	Gear(s)
France	Beam trawl (1.5 m), fyke nets
Netherlands	Anchor net (stow net), beam trawl (1.5 m)
Belgium	Fyke nets
England/Wales	Beam trawl, fyke nets, seine net
Spain/Asturias	Winged fyke net
Germany	Anchor net (stow net)
Ireland	Beam trawl, fyke nets, seine net
Northern-Ireland	Beam trawl, fyke nets, seine net, purse seine
Portugal	Beam trawl

6.2 Coordination of the conditional framework

The analysis of the various approaches led to the following conclusions, which we have taken into account within the framework of this report with regard to the fundamental methodological procedure. The methodological approach as well as the selection of the relevant variables for the northern German transitional waters are a result of the coordination of the supporting working group (Wassergütestelle Elbe, Hamburg, Landesamt für Natur- und Umweltschutz, Landesamt für Verbraucherschutz Lower Saxony, Environment Department Hamburg). The specialized coordination had the following results:

- An assessment procedure via a multimetric approach is meaningful and is also pursued for the northern German transitional waters.
- A differentiated analysis of ecological guilds in transitional waters is meaningful since the sections along the salinity gradient are important for the individual groups to a varying degree.

- Use of ecological guilds as variables is meaningful.
- The limnetic (freshwater species) and purely marine guild (marine adventitious visitors) are not used as metrics.
- The assessment is carried out by determining the deviation from a reference status.
- Taking the abundance aspect into account as 'relative abundance' is problematic and should be avoided.
- For the northern German transitional waters the aspect of 'frequency' should be taken into account through abundance categories at the species level (for selected species).
- The parameter of age structure, which is not taken into consideration as a variable in most of the procedures, should be taken into account for a few selected species. The focus here is on the Habitats Directive target species so as to enable synergy effects between the WFD and Habitats Directive.
- Taking into account already 'community-evaluating' indices (e.g. fish region index, etc.) as a metric poses a problem because the risk of undesired redundancies or 'double countings' is additionally increased here, particularly within the framework of a multimetric approach. Such indices are not used as variables here.

6.3 Selection of variables relevant for the assessment (metrics)

6.3.1 Metrics 1–4: Guilds

Similar to international assessment proposals for transitional waters (among others, Coates et al. 2004, Jager & Kranenbarg 2004, Goethals et al. 2002, Borja et al. 2004), ecological type guilds of fish are distinguished and used as metrics relevant for the assessment. Taking guilds into account is meaningful since the various guilds place different 'use demands' on the estuary and are therefore suitable for enabling identification of indications of specific impairments through their 'characteristics' (species diversity, frequency). In contrast to Elliot & Dewailly (1995), the guild of *'diadromous species'* is divided into two subguilds. We assume that the species that 'only' use the estuary as a transit section have to be emphasized less for the assessment than those diadromous species for whose lifecycle the estuary is far more important. Species belonging to the latter group, such as twaite shad (*Alosa fallax*), houting (*Coregonus oxyrhynchus*), smelt (*Osmerus eperlanus*) and sturgeon (*Acipenser sturio*), reproduce(d) in the estuary and use(d) it as maturing grounds. For this reason this subguild should be used in the assessment as a separate metric. This results in an (intended) higher weighting with respect to the assessment. The transit group, on the other hand, should be given less weight. Altogether 5 guilds are used (Table 18) and evaluated as a separate variable in each case taking into account **qualitative** aspects (species diversity).

In contrast to other assessment proposals (e.g. Coates et al. 2004), we do not include the aspect of 'type of food' in the assessment because numerous fish species fall back on different food resources depending on age so that problems arise in connection with clear allocation to a food guild. This aspect is not taken into account in the Dutch approach, for example (Jager & Kranenbarg 2004).

Neozoans are not taken into consideration either, on the one hand, due to their predominantly sporadic occurrence and their, in most cases, still unclear ecological demands and, on the other hand, because in our view their presence alone does not necessarily indicate a possible stressor in transitional waters.

Table 18: Division of the historical fish species stocks into ecological guilds (type of community) (Elliot & Dewailly 1995, slightly modified). Data from Weser and Elbe.

Ecological guilds Type of community	Definition	Historical number
Freshwater species – **this guild is not relevant for the assessment of transitional waters**	Freshwater species that are characteristic in the limnetic section, but occur only occasionally in the brackish water zone. In the transitional waters they are more or less on the fringe of their distribution boundary.	approximately 29
Metric 1a: Diadromous 'transit' migrant species (group 1)	Migrant species (anadromous or catadromous) that use the estuary differently according to specific species on a seasonal basis predominantly as a transit section.	approximately 7
Metric 1b: Diadromous 'estuarine' migrant species (group 2)	Migrant species (anadromous) that use the estuary differently according to specific species as reproduction, maturing or feeding grounds.	4
Metric 2: 'Genuine' estuarine resident species	Genuine estuarine species that for the most part spend their entire lifecycle in the brackish water zone (mesohaline, polyhaline).	19
Metric 3: Marine juvenile migrants	Marine species that migrate to the estuaries (in particular mesohaline, polyhaline zone). Use primarily as maturing grounds ('nursery').	12
Metric 4: Marine seasonal migrants	Marine species that enter the estuary (primarily meso-euhaline) regularly on a seasonal basis (refuge and feeding grounds).	9
Marine adventitious visitors – **this guild is not relevant for the assessment for transitional waters**	Marine species that occassionally appear in the estuary, predominantly as visitors.	approximately 39

6.3.2 Metrics 5–10: Abundance

As described above, 'abundance' is represented in several available assessment proposals (e.g. Coates et al. 2004, 2007 (UK), Breine et al. 2010 (B), Dußling et al. 2004 (GER), Uriate & Borja 2009 (Basque)) by the variable 'relative abundance'. This approach is not applied by Jager & Kranenbarg 2004 (NL) and in Delpeche et al. 2010 (F). This report does not take into account the aspect of 'frequency' of species as 'relative abundance' for the following reasons:

- a definition of historical reference values is (even) more difficult since no actual catch data are available;
- the (natural) variability of the abundance and the potentially resulting problems for the assessment are hardly buffered;
- rel. abundance values say little about the actual development of stocks;
- the quantitative metrics are not assessed 'independently': consequently the change in catch figures of only one species inevitably has a possibly undesired influence on the rel. abundance share of all other species/guilds.

Alternatively to the use of 'relative abundance', we use *species-specific frequency values* that are based on the actual catch figures. As far as this aspect is concerned, however, the entire species diversity occurring is not included in the assessment because it is very difficult to specify reference frequency values for every species, i.e. allocate actual catch figures to these categories. Instead, this aspect focuses on selected species, i.e. those that belong to major type guilds or different ‘user groups’ (diadromous-estuarine, estuarine residents, marine-juvenile) and, furthermore, also represent different habitat guilds: benthic, demersal or pelagic lifestyle (Elliot & Dewailly 1995).

For the assessment procedure we have selected 6 species altogether on this basis, each of which is assessed as a separate ‘variable’. With regard to their habitat requirements the selected species have different demands and temporal and spatial focal points of occurrence, and are therefore suitable for reflecting possible stressors through ‘significant’ changes in stocks. As representatives of the fish communities of transitional waters overall, they thus cover the aspect of frequency/abundance to be evaluated in accordance with the WFD. All species briefly described in the following have been described historically as frequent to very frequent in the estuaries.

METRIC 5: The **ruffe (*Gymnocephalus cernua*)** is taken into consideration here with regard to the aspect of ‘frequency’ although it belongs to the guild of freshwater species that was appraised as generally not relevant for the assessment of transitional waters. Since it is a characteristic species of the ruffe-flounder region named after it (Thienemann 1925), which extends at least to parts of the transitional waters, it appeared meaningful to include the species in the assessment. Historically the ruffe occurred frequently in the tidal estuaries and was caught in large quantities in some cases. The species is demersal and tends to populate zones with little current while reproduction takes place on vegetation or hard substrates. At the beginning of the 1960s the ruffe population in the Weser collapsed (Schuchardt et al. 1985) and significant declines in stocks have also been documented for the Elbe (Möller 1991). Possible causes may be the occasionally heavy pollution of the estuaries and the breaking of the waves due to increasing maritime traffic that could destroy the spawn clinging to stones or other substrates in shallow-water zones. The development of ruffe stocks may provide indications of the impact of stressors based on water body structure or pollution, particularly for the oligohaline section.

METRICS 6a–c + 7a–c: As characteristic species of the estuaries today, **smelt (*Osmerus eperlanus*)** and **twaite shad (*Alosa fallax*)** from the subguild of diadromous-estuarine species are taken into account in the assessment procedure since they are suitable, based on their lifestyle, for reflecting stressors such as pollution and habitat changes in their habitat due to their stock dynamics. As reproduction, maturing, feeding and refuge grounds, the entire transitional waters assume the main ecological functions. Both species occurred very frequently in all estuaries and the smelt also had great economic importance. Both smelt and twaite shad are pelagic and migrate to their estuarine spawning grounds from spring to early summer, the main spawning grounds being in the limnetic section of the estuaries (Thiel et al. 1996, Gerkens & Thiel 2001, BioConsult 2005). However, reproduction in the brackish water zone cannot be ruled out (BioConsult 2005).

Historically the smelt was fished more or less throughout the year and caught on a massive scale in some cases. Spawned smelt and young smelt functioned as fertilizer or livestock feed or as bait for eel stow net fishing (Schnackenbeck 1928). The species was the most lucrative fish species in the tidal Elbe (around 400 t/year), for example, at the turn of the century and reached its peak landing figures in 1914–1915 with approximately 1,200 t (Möller 1991). In the course of the 20th century the catch figures declined considerably, though it is unclear whether this was causally related to a reduction in stock sizes or lower economic demand for smelt led to decreased landings (Schuchardt et al. 1985). Möller (1991) presumes that the latter factor played a major role. Nolte (1976) assumes similar interrelationships for extensively similar developments in the Weser. However, an influence by pollution (oxygen deficiency) that primarily took place in the spawning and maturing grounds of the species and thus may have led to impairment of the stock density (Wilkens & Köhler 1977) cannot be ruled out. As of mid-1960 a very significant decline in smelt figures was recorded in other European estuaries, such as in the Forth estuary in east Scotland. Costello et al. (2002) attribute this development to anthropogenic influences like overfishing, pollution and habitat changes, especially in reproduction areas. As soon as pollution in the estuaries declined, the stocks started to recover. In the Elbe, and this applies in all likelihood to the Weser as well, the conditions in comparison to other estuaries were less pessimistic for the smelt, according to Thiel et al. (1995) as well as Thiel (2001), so that similar dramatic collapses in stocks as that in the Forth estuary did not take place.

