Trends in Wadden Sea Fish Fauna, Part I: Trilateral Cooperation

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1. Introduction

Twaite shad
(Photo: Z. Jager)

The shallow coastal waters of the Wadden Sea and its tributary estuaries provide indispensable ecological functions for a whole range of species in the course of their respective lifecycles. For fish, they support functions such as reproduction, maturing and feeding and they serve as an acclimatization area and transit route for long-distance migrants from sea to their spawning grounds located in fresh water (*e.g.* Haedrich 1982, Kerstan 1991, Elliott and Hemingway 2002, Elliott *et al.*, 2007). The estuaries are even more than the Wadden Sea itself characterized by a pronounced salinity gradient and a dynamic mixture of limnetic and marine elements which is also reflected by a special fish fauna composition. Thus, they constitute a habitat of a very particular nature within the Wadden Sea. At the same time there is a close relationship between estuaries and the Wadden Sea due to the intensive exchange of substances and organisms, which is reflected in the fish fauna as well. The Wadden Sea ecosystem is also connected with and influenced by the North Sea: marine juvenile and marine seasonal species form an important constituent of the Wadden Sea fish fauna.

The Wadden Sea and estuaries, especially the upstream sections, were and are subject to substantial anthropogenic pressures (Lozán *et al.*, 1994, Schuchardt *et al.*, 1999, 2007; Essink *et al.*, 2005). These pressures are reflected in the aquatic biotic communities and in the fish fauna in particular. Among the most relevant anthropogenic factors influencing the estuaries are dredging and the disposal of dredged material, coastal protection and flood defence and the direct or diffuse input of substances from industry and agriculture. In the Wadden Sea the dominance and relative importance of the anthropogenic pressures are slightly different compared to the estuaries. Recreation plays a more pronounced role here, as well as shrimp fishery and mussel culture. The North Sea in its turn is subject to increasing human demands for shipping, exploitation of resources (gas and oil, sand and gravel), fishery and wind energy.

Intermingled with the anthropogenic pressures that are exerted, natural variability plays a very important role influencing fish fauna abundance and distribution. Recently, an increasing number of publications point to the relations between the North Atlantic Oscillation (NAO) and fish populations (Attrill and Power, 2002; Henderson and Seaby, 2005) or the effects of increasing water temperatures on fish (Henderson and Seaby, 1994; Genner *et al.*, 2003; Pörtner and Knust, 2007; Van Keeken *et al.*, 2007). New species are reported in the Wadden Sea, such as the black goby *Gobius niger* (H. Asmus, pers. comm.) and the exotic Atlantic croaker *Micropogonias undulatus* which turned up in the Weser estuary in 2004 (Bioconsult, *unpubl.*).

1.1 Findings and recommendation of the QSR 2004

The previous Quality Status Report (QSR 2004; Vorberg *et al.,* 2005) described and assessed the temporal trends and spatial distribution of 20 fish species and the brown shrimp (*Crangon crangon*). It underlined the need for a regular assessment of the fish fauna and formulated recommendations on management, monitoring and research. These were adopted in the recommendations of the 11th International Scientific Wadden Sea Symposium in Esbjerg (April 2005), and it was advised to include fish monitoring in the ongoing Trilateral Monitoring and Assessment Program (further indicated as TMAP) revision process. The establishment of a trilateral expert group on fish, functioning under the Trilateral Monitoring and Assessment Group (TMAG), was recommended to support TMAP and the implementation of EU Directives.

At the time of the QSR 2004, pelagic fish monitoring was restricted to the Meldorf Bight and Hörnum Deep (Schleswig Holstein). Vorberg *et al.* (2005) judged the status of herring (*Clupea harengus*) in Meldorf Bight stable; sprat (*Sprattus sprattus*) showed a decreasing trend and anchovy (*Engraulis encrasicolus*) an increasing trend in that area, possibly related to increased temperatures. Twaite shad (*Alosa fallax*) seemed to do well in the Meldorf Bight, but in contrast, the population in the Ems seemed unstable. High densities of smelt (*Osmerus eperlanus*) occurred in the lower reaches of the Elbe, but no reliable information was available for the other estuaries. River lamprey (*Lampetra fluviatilis*) showed an increasing trend in abundance. Results from the demersal fish surveys showed that numbers of juvenile flatfish using the Wadden Sea as a nursery were declining, partly as a consequence of a distribution shift towards offshore areas. The causal factors underlying this shift in distribution are as yet not fully understood.

The trends in resident species were fluctuating up and down on a decadal scale. The brown shrimp (*Crangon crangon*) stock seemed in no way endangered and possibly benefited from low predation rates by the low population levels of cod (*Gadus morhua*) and whiting (*Merlangius merlangus*).

1.2 Trilateral policy and management

Despite the recognised importance of fish as an element of the Wadden Sea ecosystem (Vorberg *et al.,* 2005), fish was not considered in the Trilateral Wadden Sea Plan (1997). Neither did it appear in the Common Package of the Trilateral Monitoring and Assessment Program (TMAG, 1997) to a sufficient extent, nor had trilateral targets referring explicitly to fish been formulated.

In the mean time, the need to include fish in the Wadden Sea Plan and the TMAP has grown because the Water Framework Directive (WFD, 2000/60/EC) recognizes fish as a biological quality element for transitional waters (estuaries) and selected fish species are listed in the Habitats Directive (HD, 92/43/EEC); among those are the twaite shad, river lamprey and sea lamprey (*Petromyzon marinus*). In addition, characteristic fish species should be used to assess the status of the relevant habitat types described in the HD (*e.g.* H1110 submerged sandbanks, H1130 estuaries, H1140 intertidal sand- and mudflats). Furthermore, some fish species serve as main food item for birds or seals, which are listed under the Bird and Habitats Directive for the Wadden Sea. Recently, the Marine Strategy Framework Directive (2008/56/EC) has been adopted and is now being implemented. In this Directive, fish again are one of the qualitative descriptors of the good environmental status.

Because the TMAP common package does not include fish monitoring, one is dependent on information that is provided by fish monitoring for other purposes (fish stock assessment for ICES) or (European) obligations. Following the requirements of the EU Water Framework Directive, new fish monitoring was initiated in 2006 in all Wadden Sea estuaries (the 'transitional waters' of the Ems, Weser, Elbe and Eider), to collect data on particularly pelagic (herring, smelt) and diadromous (twaite shad, smelt) fish species in these water bodies.

In contrast to transitional waters, fish is not considered as a WFD biological quality element for coastal waters such as the Wadden Sea - even though fish are an important group within these ecosystems. For this reason, there still is no specific (pelagic) fish monitoring in the Wadden Sea (which should also meet the demands of the Habitats Directive) and considerable gaps remain, especially in the western Wadden Sea. From a trilateral fish monitoring perspective, another regretted gap is the missing fish monitoring in the Danish Wadden Sea.

Expansion of the ongoing monitoring to other locations, or times of the year - to cover fish species with a very strong seasonal pattern of abundance - is not feasible given the current funding available for these monitoring programs. On the functional relationship between fish species and habitats, some new data have been collected demonstrating the role of intertidal seagrass as a habitat and spawning area for fish (Polte and Asmus 2006a, 2006b).

As a result of the QSR 2004 and the recommendations following from the Trilateral Ministers Conference, a TMAP ad hoc expert group on fish monitoring was established in March 2006. This group has been given the task support the TMAP Revision process (monitoring for the Wadden Sea Plan and the EU Directives) and enhance the trilateral coordination of Wadden Sea fish monitoring, based on the QSR 2004 experiences.

1.3 Proposed Fish targets for the Wadden Sea

As one of its tasks, the TMAP ad hoc fish expert group formulated a proposal of trilateral targets for fish which should be including in the further development of the Wadden Sea Plan. Targets for Wadden Sea fish have to take into account the natural fluctuations and the fact that many fish populations in the Wadden Sea depend on the North Sea. Therefore, assessment should be based on long-term monitoring including information about development and distribution of fish stocks in the North Sea. At the other end, estuaries are part of the Wadden Sea and have their influence on the fish fauna. The proposed Fish Targets are:

- Presence of a typical Wadden Sea fish fauna;
- Occurrence and abundance of fish species according to the natural dynamics in (a)biotic conditions.

In addition to these general targets of a typical Wadden Sea fish fauna, conditional sub-targets can be formulated for the different ecological guilds:

- Unhindered migration between the sea and upstream and/or inland waters [for diadromous fish];
- Viable stocks [populations] and a natural reproduction of typical fish species;
- Diversity of habitats (subtidal areas and tidal flats, including areas with seagrass and mussel beds), to provide shelter and food for juvenile fish [nursery function] and substratum for spawning [for estuarine resident species and marine seasonal species];
- Suitable physical, chemical and morphological conditions with the underlying dynamic processes typical for tidal areas [for resident species and marine seasonal species].

In addition, existing Targets on Tidal Area (subtidal and intertidal) are regarded as beneficial:

- Natural dynamic situation in the tidal area;
- Increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas.

Furthermore, a general Target on Estuaries is proposed because estuaries provide important habitats for various fish species:

- Maintaining the tidal influences with their characteristic salt, brackish and fresh water zones.

Beside the fish targets and sub-targets, the topic of trophic integrity should be addressed in the Wadden Sea Plan targets. Fish is an important food resource for birds and marine mammals. To sustain populations of the latter the following target is proposed:

- A natural fish fauna, providing food for sustainable populations of fish-eating birds and marine mammals.

To Denmark, the houting (*Coregonus oxyrinchus*) is a very important target species.

1.4 Relation to EU Water Framework Directive (WFD) and Habitats Directive (HD)

The European Water Framework Directive (WFD) creates a regulatory framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. According to internationally standardized WFD criteria, the following water types occur in the Wadden Sea area: 'euhaline and polyhaline open coastal waters', 'euhaline and polyhaline Wadden Sea' and 'transitional waters'; the latter are found in the estuaries of the Ems, Weser, Elbe and Eider. For all surface waters the WFD aims at achieving a good ecological and a good chemical state by 2015, or (in case of heavily modified or artificial water bodies) the implementation of a good ecological potential and a good chemical state by 2015, and a ban on any deterioration of the status of the water body.

As a consequence of anthropogenic use, which led to morphological changes, all Wadden Sea estuaries have been classified as 'heavily modified'. In heavily modified or artificial water bodies a good ecological state can often not be restored, or at least not by reasonable means. In such case it is allowed to aim at a good ecological potential, which represents a lower environmental goal and which allows for continued anthropogenic uses, such as flood protection and shipping.

The directive defines the 'good ecological state/potential' as a target that should be achieved by 2015 (or in exceptional cases by 2027). In view of

Table 1:
List of fish species relevant for the Wadden Sea area according to the Habitats Directive, *) only for freshwater (TMAP, 2006).

HD No.	Fish species	Scientific name	Functional guild	Vertical distribution	Habitats Directive	Red List Status
1102	Allis shad	*Alosa alosa*	diadromous	pelagic	Annex II	nearly extinct
1103	Twaite shad	*Alosa fallax*	diadromous	pelagic	Annex II, V	endangered
1106	Salmon	*Salmo salar*	diadromous	pelagic	Annex II, V, *)	nearly extinct
1113	Houting	*Coregonus oxyrinchus*	diadromous	pelagic	Annex II, IV	nearly extinct
1095	Sea Lamprey	*Petromyzon marinus*	diadromous	demersal	Annex II	endangered
1099	River Lamprey	*Lampetra fluviatilis*	diadromous	demersal	Annex II, V	endangered

this, the current state of the water bodies must be evaluated to point out the need for action with respect to the objectives of the WFD. To be able to take this first step, it was necessary to develop suitable assessment methods for the quality components specified by the WFD. One of the biological quality elements in transitional waters (but not in coastal waters) is fish.

The Habitats Directive (HD) was installed in 1992. Up until now, most of the attention regarding the implementation of the HD has focused on the establishment of the Natura 2000 network. This "1st pillar" of the directive refers to the conservation of natural habitats and of the habitats of species. The Wadden Sea is part of this Natura 2000 network. The HD, however, comprises a "2nd pillar" which is related to the protection of species. In particular, Articles 12 and 16 are aimed at the establishment and implementation of a strict protection regime for animal species listed in Annex IV(a) of the HD within the whole territory of Member States. Species of Community Interest include all flora and fauna referred to in Annexes II, IV and V (Articles 1c and 2 of the Habitats Directive).

Good knowledge of a species (range/distribution, occurrence, biology, ecology, threats and sensitivity, conservation needs, *etc.*) and regular surveillance of its conservation status over time (as required in Article 11 Habitats Directive) are essential preconditions for any meaningful conservation strategy.

Some Wadden Sea fish species are listed in the Annexes of the Habitats Directive (Table 1).

The relations between the different EU Directives and the TMAP are summarized in Table 2. Fish species that are part of the WFD and the HD have been included in the selection of priority species that was made by the TMAP ad hoc fish expert group (see 2.4).

1.5. Guidance

This thematic report on fish presents the results and conclusions of the work that was carried out by the TMAP ad hoc fish expert group since 2006, and will give an update on the status of fish in the Wadden Sea. The contents of the report reflect the working process that was followed.

To assess the status of fish in the Wadden Sea a joint data analysis was carried out, based on the WFD approach. For a better understanding, the WFD assessment procedure is presented first. The available surveys for QSR 2009 are described and the metrics needed to describe the fish fauna are selected from the available monitoring data. The priority species and the method of selecting those are described. The joint data analysis that has been carried out on these species is described and the results are presented. Results from the preliminary WFD assessment of fish in transitional waters and the status of shrimp are also included in this report. The suitability of the WFD approach for Wadden Sea fish is discussed. The long-term trends in priority fish species are interpreted and discussed. Conclusions on the status of Wadden Sea fish and recommendations for future monitoring, research, management and policy are formulated.

Table 2:
Connections between the TMAP and the WFD and HD focused on fish.

	TMAP	WFD	HD
Where	Entire Wadden Sea area (Trilateral Cooperation Area)	Transitional waters	Natura 2000 sites
What	All relevant species (see TMAP priority species)	Selected Fish species (section 2.1)	Annex II, IV, V species (Table 1), habitat types (section 1.4)
Assessment	WSP targets (proposed)	Fish index, assessment tool	Under development

2. Methods

2.1 Towards a Fish assessment tool

The approach chosen by the TMAP ad hoc fish expert group was inspired by the work carried out in the estuaries to implement the WFD requirements for transitional waters. A WFD estuarine fish index was developed, which combines a number of fish metrics. These fish metrics are selected variables of the fish community which together are considered to give a good reflection of the status of the fish in the specific water body. In the case of the WFD, the fish metrics for transitional water bodies (estuaries) consist of species composition indices, based on the number of species in certain ecological guilds, and abundance indices of key species. These are compared with a reference situation. The underlying assumption is that the metrics are in some way related to anthropogenic pressures acting on the water system. Considerable effort and progress have been made in developing fish indices and assessment tools for transitional waters with the WFD (Jager and Kranenbarg, 2004; Bioconsult, 2006a, 2007a; Scholle *et al., in prep.*; Scholle and Schuchardt, *in prep.*; Kranenbarg and Jager, 2008). On a European level the fish indices developed in the different countries are compared and calibrated in the North East Atlantic Geographical Intercalibration Group (NEA-GIG).

Reference conditions

The reference fish community (species composition and abundance) for transitional waters was derived from historical descriptions that predominantly date from the period 1870-1920, *i.e.* a period before or at the beginning of the first large-scale river engineering measures. Since the estuaries were subject to anthropogenic use already at that time (Gaumert, 2002), the reference does not represent a pristine state, but nevertheless it does constitute a (very) good ecological state in terms of fish fauna because the species diversity was high and the principal characteristic species of the estuaries, such as sturgeon (*Acipenser sturio*), houting (*Coregonus oxyrinchus*), shad (*Alosa alosa* and *A. fallax*) and salmon (*Salmo salar*) were still caught in large quantities. A reference species list was constructed. Reference abundances were reconstructed based on existing recent and historical, methodologically comparable data (Bioconsult, 2006a).

Species composition

The species composition was differentiated according to the ecological guilds (diadromous, estuarine resident, marine juvenile, marine seasonal species) as defined by Elliott and Dewailly (1995) and Elliott *et al.* (2007). Species of these guilds have more or less specific demands on their habitat and indicate specific impairments to a certain extent. The number of species per ecological guild, in relation to the reference situation, is a variable which is relevant for the assessment.

Abundance and age structure

It was not possible to derive reference abundances for all historically documented species. For this reason the quantitative analysis was limited to selected 'indicator species', representing the most relevant ecological guilds (diadromous, estuarine resident and marine juvenile species): *Alosa fallax, Gymnocephalus cernuus, Clupea harengus, Osmerus eperlanus, Liparis liparis, Plathichtys flesus, Pleuronectes platessa, Zoarces viviparus.* These indicators are characteristic for the estuarine fish community and, with the exception of ruffe (*G. cernuus*) and sea snail (*L. liparis*), are also included in the priority species for the trilateral Wadden Sea region (see 2.4). Although age composition is not obligatory for fish in transitional waters, this parameter was included for two species representing the diadromous guild (smelt and twaite shad) to indicate the presence of a self-sustained population of those species in the estuary.