The twaite shad is taken into account in the assessment as another species of this ecological guild. This species belonging to the herring family was, and still is in some cases, characterized by substantial declines in stocks in comparison to the historical situation. Reproduction of the twaite shad takes place in the limnetic and to a certain extent also in the oligohaline zone. The eggs, which drift freely in the water column, can be found in nearly the entire oligohaline zone after the spawning period (BioConsult 2005, Gerkens & Thiel 2001). From April to at least autumn twaite shad of different age groups are present in the inner and outer estuary. For the Weser Nolte (1976) pointed out the drastically declining catch figures after 1955. As of 1960, they were no longer listed in the catch statistics for the Weser (Schuchardt et al. 1985). Wilkens & Köhler (1977) as well as Kausch (1996) point to a spatial shift in historical twaite shad spawning grounds and attribute this to the influence of pollution and the river engineering measures carried out. Both factors as well as, for example, the high losses due to removal of cooling water may also be responsible for the substantial declines in twaite shad stocks in the tidal estuaries (among others, Fricke 2004). Aprhamian et al. (2003) also makes, amongst others, the factors of water pollution and hydraulic engineering work co-responsible for the impairment of twaite shad stocks. In the recent past study results indicated an (initial) increase in stocks, such as in the Weser (Schulze & Schirmer 2004, BioConsult 2005). Fricke (2004) points to a slight recovery of stocks in the Elbe, too. The extent to which this also applies to the Ems and Eider is still open because of the limited data. However, Costello et al. (2002) refer to a fundamental lack of knowledge in connection with estimation of a theoretically possible size of twaite shad stocks.

METRICS 8 + 9: From the guild of 'estuarine resident' species the **flounder (*Pleuronectes/ Platichthys flesus*)** and the **striped sea snail (*Liparis liparis*)** are taken into account for the abundance analysis.

The **flounder** is benthic and utilizes the estuaries as maturing grounds. The stock density of the species, which in principle can be found in the entire transitional waters, also depends on anthropogenic stressors like pollution or habitat changes. The young flounder migrate out of the southern North Sea and into the estuaries as juveniles. Whether reproduction also takes place in the outer estuaries to a certain extent is unclear (Möller 1991). With an annual catch volume of approximately 400 t the flounder historically numbered among the very frequent and economically important fish. A considerable decline in flounder fishing took place after 1920, though it is not clear whether massive fishing led to a decline in stocks (Möller 1991). Further anthropogenic stressors, which at least resulted in a change in the migration behaviour of the species, can be derived from the work by Köhler (1981). Low flounder catch figures, for instance, correlated with considerable oxygen deficiencies, as indicated by catch yields near Pagensand (km 642), for example, which dropped to zero under very poor oxygen conditions (Köhler 1981). Peters et al. (1986) emphasize that flounder migrate upstream in lower numbers compared to the historical situation and accordingly the stock peaks shifted further and further towards the outer estuary.

Like the flounder, the **striped sea snail** is a benthic fish species. Striped sea snails extensively spend their lifecycle in the meso-euhaline zone of the estuaries. The rather stationary species seems to prefer shallow-water zones with algal growth, but is also widespread in deeper waters, especially in habitats characterized by hard substrate to which the striped sea snails cling with their suction disc. A high number of striped sea snails was recorded in the area of natural hard substrates (stone fields with corresponding epifauna in deeper pools) within the framework of a macrozoobenthos study in the Outer Weser (BioConsult 2001). Witt (2004) made similar observations in this area. Juvenile striped sea snails, for example, were found almost exclusively in areas of stone or areas with mussel debris and hydrozoan growth in high numbers in some cases. Because of their lifestyle with a relatively close attachment to specific habitats, the species is, in our view, suitable especially for reflecting habitat changes related to water body structure via changes in the size of their stocks. Since striped sea snails did not number among the commercially used fish species, however, there are hardly any references to historical frequencies, though it can be assumed that the species occurred frequently, predominantly in the area of the present-day transitional waters.

METRIC 10: From the group of ‘marine-juvenile’ species the frequency of the **herring (*Clupea harengus*)** is taken into account in the assessment as a marine component. Juvenile herring, which can be found in the meso-euhaline zone more or less throughout the year, use the estuary primarily as maturing and feeding grounds. Historically herring numbered among the major species in estuary fishing, though they have become less important overall. However, the estuaries still perform an ecological function as maturing grounds today. Apart from the smelt, for example, juvenile herring in the mesohaline and polyhaline zone of the Elbe are among the species with the highest number of individuals (Thiel & Potter 2001, ARGE Elbe 2004). Indications of possible impairments of the above mentioned ecological functions can be derived from the regularity and number of juvenile herring.

6.3.3 Additional metric 11 (currently not relevant for the assessment): Sturgeon

If necessary, the **sturgeon (*Acipenser sturio*)**, as a special representative of a high / good ecological status, can be given special consideration in the assessment procedure as a historical characteristic species. Its presence or absence is recorded in contrast to the frequency analysis of the above mentioned species (chapter 7.1).

However, there are currently plans for using the ‘sturgeon’ in the procedure as a variable relevant for the assessment.

6.3.4 Age structure

According to the WFD, the parameter of age structure shall be taken into account in the assessment, though it is not absolutely necessary for transitional waters. Inclusion of this parameter appears meaningful to us, however, since it can provide information on whether the estuaries adequately perform their function as reproduction and maturing grounds (among other things, mirror for conditions related to water body structure, water quality). However, this aspect is not included in the assessment procedure as a separate metric, but is taken into account within the framework of the frequency analysis.

To be able to use this parameter meaningfully, certain requirements have to be met. Species shall be analysed that occur naturally in the estuary in all age groups on a regular basis. This means the species of the marine guilds that come to the estuary only at a certain age are left out. Furthermore, it should be possible to acquire data on the various age groups to a similar degree. Therefore, it makes sense to process ‘age structure’ as a variable on the basis of only one or a few selected or special species. In our estimation the restriction to individual or a few species is compatible with the normative definitions of terms in the WFD: *“The age structures of the fish communities hardly display any signs of anthropogenic disturbances and do not indicate disturbances in the reproduction or development of any specific species”*. With regard to the twaite shad and smelt we propose two species in this context that meet the above-mentioned criteria because they are represented over several age groups in the entire transitional waters, at least from spring to autumn. In addition, they are of importance for nature conservation reasons (twaite shad, Habitats Directive, chapter 6.4) and for economic reasons (smelt).

6.4 Synergy effects with Habitats Directive

Due to the special consideration given to the twaite shad, a “species of community interest” (Annex II of the Habitats Directive (1992)), desired synergy effects result with the requirements of the Habitats Directive. Among other things, a good status for the twaite shad is formulated as an objective for both the Elbe and the Weser estuary, which are partially classified as a Natura 2000 site. The evaluation of the twaite shad stocks necessary within the framework of the Habitats Directive encompasses, similar to the WFD, inclusion of the parameters 'abundance' and 'age structure'.

Schnitter & Schütz (2004) and BfN (2010) have developed tentative evaluation criteria in this connection, which are still relatively unspecific, however. With regard to the aspect of size of stocks the authors cite the *'mass exodus'* of juvenile twaite shad as well as the *'massive occurrence'* of adult twaite shad as criteria for the *'outstanding twaite shad stocks'*. The *'regular evidence'* of both juvenile and adult specimens represents a *'good'* status. *'Rare evidence'* indicates that the twaite shad stocks are *'moderate to poor'*. An alternative proposal is made by e.g. BioConsult (2010) and Scholle (2011).

The data to be generated within the framework of WFD monitoring are completely useable for the necessary documentation of the status of the twaite shad in accordance with the Habitats Directive (size of stocks, stock structure) and vice versa should also apply. The emphasis of the twaite shad for the assessment of transitional waters against the background of the WFD thus has synergy effects in substantive and material terms.

6.5 Definition of abundance category boundaries for the frequency categories

Approach

As already mentioned above, use of species-specific frequency categories that were 'translated' from the historically mostly verbal descriptions requires allocation of actual catch figures (Figure 7, Table 19).

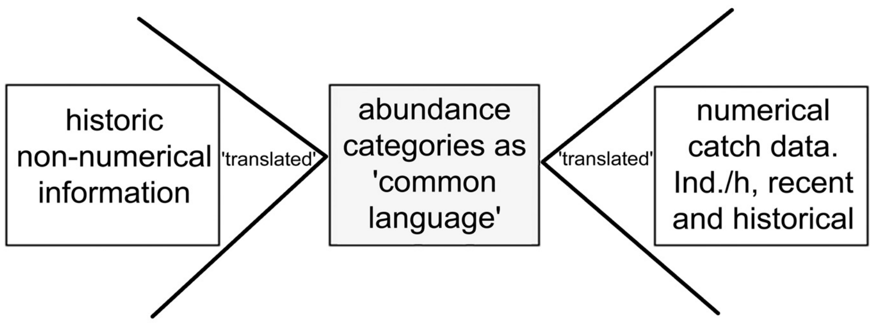


Figure 7: Abundance categories as common denominator between descriptive historical information and actual catch figures.