Requirements regarding data collection for WFD fish monitoring

The use of a fish-based assessment tool for transitional waters requires specific data collection. The assessment procedure is calibrated to catches obtained with the stow net (also called anchor net) and therefore requires this method for its application. The large spatial and temporal variability of estuarine fish communities played an important role in the development of the monitoring concept. Particularly the parameter of abundance is influenced by interannual, seasonal and diurnal as well as spatial variability. The aspects of salinity zone, seasonality and tidal phase were taken into account by careful selection of the sampling locations (one per salinity zone), sampling time (twice a year) and sampling duration (flood and ebb period) to generate reliable data for a confident assessment of the ecological state or ecological potential of the estuary. Fish monitoring conform the method stipulated by the WFD took place in all Wadden Sea estuaries in coordination with The Netherlands and Lower Saxony (Ems estuary), Schleswig-Holstein and the Elbe River Water Quality Board (Wassergütestelle Elbe, WGE), starting in 2006. These data form the basis for the WFD fish-based assessment of transitional water bodies. Nevertheless, the amount of data differs between the estuaries: in the tidal Elbe, comparable data are available for every year since 2000 (Wassergütestelle Elbe, 2000-2007), whereas bi-annual fish monitoring in the Ems started in 2006 within the scope of Dutch-German cooperation. Data for the Weser and Eider are available from one single monitoring campaign (3 sites, sampled in spring and autumn) in each estuary (Weser: 2007, Eider: 2006). In addition, comparable data of 2003 (Voigt, 2003; Schubert, 2003) can be used. The frequency at which WFD fish monitoring will take place from 2010 on will be evaluated in the near future, and will be decided based on the monitoring results.

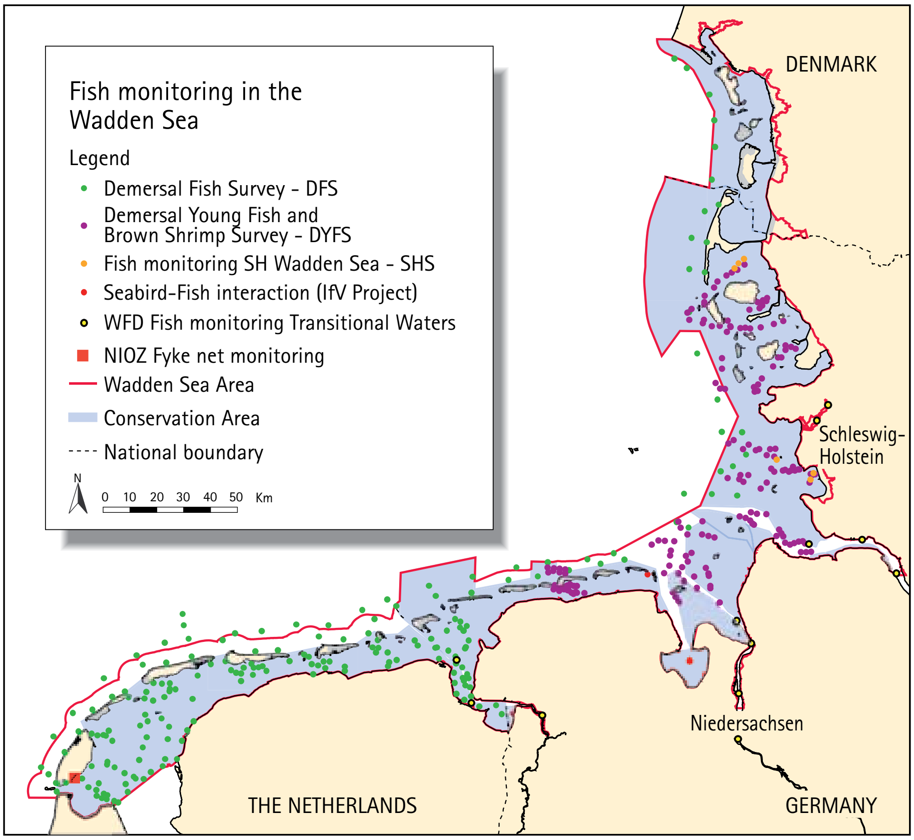
2.2 Overview of fish monitoring data available to TMAP

An overview of ongoing long-term fish monitoring programs of the different countries in the trilateral Wadden Sea area was prepared by R. Vorberg and was reported in Annex 4 of the Report of the TMAP ad hoc WG Fish (TMAP 2006). The sampling locations are indicated in Figure 1. The most extensive and long-running surveys are the Demersal Fish Survey (DFS) and the Demersal Young Fish and Brown Shrimp Survey (DYFS) (see further description in section 2.5). Pelagic monitoring with a stow net has been carried out in the Schelswig-Holstein Wadden Sea area (this survey is further indicated with SHS) since 1991 (Meldorf Bight) and since 2001 (Hörnum Deep). The Seabird-Fish interaction survey is not a regular monitoring program but was undertaken for specific research goals. Results of this study are presented in **Box 1**. The results of the NIOZ fyke net monitoring (since 1960 in the western Wadden Sea) were not available for analysis; results have been previously published in Van der Meer *et al.* (1995) and Philippart *et al.* (1996). WFD monitoring data were not suitable for trend analyses, because this monitoring was installed as from 2006 and does not yet cover long time series. However, the WFD approach is described in section 2.1 and a preliminary assessment of the transitional waters based on the WFD fish monitoring data is presented in 3.5.

2.3 Reference list of Wadden Sea fish species

As a starting point for the development and evaluation of trilateral targets for Wadden Sea fish, a basic reference list was compiled describing the fish species that (can) occur in the Wadden Sea (Annex I). Information was derived from the running monitoring programs, such as the >35-year

Figure 1: Trilateral Wadden Sea Area and Conservation Area including the locations where different fish monitoring programs are carried out: Demersal Fish Survey - DFS, Demersal Young Fish and Brown Shrimp Survey - DYFS, Fish monitoring Schleswig-Holstein Wadden Sea - SHS, Seabird-Fish interaction (IfV Project), WFD Fish monitoring Transitional Waters, NIOZ Fyke net monitoring.



data sets of the demersal (young) fish survey in The Netherlands and Germany and of the stow net surveys in Schleswig-Holstein, Lower Saxony and from the River Elbe. In addition species lists from the literature were used (Witte and Zijlstra, 1979; Fricke *et al.*, 1994; Vorberg and Breckling, 1999). Altogether the list covers a time period of several decades.

2.4 Selection of Priority Species

The objectives of (TMAP) fish monitoring are to assess the status and the development of relevant or characteristic fish species in the Wadden Sea. In practice it is impossible to do this for all the fish species potentially occurring in this area. To help select the priority fish species, different selection criteria were applied (TMAP, 2006). They were grouped into criteria on ecology (ecological guild, habitat preference), relevance for management (HD species or species belonging to the characteristic fish fauna of HD habitat types[1], WFD species, endangered or vulnerable species, food for birds or marine mammals) and sensitivity to driving forces (climate change, nutrient enrichment, habitat degradation, fishing mortality and local pressures). In addition, monitoring criteria were considered (abundance, occurrence and catchability in the ongoing monitoring programs). Applying these criteria resulted in an exhaustive table, indicating the scores of different fish species according to the criteria mentioned above. A selection of some 14 species, defined as 'priority species' because they were scoring high on these selection criteria (Table 3), was further considered in a joint data analysis (Bolle *et al.*, 2007, 2009).

The allis shad (*Alosa alosa*), sea lamprey (*Petromyzon marinus*), houting (*Coregonus oxyrinchus*) and ruffe (*Gymnocephalus cernuus*) scored high on ecological and management relevance but are not covered by the current monitoring methods and programs. Despite their relevance, they could not be taken further into the analyses.

2.5 Joint analysis of survey data

Considerable effort was put into a joint analysis of the German Demersal Young Fish Survey (DYFS, von Thünen Institut) and the Dutch Demersal Fish Survey (DFS, Wageningen IMARES), and substantial progress in tuning different monitoring data was achieved compared to the previous QSR. A joint analysis was enabled because the methods had already been harmonized in the ICES working group on beam trawl surveys (see for example ICES, 2006a). The demersal survey data have been analysed to a finer spatial resolution than in the previous QSR, namely by QSR sub-area, which allows comparison of trends in abundance of species between different parts of the trilateral Wadden Sea. In addition, the Schleswig-Holstein stow net survey (SHS; National Park Agency and Marine Science Service, Germany) was involved in the joint analysis as far as the data allowed it.

These three surveys together have a good spatial and temporal coverage (see Figure 1). The methods of these three surveys have been described elsewhere (Boddeke *et al.*, 1970; Boddeke *et al.*, 1972; Neudecker, 2001; Vorberg, 2001; ICES 2006a; Bolle *et al.*, 2009). Full descriptions of the methodology and the outcome of the joint analysis are presented in Bolle *et al.* (2009), whereas selected results are presented here for the Wadden Sea Quality Status Report 2009.

[1] For H1110A in the Netherlands, recently the following fish species have been listed as qualitative indicators (LNV Profieldocument H1110, vs. September 2008): *Clupea harengus*, *Liparis liparis*, *Myoxocephalus scorpius*, *Pholis gunnellus*, *Platichthys flesus*, *Pleuronectes platessa*, *Pomatoschistus minutus*, *Syngnathus acus*, *Zoarces viviparus*.

Table 3: Priority species to be included in the spatial and temporal trend analyses (CA=diadromous, ER=estuarine resident, MJ=marine juvenile, MS=marine seasonal), x = yes, (x) = partly, - = inadequate, From: Bolle *et al.*, 2007.

Species	Name	Ecological guild	Stratification	Caught in beam trawl	Caught in stow net
Alosa fallax	Twaite shad	CA	Pelagic	(x)	x
Osmerus eperlanus	Smelt	CA	Pelagic	(x)	x
Lampetra fluviatilis	River lamprey	CA	Pelagic	-	x
Platichthys flesus	Flounder	ER	Demersal	x	(x)
Zoarces viviparus	Eelpout	ER	Demersal	x	-
Ammodytes sp.	Sand eel	ER	Pelagic and Buried	x	-
Pleuronectes platessa	Plaice	MJ	Demersal	x	-
Solea solea	Sole	MJ	Demersal	x	-
Limanda limanda	Dab	MJ	Demersal	x	-
Gadus morhua	Cod	MJ	Demersal	x	-
Merlangius merlangus	Whiting	MJ	Demersal	x	-
Clupea harengus	Herring	MJ	Pelagic	(x)	x
Sprattus sprattus	Sprat	MS	Pelagic	(x)	x
Engraulis encrasicolus	Anchovy	MS	Pelagic	-	x

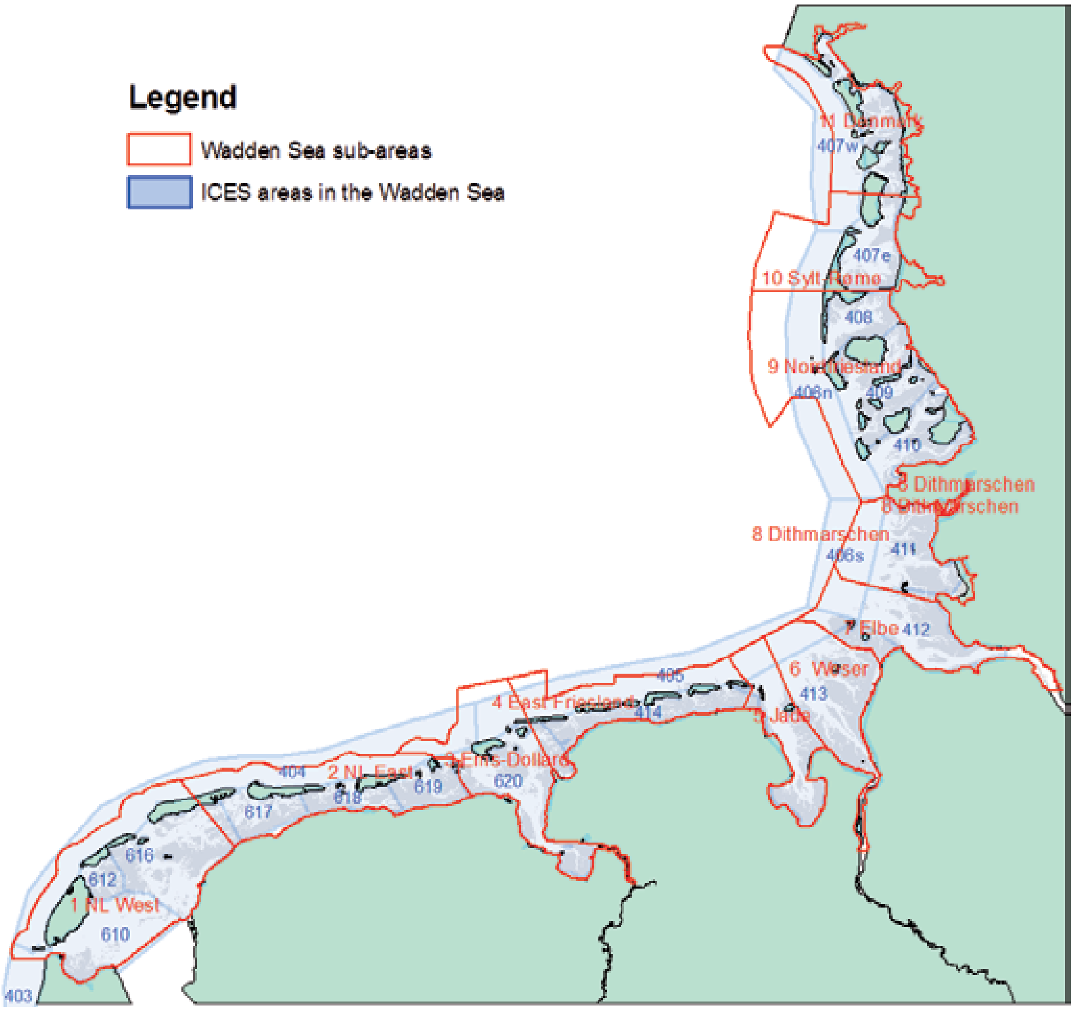


Figure 2: Map of the Wadden Sea sub-areas or QSR areas (as defined within the context of Quality Status Report), and the ICES areas or D(Y)FS areas (as defined in the original DFS/DYFS survey design). 1. Western Dutch Wadden Sea, 2. Eastern Dutch Wadden Sea, 3. Ems-Dollard, 4. East Frisia, 5. Jade, 6. Weser, 7. Elbe, 8. Dithmarschen, 9. North Frisia, 10. Sylt-Rømø, 11. Denmark. Areas 5, 6, 10 and 11 were excluded from (part of) the joint analyses due to insufficient data.

2.6 Selection of fish metrics in the joint analysis

Within the TMAP ad hoc fish expert group, the experiences from the WFD approach were discussed. It was evaluated whether the WFD fish index could also be implemented for the entire Wadden Sea, taking into account differences in fish populations and environmental pressures, as well as the difficulty in defining reference conditions for the entire Wadden Sea area. A WFD-similar approach with respect to selecting fish metrics was chosen for the Wadden Sea fish fauna.

The following fish metrics were included in the analyses:

- Species richness and composition (by ecological guilds) by year and region;
- Mean abundance of priority species by year and region;
- Mean length of priority species by year and region.

Species richness

Species richness is defined here as the total number of species observed in a region in a year. In principle all fish were scored at the species level, but due to identification problems a higher taxonomic level was chosen for some groups of species. These were: *Pomatoschistus sp.* for *Pomatoschistus microps* and *P. minutus* (and *P. lozanoi*); *Liparis sp.* for *Liparis liparis* and *Liparis montagui; Ammodytes sp.* for *Ammodytes tobianus* and *Ammodytes marinus* and *Hyperoplus lanceolatus; Syngnathus sp.* for *Syngnathus acus* and *S. rostellatus* (but most of them are *S. rostellatus*); Triglidae for *Eutrigla gurnardus*, *Trigla lucerna*, *Trigla sp.*

Species composition

Species composition was defined as the total number of species per ecological guild (calculated for each year and region). The ecological guilds considered most relevant for the Wadden Sea are CA (diadromous), MJ (marine juvenile) and ER (estuarine resident). The other categories (excluding freshwater species) were combined in one group. The name estuarine resident (ER) may be confusing in relation to the Wadden Sea, because some scientists do not consider the Wadden Sea to be a true estuary. In this study we define ER as species that are resident in the Wadden Sea, *i.e.* they spend the majority of their life span in the Wadden Sea. Whether or not the species also occurs (abundantly) outside the Wadden Sea is irrelevant for the status of ER. The aggregation of species due to identification problems sometimes caused problems for the calculation of the number of species per ecological guild. Greater sandeel (*Hyperoplus lanceolatus*) is considered to be a MA, but the sandeel group (Ammodytes *sp.*), to which the greater sandeel has been added because of identification problems, is classified as ER.

Mean abundance

The catch rates per haul were standardized. In the case of the beam trawl catches they were converted to numbers per 1000 m^2, in the case of the SHS stow net catches to numbers per 1,000,000 m^3. These abundance estimates were then averaged by year and region. For the beam trawl surveys, a weighted mean was calculated in which the abundance estimates were weighed by the surface area of the depth strata (for further details see Bolle *et al.,* 2009).

Mean length

A shift in mean length indicates a change in the (sub-)population structure. This can be expected for species such as plaice, in which trends in abundance in the Wadden Sea are more apparent for one age group than the other. Length (mean, median, maximum) is commonly used as an indicator in marine ecosystems (see literature review in Appendix 4 of Bolle *et al.,* 2007). The mean length was calculated as the $\Sigma(N^*length)/\Sigma N$, in which N is number of fish; for further details see Bolle *et al. (*2009).

Trends in abundance

For the DFS and DYFS, trends in mean abundance were analysed using TrendSpotter, which is an analytical method based on structural time-series models in combination with a Kalman filter (Visser, 2004). Full details of this analysis are described in Bolle *et al. (*2009). TrendSpotter was used to model the trend between 1970/1974 and 2006 and to assess the significance of a positive or negative trend.

3. Results

3.1 Fish species in the Wadden Sea

The compilation of Wadden Sea fish species yielded a total of 150 records, of which 13 are freshwater species (Annex 1). The total number of North Sea fish species recorded in FishBase is 190 (Fröse and Pauly, 2007), which means that about 72% of all North Sea fish species potentially occur in the Wadden Sea. (However, 13 of the Wadden Sea species listed in Annex I are not listed for the North Sea in FishBase.) With regard to a trilateral monitoring and assessment program only half of all species is of practical importance: 50 species (33,6%) are common, 25 species (16,8%) are fairly common, whereas 74 species (49,7%) have to be considered as rare or even extremely rare in the Wadden Sea (Table 4). The reference species list presented in Annex I has been used as input for the World Heritage nomination of the Wadden Sea (Common Wadden Sea Secretariat, World Heritage Nomination Project Group, 2008).