The great (natural) variability of abundance can be buffered by the allocation to frequency categories, but in the end it always remains subject to error. An assessment of the derived abundance categories additionally requires a plausibility test by means of an expert judgement. Since actual stow net catch figures are available only to a very limited extent, the main focus here was placed on the approach of establishing the plausibility of the reference abundance categories via the current data records. As already mentioned above, historical abundance data are available for species like twaite shad, flounder, ruffe and smelt to a limited degree (Apstein 1894, Schräder 1941). Like the current data, these data stem from stow net fishery along the salinity gradient. To make the data comparable overall as far as possible, the historical data as well as the current data records have been standardized to individuals*h^{-1}*80 m^{-2}. At the same time solely spring and autumn catches were taken into account because the investigations carried out in 2000 for the Weser, Elbe and Eider took place only at these two seasonal points in time. Low and high tide catches were combined in each case. In this connection, however, it must be pointed out that the catches differ methodologically to the extent that very different stow net sizes were used in some cases. Especially the historical stow nets were significantly smaller than the modern nets. An influence on the catch success can be assumed.

Peters et al. (1986) and Möller (1988, 1991) are to some extent controversial in their treatment of the comparability of the historical with current stow net catches.

Table 19: Allocation of verbal frequencies and actual catch figures to abundance categories (schematic).

Category – verbal	Abundance categories / species-specific frequency values	Catch data (example)
very frequent – on massive scale	VI	0.9-Quantile of historical and recent catch data (stow net standardized)
frequent	V	0.83-Quantile of historical and recent catch data (stow net data standardized)
medium – frequent	IV	0.68-Quantile of historical and recent catch data (stow net standardized)
rare	III	0.5-Quantile of historical and recent catch data (stow net standardized)
very rare	II	0.33-Quantile of historical and recent catch data (stow net standardized)
single individuals	I	0.16-Quantile of historical and recent catch data (stow net standardized)

The standardization carried out here cannot compensate for a possible (hardly quantifiable) error regarding catch methodology. Furthermore, it must be kept in mind that, strictly speaking, the overwhelming majority of the available catch figures do not represent reference data. Two fixed points are necessary to define the abundance categories though the lower abundance categories can be defined comparatively easily. The lower fixed point is reflected by very few individuals. In addition, we assume that the highest catch figures represent the upper fixed point, i.e. they correspond to the high frequency categories. At the same time the historical stow net catch data were used to a certain extent as an orienting benchmark. It turned out that in some cases the highest current individual catch figures were absolutely comparable or were even higher than the historical values.

Note: In statistics the quantile of the order p or p-quantile (Qp; obsolete also “fractile“) refers to a characteristic value below which a specified proportion p of all cases of the distribution lies. Every value below Qp is under this specified proportion. Therefore, p is also designated as the undershoot proportion. p is a real number between 0 (no case of the distribution at all) and 1 (all cases or 100% of the distribution). More generally the p-quantile is defined in mathematics as follows. If X is a random variable and F its distribution function, the thus defined function is then F − 1 quantile function. F − 1(p) is designated as p-quantile of F (or X). Example: The quantile Q.3 (or 0.3-quantile) is the value of the point of a distribution below which 30% of all cases of the distribution are found.

As far as the boundaries of the frequency categories are concerned, the procedure for the 6 selected fish species whose frequencies are included in the assessment as variables was as follows:

1. Maintaining the ‘anonymity’ of the individual catch data available (mean value of low / high tide catches, standardized to individuals*h^{-1}*80 m^{-2}) by combining the catch data from all estuaries, all salinity zones and catch times (only spring and autumn) for each of the selected species (Weser: data from Schräder (1941; data from 1928), Voigt (2003), Elbe: data from Apstein (1894), Möller (1984, 1988), ARGE Elbe (2004), Eider: Hagge (2003)). At present no digitized data are available for the river Ems.

2. No consideration is given to zero catches (we assume that there was always evidence of all species at the reference time).
3. Ascending sorting of the standardized catch figures.
4. Analysis of the data by means of descriptive statistics. Among other things, determination of skew, media, mean value of the data series. If there was a large skew in the data records as a result of very many low values, the data records were modified (point 5).
5. To reduce the influence of very many low measured values (recent data), dominating 0-catches have thus not been taken into account in the calculation of the abundance categories.
6. Depending on the historical frequency, determination of quantiles of the data series. The division of the data series into corresponding quantiles enables allocation to the differentiated frequency categories (Table 19). This means the range of data in the first quantile of the data record is allocated to the frequency category 1, the second quantile to frequency category 2, etc. If a pronounced asymmetry remained despite modification, the last two quantiles (which correspond to abundance categories 5 or 6) were scaled down.

This methodological procedure was carried out with all 6 selected species both for twaite shad and smelt as well as for their differentiated age groups. The calculated abundance values are inputted in the assessment procedure and serve as reference values for the frequency categories.

Example: twaite shad

<u>1st step</u>: Compilation of all stow net catch data for adult twaite shad, sorting of catches according to number of catches (Figure 8).

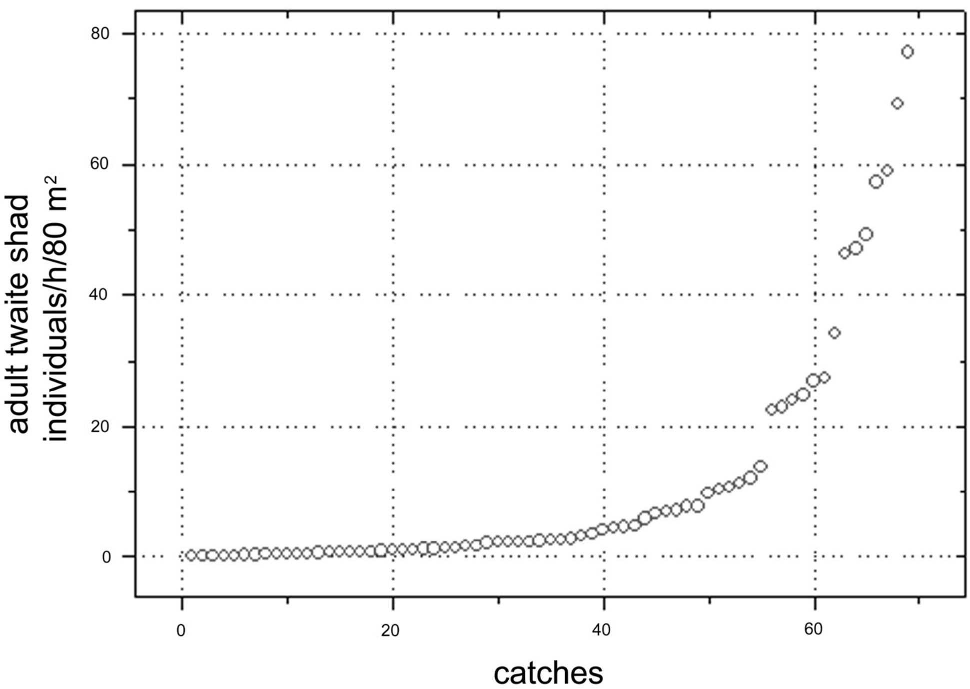


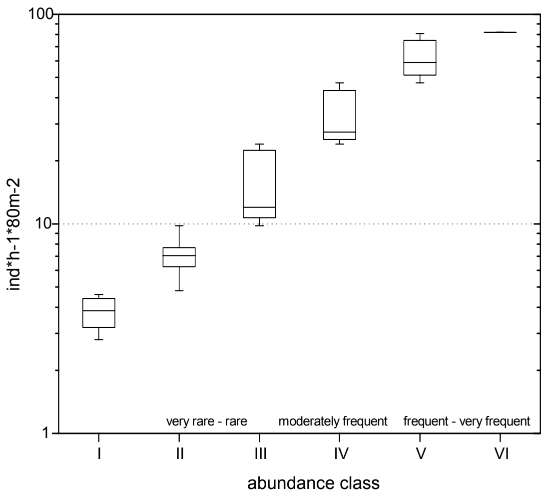
Figure 8: Catch figures (individuals/h/80 m²) for adult twaite shad (> 25 cm total length) from the northern German estuaries. Data source Table 21.

<u>2nd step:</u> Determination of key data values such as median and mean (Table 20) and exclusion of very low values by modifying the data record (shifting mean value to the median, see above).

Table 20: Descriptive key figures of the stow net catch data records of the 6 selected species. Recent data from Eider (2003), Ems (2003), Weser (2003–2005), Elbe (1984–1986, 2000–2004), historical data (1894, 1941).

$Ind*h^{-1}*80\ m^{-2}$	Smelt adult	Smelt subadult	Smelt 0+	Twaite shad ad.	Twaite shad sub.	Twaite shad 0+	Flounder	Herring	Seesnail	Ruffe
No. of countings > 0	79	56	68	69	63	75	85	85	37	67
Mean	291.2	1728.61	2877.2	11.1	20.2	118.8	33.2	324.2	506.5	52.2
Standard deviation	493.9	2425.0	4192.4	18.0	23.5	378.5	48.3	444.0	760.2	109.7
Variation coeff.	1.7	1.4	1.5	1.6	1.2	3.2	1.5	1.4	1.5	2.1
Rel. V. coeff. (%)	19.1	18.7	17.7	19.5	14.7	36.8	15.8	14.9	24.7	25.7
Asymentry	3.6	2.8	1.9	2.1	1.5	5.5	3.2	1.7	1.5	3.6
Minimum	2.2	0.6	0.4	0.1	0.1	0.1	0.3	0.1	0.2	0.1
Maximum	2781.0	13792.9	17222.0	77.1	110.0	2502.0	308.4	1997.7	2873.0	661.7
5. percentile	3.1	23.6	0.7	0.2	0.2	0.1	0.9	0.2	0.3	0.1
10. percentile	5.3	85.9	2.4	0.3	0.3	0.2	2.2	1.2	1.5	0.1
25. percentile	28.0	279.7	130.6	0.8	1.7	1.8	6.6	14.3	5.7	0.8
Median	129.0	853.2	921.6	2.6	11.4	22.6	15.2	106.9	73.0	7.5
75. percentile	358.3	2037.8	4158.2	11.0	35.7	108.1	41.2	534.9	938.2	37.9
90. percentile	643.3	5395.6	8687.7	46.3	53.4	228.2	85.7	950.4	1739.9	182.1
95. percentile	1310.0	6697.4	14002.4	58.1	70.1	341.6	120.9	1246.5	2202.4	241.3

3rd step: Determination of abundance category boundaries on the basis of 16.7% quantiles. Abundance category VI reflects the reference value (Figure 9).