Table 4: Occurrence of fish species in the Wadden Sea, as derived from the species list in Annex I (version December 2008).

Occurrence	Counts	Species	%
(Extremely) rare	1-3	74	49,3
Fairly common	4-6	26	17,3
Common	7-9	50	33,3
Total		150	100

Of the 76 (fairly) common species, 9 were diadromous, 15 estuarine resident, 12 marine juvenile, 9 marine seasonal and 28 marine adventitious, plus 3 fresh water species (*cf.* Elliott and Hemingway, 2002).

3.2 Species richness and species composition

The species richness as determined by the analysis of the DFS and DYFS ranged between 11 and 33 species per year over the period (October) 1970-2007 (Figure 3). The low number of species observed in 1995 in the North Frisian area is suspect and may have to do with the fact that the German DYFS data prior to 1996 have not been (sufficiently) quality controlled yet (Bolle *et al.*, 2009). Overall there appears to be no clear temporal trend, neither in species richness, nor in species composition in terms of ecological guilds (Figure 3). The number of estuarine resident species is remarkably stable, especially in the western and eastern Dutch Wadden Sea. Not much variation is observed in the number of marine juvenile species either. Most of the variation in species richness is caused by the number of diadromous species or other (marine seasonal and marine adventitious) species.

The number of species in the SHS survey (August) ranged from 18 to 29 for the period 1991-2008 (Meldorf Bight, sub-area 8 Dithmarschen) or 22 to 27 (Hörnum Deep, sub-area 9 North Frisia) over the period 2001-2008 (Figure 4).

A major drawback of the parameter 'species richness' is its dependence on the number of hauls in an asymptotic fashion. In principle, the number of species will increase asymptotically with the number of samples. Figure 5 clearly illustrates that the number of species encountered in the Dutch DFS increases with the number of hauls (per year and region). This relationship, at least partly,

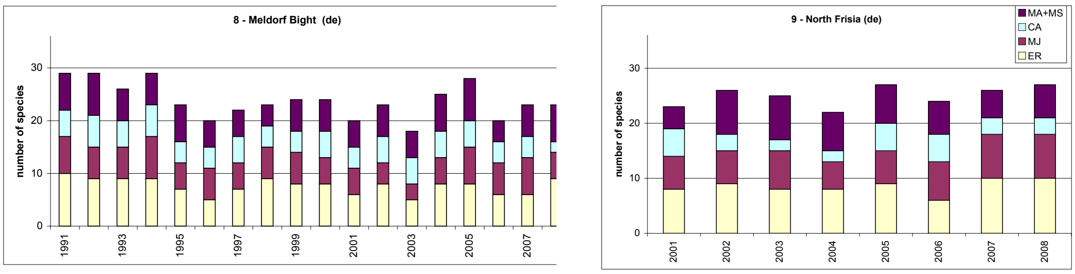


Figure 4: Number of fish species in all catches in August per year and ecological guild, derived from the Schleswig-Holstein stow net monitoring in the Meldorf Bight (left panel) and Hörnum Deep (right panel). Source: SHS.

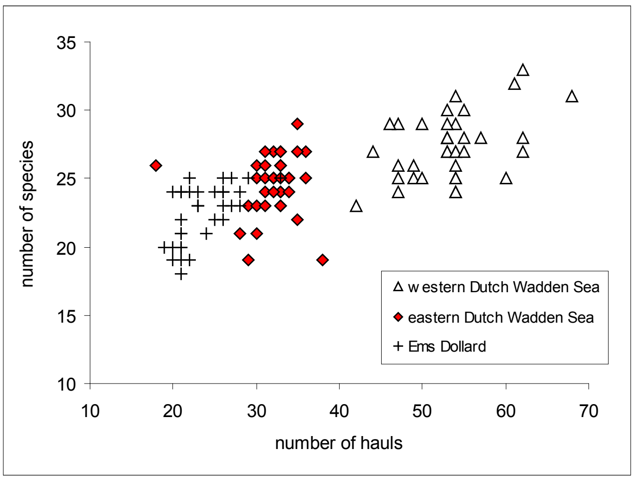


Figure 5: Number of species per year and region in relation to the number of hauls per year and region (Bolle *et al.*, 2009).

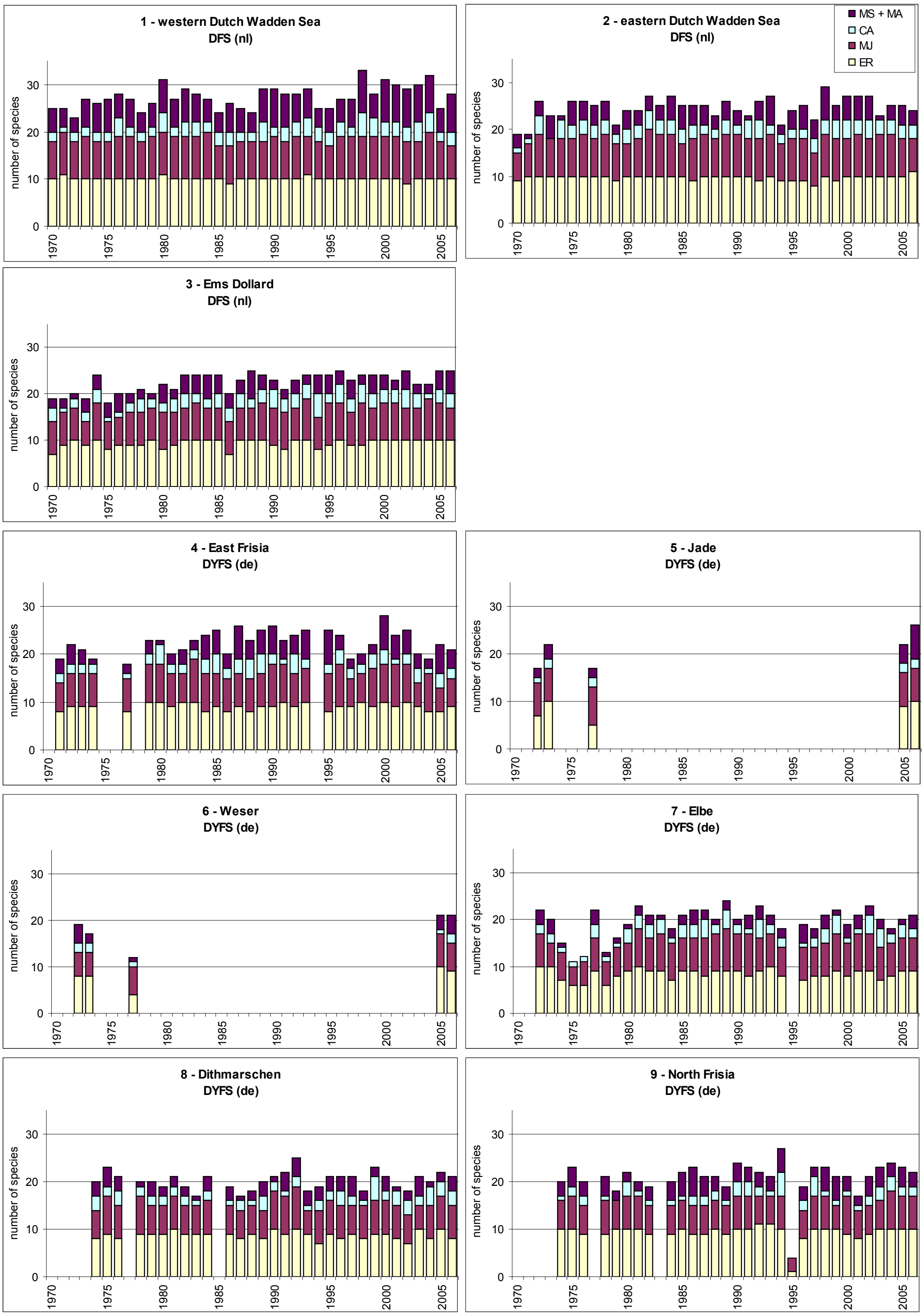


Figure 3: Number of species per year and ecological guild for each region and survey (based on DFS and DYFS; Bolle *et al.*, 2009). DYFS data prior to 1996 are still subject to (ongoing) quality control. ER=estuarine resident, MJ=marine juvenile, CA=catadromous / anadromous, MS/MA=marine seasonal and marine adventitious guild.

explains the differences in species richness between the Dutch QSR-areas (western and eastern Wadden Sea, Ems-Dollard). Species richness thus seems a less suitable metric because it cannot be compared between regions if the number of hauls differs. Furthermore, one should be careful when examining trends in species richness if the number of hauls varies seasonally and between years.

3.3 Trends in abundance of selected Wadden Sea fish species ("priority species")

The selected results of the beam trawl surveys (DFS, DYFS), presented here, are based on the joint analysis which is described and reported in full detail in Bolle *et al.* (2009).

The trends in abundance of 'priority species' are summarized in Table 5 (as in Table 3, ordered by ecological guild). The observed trends differ between species and regions. Overall, more downward than upward trends are observed. A pattern that emerges in several species and regions is an increase in abundance in the 1970s, followed by a decrease during the 1980s or 1990s. During the period covered, an overall increase was shown in the smelt, flounder, herring and sprat. An overall decrease was found in eelpout, plaice, sole, dab, cod and whiting. No significant trends were ob-

Table 5: Summary of trends in abundance of priority fish species by Wadden Sea sub-area, determined by TrendSpotter analysis of the DFS and DYFS (Bolle *et al.*, 2009). The period in which the trend was significant is indicated. Grey color means that there was no sampling. Green indicates a significant increasing trend, red a significant decreasing trend in fish abundance of a species. Explanation of the area codes: 1. Western Dutch Wadden Sea, 2. Eastern Dutch Wadden Sea, 3. Ems-Dollard, 4. East Frisia, 7. Elbe, 8. Dithmarschen, 9. North Frisia. * potential data errors, see text.

Twaite shad	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no significant trend
area 2									no trend
area 3									no trend
area 4									no significant trend
area 7									no significant trend
area 8									no significant trend
area 9									no significant trend

Smelt	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase>decrease *
area 2									no significant trend
area 3									increase>decrease *
area 4									no significant trend
area 7									increase>decrease
area 8									increase
area 9									increase

Flounder	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no trend
area 2									no trend
area 3									increase
area 4									no significant trend
area 7									increase
area 8									increase
area 9									no significant trend

Eelpout	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									decrease
area 2									increase<decrease
area 3									increase<decrease
area 4									increase<decrease
area 7									no significant trend
area 8									increase<decrease
area 9									decrease

Sandeel	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no trend
area 2									no trend
area 3									no trend
area 4									no significant trend
area 7									increase>decrease *
area 8									no trend
area 9									no trend

Plaice	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase=decrease
area 2									increase<decrease
area 3									increase=decrease
area 4									increase=decrease
area 7									no significant trend
area 8									no significant trend
area 9									no significant trend

served in twaite shad and sandeel. Sometimes the trends were only significant during a few years, or more pronounced in one sub-area or period than in another (Table 5).

Some examples are highlighted below by a selection out of the large amount of figures reported in Bolle *et al.*, 2009 from the DFS and DYFS and the SHS (pelagic species). Note that the Y-axes (abundance) of the scatter plots (DFS and DYFS) are on a log-scale.

Twaite shad (*Alosa fallax*)

The catch densities of twaite shad in the demersal surveys are variable and at a low level (Bolle *et al.*, 2009). Significant trends could be detected in none of the Wadden Sea sub-areas (Table 5). The abundances in the sub-areas Ems Dollard (3) and Elbe (7) are shown (Figure 7).

In summer the twaite shad catches in Meldorf Bight/Hörnum Deep mainly consisted of juveniles

Table 5 (continued)

Sole	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									decrease
area 2									decrease
area 3									no significant trend
area 4									increase<decrease
area 7									increase<decrease
area 8									increase<decrease
area 9									decrease

Dab	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									decrease
area 2									decrease
area 3									decrease
area 4									increase<decrease
area 7									decrease
area 8									decrease
area 9									decrease

Cod	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no significant trend
area 2									increase<decrease
area 3									increase<decrease
area 4									increase=decrease
area 7									increase=decrease
area 8									decrease
area 9									decrease

Whiting	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase<decrease
area 2									increase<decrease
area 3									increase<decrease
area 4									increase=decrease
area 7									no significant trend
area 8									no significant trend
area 9									no trend

Herring	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase>decrease
area 2									increase>decrease
area 3									increase>decrease
area 4									increase=decrease
area 7									increase>decrease
area 8									no significant trend
area 9									no significant trend

Sprat	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no significant trend
area 2									increase=decrease
area 3									no significant trend
area 4									increase=decrease
area 7									increase=decrease
area 8									no significant trend
area 9									no significant trend

* potential data errors, see text

Figure 6: Catch density (N/1000 m²) of twaite shad in the Ems-Dollard (left panel) and the Elbe (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

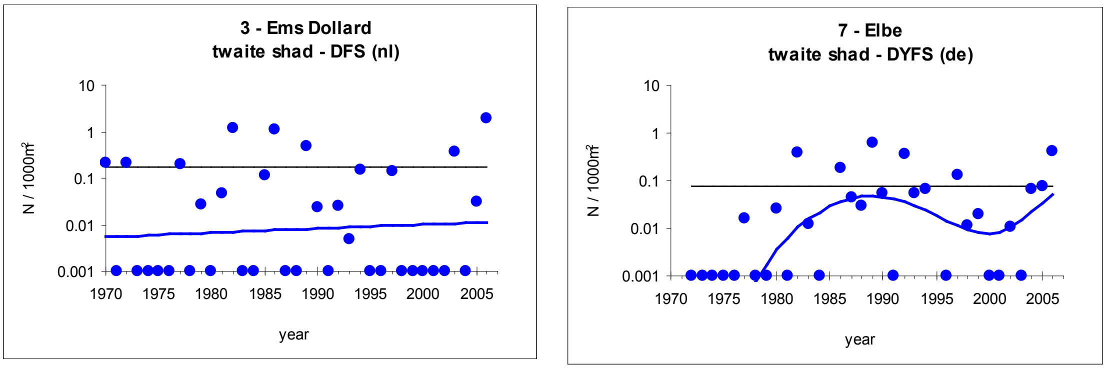
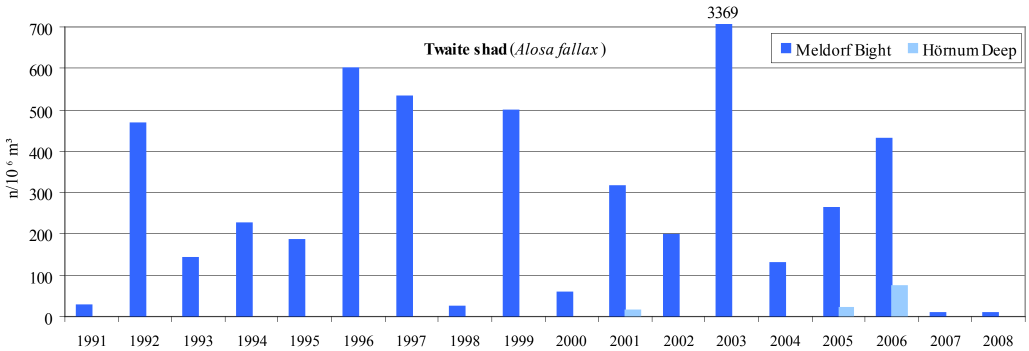


Figure 7: Abundance of twaite shad in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.



of 6-9 cm length, while adults occurred only occasionally in the SHS. Despite its status as a vulnerable Red List species (Berg *et al.*, 1996), twaite shad was regularly caught in the Meldorf Bight showing ups and downs in abundance, whereas catches in the Hörnum Deep were generally low due to the distantly situated estuaries which this species needs for spawning. After extremely high abundances in 2003, in 2007 a remarkable decline became evident in the Schleswig-Holstein area (Figure 7).

Smelt (*Osmerus eperlanus*)

The abundance of smelt in the demersal surveys showed a significant increase between 1970 and the early 1980s in most of the Wadden Sea subareas. In the areas of Dithmarschen and North Frisia, smelt shows a significant increasing trend up to 2007 although catches remain at a low level. The abundance of smelt in Ems-Dollard tends to be declining in recent years, but the trend is not significant. A somewhat similar pattern was observed in the Elbe area (Figure 8).

Smelt abundance showed a decreasing trend between 2001 and 2006 in the Meldorf Bight, but recovered in the last two years (SHS survey). In 2008, the smelt catches in Meldorf Bight were the highest on record (Figure 9). In comparison the catch numbers of the Hörnum Deep are generally on a low but constant level.

Flounder (*Platichthys flesus*)

Flounder showed significant (increasing) trends in abundance only in the Ems-Dollard, Elbe and Dithmarschen areas. The increasing trend in the Ems-Dollard occurred between 1995 and 2005, in the Elbe between 1974 and 1985, whereas the increase in Dithmarschen continues up to date (Table 5). North Frisia showed no significant trend in flounder abundance (Figure 10).

Eelpout (*Zoarces viviparus*)

The abundance of eelpout significantly declined in the Dutch Wadden Sea and part of the German Wadden Sea (Table 5). In the Ems-Dollard and Dithmarschen, among other areas, the numbers of eelpout fluctuated up and down (Figure 11), but the abundance is presently lower than at the beginning of the demersal surveys (1970).

Plaice (*Pleuronectes platessa*)

The abundance of plaice in most of the Wadden Sea sub-areas increased until the mid-1980s and declined thereafter (Table 5). Except for the

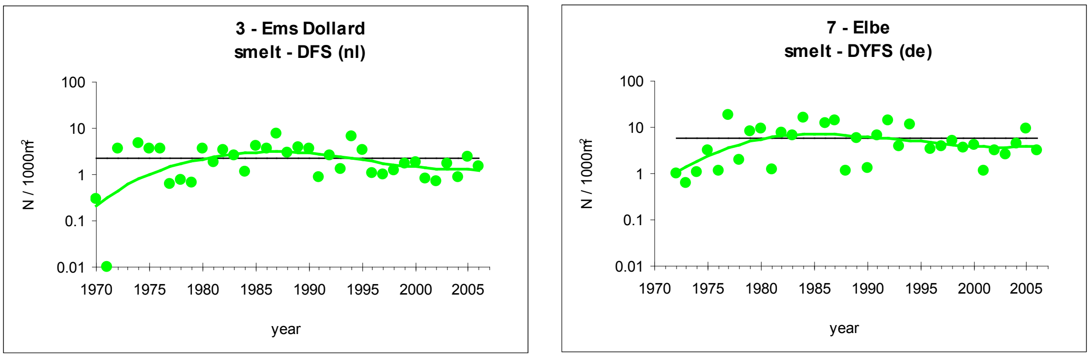


Figure 8: Catch density (N/1000 m²) of smelt in the Ems-Dollard (left panel) and Elbe (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

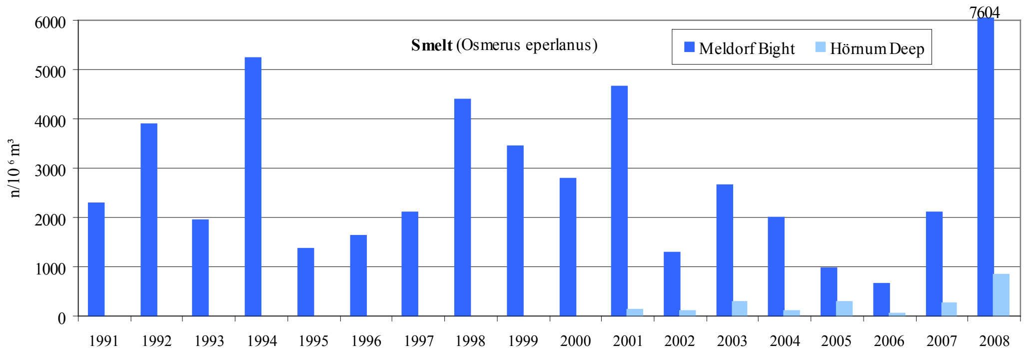


Figure 9: Abundance of smelt in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.

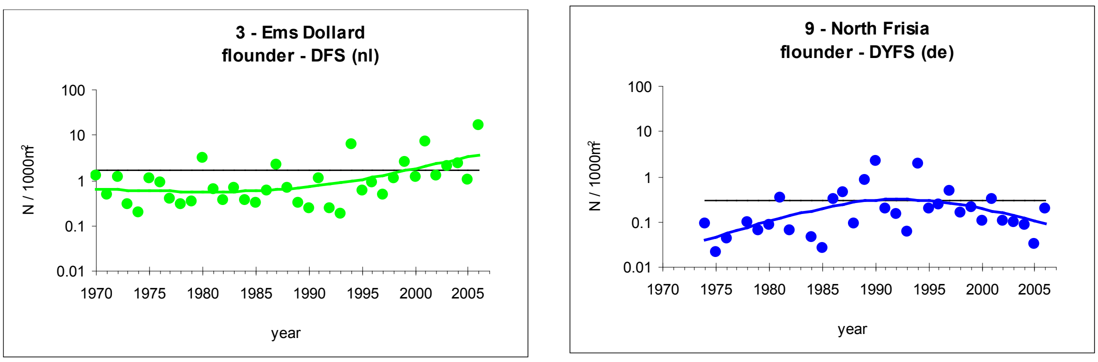


Figure 10: Catch density (N/1000 m²) of flounder in the Ems-Dollard (left panel) and North Frisia (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

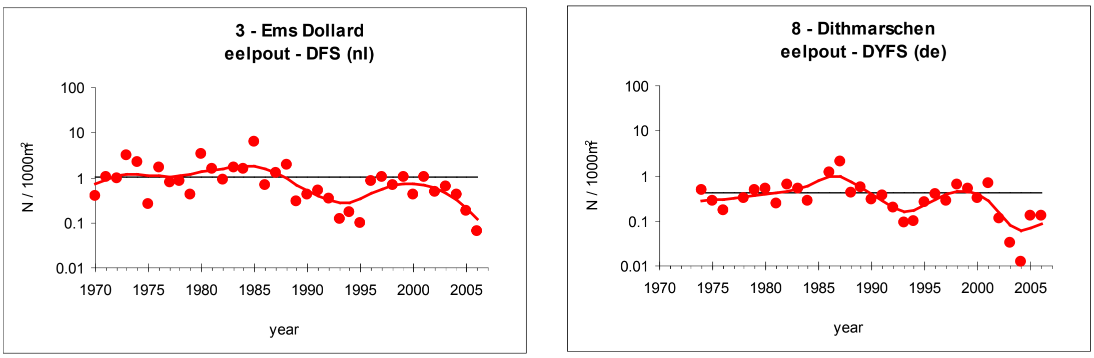


Figure 11: Catch density (N/1000 m²) of eelpout in the Ems-Dollard (left panel) and Dithmarschen (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

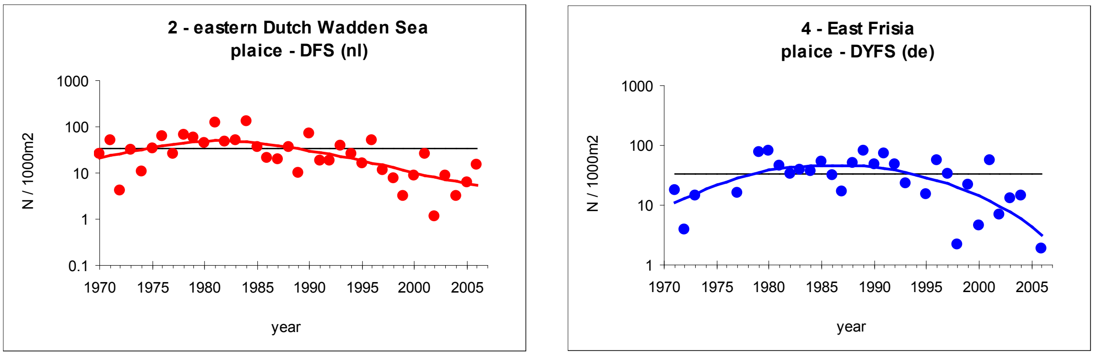


Figure 12: Catch density (N/1000 m²) of plaice in the eastern Dutch Wadden Sea (left panel) and East Frisia (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

eastern Dutch Wadden Sea (Figure 12, left panel), over the whole time series the increase often more or less equalled the decrease (Figure 12, right panel).

Sole (*Solea solea*) and dab (*Limanda limanda*)

Significant negative trends in sole and dab abundance are found in nearly all sub-areas of the Wadden Sea (Table 5). Although the abundance of sole shows considerable variations (Figure 13, left panel), the decrease is dramatic in dab, for example in the area of Dithmarschen (Figure 13, right panel).

Cod (*Gadus morhua*) and whiting (*Merlangius merlangus*)

The abundance of cod increased up to the early 1980s and steadily decreased thereafter (Table 5). In East Frisia, the decrease more or less equalled the previous increase (Figure 14, left panel). In the Dutch Wadden Sea, the whiting abundance significantly decreased (Figure 14, right panel) whereas in other Wadden Sea areas similar trends were not significant (Table 5).

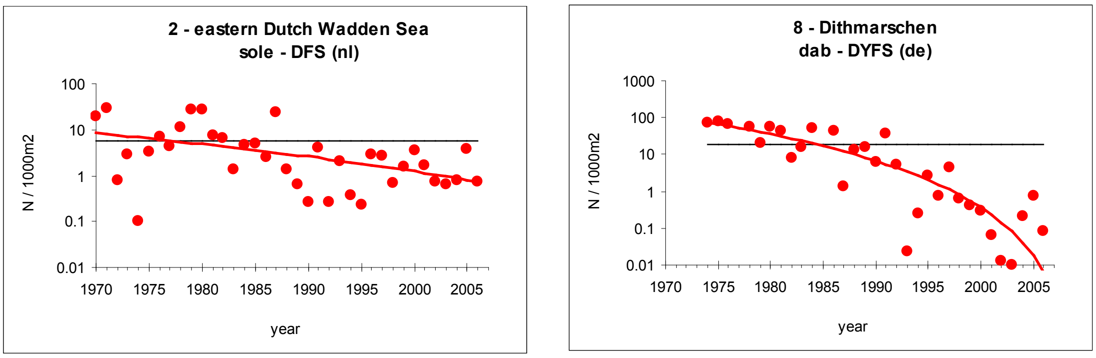


Figure 13: Catch density (N/1000 m²) of sole in the eastern Dutch Wadden Sea (left panel) and dab in Dithmarschen (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

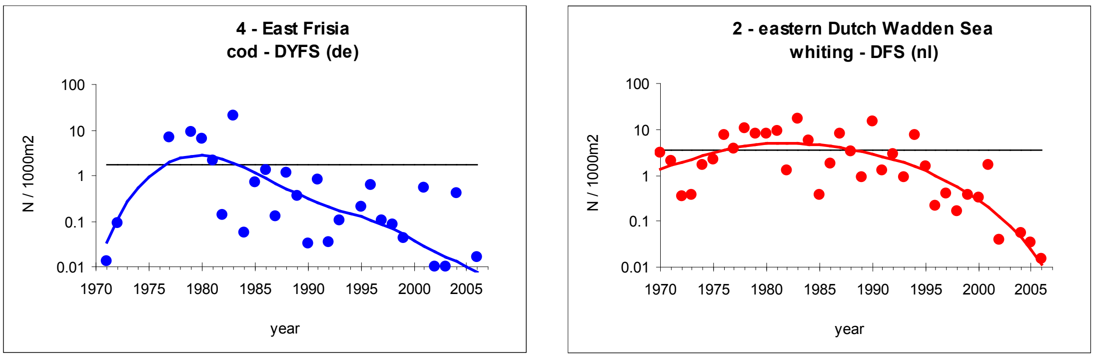


Figure 14: Catch density (N/1000 m²) of cod in East Frisia (left panel) and whiting in the eastern Dutch Wadden Sea (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

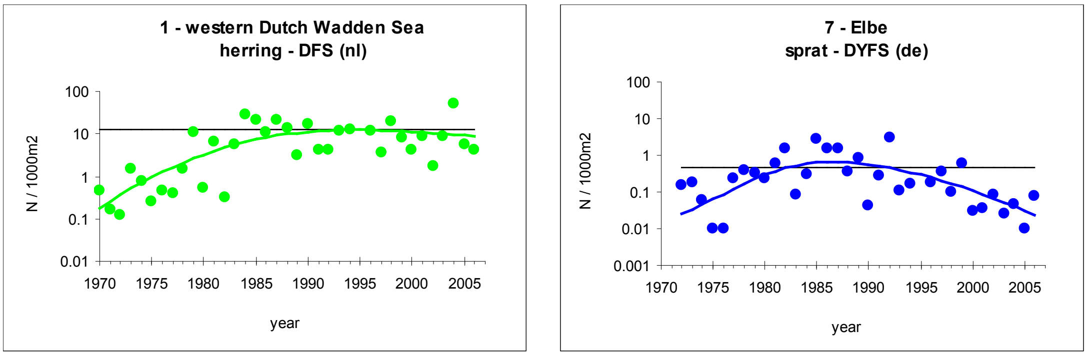


Figure 15: Catch density (N/1000 m²) of herring in the western Dutch Wadden Sea (left panel) and sprat in the Elbe sub-area (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

Herring (*Clupea harengus*) and sprat (*Sprattus sprattus*)

In the demersal surveys, herring showed significantly increasing trends in the 1970 and 1980s. The abundance in the western Wadden Sea recently seems to decrease, but the trend is not significant (Figure 15, left panel). The abundance of sprat showed an increase which was equalled by a decrease (Figure 15, right panel).

Both pelagic species regularly occur in both the Meldorf Bight and the Hörnum Deep and can become extremely abundant in the SHS fish monitoring. Catches are dominated by juveniles of maximum 10 cm length which are known to use the Wadden Sea area as a nursery. While there is no clear trend in abundance for herring (Figure 16), sprat showed a decreasing trend since 2000 in the Meldorf Bight and only occurred in low abundance in the Hörnum Deep since 2003 (Figure 17).

Anchovy (*Engraulis encrasicolus*)

The QSR 2004 reported increasing catches of adult anchovies (*Engraulis encrasicolus*), caught for the first time in the Meldorf Bight during the sampling period of June (1997-2002). Juveniles were found in August in the Hörnum Deep in 2004 and 2005. Since then juveniles seem to have disappeared from this area and anchovy is only sparsely distributed in the Schleswig-Holstein Wadden Sea. No anchovies were caught in 2008 (Figure 18).

River lamprey (*Lampetra fluviatilis*)

During the first monitoring period from 1991-2000, river lampreys in the Meldorf Bight showed strong annual fluctuations in abundance, followed by drastically declining catch rates which have remained low since 2001. Catches in the Hörnum Deep demonstrate the occurrence of this species in the entire Schleswig-Holstein Wadden Sea area (Figure 19).

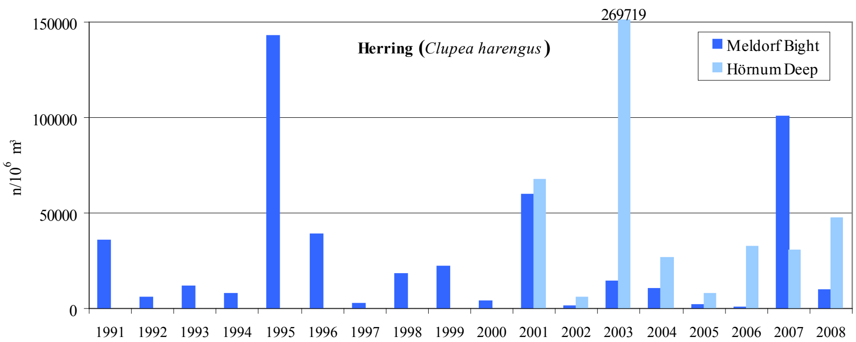


Figure 16: Abundance of herring in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.

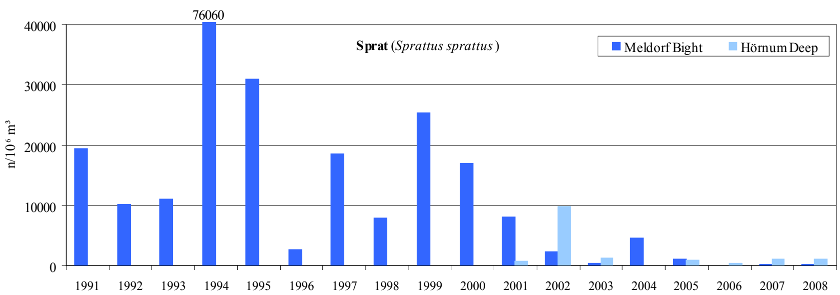


Figure 17: Abundance of sprat (*Sprattus sprattus*) derived from the fish monitoring program in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.

Figure 18: Abundance of anchovy (*Engraulis encrasicolus*) derived from the fish monitoring program in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of the catches in June and August in the Meldorf Bight and in August in the Hörnum Deep. The bars for 2004 and 2005 indicate only the occurrence of post larvae not a calculated value. Source: SHS.

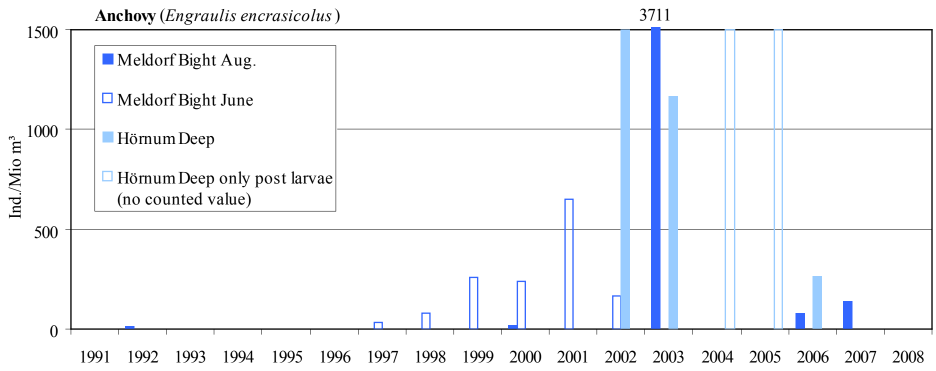
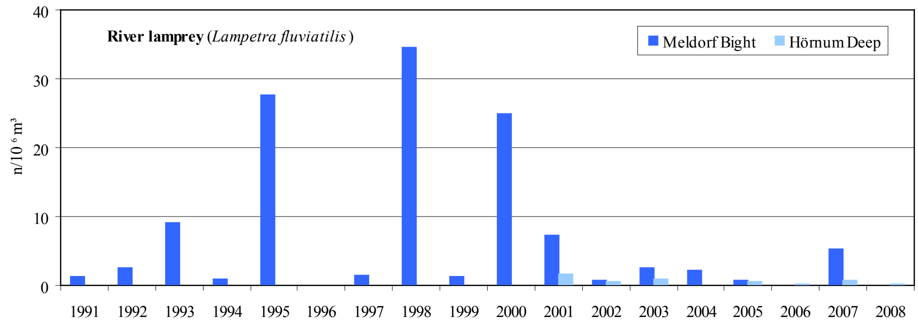


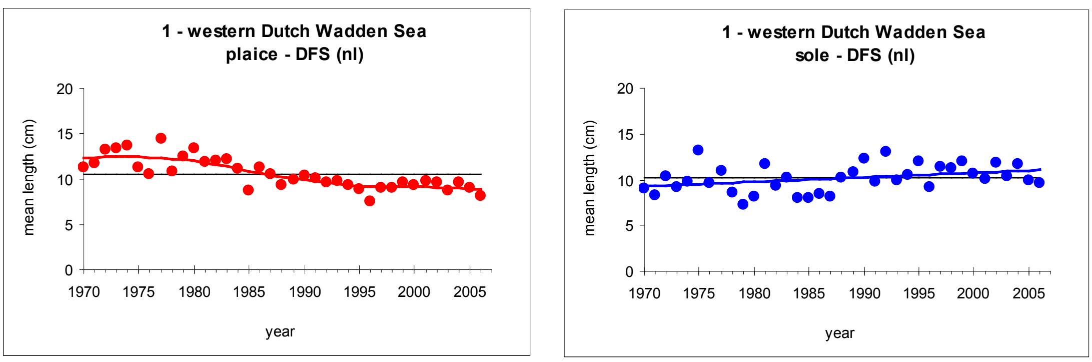
Figure 19: Abundance of river lamprey (*Lampetra fluviatilis*) in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.