Abundance category	mean value spring data only
	Alosa fallax, adult
	$Ind.*h^{-1}80\ m^{-2}$
I	< 5
II	> 5–10
III	> 10–25
IV	> 25–42
V	> 42–80
VI	> 80

Figure 9: Definition of the abundance categories on the basis of 0.16 quantiles for adult twaite shad – *Alosa fallax* (> 23 cm) from the stow net catches from the northern German estuaries.

Due to the fact that adult twaite shad enter the estuaries in large numbers only in spring and their presence can thus be verified then (BioConsult 2004, 2005), only the spring catches are taken into account in the assessment procedure. The abundance categories given are based on the spring survey (mean individuals*h^{-1}*80 m^{-2}) of the entire transitional waters (all salinity zones) depending on the number of catches. Subadult twaite shad are present in the outer estuaries both in spring and autumn. The assessment procedure only gives consideration to data from the mesohaline and polyhaline zone for this age group. The abundance categories are therefore based on the annual mean (individuals*h^{-1}*80 m^{-2}) of the indicated salinity zones. Only the autumn catches should be taken as the basis for recording or evaluating the twaite shad of the age group 0+.

The abundance categories were defined for all 6 indicator species according to the above described method (not shown graphically here). The derivation of the reference abundance for the selected species based on the following data source is shown in Table 21.

Similar to the example of the twaite shad, the species-specific temporal and spatial occurrence patterns were taken into account in the determination of the respective reference values (Table 22). The determined abundance categories of the indicator species are shown in Table 24.

Table 21: Data source in regard to the derivation of reference abundance for the selected indicator species (flounder, herring, smelt, striped sea snails and twaite shad).

Data source	Year(s)	Period	Estuary	Reason	Gear	N hauls (ebb- & floodtide)	Season	Salinity zone
Apstein	1894	historic	Elbe	scientific	small anchor net	79 (summer samples not considered)	late spring, early autumn	oligo – meso/poly-haline
Schräder	1941	historic	Weser	commer-cial	divers	only single hauls considered	autumn, spring	oligo – meso/poly-haline
Möller	1982–1986	recent	Elbe	scientific	anchor net (commer-cial)	66 (summer samples not considered)	late spring, early autumn	oligo – meso/poly-haline
Arge Elbe, Wasser-gütestelle	2000–2004	recent	Elbe	scientific	anchor net (commer-cial)	40	autumn, spring	oligo – meso/poly-haline
Laves (Vogt)	2002–2003	recent	Weser	scientific	anchor net (commer-cial)	8	autumn, spring	oligo – meso/poly-haline
Bio-consult	2004–2005	recent	Weser	scientific	anchor net (commer-cial)	24	spring	mesohaline
Hagge	2002/2003	recent	Eider	scientific	anchor net (commer-cial)	6	autumn, spring	oligo – meso/poly-haline
Arntz	1992	recent	Ems	scientific	stow net near shore	318 (in total, partly considered)	autumn, spring	freshwater – oligo/meso-haline
LFV	2001/2002	recent	Ems	scientific	stow net near shore	6	autumn, spring	oligohaline

6.6 General remarks on the quantitative variables

For the determination of the ecological status/potential the catch results (fundamentally as mean value of the high and low tide catches) exclusively from the respective optimal catch time (seasonal) and optimal catch site (salinity zones) should be used as the basis for every 'indicator species' that is quantitatively relevant in the assessment (metrics 5–10). The procedure must be examined in this regard and its plausibility established. Related specifications are listed in Table 22.

Table 22: Differentiation of the size categories for twaite shad – *Alosa fallax*, smelt – *Osmerus eperlanus* as well as indication of the respectively optimal time of catch and catch site for all quantitatively relevant species. Division of the age groups slightly modified according to Landesamt für Verbraucherschutz, Freshwater Fishery Dept. * = At present no indicator for transitional water bodies of the Ems and Eider. ** = At present indicator only for the transitional water body of the Ems (fishing method: beam trawl, data from the Dutch Demersal Fish Survey (DFS) Programme).

Species	Age group classification according to size (cm)	Catch season relevant for the assessment	Catch site relevant for the assessment	Abundance considered
Alosa fallax 0+	< 11	autumn abundances	mesohaline and polyhaline zone	mean value (spatial)
Alosa fallax subadult	11–23	spring abundances	mesohaline and polyhaline zone	mean value (spatial)
Alosa fallax adult	> 23	spring abundances	oligohaline, mesohaline and polyhaline zone	mean value (spatial)
Osmerus eperlanus 0+	< 7	autumn abundances	mesohaline and polyhaline zone	mean value (spatial)
Osmerus eperlanus subadult	7–10	no differentiation	oligohaline, mesohaline and polyhaline zone	mean value (spatial + time)
Osmerus eperlanus adult	> 10	spring abundances	oligohaline, mesohaline and polyhaline zone	mean value (spatial)
Gymnocephalus cernuus	no differentiation	no differentiation	oligohaline	mean value (spatial)
Platichthys flesus	no differentiation	no differentiation	oligohaline, mesohaline and polyhaline zone	mean value (spatial + time)
*Liparis liparis**	no differentiation	spring or autumn abundances	mesohaline and polyhaline zone	mean value (spatial)
Clupea harengus	no differentiation	no differentiation	mesohaline and polyhaline zone	mean value (spatial + time)
*Pleuronectes platessa***	no differentiation	autumn abundances	mesohaline and polyhaline zone	mean value (spatial)
*Zoarces viviparus***	no differentiation	autumn abundances	mesohaline and polyhaline zone	mean value (spatial)

7 The assessment tool

7.1 Assessment process

The assessment process will be explained briefly in the following. The ecological status/potential is determined via the deviation from or similarity to the historical reference.

This is possible without restriction for the aspect of 'species diversity' at the level of user guilds (chapter 6.3.1: metrics 1–4). The historical numbers of species in each guild represent the 100% value. If the current species diversity of each guild were completely identical to the reference, a similarity of 100% would exist accordingly in each case for the variables involved. If species of an ecological guild were not represented at all, for example, the similarity to the reference, by contrast, would be 0%.

A similar procedure takes place at the level of selected species for the aspect of abundance (chapter 6.3.2: metrics 5–10). A 100% similarity to the reference value would exist if the current catch data were allocated to a frequency category that was also derived historically for this species. If this historical value corresponded to frequency category V, for instance, a similarity of 80% would then be attained if the current catch figures were allocated to frequency category IV. If the catch figures were on the order of magnitude of

- frequency category III a similarity of 60%,
- frequency categorie II a similarity of 40%,
- frequency category I a similarity of 20%

would exist.

This approach is not directly applicable for the aspect of age structure because of the lack of a historical reference status. However, this aspect is included indirectly in the procedure. This is done by means of a frequency analysis of two characteristic species based on age group (twaite shad, smelt, chapter 6.3.2: metrics 6a–c, 7a–c). In this connection a distinction is made between 3 age groups: 'adult', 'subadult' and 'juvenile' (0+ group). The reference values for the three age groups were determined according to the same method as described for the aspect of abundance (chapter 6.5). This also applies to the assessment. However, a difference exists in this regard in that the age groups are not included in the procedure as separate variables, but on a summary basis as metrics via the formation of the mean value. This can be illustrated briefly using a hypothetical example: if juvenile twaite shad were not represented in current catches, this would lead to a similarity value of 0% for metric 6a (chapter 6.3.2). If at the same time subadult and adult twaite shad were present according to the reference, this would mean similarity values of 100% for metrics 6b and 6c. The mean value of all three similarity values would be approximately 66.7% and this would then represent the value of relevance for the assessment for metric 6. Deviation of only one age group value compared to the defined reference frequency can therefore lead to a more or less significant devaluation of the metric 'twaite shad frequency'. Since the aspect of 'age structure' is not included in the procedure as a separate variable, but indirectly via the abundance, however, this aspect has less 'weight' against the background of the entire assessment.

7.1.1 Awarding scores

After determination of the similarities or deviations of the respective metrics to/from the reference so-called scores are awarded according to the calculated similarity value. The scale encompasses values between 1 and 5 with a score of 5 being awarded if the deviation from the worst-case reference status is very small in accordance with the normative definition of terms according to WFD REFCOND 2.3 (2000). This is the case if the variable displays a similarity to the reference of at least 90% in this assessment system.

A score of 1 is awarded if the similarity of the metric to the reference is very small. A similarity of > 20% is defined here as a very low concordance. Since a high status is very narrowly defined according to the definition of terms of the WFD (chapter 3.5), this specification is also reflected in the definition of the category boundaries of the similarity values with respect to the allocation of the scores. The gradation in connection with allocation of scores can be seen in Table 23.

Table 23: Allocation of similarity (%) to scale of scores.

Similarity	Score
>/= 90%	5
60% – < 90%	4
40% – < 60%	3
20% – < 40%	2
> 0% – < 20%	1

Additional note: In contrast to the previous methodological approach, the optional **metric 11** (presence of sturgeon) is not (would not be) assessed via a reference benchmark, but using the following 3 simple specified categories:

- Verified evidence/indication of several specimens leads to a score of 5
- Verified evidence of individual specimens leads to a score of 3
- No evidence of sturgeon leads to a score of 1

7.1.2 Assessment tool

The assessment itself takes place computer-aided on the basis of a 'database' that encompasses the historical and species-specific characteristics (belonging to user, habitat or reproduction guilds, species-specific frequency, etc.). Current catch data can be entered by means of an input mask. The assessment procedure then takes place automatically while taking into account the chosen metrics via the comparison of similarity between actual status and reference. The result will be a mean value of the results of all metrics, all of which in principle go into the end result equally weighted (with the exception of metric 1a and the aspect of age structure).

The final step is allocation of the result to the EQR (Ecological Quality Ratio), which has values between 0–1 according to a 5-level system and displays a corresponding status category (ecological status and/or ecological potential) (chapter 7.2).

Table 24 and Table 25 provide a summary overview of the metrics and allocation of the similarity values to the scores.

Table 24: Reference and class boundaries for species composition of fish in the transitional water.