3.4 Mean length of fish in the Wadden Sea

The mean length of the plaice population in the western Wadden Sea decreased from approximately 13 cm during the 1970s to about 9 cm in the last decade. The mean length of sole, in contrast, did not show a significant trend but fluctuates around a long-term average of 10 cm (Figure 20; Bolle *et al.*, 2009). Nevertheless, the abundance of sole in the Wadden Sea decreased significantly (see *e.g.* Figure 13) but this apparently involves all length-classes.

Figure 20: Mean length of plaice (left panel) and sole (right panel) in the western Dutch Wadden Sea. Source: DFS (Bolle *et al.*, 2009).



3.5 Status of estuarine fish, biological quality element in WFD transitional waters

Over 121 species (excluding present-day neozoans) were documented for the estuaries of the Wadden Sea, based on historical and recent data (in Bioconsult, 2006a), of which 52 represent typical functional guilds such as diadromous species, estuarine resident species, marine juvenile and marine seasonal migrants. About one third belong to the marine adventitious guild (marine stragglers) and are found in estuaries only occasionally. There is also a number of fresh water species that wander into the transitional waters or that are restricted to the tidally influenced freshwater section of the estuary. Neozoans probably do not play a major role in the Wadden Sea estuaries at the moment; the neozoan Atlantic croaker (*Micropogonias undulatus*) was encountered in the Weser estuary only once in 2004 (Bioconsult, *unpubl.*). Recent studies show that species diversity is still relatively high and shows pronounced spatial and temporal variability. In the stow net monitoring, between 37 (Elbe) and 46 species (Ems) were recorded in 2007, while 40 species were documented for the Weser (Wassergütestelle Elbe, 2007; Bioconsult, 2007; 2008a,b) and 31 species were detected in the Eider in 2006 (Scholle *et al.,* 2007a).

In the period 2000-2007, altogether 68 species were recorded in the Elbe (Wassergütestelle Elbe, 2000-2007).

In 2008 an initial WFD fish-based assessment was conducted on the basis of the defined type-specific reference conditions (species composition, abundance, age structure) and the available, sometimes scanty, database. At the metric level all estuaries show considerable deviations, in some cases of >80%, from the reference situation. For this reason the indexed ecological state is 'poor' for the Ems, Weser and Eider and 'moderate' for the Elbe (Table 7).

In nearly all estuaries considered, the species composition does not differ substantially from the reference. More significant deviations can be noted in the quantitative metrics of abundance and age structure. In the Ems, pronounced deficits are observed for the diadromous species (smelt, twaite shad) that reproduce within the estuary. A more detailed analysis reveals that fewer deficits are indicated for the outer Ems (mesohaline and polyhaline zone) for the twaite shad, which is illustrated by the comparatively high abundance of sub-adult shad in that area. The situation is different in the inner estuary. Successful reproduction evidently does not take place here; this is shown by the very low numbers of adult twaite shad as well as the lack of twaite shad larvae (Bioconsult, 2006b). Substantial deficits are also indicated for smelt; the abundances of all differentiated age groups are very low in comparison to the reference values. Similar to twaite shad, the reasons for the deficits in smelt are found primarily in the upper/middle section of the estuary. Very high concentrations of suspended matter and oxygen

Estuary	Ems	Weser	Elbe	Elbe	Eider
Year of sampling	2007	2007	2007	2000-2007	2006
Estuarine section	ol,me, po	fw, ol, me, po	fw, ol, me, po	fw, ol, me, po	fw/ol, me/po
No. sampling sites	3	4	14	7-14	2
Freshwater sp.	10	7	17	26	10
Diadromous sp.	7	9	8	9	7
Estuarine sp.	11	9	5	11	4
Marine juvenile sp.	11	9	3	9	6
Marine seasonal sp.	5	4	3	7	2
Marine stragglers	2	2	1	6	2

Table 6: Number of fish species in the Wadden Sea estuaries differentiated by ecological guilds on the basis of current catches with stow nets (Source: Wassergütestelle Elbe 2000-2007; Bioconsult 2007; Scholle *et al.,* 2007a). Fw = freshwater section, ol = olighaline section, me = mesohaline section, po = polyhaline section.

Estuary	Data	Species composition	Abundance	Ecological State
Ems*	2007	Moderate-Good	Bad-Poor	Poor
Weser	2007	Moderate	Poor	Poor
Elbe	2005-2007	Moderate-Good	Poor-Moderate	Moderate
Eider	2003/2006	Poor	Poor	Poor

Table 7: Tentative WFD assessment of the Wadden Sea estuaries (transitional water bodies) based on the biological quality element Fish. * = sample assessment by unmodified assessment tool (Bioconsult, 2006a), modifications have taken place for these estuaries (Ems) or are still subject of discussion (Eider).

deficits occurring from early to late summer are in all likelihood major factors here (see Box 2: description and results of concomitant research on the recruitment of smelt in the Ems).

The assessment results presented must still be regarded 'preliminary' for the following reasons:

- The present assessment criteria apply to natural waters, whereas all Wadden Sea estuaries have been classified as 'heavily modified'. This implies that the 'ecological potential' should be assessed, which represents a lower environmental goal than the 'ecological state'. However, it has not been decided yet how to assess the ecological potential.
- The database is not yet fully adequate for the WFD assessment (Ems, Weser, Eider).
- The assessment procedure, based on Weser and Elbe, should be adjusted to Ems and Eider.
- A critical review of the reference conditions and the currently defined class boundaries (especially the boundary between the 'moderate' and 'good' status or potential) is required; it should be based on all WFD monitoring results available up to and including 2009. Depending on the outcome of this analysis, further adjustments will be implemented.

Despite not being a fish, the status of brown shrimp (*Crangon crangon*) in the Wadden Sea is described in Box 3 because shrimps are very important food for fish species, and also a predator on some stages of (juvenile) fish.

4. Discussion

4.1 Assessing the status of Wadden Sea fish

The aim of the joint data analysis was to establish fish metrics that are suitable to describe trends in a comparable way for different sub-areas of the Wadden Sea. A choice for scientifically sound metrics has been made, and the long-term average in these metrics has now been calculated over a time period of >35 years from the demersal fish surveys that are available for the Dutch and German Wadden Sea. The metrics that were analyzed are the species richness and composition by ecological guild, (trends in) species abundance and mean length of selected fish species. These metrics could serve as input to a tool (to be developed) that can be used to describe and/or evaluate the status of the Wadden Sea by its fish fauna.

The joint analysis resulted in a more detailed and robust description of long-term trends in fish species. By applying the TrendSpotter methodology, a more objective way of determining the trends in abundance became available. The spatial resolution is now to the level of QSR sub-areas, giving much more detail than the previous QSR which considered only the Dutch or German Wadden Sea, but this also raises new questions. A next step might be to correlate the relevant parameters (as formulated in hypotheses, based on expert knowledge of the ecology of the species concerned) to fish metrics. For this purpose, an overview of available abiotic data has already been made on a meta-data level (Bolle *et al.,* 2007).

The status of fish in nearly all WFD transitional waters shows moderate to large deviations from the 'undisturbed' situation for natural estuaries. Although species composition is still considered to resemble reference conditions, with the exception of the number of diadromous species, the abundance of typical indicator species is currently at a very low level compared to the situation of the early 20th century.

Focusing on priority species brings the risk of overlooking developments in other fish species. However, it is inevitable to accept that the existing Wadden Sea fish monitoring has its limitations for analyzing trends in the fish fauna. Fortunately, the newly installed WFD monitoring provides additional information for the status of fish in the estuaries, where anthropogenous influence seems to be relatively more determining than natural variations compared to the Wadden Sea.

The selected metrics (species richness, species composition by ecological guild, [trends in] abundance and mean length) are a first step to develop an assessment tool. It was shown that species richness can only be compared between years and areas if monitoring effort is at the same level and constant between years. The species composition (number of species by ecological guild) is not so much dependent on individual species but focuses on the functional aspects of the fish fauna. On the other hand, this metric appears not to be very sensitive to changes that occur in the Wadden Sea. By looking at the parameter of mean length, the distribution shift occurring in some species or specific age-groups may remain concealed. Abundance by age group/length class may be more revealing in this respect.

Although we might like to draw conclusions on the status of the Wadden Sea fish in terms of 'good', 'moderate' or 'poor', from a scientific point of view it is not possible to give such qualifications to the outcome of the analyses due to the present lack of knowledge on the causal factors underlying the changes observed in the Wadden Sea. Many of the selected fish species are influenced to a large extent by natural variations, the causes of the variations are hardly understood, and the level of knowledge is not advanced enough to allow this kind of judgement. Furthermore, (historic) reference conditions are not known; but even if they were, one might ask why it would be desirable to go back to the status of hundred (or even thousand) years before.

These difficulties to define scientifically sound assessment criteria are fuelled by the topicality, because at present we are experiencing a period of rapid climatic changes (which reflect in the fish fauna) and the presence of 'regime shifts' is increasingly substantiated (*e.g.* Weijerman *et al.,* 2005). It will be interesting to monitor how these changes affect the Wadden Sea fish fauna.

4.2 Presence of a typical Wadden Sea fish fauna

To decide if a typical Wadden Sea fish fauna is present (the first target, mentioned in the introduction), the species caught in the fish surveys are compared with the reference species list (Annex 1). In the demersal surveys, 11-33 species were observed, which number could be increased with max. 6 to account for the taxonomic grouping. This is at least 14-43% of the amount of (fairly) common species on the reference species list (Annex 1) within one year and sub-area. The number of species in the SHS (18-29 in the Meldorf Bight, 22-27 in Hörnum Deep) was max. 38% of the (fairly) common species. As stated before, these numbers should not be taken too literally since an increased monitoring intensity would result in higher species numbers, because of the positive correlation between the number of hauls and the number of species. Likewise, the aggregation of regions and years would result in higher species numbers. Species richness and composition (number of species by ecological guilds) stayed more or less the same over the observed time-span, at a more or less constant monitoring effort.

"Typical" of course also refers to specific characteristics that fish species developed to adapt to the highly dynamic Wadden Sea environment. This is expressed in a variety of reproduction strategies (viviparous blenny, pipefish with brood pouch, nest-protection by gobies and bullrout), adaptations to resist strong currents (sucking disk of sea snail and lumpsucker, hooks of hooknose), fish behavior (tidal migration to tidal flats by flatfish and mullets), or by the only seasonal occurrence in the area at the time when conditions are favorable.

4.3 Abundance of fish in the Wadden Sea according to natural dynamics

Priority species

Twaite shad showed a remarkable decline in the Schleswig-Holstein area since 2007, after previous years of higher abundance. Although the Weser and Elbe still sustain twaite shad populations (Bioconsult, 2005; Gerkens and Thiel, 2001), it is questionable whether twaite shad can reproduce successfully in the Ems estuary: the numbers of adults are low, and twaite shad recruitment is very variable (Bioconsult. 2006b). Bottlenecks are found in the upstream parts of the Ems estuary, where unfavourable conditions during summer (oxygen deficits and fluid mud) hamper successful reproduction. This situation also affects the smelt, as was illustrated in Box 2 (Scholle *et al.*, 2007b).

Sandeel is not adequately covered in the D(Y)FS, SHS surveys or the WFD monitoring because it lives buried in the bottom during night. Despite its importance as a food item for sea mammals and birds, which are protected under the Bird and Habitats Directive, no reliable information on the abundance of sandeel in the Wadden Sea area is available. Due to its combined benthic (buried) and pelagic lifestyle, this species requires very specific monitoring which cannot be provided by the current programs.

Herring and sprat are pelagic species, and just like the species mentioned above, they are not sampled well by the demersal surveys. Juvenile herring are found in the Wadden Sea in considerable numbers and their abundance to a large extent reflects the processes that act during the larval phase on the North Sea. Since 2001, poor herring recruitment has been observed for 6 years in a row. Among probable causes are the changes in the hydrography, and a shift in the dominant food items (from *Calanus finmarchicus* to *C. helgolandicus*) (ICES, 2007).

The initial increase in herring abundance during the 1970s and 1980 reflects a period of recovery of the collapsed North Sea herring populations after the closure of the fishery between 1977 and 1983. To understand the trends in juvenile Wadden Sea herring, a good knowledge of the North Sea trends in recruitment and development of the populations is required.

The eelpout showed up and down trends, with a significant net decline over the last 35 years. A recent study on eelpout in the German Wadden Sea showed that thermally limited oxygen delivery in the fish tissues closely matches environmental temperatures beyond which growth performance and abundance decrease (Pörtner and Knust, 2006). The estimated putative upper critical temperature for eelpout is 22.5 °C, a level which was repeatedly exceeded during the summer periods of the 1990s and early 2000s. In the Ems estuary, high exposure to mercury (until 1976) affected the reproduction of eelpout by reduced survival of the fry (Essink, 1989).

For another estuarine resident species, the hooknose *Agonus cataphractus* (not analysed in this report), fluctuations in the abundance were linked to changes in estuarine environmental conditions, particularly temperature, freshwater flow, salinity and the abundance of suitable prey organisms which themselves depend on the maintenance of appropriate estuarine conditions. Patterns of seasonal migration also play an important role in determining fluctuations in estuarine *Agonus* abundance (Power and Attrill, 2002).

Dab and sole showed very pronounced decreases in abundance in most of the sub-areas in the Wadden Sea and a similar trend occurred in I-group plaice (Vorberg *et al.,* 2005), although this was masked in the current analysis by the still abundant presence of 0-group individuals that dominate the catches. The declining trend in I-group plaice abundance is reflected in the decrease in mean length of plaice in the western Wadden Sea (Figure 20).

An offshore shift in the spatial distribution of young plaice appeared to occur in the 1990s, which is attributed primarily to a response to increased summer temperatures. At the same time, a decrease in predation risk and competition in the offshore areas allowed the juvenile plaice to distribute more widely (Van Keeken *et al.*, 2007). The shift in distribution of juvenile plaice was also manifest in the German Wadden Sea. By comparing 1987 to 1991 and 2002 to 2006 abundance data, it could be demonstrated that the distribution of young plaice shifted within the 5 m depth strata towards the deeper as well as from inshore areas towards the further off-shore areas (Schmidt, 2008). This is an indication that throughout the Wadden Sea young plaice have either changed their preference towards deeper and more off-shore areas or that an earlier exodus occurs in that species. Whether it is caused by faster growth and/or differences in environmental conditions needs still to be proven.

Juvenile dab are, unlike plaice, sole or flounder, not confined to coastal nurseries, but can occur over a wide depth-range (Bolle *et al.*, 1994). In autumn, the 0-group migrates inshore and enters the Wadden Sea and estuaries. The catchability of dab fluctuates due to wind stress, temperature and turbidity, although these factors only explain a small proportion of variability in catch numbers (Bolle *et al.*, 2001). Dab catches in the DFS showed an inverse relation with temperature and were also inversely related to secchi-depth (>1 m), although dab density seemed to decrease again at secchi-depths of <1 m (Bolle *et al.*, 2001). Increasing catches in the BTS (beam trawl survey, North Sea) indicate that the decrease in juvenile dab abundance in the Wadden Sea must be the consequence of a distribution shift toward the offshore waters (Bolle *et al.*, 2001). The decrease in abundance of sole concerned all age groups, since the mean length in the demersal surveys remained more or less constant (Figure 20). A dynamic factor analysis (DFA) indicated for the Wadden Sea a best-fit-model with the number of seals and beam trawl intensity as the two dominant environmental variables. In this model, sole showed a significant negative relation with beam trawl effort (Tulp *et al.*, 2008).

The period of increasing trend in cod abundance in the Wadden Sea until the early 1980s reflects the 'gadoid outburst' of the 1960s and 1970s that occurred in the North Sea (Hislop, 1996; Beaugrand *et al.*, 2003). Cod recruitment is affected by overfishing and fluctuations in plankton; the survival of larval cod depends on mean size of its prey, seasonal timing and prey abundance. Beaugrand *et al.* (2003) conclude that rising temperature since the mid-1980s has modified the plankton ecosystem in a way that reduces survival of young cod. It seems therefore likely that the present low abundance of cod in the Wadden Sea is mainly connected with processes acting in the North Sea. Whiting recruitment since 2002 has been below the long-term average probably due to low stock size and environmental factors (ICES, 2008). The abundance of whiting in the Wadden Sea reflects the North Sea recruitment pattern.

Shrimp

Similar to the observed phenomenon in juvenile flatfish, shrimp also seem to have undergone a distribution shift to more offshore, and also to northerly waters. Trends in abundance from the D(Y)FS have not been part of the present analyses; accordingly an important explanatory factor for understanding trends in fish abundance is missing.