	Reference	Class boundary high–good	Class boundary good–moderate	Class boundary moderate–poor	Class boundary poor–bad
Score		5	4	3	2/1
Number of diadromous species	12	11	8	5	2
Number of est. resident species	19	17	11	7	4
Number of marine juvenile species	13	12	8	6	3
Number of marine seasonal species	9	8	5	3	1
Ecological Quality Ratio (EQR)	1.0	0.9	0.68	0.4	0.2

Table 25: Reference and class boundaries for the abundance for the selected indicator species in the transitional water (data source Table 21)

Class	Reference	High	Good	Moderate	Poor	Bad
Abundance class	VI	V	IV	III	II	I
Score	5	5	4	3	2	1
Smelt [(a)]						
0+	> 11285	4955–11285	2855–4955	1542–2855	777–1542	0–777
Subadult	> 5900	2096–5900	1696–2096	1079–1696	580–1079	0–580
Adult	> 1145	440–1145	313–440	226–313	104–226	0–104
Twaite shad [(a)]						
0+	> 2.500	330–2.500	131–330	64–131	45–64	0–45
Subadult	> 110	52–110	30–52	15–30	5–15	0–5
Adult	> 81	44–81	25–44	10–25	6–10	0–6
Flounder [(a)]	> 121	57–121	33–57	20–33	15–20	0–15
Seesnail [(a)]	> 2.100	1.250–2.100	240–1.250	40–240	4–40	0–4
Herring [(a)]	> 2.000	1.120–2.000	480–1.120	190–480	100–190	0–100
Ruffe [(a)]	> 675	225–675	75–225	38–75	18–38	0–18

[(a)] number of individuals per 80 m^{-2} per hour caught with the anchor net

7.2 EQR (Ecological Quality Ratio)

The final assessment of the ecological status/potential is carried out on the basis of the so-called EQR (Ecological Quality Ratio). The EQR has no units and measures the status as the degree of deviation from the reference on the basis of ecological quality ratios. A similar approach was already applied in the procedure examined here at the level of variables. The EQR can be calculated as follows:

EQR = observed value /reference value of a biological quality element.

The EQR has values between 0 and 1 and the status is reflected on the basis of the EQR value by specifying quality categories according to a 5-level system.

Depending on the specification of the category boundaries for the various ecological states (WFD REFCOND 2.3 2000), an EQR value of > 0.8 usually indicates a high status, < 0.6–0.8 a good status, etc. However, this linear scaling is not binding, but can be modified according to the derivation.

Calculation of the EQR

With the 10 variables of relevance for the assessment defined in the procedure examined here (excluding the metric 'sturgeon'), each of which can attain between 1 and 5 points, it is possible to reach a maximum of 55 points and a minimum of 10 points. The calculation is carried out according to the following procedure:

$$EQR\text{-}TW = sum\ Actual - sum\ Min\ /\ sum\ Max - sum\ Min$$

With a hypothetical total number of 34 points, for example, an EQR of 34 – 10/55 – 10 = 0.53 would result according to the above formula.

The division of the category boundaries for determining the EQR or the ecological quality is oriented to the 'normative definition of terms' stated in the WFD. At the same time the category boundaries were defined interpretatively on the basis of the normative terms, though the methodology differed slightly from the division of category boundaries proposed according to REFCOND (2.3) (Table 26) against the background of the great variability of the fish community in transitional waters. The allocation is illustrated in the second overview (figures in parentheses indicate division according to WFD REFCOND 2.3, 2.4 (2000) for all types of rivers).

Table 26: Characterisation and boundaries of the quality classes according to WFD REFCOND 2.3 (2000).

Normative definition of terms	Assessment/similarity to reference	Definition of EQR value	Ecological status
... completely or nearly …, hardly any deviations	>/= 90% concordance of all variables (mean)	>/= 0.9 (>/= 1–0.85)	High (5* see below)
... slight deviation ..., signs of anthropogenic disturbances	at least 60% concordance of all variables (mean)	0.7–< 0.9 (0.85–0.7)	Good (4)
... moderate deviation, considerable signs of	at least 40% concordance of all variables (mean)	0.5–< 0.7 (0.7–0.55)	Moderate (3)
... significant deviation ...	at least 20% concordance of all variables (mean)	0.25–< 0.5 (0.55–0.4)	Unsatisfactory (2)
... large parts of the biocoenoses are lacking ...	< 20% concordance of all variables (mean)	< 0.25 (< 0.4)	Poor (1)

An outline of when what status category is reached on the basis of the assessment procedure proposed here is provided in an exemplary manner below:

- A high status (5) can only be reached if 9 of the 10 metrics conform to the reference status.
- A good status (4) is reached if 1 metric conforms to the reference status and 8 other metrics display at least one similarity value of at least 60%.
- A moderate status (3) based on its lower category boundary exists if, for example, at least 2 metrics reach a similarity value of 60% and all other have at least a 40% conformity with the reference.
- An unsatisfactory status (2) based on its upper category boundary exists if, for example, 1 metric reaches a similarity value of 60% and 8 other metrics have at least a 40% conformity with the reference.

- A poor status (1) based on its upper category boundary exists, assuming the 'lacking' sturgeon, if all variables have a similarity to the reference below 40%.

7.3 The maximum / good ecological potential

Ways of determining the ecological potential

Since the transitional waters of the type T1 are presumably classified as 'greatly altered waters', the goal of implementation of the WFD is not a good ecological status, but achievement of a good / maximum ecological potential. This also becomes evident in view of the morphological and hydrological changes in the estuaries that have taken place, as described in section 4 and in future, too, the estuaries will inevitably be exposed to considerable anthropogenic use.

The question regarding how the ecological potential for the estuaries classified as 'heavily modified' is determined in the end cannot be clarified within the scope of this paper. A BMBF project on this aspect is currently in progress. The objectives of the MAKEF joint project are mentioned briefly here (Glacer et al. 2008): "*a definition of the HMBW waters* [...] *is provided in the EU WFD exclusively via use criteria. Thus far there is a lack of feedback on the biotic requirements. The BMBF joint research project "MAKEF" forges this link through the use of modern GIS technology in combination with hydrobiological field studies and socio-economic assessment methods. The results of the project will be inputted as case studies in the EU research project: "Identification and Designation of Heavily Modified Water Bodies under the Water Framework Directive".*

At this juncture, however, we should make brief reference to some general points on determination of the ecological potential:

The following general approaches are conceivable:

1. CIS HMWB approach: Derivation of reference conditions for specific types of water bodies while maintaining the use and taking into account the maximum number of feasible measures. On this basis the characteristics of the biological quality components would have to be described either with regard to the specific site, exemplarily or via expert knowledge. Starting from the 'maximum ecological potential', determination of the further levels of potential takes place by means of downscaling via the EQR.
2. Substance-related adaptation of the reference conditions (similar to CIS approach). Generally water-body-specific changes in the composition of the quality components that are either generally applicable or use-specific would be necessary; change in the reference points defined for determination of the ecological status and, if applicable, also change in the 'key metrics' (Podraza 2008; Glacer et al. 2008). In our estimation this approach appears difficult to implement at present. It would require, on an appropriate scientific basis, removing those species from the list of reference species whose occurrence could be ruled out under the current conditions or also after implementation of conceivable improvement measures.
3. 'Measure-based' specification of the potential. A definition of good ecological potential was proposed during the 'Water Framework and Hydromorphology' workshop in Prague (October 2005) (Podraza 2008). According to the latter, the ecological potential is determined on the basis of the current situation and a certain number of ecological improvement measures resulting from a pool of 'all' possible measures taking into account cost-benefit as well as efficiency aspects. This 'pragmatic' approach, however, is not oriented or not directly oriented to the biological quality components. Various modifications of this approach have been the subject of discussion in the recent past (Podraza 2008).
4. The Dutch proposal (Jager et al. 2009) for the definition of good ecological potential (GOP) for the considerably modified water bodies is based on the EQR average value of the ecological status assessment and the boundary for moderately good (0.6).

For a specific water body with an ecological status classified, for instance, as ‘moderate’ and an assumed EQR_{es} = 0.42 the water-body-specific boundary for the GOP results from (0.6 + 0.42)/2. In the case of this example, the GOP is thus EQR_{GOP} = 0.51. For water bodies currently classified better or worse the EQR_{GOP} for good ecological potential would be correspondingly higher or lower compared to the example provided here.

5. Determination of ‘good’ or ‘maximum’ potential at the level of the EQR. By means of a shift in scale, it would be possible to define the EQR value for a ‘moderate ecological status’ as a relevant variable for ‘good ecological potential’ (Figure 10). This appears plausible to us since in view of the extensively irreversible morphological changes we probably cannot assume that the historically diverse fauna community with a large number of individuals can again attain a ‘very good’ or ‘good’ ecological status even after implementation of conceivable measures. If, for example, the boundary between good and moderate ecological potential is set at an EQR of > 0.4–0.5, this means that a similarity of > 40–50% to the current reference is necessary to reach the status classification ‘good potential’. This would be a possible approach in view of the pronounced variability of fish fauna and also taking into account the changes in the water body structure of the estuaries.

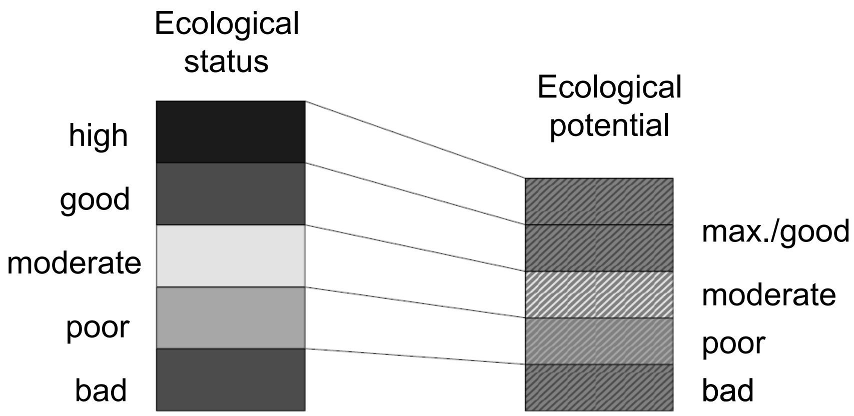


Figure 10: Schematic approach for definition of ecological potential: downscaling (Bioconsult 2006, Podraza 2008).