Food availability for fish-eating birds

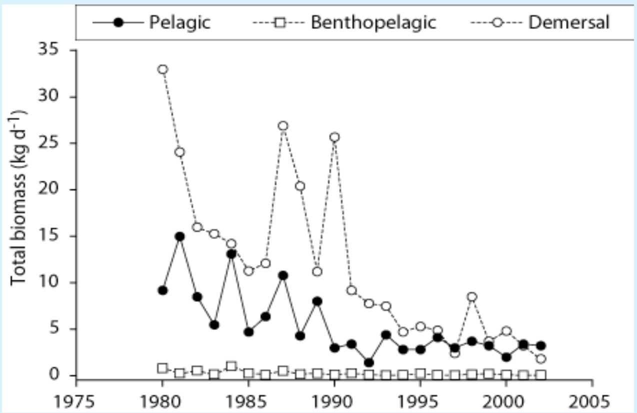
Herring, sprat, sand eel, smelt, as well as whiting (when abundant) and brown shrimp are the preferred food items for common tern (*Sterna hirundo*) and other piscivorous birds, as follows from the research project on fish-eating birds breeding in colonies near Wilhelmshaven and on Minsener Oog (Lower Saxony) (Dänhardt and Becker, 2008; see **Box 1**). In some years food can be limiting, but other factors (predation, summer storms and/or high tides causing drowning of nests and chicks) also determine breeding success. The recruitment index of North Sea herring is not always a good predictor of food availability, because the abundance of herring in the Wadden Sea may deviate due to local conditions (Dänhardt and Becker, 2008). For birds, the availability of fish at a very local scale is relevant. Therefore, specific monitoring is required to determine if food is a limiting factor for fish-eating birds (and marine mammals).

4.4 The status of Wadden Sea fish

The broad decrease in fish abundance and biomass in the Wadden Sea since the 1980s, as evident from the present results and also described by Tulp *et al.* (2008), seems to be confirmed by data from the western Wadden Sea long-term fyke monitoring by the NIOZ (Figure 21, van der Veer, unpublished data).

The diadromous fish currently seem to suffer most from bottlenecks in the upstream parts of (some) estuaries, where water quality and essential habitats are failing, resulting in some species missing and low abundance of the remaining.

Figure 21: Trends in fish biomass (kg d^{-1}) caught in the NIOZ fyke net monitoring in the western Wadden Sea. Source: H.W. van der Veer (unpublished data).



Not only unhindered migration (as formulated in one of the sub-targets for fish) but in addition the availability of suitable spawning habitats and favorable conditions for larval recruitment are essential to maintain vital populations of diadromous fish in the estuaries and in the Wadden Sea. It illustrates that Wadden Sea fish should be evaluated in connection with the estuarine water systems.

Distribution shifts of juvenile flatfish indicate changed conditions in the Wadden Sea nursery, which may have become less favorable due to higher water temperatures during summer. At the same time, the North Sea coastal and offshore area may now offer increased chances of survival due to decreased predation risk and competition since commercial fish stocks are at low levels. Here, a combination of high fishing pressure on the North Sea and regime-shifts in the North Sea and Wadden Sea ecosystems plays a role. The low abundance of cod, whiting, herring and sprat reflect trends in North Sea recruitment to a large extent. Here again, predominant influence of fishery and climatic factors may be responsible for declining abundances. The Wadden Sea fish fauna and, more specific, the abundance of marine juvenile species cannot be seen detached from what is going on in the North Sea. Nevertheless, local conditions in the Wadden Sea may cause abundance patterns that deviate from those in the North Sea.

The estuarine resident species are as usual the least known and understood group, although, of all fish species, they may reflect the status and quality of the Wadden Sea ecosystem to the largest extent.

5. Conclusions and recommendations

5.1 Conclusions

Assessment method

The assessment of fish in estuaries has advanced by the requirements of the WFD, which urged the development of an assessment tool and according (fish) monitoring. For Wadden Sea fish, a first step toward a common assessment and the selection of suitable underlying metrics has been made. However, further effort is needed to end up with an applicable tool. The chosen metrics each have their limitations and need to be further evaluated and adapted if necessary.

Target: Presence of a typical Wadden Sea fish fauna

Concluding, a typical Wadden Sea fish fauna is defined as those species regularly found over the last century. As a reference, the table with (fairly) common species in Annex I is adopted. The term "typical" thus refers to a species composition which has been manifest over a long period (*e.g.* over the last 40 years as documented by the demersal fish surveys, and over the last 18 years as documented by the Schleswig-Holstein pelagic fish monitoring). Monitoring results of only one year can never demonstrate the presence of all species on the reference list.

Nevertheless, it is concluded that nearly all of the typical Wadden Sea species are still present.

Target: Occurrence and abundance of fish species according to the natural dynamics in (a)biotic conditions

The occurrence of fish species seems to be according to the natural dynamics. The recently experienced climatic changes, however, have led to according changes in fish abundance that are sometimes outranging the long-term average and can lead to a regime shift in the ecosystem. The marine juvenile fish species in the Wadden Sea seem to reflect the heavy fishing pressure in the North Sea in combination with the climatic and hydrographic changes. The abundance of several other fish species have decreased to levels below the long-term average, but factors (natural or anthropogenic) causing these changes are still largely unknown.

Sub-target: Unhindered migration between the sea and fresh waters

The present analyses do not allow an assessment of this sub-target. The abundance of smelt in the demersal fish surveys do not (yet) indicate declining trends although the study on smelt (Scholle *et al.*, 2007b) indicates that problems occur in some estuaries. Unhindered migration as such cannot guarantee self-sustained populations of diadromous species; in addition good water quality and availability of spawning habitats are required. There should be no bottlenecks of any kind preventing the completion of the species' life cycle in the different water systems.

Sub-target: Viable stocks and a natural reproduction of typical fish species

This sub-target cannot be assessed by the current analyses; assessment requires concomitant research.

Sub-target: Diversity of habitats and substratum for spawning

Basically, this is not a fish target and it cannot be assessed by the current analyses.

Sub-target: Suitable physical, chemical and morphological conditions with dynamic processes typical for tidal areas

This sub-target, too, has no relation with the metrics that were analysed in the current report.

Sub-target: Suitable feeding ground for all relevant ecological guilds of Wadden Sea fish

This sub-target cannot be assessed by the current analyses; assessment requires concomitant research.

Target on trophic integrity: a natural fish fauna, providing food for sustainable populations of fish-eating birds and mammals

This complex item cannot be assessed from the current analysed metrics or monitoring. Specific research is needed to further improve on our understanding of food availability and other factors determining population levels of birds and marine mammals.

In order to advance our understanding of the Wadden Sea fish fauna we should continue monitoring the occurring changes in the (Wadden Sea) fish fauna in an effective way by making the best use of available surveys and to develop a system by which we can adequately describe trends in a consistent way for future quality status reports.

Concomitant research should provide additional information to increase our fundamental knowledge of the ecology of Wadden Sea fish – a topic which deserves attention and is in need of progress.

5.2 Recommendations

Monitoring

- Comprehensive trilateral monitoring of the Wadden Sea requires expansion of the spatial coverage of the demersal fish surveys to the Danish Wadden Sea.
- The present sampling sites for pelagic fish monitoring should be extended to get reliable information on these species, which are considered as indicators of trophic integrity (food for fish-eating birds and mammals).
- For species showing strong seasonal patterns in abundance, the present monitoring periods must be extended to at least two times a year (with the appropriate seasonal timing).
- The value of new national monitoring programs can be increased by trilateral 'tuning' and harmonization of methods, gear, sampling sites and sampling times.
- Further elaboration of the TMAP Handbook and technical adaptation to integrate the results of the QSR fish report is recommended.

Research

For a better understanding of the observed changes in the fish community,

- More fundamental research on processes (ecosystem level, species level), anthropogenic impacts and climate change is required.
- More knowledge on the dynamics of Wadden Sea fish populations in relation to North Sea and estuarine populations is required.
- The functional relationship (*e.g.* food, shelter) between fish species and habitats (*e.g.* tidal flats, mussel beds, reed beds, salt marshes) should be investigated.
- The international accessibility of data and results from applied research projects (such as EIA studies on fish) should be enhanced.
- Funding for concomitant research on the ecology and changes in abundance of fish remains indispensable to understand trends observed in TMAP fish monitoring.

Management

- For now, include the metrics selected as TMAP parameters in the revised TMAP fish monitoring which should consist of a combination of (multi-method) fish surveys (Table 8).
- The further development and implementation of trilateral targets concerning fish is necessary to structure and focus the TMAP fish monitoring.
- Continue with the initiated development of a suitable and acceptable assessment tool, taking into account the lack of knowledge on reference conditions and cause-effects-relationships.
- Effective management of Wadden Sea fish cannot be achieved without tuning with North Sea and estuarine management.

Trilateral policy

- Involve Denmark in the trilateral (in practice bilateral) work of the TMAP fish expert group.
- Consider the most appropriate way and enable the continuation of the fruitful and stimulating cooperation on the joint analyses of fish monitoring data.

Table 8: Parameters of the revised TMAP for monitoring and assessment of targets on fish (TMAP Handbook 2008)

TMAP parameters	Monitoring	Remarks	Legal obligations
• species richness, • representation of ecological guilds, • distribution and abundance of species in the Wadden Sea; • length distribution of selected species	Existing beam trawl surveys for demersal fish (IMARES, vTI), stow net surveys for pelagic fish (SHS survey) and the NIOZ fyke monitoring in the western Wadden Sea.	Wadden Sea fish index under discussion (*cf* WFD fish index transitional waters).	None at present, but potential contribution to HD assessment
• species composition • abundance of type-specific fish species in transitional waters; • length distribution of twaite shad and smelt	WFD stow net monitoring on 3-4 stations in Ems, Weser, Elbe, Eider	Guidelines developed for WFD monitoring and integration of monitoring results; Assessment tool to judge the status of the water body based on the fish fauna	Obligatory under WFD

Box 1: Seabird - fish interaction

Seabird-Fish interactions in the Lower Saxon Wadden Sea

(Dänhardt and Becker, 2008)

Common tern (*Sterna hirundo*) in the Wadden Sea have synchronized their breeding phenology with the seasonal occurrence of their prey fish. Herring (*Clupea harengus*), sprat (*Sprattus sprattus*), sandeel (*Ammodytes spec.*) and smelt (*Osmerus eperlanus*) are the preferred food items, while whiting (*Merlangius merlangus*) and cod (*Gadus morhua*) are also utilised extensively in years of mass occurrence (Becker *et al.*, 2001; Fresemann, 2008). Since 2002, the tern's breeding success was below average, possibly caused by poor food supply. Despite the key role fish play in the Wadden Sea food web, distribution patterns and abundance dynamics, especially of pelagic species, are only fragmentarily documented, presumably because fish is only recently considered in species and habitat protection concepts.

Between 2005 and 2007 fish was sampled from the cooling water system of a power plant in Wilhelmshaven and with a vertically resolving stow net near two of the most important German tern breeding colony sites at Banter See (BS) in Wilhelmshaven and on Minsener Oog (MO) in the National Park Lower Saxon Wadden Sea, where courtship and chick feedings were observed in synchrony with the fish sampling. Data on the breeding biology of the tern were collected using standard techniques (Wagener, 1998).

Among the 59 fish and 14 invertebrate species found, only a few were utilised as prey by the tern. Within the three years of investigation, the main prey species, herring, was most abundant in 2007 (Table 9).

Fish abundance peaked in early summer, corresponding well with the greatest food demand within the terns' breeding season. The composition of courtship (co) and chick (ch) prey as well as the fish samples differed between BS and MO: Clupeids were the most important tern prey on MO (co: 36-58%, ch: 72%). Other prey items were sandeel (co: 11-19%), brown shrimp (*Crangon crangon*, co: 7%) and in 2007 gadoids (presumably whiting, as inferred from the stow net catches, co: 12-37%, ch: 15%). Pipefish (*Syngnathus spec.*) were fed neither to partners nor to chicks by the common terns on MO, while at BS, together with brown shrimp, it made up 5-12% of courtship and chick prey. In 2007, 12% of the chicks' diet at BS consisted of gadoids. In addition to clupeids (co: 6-26%, ch: 26-33%), smelt was extensively fed (co: 24-63%, ch: 16-18%). This anadromous fish is hardly available more offshore (*e.g.* MO), but seems to considerably improve the food supply for avian piscivores breeding further inshore (*e.g.* BS, Neufelderkoog, Eidersperrwerk, Dänhardt and Markones, *unpubl.*).

In 2006, herring abundance in the Jade bay and the daily mean water temperature were positively correlated up to the beginning of June (Spearman rank correlation, r_s = 0.63, p<0.003), thereafter the correlation was negative (r_s = -0.52, p<0.006), culminating in the sudden disappearance of this main prey species in the 3rd quarter of July, possibly due to water temperatures exceeding 23°C. The common terns at BS replaced herring with 0-group twaite shad (*Alosa fallax*) that immigrated into the study area around the same time, as revealed by length comparisons between stow net catches and feeding observations. Despite this switch to a presumably equivalent prey alternative, chick growth rates were temporarily reduced.

Year	2005	2006	2007
Fish abundance per 10 000 m³			
mean ± SD (number of hauls)			
Herring catches stow net Jade bay	-	18 ± 19 (31)^{7}	73 ± 108 (38)^{6}
Herring catches stow net Minsener Oog	-	299 ± 712 (30)^{7}	1570 ± 3518 (24)^{6}
Herring catches cooling water intake	13 ± 26 (84)	6 ± 16 (101)	4 ± 9 (33)
Common tern breeding parameters			
(main breeding period May 1st – June 9th)			
Mean egg laying date (pentad)	29.3 ± 1.4 (455)^{7}	29.1 ± 1.9 (442)^{7}	28.2 ± 1.7 (411)^{5,6}
Clutch size (no. of eggs per clutch)	2.5 ± 0.7 (455)^{6,7}	2.3 ± 0.7 (442)^{5,7}	2.6 ± 0.6 (411)^{5,6}
Fledglings per breeding pair	0.16 ± 0.41 (455)^{6,7}	0.57 ± 0.61 (442)^{6,7}	0.45 ± 0.60 (411)^{5,6}
Weight gain (g per day, age 3–13 days)	6.8 ± 1.6 (31)^{6}	5.3 ± 2.2 (76)^{5,7}	7.2 ± 1.6 (93)^{6}
Maximum chick weight (g)	121 ± 8 (72)^{7}	121 ± 10 (272)^{7}	128 ± 10 (222)^{5,6}
Weight at fledging (g)	112 ± 9 (72)^{7}	113 ± 11 (272)^{7}	117 ± 11 (222)^{5,6}

Table 9: Fish abundance and breeding parameters obtained from the common tern colony at Banter See, Wilhelmshaven. In 2005, owl predation and in 2007 a storm flood reduced breeding success. Except for the herring catches in the cooling water intake, all differences between years were highly significant (ANOVA, GLM, χ^2-, K-W-Tests, p < 0,001). Differences are marked by the respective year: ^{5}, ^{6}, ^{7} = 2005, 2006, 2007.

In 2007, gadoids comprised up to 15% of prey fed to chicks, being attributed to a mass invasion of whiting. Together with the high abundance of herring, whiting was part of an excess food supply for the tern chicks that were observed to reject high quality prey items at the Banter See colony (Braasch, A., *pers. comm.*). Exceptional events such as the disappearance of a main prey species or the mass occurrence of another can prove either catastrophic or beneficial for the terns' reproductive performance, depending on available prey alternatives and baseline food supply, respectively.

Fish were usually located in midwater and were consequently out of reach of the terns, which are confined to prey near the surface by their plunge-diving foraging mode. Within a tidal cycle, pelagic prey was fed in highest proportions around high water, while benthic prey became more abundant during receding tide and low water. Prey diversity increased towards sub-maximal water coverage, presumably due to a greater diversity of foraging habitats. Factors determining the accessibility of prey include hydrographic phenomena (*e.g.* turbulence, upwelling, fronts), bottom topography (*e.g.* submerged sand banks, tidal pools, shorelines) or subsurface foragers chasing fish to the surface (Camphuysen and Webb, 1999). The terns' ability to use these diverse foraging conditions and thus exploit a wide variety of prey sources may explain the rather poor accordance of species proportions between the feeding observations and the stow net catches. Furthermore, direct observations of foraging terns showed that profitable prey was brought to chicks more often (clupeids: 14-28%, smelt: 50%, gadoids: 37%, gobies: 17-50%) than less favourable items (brown shrimp and pipefish 0%, respectively). These individual decisions about which prey type would be consumed directly by the forager or brought to the colony (where prey items would eventually be recorded by the human observer) may have been another source of mismatch of species percentages, yet indicate that the more unprofitable the prey that arrives at the nest, the worse is the food situation.

A storm flood in 2007 and predation in 2005 (BS) and 2006 (MO) reduced the number of fledged chicks per breeding pair, resulting in below average breeding success (Frick and Becker, 1995; Becker, 1998). According to other reproduction parameters (Table 9), feeding conditions in 2007 were superior to those of the previous two years: egg laying, hatching and fledging occurred earliest, average clutch size, weight gain, maximum and fledging weight of chicks was highest in 2007. Additionally, body mass values of chicks in 2005 and 2006 were among the lowest within 25 years, whereas 2007 was well above the long-term average. Only the storm flood at the end of June prevented an above average breeding success in 2007 (Table 9).

Together with the food supply, meteorological extremes and predation are the main determinants of breeding success, which integrates all environmental variables affecting adults, eggs and chicks over the whole breeding season, and may thus be only of limited use to draw inferences about the food availability, compared to a combination of more specific reproduction parameters (Table 9).

Box 2: Smelt recruitment in the Ems

Smelt recruitment in the Ems in relation to water quality

(Scholle *et al.*, 2007b)

The smelt (*Osmerus eperlanus*) is a diadromous species. Spawning grounds are situated upstream in the rivers (upstream of the tidal limit) whereas the estuary is used as a nursery and the adults overwinter in open sea. Smelt is sensitive to water quality (mainly dissolved oxygen, high concentrations of suspended matter). In the Water Framework Directive (WFD), smelt was chosen as one of the indicator species of transitional waters. The presence of the species contributes to the index on species composition, whereas the abundance of smelt (0-group, sub-adult and adult) is considered relevant for the index on abundance (Kranenbarg and Jager, 2008). There were indications that the abundance of smelt may have declined in the Ems since the 1990s (Jager and Kranenbarg, 2004), for which the following hypotheses were formulated:

- the reproduction of the smelt is hampered by changes in hydromorphology which caused a decrease in natural spawning habitats and a decline of the spawning conditions;
- low oxygen concentrations and high turbidity enhance larval mortality. Under these conditions, lower abundances of smelt larvae and juveniles can be expected.