A generally accepted numeric method for determining the ecological potential does not exist at the moment. An in-depth analysis or stipulation of one of the above mentioned approaches is not possible on a meaningful basis in the framework of this project.

In the procedure proposed here the latter approach (point 5) is pursued, i.e. the reference community (= high ecological status) is not modified, but the benchmark for the good / maximum ecological potential is controlled through the definition of the category boundaries of the assessment levels (Table 27).

Table 27: Allocation of the EQR value to an ecological status category or to the categories of the ecological potential (ep).

EQR_es	Ecological status	Ecological potential (proposal)	EQR_ep
0.9	high		
0.68–< 0.9	good		> 0.68
0.5–< 0.7	moderate	max./good	> 0.5–0.68
0.25–< 0.5	poor	moderate	> 0.25–0.5
< 0.25	bad	poor	> 0.15–0.25
		bad	< 0.15

In this connection we suggest that the EQR value for a moderate ecological status be regarded as a relevant variable for a ‘good ecological potential’. This appears plausible to us because, in view of the use demands on the estuaries and their extensively irreversible morphological changes, one cannot assume that the historically diverse fish community with a multitude of individuals can re-establish itself in a high or good ecological status through conceivable measures. This applies both at the qualitative level (reestablishment of currently vanished species) and, in particular, at the quantitative level (stock densities). Alone because of the extensive losses of areas in the estuaries (loss of side arms, backwaters, shallow-water zones) due to concentration on the shipping channel, one can assume that the former stocks of the species can reattain historical population sizes only to a very limited extent. [* ***Supplementary note:*** An examination of the latter aspect, however, is hardly possible by means of monitoring since, based on a single fishing operation, the catch figures may in some cases resemble historical catch figures of a single fishing operation, as shown by the comparison of current to historical quantitative data. However, it must be pointed out that fishery activities in the estuary today are only marginal compared to a historical situation and thus the total catch yields today are generally lower in comparison.]

If the boundary between good and moderate ecological potential is set at an EQR of > 0.5, this means that, in terms of both the qualitative and the quantitative metrics, more than 50% similarity to the reference is necessary to achieve the status category ‘good potential’. This appears to be a plausible limit in view of the pronounced variability of the fish communities as well as taking into account the changes in the water body structure of the estuaries.

7.4 Indications for validation of the assessment

To obtain indications of the plausibility of the formal assessments, the latter were compared to expert assessments. To better identify possible critical points in the methods, experts were given hypothetical and real data records. The expert judgement was to be based on a historical status (largely not yet subject to any human influence). Orientational background information on basic physico-chemical and hydromorphological conditions, among other things, was provided to the experts. Altogether 12 experts submitted assessments (anonymous) and they did not know which data were hypothetical and which scenarios were based on actual monitoring investigations. Table 28 shows the basis (5 scenarios) for the expert judgement.

Table 28: Database for the expert judgement assessment of transitional waters, differentiated according to 5 scenarios. Ecological guilds according to Elliot & Dewailly (1995), Franco et al. (2008). Aes = estuarine resident species, FW = freshwater species, dia = diadromous Species, marin-sais = marine seasonal migrants (periodical), mar-juv = marine juvenile migrants (periodical), mar = marine stragglers (only occasionally). Number = individuals*h^{-1}*80 m^{-2}.

Transitional waters (oligohaline -	**Type: large estuary, mesotidal**	**scenario 1**	**scenario 2**	**scenario 3**	**scenario 4**	**scenario 5**
Abundance: mean values (ind.*h^{-1}*80m^{-2}) per year		**T1_A**	**T1_B**	**T1_C**	**T1_D**	**T1_E**
	No. sampling	**2**	**2**	**2**	**2**	**2**
Ecological guild	**No. sample sites**	**4**	**4**	**4**	**4**	**4**
Aes	Flounder	44	89	35	30	197
Aes	Nilssons's pipefish	4	10	45	0.4	60
Aes	Sand goby	30	13		0.3	43
Aes	Common goby	11	14	2	1	28
Aes	Striped seasnail	5	1			5
Aes	Hooknose	1	1			2
Aes	Greater pipefish		1	0.4		1
Aes	Shorthorn sculpin	0.2		0.03	0.3	1
Dia	Smelt	3312	3366	5480	2758	14916
Dia	Twaite shad	5	56	36	5	320
Dia	Three-spined	103	97	20	15	235
Dia	Eel	2	2	2	1	6
Dia	River lamprey	1	2	1	1	4
Dia	Sea trout	1	1	0.3	0	3
Dia	Salmon	0.5	0.4	0.4	0.2	1
Dia	Sea lamprey	0.1		0.1	0.1	0.3
Dia	Houting	0.1	0.04	0.06	0.03	0.2
Fw	Ruffe	194	55	93	221	563
Fw	Pike-perch	1	1	10	2	14
Fw	Common bream	0.4	0.4	1	7	9
Fw	Die	0.2		3	0.2	3
Fw	Asp	0.4	0.1	0.03	0.1	1
Fw	Bleak	0.1	0.03		0.1	0.2
Fw	White bream	0.1		0.02	0.1	0.2
Fw	European pearch			0.1		0.1
Fw	Roach		0.02			0.04
Fw	Carp		0.02			0.03
Fw	Burbot			0.02		0.03
Fw	Prussian carp			0.03		0.03
Fw	Barbel	0.02				0.02
Marin-sais	Sprat	13	33	61	2	109
Marin-sais	Thicklip grey mullet	0.2	0.4		0.2	1
Marin-sais	Fivebeard rockling	0.2	0.4			0.3
Marin-sais	European anchovy				0.2	0.2
Marin-sais	Grey gurnard	0.2				0.2
Mar-juv	Atlantic herring	159	157	9	12	337
Mar-juv	Sole	0.4	14	4	0.2	18
Mar-juv	Plaice	3	10	1		14
Mar-juv	Cod	4	0.5	1		5
Mar-juv	Whiting	1	0.03			1
Mar-juv	Turbot	0.1	0.1	0.2	0.03	0.4
Mar-juv	tub gurnard					0.03
Mar-juv	European seabass					0.03
Mar	Snake pipefish		0.03	0.1	1	1
Mar	Scaldfish		0.3			0.3
Mar	Ctenolabrus rupestris		0.03			0.03
Mar	Maurolicus muelleri		0.03			0.04
Mar	Horse mackerel	0.03				0.03
Species number		19	19	17	14	28
Total abundance (ind.*h^{-1}*80 m^{-2})		3,893	3,921	5,804	3,056	16,900

Table 29 shows the respective basic values of the various data records stated here as ‘scenarios’ (indicated as hypothetical or real) as well as the respective formal assessment according to FAT-TW_de and expert classification.

The numbers of species of the five ‘scenarios’ vary between 28 as the minimum (scenario 4) and 48 as the maximum (scenario 5). The abundance values ranging from 3,058 individuals*h^{-1}*$80m^{-2}$ (scenario 4) to 16,902 individuals*h^{-1}*80 m^{-2} (scenario 5) display a high amplitude. FAT-TW_de indicates quality classes good/moderate (scenario 5), ‘moderate’ (scenario 1) as well as ‘poor’ (scenario 2–4).

Note: Besides the assessment according to FAT, alternative assessments are additionally listed on the basis of a proposal on classification of the data regarding the ‘ecological potential’ (tentative proposal in the assessment tool) as well as on the basis of the Dutch methodology for determination of the class boundaries of the ecological status (which is currently being discussed for the transitional waters of the Ems). The difference between the German and Dutch approach is a somewhat different EQR calculation and a lower class boundary between ‘good’ and ‘moderate’. As a result of these differences, data tend to be assessed “more optimistically” according to the Dutch methodology. Because of this, different status classes may also be indicated. This is the case, for example, in scenario 5 or scenario 2 (Table 29).

Table 29: Comparison of formalized assessment (FAT-TW) and expert judgement assessments of different data records (hypothetical and real) for water body type T1 (transitional waters) of the tidal Elbe. Red = guilds not relevant for assessment regarding T1. gd = good. Stat = ecological status; pot. = ecological potential.

Type TW	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	hypothetical	original data 05	original Data 06	original data 07	Original data 04-07 OWK Elbe T1
	Abundances: high flounder, ruffe, herring	Mean ind.*h*80m²	Mean ind.*h*80m²	Mean ind.*h*80m²	mean Ind.*h*80m²) pooled + summed
	3,896	3,925	5,806	3,058	16,902
Species no. total	37	35	30	28	48
Frehwater	7	7	9	7	13
Diadromus	9	8	9	9	9
Estuarine	7	7	5	5	8
Marin-juveniles	8	6	5	3	8
Marin-seaisonal	4	3	1	3	5
Marine	1	4	1	1	5
EQR	0.525	0.45	0.35	0.3	0.65
Stat.- FAT_de	mod	poor	poor	poor	mod–good
Pot.l-FAT_de/alt. NL	good–mod	mod/mod	mod–poor	mod–poor	good/good
Status – expert-judgement	gd	mood	mod	poor	high
	gd	gd	mod	poor	gd
	mod	poor	poor	bad	gd
	gd	gd	mod	mod	high
	gd	mod	poor	bad	high
	gd	poor	mod	bad	high
	gd	mod	poor	bad	high
	mod	gd	poor	bad	high
	gd	mod–good	mod	mod–poor	gd
	mod	mod–poor	poor	poor	gd
	md	mod	mod	poor	gd

Scenarios with assessment result 'moderate (good)'

Scenarios 1 & 5 are assessed as 'moderate' and 'good/moderate' respectively according to FAT-TW_de although scenario 5 differs from scenario 1 by virtue of significantly higher species numbers and abundances. However, differences emerge at the EQR level. For scenario 1, for instance, an EQR of 0.525 (moderate) is documented and for scenario 5 an EQR of 0.65 (good–moderate).