The hypotheses were tested by carrying out a pilot study during 2007 in the Ems estuary.

To identify the spatial and temporal distribution of smelt larvae in the Lower Ems, samples were taken along a longitudinal transect in the Lower Ems (Emden-Weener) and also in the tributary Leda using a Bongo net on seven different dates from the end of April to mid June 2007. In addition, samples were taken at a station 7 km downstream of Herbrum and a station 2 km upstream of the Herbrum weir. Details on the methods and nets used are given in Scholle *et al.* (2007b). Abiotic parameters were obtained from NLWKN (data of 6 locations in the Unterems, 2000-2007) or measurements taken during the survey (Scholle *et al.*, 2007b). Additional information on the smelt population was obtained from sampling with stow net (also called anchor net) in the Ems estuary at different locations between 3 May and 22 June 2007. Data on smelt landings were obtained from the State Fisheries office of Lower Saxony (Germany) and from Jaarboeken Visserij (1947-1965, Dutch fisheries data). Anecdotal information from fishermen was collected to find out where spawning locations of smelt were and are situated in the Ems.

The river discharge in 2007 followed the regular seasonal pattern of high discharges of up to 300 $m^3 s^{-1}$ in winter/early spring and significantly lower values (<100 $m^3 s^{-1}$) starting in May. Winter discharges were relatively high in 2007, compared to 2006, whereas from mid April to mid June 2007, river discharges corresponded to those of an average year. Water temperatures were relatively high, especially in the winter months when water temperature was mostly above 5 °C, except for two short periods at the end of January and beginning of February 2007. Average January temperature was 2.6 °C above the average of the last 8 years. From April onwards, temperatures were comparable to the long-term average (15-20 °C). At the tidal freshwater location (Weener) daily and seasonal fluctuation ranges of <0.3 and 0.9 psu were measured, and average salinity varied between 0.3 and 1 psu. At Terborg (oligohaline zone) much higher variation in salinity occurred, both on a daily and seasonal scale. Salinity varied between <0.5 and 11 psu. Data of suspended matter were available for the tidal freshwater location of Leer. As early as January extremely high concentrations of suspended matter (10 g l^{-1}) were recorded, followed by a significant decline until mid March (values ranging between <0,3-1,5 g l^{-1}). Thereafter, suspended matter concentrations increased again, reaching maximum values up to 25 g l^{-1}. Suspended matter concentrations were highest during phases of low river discharge and were related to the tidal phase. Oxygen concentrations dropped lower at Weener, the more upstream of the two, than at Terborg. From April on they dropped below 5 mg l^{-1}. After a brief 'recovery' at the beginning of May, a phase of extreme oxygen depletion (around 1 mg l^{-1}) occurred between mid May and mid June both at Terborg and Weener, although again more pronounced at Weener. A tidal influence was apparent in the oxygen fluctuations, with lowest values during low tides.

Between the end of April and the beginning of June no smelt larvae were detected in the Bongo net catches between Herbrum and Emden. The stow net catches demonstrated the absence of 0-group smelt between May and the end of June in the Ems estuary. The majority of the smelt catches consisted of subadult individuals (7-10 cm length). However, the more downstream the catch was made, the more adult smelt were observed in the catches. The highest numbers of smelt were caught in the meso-polyhaline section of the estuary.

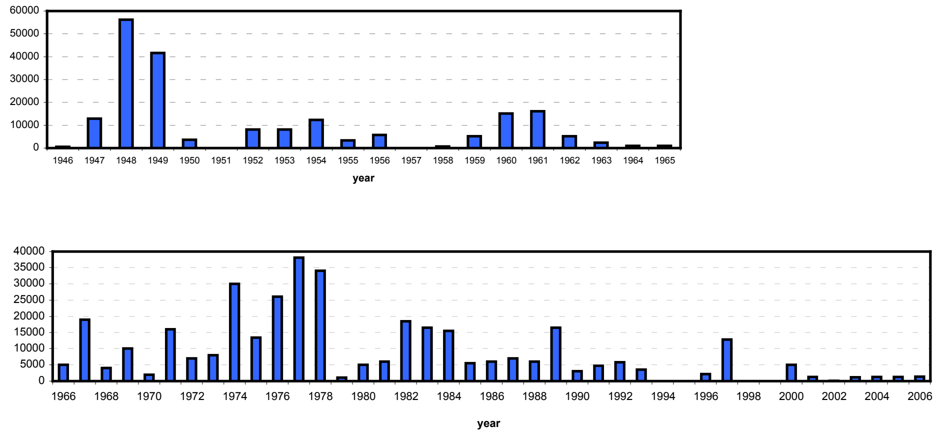


Figure 22: Landings of smelt from commercial fishery in the Ems estuary (kg yr^{-1}). Top panel: Dutch landings (Jaarboeken Visserij); bottom panel: German landings (Staatliches Fischereiamt Bremerhaven).

The historical Dutch landings of smelt in the Ems Dollard comprise the period 1946-1965 (Figure 22). Low landings around 1945 are assumed to result from low fishing effort due to World War II. During the following years, landings increased strongly and decreased again in the 1950s. Since then, no Dutch landings have been recorded from the Dollard, probably because the (smelt) fishery was no longer profitable in this area. The German catch statistics commence in 1966 and indicate substantial annual fluctuations as well as an overall decline in the catches, which commenced already in 1979. Landings dropped to about 1,000 kg yr^{-1} since the year 2000.

According to the five fishermen who were interviewed, the spawning locations of smelt are located between Oldersum (between Petkum and Terborg) and Papenburg, and maybe also in the tributary Leda. However, the location of the spawning grounds of smelt in the Ems could not be identified in this study. Based on comparisons with the Elbe and Weser, the spawning locations could be situated across the entire tide-influenced freshwater section or even upstream of the Herbrum weir. This includes the tributary Leda as a spawning site. Therefore, the statements of the local fishermen seem plausible.

Wherever the exact spawning locations in the Ems may be, they coincide with the zone that is presently suffering poor water quality. There also seems to be a lack of suitable spawning habitat in this stretch of the Ems, since the fairway has been canalised and the riverbed is covered with silt and fluid mud (Haberman, 2006). Successive deepenings of the upper Ems caused hydromorphological changes which led to this drastic increase in the concentrations of suspended matter in the water column and the occurrence of 'fluid mud' on the channel bottom. These changes are most pronounced in the tide-influenced freshwater section between Herbrum and Leer. The concentrations of suspended matter may reach levels above 5 g l^{-1} near the surface, which is two orders of magnitude above those in the Elbe/Weser (Bioconsult, 2007). The suspended matter is imported from the sea, due to so-called 'tidal pumping'. In the zone where freshwater and seawater mix, the sediments settle on the bottom during slack tides and move back and forth on the tidal currents because they are not consolidated.

Thiel et al. (1994) showed for the Elbe that low smelt biomasses and low oxygen concentrations were correlated to each other. Möller and Scholz (1991) pointed out that pronounced oxygen deficits may lead to a complete absence of smelt recruitment. While adult fish are able to avoid these unfavourable situations, this is not possible for eggs and early larvae. The significance of oxygen as a factor for anadromous migratory species was recently underlined by various authors (e.g. Turnpenny et al., 2004, 2005, 2006; Maes et al., 2007). Whereas Maes et al., 2007 regard an O_2 concentration of 5 mg l^{-1} as a minimum for anadromous migratory species, lower limit values are proposed by Turnpenny et al. (2006) below which substantial impairment of the estuarine fish fauna can be expected. At the same time the authors differentiate according to different standards. The 'one-week standard', for example, was defined as 4 mg l^{-1} (1-year return period, >29 tides) and was selected to ensure protection against chronic effects; these would include depression of growth and avoidance of hypoxic areas. The lowest standard (1.5 mg l^{-1}) was included to ensure protection from mass mortalities. The very pronounced summer oxygen deficits in the Ems since 2000 are clearly outside the fish tolerance ranges specified for estuaries (e.g. Turnpenny et al., 2006) (Figure 23).

No smelt larvae were detected between Emden and Herbrum in the period 23 April-11 June. Although reproduction may have occurred early, due to the high winter water temperatures, smelt larvae were present at the same time in the neighbouring lower Weser where numerous smelt larvae were verified in May 2007 (Bioconsult, unpublished data). It is thus likely that reproduction in the Ems was not successful or took place only to a small extent, if at all. The absence of 0-group smelt in the stow net/anchor net catches in May-June 2007 may partly have been caused by gear selectivity. In this type of net, 0-group smelt can be caught effectively from the beginning of August, depending on the mesh size (Kleef and Jager, 2002).

Catches of the commercial fishery should always be interpreted with caution, because fishing effort and market prices may influence the landings. However, the 'Jaarboeken Visserij' describe that the decrease in the Dutch landings during the 1950s were the consequence of deteriorating water quality, caused by the discharge of organically polluted waste water from the potato industry in autumn in those years. Fishery was no longer profitable and finally ceased in the 1960s. In the 1990s, the waste water sanitation has been completed for this industrial activity and its discharges no longer cause oxygen deficits in the Dollard. Nowadays, there is practically no commercial fishery left in the Dutch part of the Ems-Dollard and the origin of the landings is no longer documented. In contrast to the low numbers of smelt in the Ems, recent smelt population data from the other North Sea estuaries do not indicate an extensive decline in smelt stocks in the coastal area of the Wadden Sea or in the other estuaries, that could account for the low numbers of smelt in the Ems. Substantial differences between the Ems and the Weser, Elbe and Eider estuaries, rather indicate the involvement of Ems-related problems. The initial hypotheses were thus supported by the present findings.

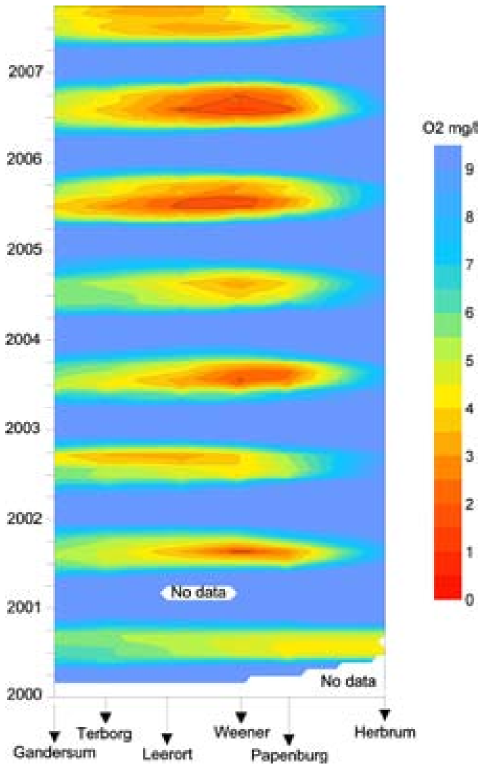


Figure 23: Spatio-temporal plot of the Ems estuary (between Herbrum Km -12.7, and Gandersum Km 35. Papenburg is situated at Km 0). Avoidance levels (<4 mg l^{-1}) are indicated in orange grades with a grey contour line, mortality levels for fish (<2 mg.l^{-1}) are indicated in red with a black contour line (source: data NLWKN).

Box 3: Status of shrimps

Status of shrimp (*Crangon crangon*) in the Wadden Sea

The stocks of brown shrimp have been monitored by the Demersal Young Fish and Brown Shrimp Surveys (DYFS) in the Wadden Sea and coastal waters since 1970. Though these surveys - being confined to a fixed survey area - show a declining trend in shrimp abundance, the yield of the fisheries on the species remained high. Increasing landings peaked in 2005, exceeding 38,000 tonnes of marketable shrimp from the North Sea. There was obviously no danger of over-fishing in the recent years.

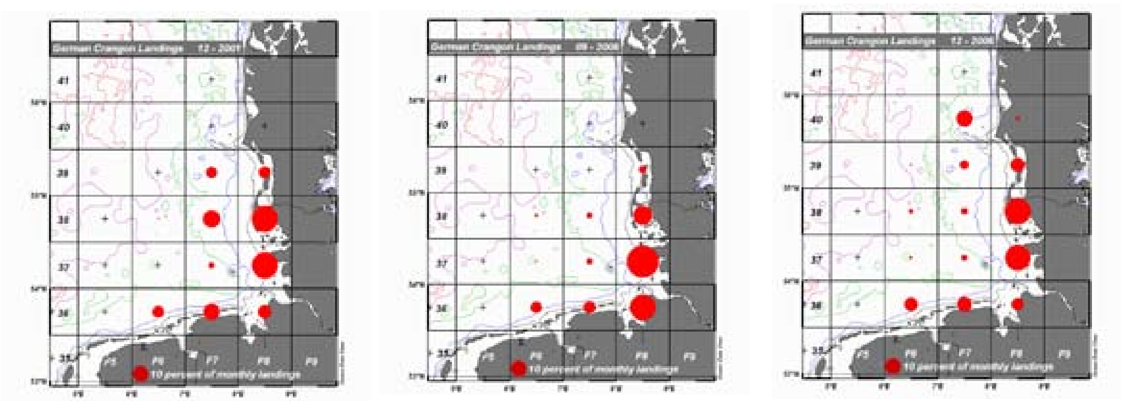
The observed decline in shrimp abundance in the Wadden Sea may be caused by a distributional shift towards deeper and more offshore waters, as well as towards a more northern distribution outside the survey areas. This can also be concluded from fishery patterns. The shrimp fleets have shifted their fishing areas towards deeper and more northerly, even northern Danish waters, according to log-book data (Figure 24). They followed the changed shrimp distribution which might be an effect of climate change, a hypothesis which still needs to be investigated, as the opposite geographical shift has been reported in earlier decades.

The increase in landings could also be an effect of increased effort, as especially Dutch and Danish vessels increased their shrimp fishing capacity due to reduced fishing possibilities in other fishery sections. Nevertheless, landings per unit of effort (LPUE) in shrimping showed an increasing trend as well until 2006, indicating high and viable shrimp stocks, which probably benefited from reduced predation by cod. Even the high whiting presence in some years and areas led only to some smaller drawbacks of landings, instead of a collapse of the fishery which occurred in former decades.

A study on the effect of environmental factors on shrimp landings showed clear correlations (ICES 2006b). The decision to rely on landings without standardizing by effort was dictated by the absence of a consistent effort series. The study identified, as climatic factors, the North Altantic Oscillation (NAO) winter index plus the sea surface temperature (SST) in winter as significantly influencing the level of shrimp landings in the subsequent autumn and spring fishing seasons. Most likely this works through enhanced recruitment of larvae into the tidal nursery area. Predation has a significant influence in years with extreme gadoid (recently particularly whiting) invasions into the shrimp distribution area and feeding on pre-recruits, but there is no signal from about-average levels of predator abundance.

The statistical model built on these relationships performs best for the years 1980–1997. Extending the year range to 1950–2002 weakens the significance, but does not destroy the relationship (Neudecker, unpublished data). The earlier years were the phase of technical development, where most of the stock distribution area became accessible to the fishery, as opposed to the predominantly inshore fishing in the early years after World War II. Also, Dutch and Danish fleets were developing during that time. This went along with rising landings of consumption shrimp. With the year 1998, a regime of voluntary catch restrictions came into force which affected the assumed relationship between stock abundance and landings. This regime was lifted in 2003, but model-based predictions of landings for the years thereafter were only of varying quality probably due to the variations in effort and predation. It seems wise to incorporate data, since recent years available from the EU logbook system, for these parameters into the model algorithm to improve future stock assessment and catch predictions.

Figure 24: Comparison of log book data of fishing areas of the German fleet by ICES rectangle: Winter situation 2001 and 2006 showing the northern directed shift of fishing activity (A and C) and the seasonal shift from summer to winter activity in 2006 (B and C).



A: Landings (%) in December 2001 B: Landings (%) in September 2006 C: Landings (%) in December 2006

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Annex 1: Reference species list of fish

Fish species found in the Wadden Sea since 1960 (* Fresh water species). Table 1: Common and fairly common species; Table 2: (Extremely) rare species.
Surveys in which the species were encountered: a. DYFS, b. DFS, c. Stow net Schleswig-Holstein, d. Stow net Lower-Saxony, e. Stow net Elbe, f. Witte & Zijlstra (1978), g. Atlas Schleswig-Holstein, h. Red List Germany (Fricke et al., 1994). N= number of counts in a-h as an indication of occurrence: N≥3 (fairly) common; N<3 (extremely) rare.

Table 1: Common and fairly common fish species in the Wadden Sea (for explanation see text).