The reasons for the classification 'moderate' are primarily attributable to unfavourable partial assessments for some indicator species like twaite shad (*Alosa fallax*) or the estuarine seasnail (*Liparis liparis*) because of their low abundance in comparison to the respective reference values. The species diversity (at the guild level in each case) corresponds in part to the reference, but also shows deficits, such as with regard to the guild of 'estuarine species', as their number species deviates substantially from the reference value. Whereas the formal assessment for scenario 1 – as already illustrated above by the EQR values – tends to produce a result in the lower range of the 'moderate' status, the result for scenario 5 is on the boundary to 'good'. At present the class boundary between 'moderate' and 'good' is defined at an EQR of > 0.68 (FAT-TW tool).

In comparison to the expert judgement (EJ) a concordant classification turns out for scenario 1 in 36% of the cases while 64% of the EJ deviate by one status class higher. The latter cases thus correspond to the classification for the ecological potential ('good', Table 29: column "*Potential FAT-TW_de / alternatively FAT-TW_nl"*).

Significant differences result between FAT-TW_de and the EJ with respect to scenario 5 insofar as all experts assessed the ecological status better according to this database. Here 45% of the assessments deviate by one status class higher and 55% by two classes higher. In the case of scenario 5, the concordance of the EJ tends to correspond to the 'potential classification' or the classification based on the Dutch methodology (in each case 'good': Table 29: column "*Potential FAT-TW_de / alternatively FAT-TW_nl"*). The reasons for the EJ 'good' to 'high' essentially related to the high numbers of species. In their rating assessments all experts also took into account the freshwater species that are (formally) not relevant for this type of water body and are well represented here with 13 species. The very low abundance (but relevant for the assessment in the framework of FAT) of the seasnail was, by contrast, not seen as a deficit.

Scenarios with assessment result 'poor'

The data for scenarios 2–4 are classified by FAT-TW_de as 'poor' in each case – though with slight differences. The assessment of scenario 2, for instance, has an EQR of 0.45, putting it on the boundary to 'moderate' while scenario 4 is in the lower third of this status class at 0.3. Scenario has a middle position with an EQR of 0.35. The main reasons for the unfavourable assessment relate to deficits in the marine guilds (juvenile, seasonal) and the estuarine residents, whose species diversity displays considerable differences compared to the reference. This also applies to some quantitative parameters (twaite shad, ruffe – *Gymnocephalus cernuus*, striped sea snails – *Liparis liparis*).

At 27% the comparison with the EJ shows a corresponding indication of the status class for scenario 2. On the basis of the data, 73% assessed the status one class (42%) or two classes (33%) better. This corresponds in some cases to the assessment result on the basis of the Dutch methodology (Table 29: column "*Potential FAT-TW_de / alternatively FAT-TW_nl*").

For scenario 3 the concordance between FAT-TW_de and EJ at 45% is comparatively high. However, 55% assessed the data as 'moderate' and thus one class better. The decisive factor for the latter assessment according to EJ was primarily the relatively high number of species with a total of 30 taxa. The numbers of individuals, which are very low, with the exception of the smelt, were also mentioned as deficits, but the actual partial assessments in this regard vary between 'poor' and 'moderate'.

Scenario 4, too, shows a concordance of approximately 45% between FAT-TW_de and EJ. About 10% assessed the data as 'moderate' and thus one class better while 45% came to a result that was one class lower. The reasons were the lowest numbers of species in a comparison of all scenarios and, furthermore, the low abundance of all species with the exception of the smelt (*Osmerus eperlanus*). However, its numbers of individuals are also the lowest here in a comparison of all data records.

Degree of distinction

To determine whether and how the method is able to reflect various catch data via the assessment result, community analyses were exemplarily carried out by means of MDS analysis (Clarke & Warwick 1994) on the basis of hypothetical and real data records. The hypothetical data are selected such that they cover all status classes (‘high’–‘bad’) according to FAT-TW_de with two data records each.

The analyses were carried out, differentiated according to metric groups (species composition) and (abundance of selected indicator species), where the data record for species composition is based on presence/absence data and the data record for ‘abundance’ is based on abundances transformed into categories (I–VI) (section 6).

Stow net catch data from the Ems (2007 & 2008), Weser (2009) as well as data from the Elbe were used as “real data records” in the MDS analysis. The data from the Elbe here correspond to scenarios 4 & 5 (Table 28).

Figure 11 and Figure 12 illustrate the results in an ordination diagram. The calculated stress values of 0.07 (species composition) and 0.04 (abundance) indicate a good to very good distinction between the groups (bad–high).

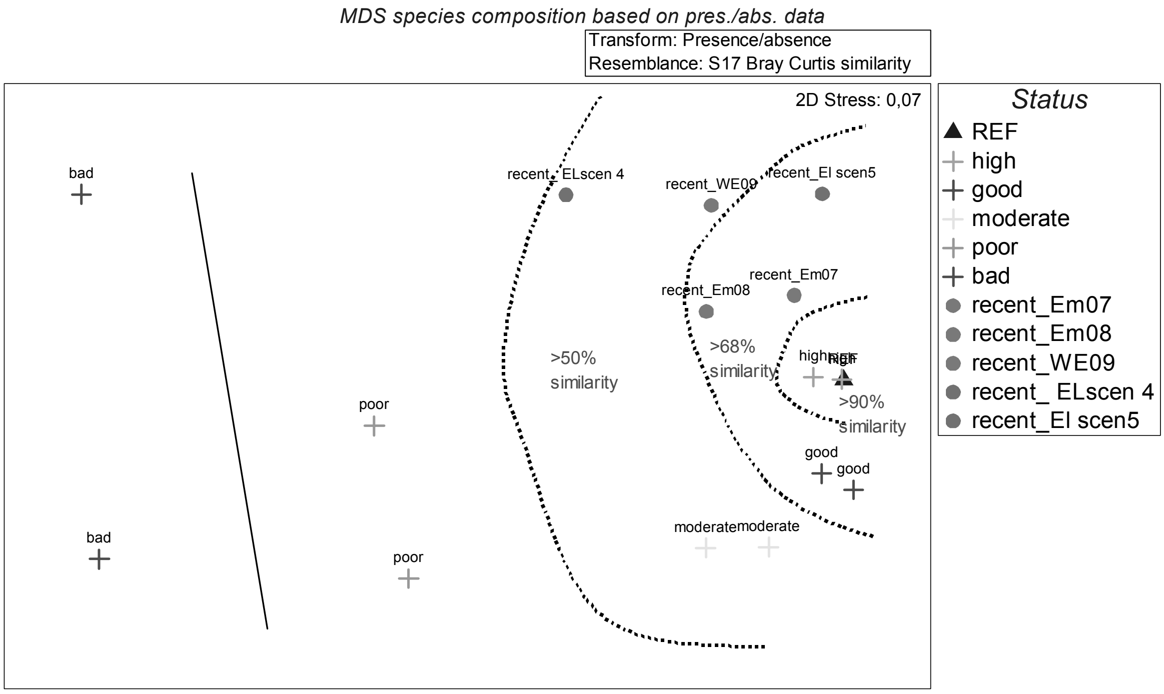


Figure 11: MDS ordination on the basis of hypothetical data (“high”–“bad“) as well as real anchor net data (Ems – Em07/08, Weser – We09, Elbe – El-scen 4 & 5, from WFD monitoring for fish in transitional waters). Data as presence/absence. ANOSIM: Global R = 0.546

The ordinations show that a pronounced gradient in terms of the status classes “high”–“bad” is reflected on the basis of the data used here for both metric groups (species composition, abundance). According to ANOSIM, the distinction between the groups shown in the ordination can be classified as ‘good’ overall. This is indicated by R values of 0.546 (species composition) and 0.74 (abundance of selected species).

At the same time the similarity (Bray Curtis similarity) to the reference is an indication of the allocation of the real data records to a status class in the ordination. Using the FAT-TW_de boundaries, the species diversity with a similarity of 52% (El scenario 4) and 65% (We_09) respectively to the reference indicates a "moderate ecological status" though We_09 is close to the boundary to 'good'. The relatively high number of species in the Ems (Em07/08) and Elbe (scenario 5) is reflected in a respectively higher similarity (69.8–80%) to the reference and a different status class ('good').

The analysis also clearly points out that deficits exist in terms of the frequency of species. With the exception of El-scen5 (= cumulative data record from 3 investigation years 2004–2007), all other catch results indicate rather unfavourable conditions ('poor') where the similarity to the reference is < 50% (Figure 12, bottom graph).

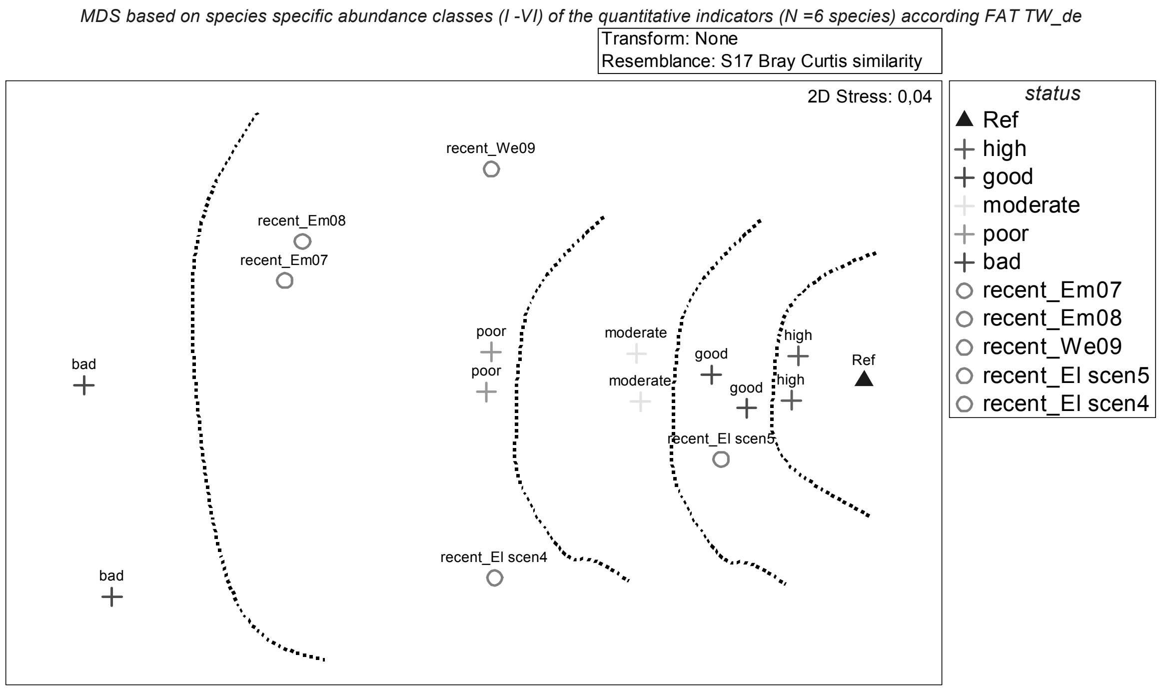


Figure 12: MDS ordination on the basis of hypothetical data ("high"–"bad") as well as real anchor net data (Ems – Em07/08, Weser – We09, Elbe – Elscen 4 & 5, from WFD monitoring for fish in transitional waters). Only selected indicator species (flounder, herring, striped sea snails, smelt, twaite shad, ruffe). Abundance data transformed into categories defined on a species-specific basis (I–VI). ANOSIM: Global R = 0.74