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Abramis brama *	Carp Bream	Brasse	Brasem	Brasen	x				x	x			3
Agonus cataphractus	Hooknose	Steinpicker	Harnasmannetje	Almindelig panserulk	x	x	x	x	x	x	x	x	8
Alosa alosa	Allis Shad	Maifisch	Elft	Majsild		x	x	x		x		x	5
Alosa fallax	Twaite Shad	Finte	Fint	Stavsild	x		x	x	x	x	x	x	7
Ammodytes marinus	Lesser Sandeel	Kleiner Sandaal	Noorse Zandspiering	Havtobis	x	x	x	x		x	x	x	7
Anguilla anguilla	Eel	Aal	Aal	Europæisk ål	x	x	x	x	x	x	x	x	8
Aphia minuta	Transparent Goby	Glasgrundel	Glasgrondel	Glaskutling		x	x	x		x	x	x	6
Arnoglossus laterna	Scaldfish	Lammzunge	Schurftvis	Almindelig tungehvarre	x	x		x	x	x		x	6
Atherina presbyter	Sand-smelt	Ährenfisch	Koornaarvis	Almindelig stribefisk	x	x	x	x		x	x	x	7
Belone belone	Garfish	Hornhecht	Geep	Almindelig hornfisk	x	x	x	x		x	x	x	7
Buglossidium luteum	Solenette	Zwergzunge	Dwergtong	Glastunge	x	x		x		x	x	x	6
Callionymus lyra	Dragonet	gestreifter Leierfisch	Pitvis	Stribet Fløjfisk	x	x	x		x	x	x	x	7
Chelon labrosus	Thick-lipped Mullet	Dicklippige Meeräsche	Diklipharder	Tyklæbet multe	x	x	x		x	x	x	x	7
Ciliata mustela	Five-bearded Rockling	Fünfbärtelige Seequappe	Vijfdradige Meun	Femtrådet havkvabbe	x	x	x	x	x	x	x	x	8
Clupea harengus	Herring	Hering	Haring	Atlantisk sild	x	x	x	x	x	x	x	x	8
Coregonus oxyrinchus	Houting	Nordseeschnäpel	Houting	Snæbel					x	x	x	x	4
Cyclopterus lumpus	Lumpsucker	Seehase	Snotolf	Almindelig stenbider	x	x	x	x		x	x	x	7
Dasyatis pastinaca	Common Stingray	Stechrochen	Pijlstaartrog	Europæisk pigrokke		x				x		x	3
Dicentrarchus labrax	Sea Bass	Wolfsbarsch	Zeebaars	Havbars	x	x		x	x	x		x	6
Echiichthys vipera	Lesser Weever	Vipernqueise	Kleine Pieterman	Lille Fjæsing	x	x		x		x		x	5
Enchelyopus cimbrius	Four-bearded Rockling	Vierbärtelige Seequappe	Vierdradige Meun	Firtrådet havkvabbe		x				x	x	x	4
Engraulis encrasicolus	Anchovy	Sardelle	Ansjovis	Europæisk ansjos	x	x	x	x	x	x	x	x	8
Entelurus aequoreus	Snake Pipefish	Große Schlangennadel	Adderzeenaald	Snippe	x	x	x	x	x	x	x	x	8
Eutrigla gurnadus	Grey Gurnard	Grauer Knurrhahn	Grauwe Poon	Grå knurhane	x	x	x	x	x	x	x	x	8
Gadus morhua	Cod	Kabeljau	Kabeljauw	Almindelig torsk	x	x	x	x	x	x	x	x	8
Gaidropsarus vulgaris	Three-bearded Rockling	Dreibärtelige Seequappe	Driedradige Meun	Tretrådet havkvabbe	x	x	x			x		x	5
Galeorhinus galeus	Tope Shark	Hundshai	Ruwe Haai	Almindelig gråhaj			x			x	x	x	4
Gasterosteus aculeatus	Stickleback	Dreistacheliger Stichling	Driedoornige Stekelbaars	Trepigget hundestejle	x	x	x	x	x	x	x	x	8
Glyptocephalus cynoglossus	Witch	Hundszunge	Witje	Skærising	x						x	x	3
Gymnocephalus cernuus *	Ruffe	Kaulbarsch	Pos	Nøgentobis	x	x			x				3
Hippoglossoides platessoides	American Plaice	Doggerscharbe	Lange Schar	Håising	x			x				x	3
Hyperoplus lanceolatus	Great Sandeel	Gefleckter Großer Sandaal	Smelt	Plettet tobiskonge	x	x	x	x	x	x	x	x	8
Lampetra fluviatilis	River Lamprey	Flußneunauge	Rivierprik	Almindelig flodlampret	x	x	x	x	x	x	x	x	8
Limanda limanda	Dab	Kliesche	Schar	Ising	x	x	x	x		x	x	x	7
Liparis liparis	Sea Snail	Großer Scheibenbauch	Slakdolf	Finnebræmmet Ringbug	x	x	x	x	x	x	x	x	8
Liparis montagui	Montagu's Sea Snail	Kleiner Scheibenbauch	Montagu's Slakdolf	Særfinnet Ringbug	x		x	x	x		x	x	6
Maurolicus muelleri	Pearlsides	Lachshering	Lichtend Sprotje	Laksesild					x	x	x	x	4
Merlangius merlangus	Whiting	Wittling	Wijting	Hvilling	x	x	x	x	x	x	x	x	8

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Merluccius merluccius	European Hake	Seehecht	Heek	Europæisk kulmule	x					x		x	3
Micromesistius poutassou	Blue Whiting	Blauer Wittling	Blauwe Wijting	Blåhvilling			x			x		x	3
Microstomus kitt	Lemon Sole	Limande, Rotzunge	Tongschar	Rødtunge	x	x	x	x		x	x	x	7
Mullus surmelutus	Surmullet	Streifenbarbe	Mul	Stribet mulle	x	x	x	x		x	x	x	7
Myoxocephalus scorpius	Bull Rout	Seeskorpion	Zeedonderpad	Almindelig ulk	x	x	x	x	x	x	x	x	8
Osmerus eperlanus	Smelt	Stint	Spiering	Europæisk smelt	x	x	x	x	x	x	x	x	8
Petromyzon marinus	Sea Lamprey	Meerneunauge	Zeeprik	Havlampret		x		x	x	x	x	x	6
Pholis gunellus	Butterfish	Butterfisch	Botervis	Tangspræl	x	x	x	x		x	x	x	7
Platichthys flesus	Flounder	Flunder	Bot	Skrubbe	x	x	x	x	x	x	x	x	8
Pleuronectes platessa	Plaice	Scholle	Schol	Rødspætte	x	x	x	x	x	x	x	x	8
Pollachius pollachius	Pollack	Pollack	Pollak	Lubbe		x				x		x	3
Pollachius virens	Saithe	Seelachs	Koolvis	Gråsej	x	x				x	x	x	5
Pomatoschistus lozanoi	Lozano's Goby	Lozanos Grundel	Lozano's Grondel	Lozanos kutling		x				x		x	3
Pomatoschistus microps	Common Goby	Strandgrundel	Brakwatergrondel	Lerkutling	x		x	x	x	x	x	x	7
Pomatoschistus minutus	Sand Goby	Sandgrundel	Dikkopje	Sandkutling	x		x		x	x	x	x	6
Pomatoschistus pictus	Painted Goby	Fleckengrundel	Kleurige Grondel	Spættet kutling					x	x	x		3
Psetta maxima	Turbot	Steinbutt	Tarbot	Pighvarre	x	x	x	x	x	x	x	x	8
Pungitius pungitius *	Ninespine Stickleback	Zwergstichling	Tiendoornige stekelbaars	Nipigget hundestejle	x			x			x	x	4
Salmo salar	Salmon	Lachs	Zalm	Atlanterhavslaks	x		x		x	x	x	x	6
Salmo trutta	Sea Trout	Meerforelle	Zeeforel	Almindelig ørred	x		x		x	x	x	x	6
Sardina pilchardus	Sardine	Sardine	Sardien	Almindelig sardin	x	x		x	x	x	x	x	7
Scomber scombrus	Mackerel	Atlantische Makrele	Makreel	Makrel	x	x	x	x		x	x	x	7
Scophthalmus rhombus	Brill	Glattbutt	Griet	Europæisk slethvarre	x	x	x	x	x	x	x	x	8
Solea solea	Sole	Seezunge	Tong	Almindelig tunge	x	x	x	x	x	x	x	x	8
Spinachia spinachia	Sea Stickleback	Seestichling	Zeestekelbaars	Tangsnarre	x					x	x	x	4
Sprattus sprattus	Sprat	Sprotte	Sprot	Europæisk brisling	x	x	x	x	x	x	x	x	8
Stizostedion lucioperca	Pike Perch	Zander	Snoekbaars	Sandart	x	x			x			x	4
Syngnathus acus	Great Pipefish	Große Seenadel	Grote Zeenaald	Stor Tangnål		x	x	x	x	x	x	x	7
Syngnathus rostellatus	Nilsson's Pipefish	Kleine Seenadel	Kleine Zeenaald	Lille Tangnål	x	x	x	x	x	x	x	x	8
Syngnathus typhle	Deep-snouted Pipefish	Grasnadel	Trompetterzeenaald	Almindelig tangnål				x		x		x	3
Taurulus bubalis	Long-spined Sea Scorpion	Seebull	Groene Zeedonderpad	Langtornet Ulk				x		x	x	x	4
Trachinus draco	Greater Weaver	Petermännchen	Grote Pieterman	Almindelig fjæsing	x					x		x	3
Trachurus trachurus	Horse Mackerel	Stöcker	Horsmakreel	Almindelig hestemakrel	x	x	x	x	x	x	x	x	8
Trigla lucerna	Tub Gurnard	Roter Knurrhahn	Rode Poon	Rød knurhane	x	x	x	x	x	x	x	x	8
Trisopterus esmarki	Norway Pout	Stintdorsch	Kever	Calypso	x						x	x	3
Trisopterus luscus	Bib	Franzosendorsch	Steenbolk	Skægtorsk	x	x	x			x	x	x	6
Trisopterus minutus	Poor Cod	Zwergdorsch	Dwergbolk	Glyse	x	x				x	x	x	5
Zoarces viviparus	Eelpout	Aalmutter	Puitaal	Almindelig ålekvabbe	x	x	x	x	x	x	x	x	8

Table 1: (Extremely) rare fish species in the Wadden Sea (for explanation see text).

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Acipenser sturio	Sturgeon	Stör	Steur	Almindelig stør						x		x	2
Alburnus alburnus *	Bleak	Ukelei	Alver	Almindelig løje					x				1
Alopias vulpinus	Thresher	Fuchshai	Voshaai	Almindelig rævehaj						x			1
Ammodytes tobianus	Small Sandeel	Tobiasfisch	Zandspiering	Kysttobis						x		x	2
Anarhichas denticulatus	Northern Wolffish	Blauer Seewolf	Blauwe Zeewolf	Blå havkat								x	1
Anarhichas lupus	Wolf-fish	(Gestreifter) Seewolf	Gewone Zeewolf	Almindelig havkat						x			1
Argyrosomus regius	Meagre	Umberfisch	Ombervis	Almindelig ørnefisk								x	1
Aspitrigla cuculus	Red Gurnard	Seekuckuck	Engelse Poon	Tværstribet knurhane						x		x	2
Aspius aspius *	Asp	Rapfen	Roofblei	Asp					x				1
Atherina boyeri	Big-scale Sand Smelt	Kleiner Ährenfisch	Kleine Koornaarvis	Lille Stribefisk						x		x	2
Balistes carolinensis	Trigger-Fish	Grauer Drückerfisch	Trekkervis	Almindelig aftrækkerfisk						x			1
Barbus barbus *	Barbel	Barbe	Barbeel	Barbe					x				1
Blicca bjoerkna *	White Bream	Güster	Kolblei	Flire	x				x				2
Boops boops	Bogue	Gelbstrieme	Bokvis	Okseøjefisk						x		x	2
Brama brama	Ray's Bream	Brachsenmakrele	Braam	Almindelig havbrasen						x		x	2
Callionymus maculatus	Spotted Dragonet	gefleckter Leierfisch	Rasterpitvis	Plettet Fløjfisk	x						x		2
Callionymus reticulatus	Reticulated Dragonet	Ornament-Leierfisch	Gevlektepitvis	Kortfinnet fløjfisk	x					x			2
Carassius carassius *	Crucian Carp	Karausche	Kroeskarper	Karusse				x					1
Cetorhinus maximus	Basking Shark	Riesenhai	Reuzenhaai	Brugde						x			1
Cheilopogon heterurus	Atlantic Flying-Fish	Fliegender Fisch	Noordse Vliegende Vis	Almindelig flyvefisk								x	1
Conger conger	Conger Eel	Meeraal	Congeraal	Almindelig havål						x		x	2
Crystallogobius linearis	Crystal Goby	Kristallgrundel	Kristalgrondel	Krystalkutling								x	1
Ctenolabrus rupestris	Goldsinny	Klippenbarsch	Kliplipvis	Havkarusse					x	x			2
Cynoglossus browni	Nigerian tonguesole	Hundszunge	Nigeriaanse Hondstong	Nigeriansk hundetunge								x	1
*Cyprinus carpio**	Carp	Karpfen	Karper	Karpe					x				1
Dentex maroccanus	Morocco Dentex	Marokkanische Zahnbrasse	Rode Tandbrasem	Marokkansk havrude								x	1
Gaidropsarus mediterranaeus	Shore Rockling	Mittelmeer-Seequappe	Zuidelijke Meun	Middelhavshavkvabbe					x		x		2
Galeus melastomus	Blackmouth Catshark	Fleckhai	Spaanse Hondshaai	Ringhaj								x	1
Gobiusculus flavescens	Two-spotted Goby	Schnappgrundel	Blonde Grondel	Toplettet kutling								x	1
Hexanchus griseus	Bluntnose Sixgill Shark	Grauhai	Grauwe Haai	Almindelig seksgællet haj								x	1
Hippocampus hippocampus	Sea-Horse	Seepferdchen	Zeepaardje	Søhest						x			1
Hyperoplus immaculatus	Greater Sand-Eel	Ungefleckter Großer Sandaal	Effen Smelt	Uplettet tobiskonge								x	1
Labrus bergylta	Balan Wrasse	Gefleckter Lippfisch	Gevlekte Lipvis	Berggylte						x			1
Lamna nasus	Porbeagle	Heringshai	Neushaai	Almindelig sildehaj						x			1
Leucaspius delineatus *	Sunbleak	Moderlieschen	Vetje	Regnløje					x				1
Leuciscus idus *	Ide	Orfe	Winde	Almindelig Rimte					x				1
Lipophrys pholis	Shanny	Schan	Slijmvis	Tangkvabbe						x		x	2

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Liza aurata	Golden Grey Mullet	Goldmeeräsche	Goudharder	Guldmulte						x		x	2
Liza ramada	Thin-lipped Grey Mullet	Dünnlippige Meeräsche	Dunlipharder	Multe						x		x	2
Lophius piscatorius	Angler	Seeteufel	Zeeduivel	Europæisk havtaske						x			1
Melanogrammus aeglefinus	Haddock	Schellfisch	Schelvis	Kuller						x		x	2
Mola mola	Sunfish	Mondfisch	Maanvis	Almindelig klumpfisk						x		x	2
Molva molva	Ling	Leng	Leng	Almindelig lange							x		1
Mullus barbatus	Red Mullet	Rote Meerbarbe	Gewone Zeebarbeel	Rød mulle								x	1
Mustelus mustelus	Smooth Hound	Glatthai	Gladde Haai	Almindelig glathaj						x			1
Nerophis lumbriciformis	Worm Pipefish	Krummschnauzige Schlangennadel	Kleine Wormzeenaald	Stor næbsnog								x	1
Onchorhynchus mykiss	Rainbow Trout	Regenbogenforelle	Regenboogforel	Kamchatka-ørred					x				1
Pagellus acarne	Axillary Seabream	Achselfleckbrasse	Spaanse Zeebrasem	Akarnaisk blankesten								x	1
Pagellus bogaraveo	Blackspotted Seabream	Graubarsch	Rode Zeebrasem	Almindelig blankesten								x	1
Pagellus erythrinus	Common Pandora	Rotbrasse	Gewone Zeebrasem	Rød blankesten								x	1
Parablennius gattorugine	Tompot Blenny	Gestreifter Schleimfisch	Gehoornde Slijmvis	Stribet slimfisk						x		x	2
Perca fluviatilis *	European Perch	Flussbarsch	Baars	Europæisk aborre		x				x			2
Phrynorhombus norvegicus	Norwegian topknot	Norwegischer Zwergbutt	Dwergbot	Småhvarre								x	1
Pterycombus brama	Atlantic Fanfish	Silberbrassen	Zilverbraam	Sølvbrasen								x	1
Raja clavata	Thornback	Nagelrochen	Stekelrog	Sømrokke						x		x	2
Raniceps raninus	Tadpole-Fish	Froschdorsch	Vorskwab	Sortvels				x		x			2
Remora remora	Common Remora	Ansauger	Remora	Almindelig sugefisk								x	1
Rutilus rutilus *	Roach	Rotauge	Blankvoorn	Almindelig Skalle		x			x				2
Scomber japonicus	Chub Mackerel	Mittelmeermakrele	Spaanse Makreel	Spansk makrel								x	1
Scomberesox saurus	Skipper	Makrelenhecht	Makreelgeep	Almindelig makrelgedde					x				1
Scyliorhinus caniculus	Lesser spotted Dogfish	Kleingefleckter Katzenhai	Hondshaai	Småplettet rødhaj						x		x	2
Scyliorhinus stellaris	Greater spotted Dogfish	Großgefleckter Katzenhai	Kathaai	Storplettet rødhaj								x	1
Sebastes marinus	Redfish	Rotbarsch	Roodbaars	Stor rødfisk						x			1
Serranus cabrilla	Comber	Sägebarsch	Zaagbaars	Lille Rødfisk								x	1
Spondyliosoma cantharus	Black Sea Bream	Streifenbrasse	Zeekarper	Almindelig havrude						x			1
Squalus acanthias	Spur-Dog	Dornhai	Doornhaai	Almindelig pighaj						x			1
Squatina squatina	Monkfish	Meerengel	Zeeengel	Europæisk havengel						x		x	2
Symphodus melops	Corkwing	Goldmaid	Zwartooglipvis	Almindelig savgylte						x			1
Taractes asper	Rough pomfret	Kleine Brachsenmakrele	Hoogvinbraam	Højfinnet havbrasen								x	1
Taractichthys longipinnis	Bigscale Pomfret	Langflossen-Brachsenmakrele	(Langvinbraam)	Langfinnet havbrasen								x	1
Trachinotus ovatus	Derbio	Gabelmakrele	Gaffelmakreel	Almindelig gaffelmakrel								x	1
Xiphias gladius	Sword-Fish	Schwertfisch	Zwaardvis	Sværdfisk						x			1
Zeugopterus punctatus	Topknot	Haarbutt	Gevlekte Griet	Hårhvarre						x		x	2
Zeus faber	Dory	Heringskönig	Zonnevis	Sanktpetersfisk						x			1