7.5 Summary

The assessment results of the real and hypothetical data records are predominantly plausible, with qualifications, and remain (with exceptions) within the framework of the assessment of the experts surveyed. The results also showed that the method may tend towards pessimistic assessments, especially at the boundary between 'good' and 'moderate'. There may be a connection here with the current selection of individual indicator species. The results of the exemplary MDS analysis indicate that the status classes defined here are more or less easily distinguishable from one another.

8 Requirements regarding data collection

Data collection requirements

Application of the fish-based assessment approach for transitional waters of the type T1 as proposed here places specific demands on data collection. The procedure is calibrated for the anchor net fishing method and therefore requires this method for application.

The high spatial and temporal variability of the estuarine fish communities plays an important role with regard to designing a suitable monitoring system. Furthermore, it must be kept in mind that the reference conditions were derived from anchor net data that were collected in spring and autumn. This seasonal aspect was also taken into account in the concept for the current monitoring.

To generate reliable assessment results in terms of the ecological status and/or ecological potential of transitional waters, the following aspects should be taken into consideration (scope per investigation year):

1. Sample sites along the salinity gradient (oligohaline, mesohaline and polyhaline zone); the number of sites is geared to the size of the estuary and should be at least 2 in the case of the Eider and 3–4 sites in the case of the other estuaries;
2. investigation times in spring and autumn;
3. catches during both tidal phases (low and high tide);
4. the spring investigation should take place in May as the best time for recording (adult) twaite shad and striped sea snails. This means a certain loss of information can be expected with respect to the smelt, which as a rule reaches its abundance maximum before May. However, one can expect on the basis of the existing data that sufficient smelt can also be recorded in May;
5. definition of 3 age groups in accordance with the existing practice of ARGE Elbe (2004) (stow net fishing operations);
6. survey and acquisition of information from third parties to verify presence of sturgeon.
7. Additional data collection with regard to fish eggs and larvae has taken place in spring since 2010. In this case a total of 6 bongo net catches (diameter 0.5 m, 500 µm mesh size) are carried out for each sample site. Sampling takes place from the cutter during anchor net fishing.

Further details and a tabular summary of the fishing method requirements for application of the assessment procedure are described in the supplementary information following the references.

Investigation frequency in the 6-year report periods

Until the first management plan according to WFD is drawn up, we proposed annual data collection to ensure that an adequately broad database is available for practical application of the procedure for all T1 transitional waters by the time of preparation of the report in 2009. This applies especially in view of a necessary fundamental review / verification of the assessment procedure that is essentially based on Elbe data.

For the second reporting period (2010–15) threefold sampling (at 2-year intervals) should be sufficient. The further investigation frequency should then be specified on the basis of this database.

Application options

We assume that both the metrics and the category boundaries specified for assessment of the metrics for type T1 transitional waters (Elbe, Weser, Ems) are fundamentally applicable. A certain modification of the assessment scale is presumably necessary for the transitional waters of the Eider (type T2 transitional waters), which have a mesohaline zone with limnetic characteristics that is very small as compared to the other estuaries. The assessment scale has to be finally evaluated within the framework of a test that requires a sufficient database.

9 Conclusions

The procedure for assessment of the ecological status of transitional waters developed in this study is oriented to a historical status serving as the reference point for the definition of a high ecological status, i.e. a state in which only minor anthropogenic interventions and influences are brought to bear and the biotic communities specific to the water body type are extensively unchanged. This serves as the basis for the 5-level classification of the ecological status of transitional waters according to the WFD based on fish fauna. For elaboration of the reference the WFD requires that both the qualitative (species diversity) and the quantitative aspect (abundance) are taken into account, a prerequisite met by the approach developed here.

In this context we assume that the same reference community with only minor specific adaptations in each case can be defined for the transitional waters of the northern German estuaries (type T1). Application to type T2 (Eider) has to be examined. Presumably modifications are necessary since the transitional waters of the Eider also include a limnetic component.

Initial exemplary tests for validation of the FAT-TW index showed plausible results that extensively corresponded to expert judgement results. On the basis of hypothetical data records, there were indications that the ecological status classes were distinguishable from one another.

Outlook

The water-body-specific class boundaries of the national EQR values are currently undergoing review and possibly adaptation in the framework of European intercalibration. In this connection we would like to point out that determination and specification of the class boundaries of the EQR for transitional waters, which still differ slightly at the moment, are to be harmonized in the short term within the scope of Dutch-German cooperation for the Ems transitional waters (both countries use the assessment approach [FAT-TW_de FAT-TW_nl]). The Dutch class boundaries will presumably be used in the future (starting approximately at the end of 2011).

In addition, as part of the planned harmonization with the Dutch assessment approach (Jager & Kranenbarg 2004), evaluation of the FAT-TW index is scheduled to take place in 2012 using the more extensive database that will be available then.

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Fishing method requirement (updated)

As already explained, application of the assessment method requires stow net fishing as the method for data acquisition, which is described in summary form below.

The net sizes used in the northern German estuaries in the recent past varied from approximately 90 m² (Elbe), 95 m² (Eider) to approximately 150 m² (Weser). A precise definition or specification of the net size cannot be carried out in our opinion since it is necessary to make use of the existing equipment of commercial cutters for fishing purposes. By means of the computational standardization to 80 m², differences related to the fishing method that are due to the net sizes can at least be partially compensated for. In our view, however, the net size should not be less than a minimum of about 70 m².

The typically employed mesh sizes (at the cod end) were 8–11 mm in the Elbe, 6–12 mm in the Weser as well as 8 mm in the Eider. Future fishing should be carried out within this range.

With the anchor net vessels available in the river Weser, fishing can only be performed on one side. For data acquisition regarding stocks in the Elbe, fishing was also carried out on one side. In our view this should also be done in the future. From our point of view one survey for each fishing site and catch date during one entire tidal phase (1 low-tide and 1 high-tide catch in each case) is adequate. The low-tide and high-tide catches should be evaluated separately, similar to the series of investigations carried out in the recent past (ARGE Elbe 2004).

Weight and length measurements at the species level (in the case of large catch volumes by means of suitable subsamples, see below) are part of the routine programme of the fishing operations. Even if such data (particularly weight determination) are not used directly for the Water Framework Directive assessment, they should not be dispensed with in the future in our estimation. Dispensing with determination of the above-mentioned parameters does not lead to a significant cost reduction, but to a considerable loss of information.

The sampling procedure and the size of subsamples for abundance and biomass determination differ according to specific species and catch so that a general specification in % cannot be generally defined with regard to a minimum size of the subsample. However, it must be ensured that it is a representative subsample in each case and that the procedure is recorded in an adequately comprehensible manner. The persons conducting the investigation must have suitable specialized qualifications. However, we will examine whether removal of subsamples can be standardized methodologically as far as possible. In contrast to the above-mentioned quantitative parameters, the catch must always be processed completely for determination of the biodiversity.

Further information on implementation of the fish fauna study is provided in the overview in Table 30 below.

Table 30: Data on methodological approach for acquisition of fish fauna data in northern German transitional water bodies.

	Quality component fish fauna in transitional waterbodies	
	Conditional framework regarding catch method	
1	**Number and position of measuring points**	at least 1 measuring point per salinity zone
2	**Fishing method**	stow net
3	**Net size**	>70 m²
4	**Mesh size (at cod end)**	6 - 12 mm
5	**Net position**	on one side (possibly both sides with small net sizes)
6	**Exposition/investigation date**	over entire tidal phase
7	**Tidal phase - a**	low-tide catch
8	**Tidal phase - b**	high-tide catch
	Times of investigation	
9	**Spring**	mandatory, May
10	**Summer**	not mandatory, (July, August)
11	**Autumn**	mandatory, September/October
12	**Winter**	not mandatory
	Catch documentation	
10	**Exposition time**	per catch (in min., from letting out to hauling in net)
11	**Filtered water volume**	measurement per catch (in m³)
	Evaluation of catch	
12	**Low-tide and high-tide catches**	separate evaluation
13	**Taxonomic identification**	entire species spectrum
	Length measurements	yes, 1cm below, individual level/species
		(for high catch numbers suitable subsample)
14	**Weight determination**	yes, in g, total catch weight/species
		(for high catch numbers suitable subsample)
	Age groups	
15	**Number 0+**	yes (mandatory for twaite shad and smelt)
16	**Number subadult**	yes (mandatory for twaite shad and smelt)
17	**Number adult**	yes (mandatory for twaite shad and smelt)

Relevant catch data for assessment of the quantitative variables (abundance of selected species)

Because of the time and spatial variability of the fish, not all catch data are relevant for assessment of the quantitative variables (frequencies of the 6 selected species). Use of the tool requires that consideration be given to the following specifications:

- Combining low-tide and high-tide catches (mean value) and standardization of the catch data to individuals/80m²/h.
- For use of the quantitative variables (frequencies of quantitative indicator species) the aspects listed in Table 22 must always be taken into account prior to inputting the data in the assessment tool.

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