Trends in Wadden Sea Fish Fauna

Part I: Trilateral Cooperation

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Summary

The shallow waters of the Wadden Sea and the connected estuaries and coastal waters provide indispensable habitats for a whole range of fish species in the course of their life-cycle. These areas provide spawning, feeding and nursery grounds and serve as transit route for diadromous species migrating between marine and fresh water habitats. Environmental changes (e.g. climate change) and anthropogenic pressures (e.g. fisheries) will likely result in changes in the abundance and species composition of the fish fauna in the Wadden Sea.

Data from the Demersal Fish Survey (IMARES, The Netherlands), the Demersal Young Fish Survey (von Thünen Institute, Germany) and the Schleswig-Holstein Survey (Marine Science Service & National Park Agency, Germany) were used to examine trends in fish fauna. Fourteen species were selected based their occurrence in these surveys and several selection criteria including their relevance for management. Trends in species richness, species composition (in terms of functional guilds), abundance and mean length were examined. The abundance time series were analysed for each species, survey and Wadden Sea subarea (as defined within the context of the Wadden Sea Quality Status reports) using TrendSpotter, a univariate non-linear method for estimating and detecting flexible trends.

The temporal trends in abundance varied widely among individual species and also varied between areas for a single species. Often the trends were only significant during a few years, or more pronounced in one area or period than in another. Overall more downward trends than upward trends were observed. Comparison of present (2006) catch rates with those at the beginning of the survey period showed an overall increase in the abundance of smelt, flounder and herring, an overall decrease in the abundance of eelpout, plaice, sole, dab, cod, whiting and river lamprey, and no significant changes for twaite shad, sandeel, sprat, anchovy. A pattern that emerged in several species and regions is an increase in abundance in the 1970s and early 1980s followed by a decline. Almost all marine juvenile and marine seasonal species showed a decline in abundance since approximately 1985, but this negative trend was not always significant. The trends differed among species for the estuarine residents and diadromous species.

An overview of fish monitoring programs carried out in the Wadden Sea revealed 2 mayor limitations. Firstly, the spatial coverage of surveys targeting pelagic species is limited. Secondly, the seasonal coverage of the beam trawl surveys is limited. Improved spatial and seasonal coverage will provide more insight in the dynamics of fish populations in the Wadden Sea.

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1 Introduction

The shallow waters of the Wadden Sea and the connected estuaries and coastal waters provide indispensable habitats for a whole range of fish species in the course of their life-cycle. These areas provide spawning, feeding and nursery grounds and serve as transit route for diadromous species migrating between marine and fresh water habitats (Zijlstra 1978, Elliott & Hemingway 2002, Elliott et al. 2007). Fish play an important role in the Wadden Sea ecosystem. They form a mayor component of the total biomass and they are in the middle of the food chain; they feed on zooplankton and benthos and are eaten by birds, mammals and predatory fish.

The Wadden Sea is a dynamic environment characterized by pronounced salinity gradients and temperature fluctuations related to tidal water movements. There is a close relationship between the Wadden Sea and the estuaries (Ems, Weser, Elbe, Eider) due to the exchange of substances and organisms, which is reflected in the fish fauna. At the same time the Wadden Sea is also connected with and influenced by the North Sea: marine juvenile and marine seasonal species, which spend the later part of their life or part of the year in the North Sea, form an important constituent of the Wadden Sea fish fauna.

The Wadden Sea and its tributary estuaries are subject to substantial anthropogenic pressures, such as shrimp fishery and mussel cultures, dredging and the disposal of dredged material, coastal protection and flood defence, and the direct or diffuse input of substances from industry and agriculture (Lozán et al. 1994, Essink et al. 2005). The North Sea is also subject to human demands, e.g. fisheries, shipping, oil and gas mining, sand and gravel extraction, and the rapidly expanding construction and exploitation of wind farms. These human pressures exerted in the Wadden Sea proper or adjacent areas may directly or indirectly affect the Wadden Sea fish fauna. Intermingled with these localised anthropogenic pressures, large-scale environmental changes (man-induced or not) may play an important role in determining the abundance and distribution of many fish species. Recently, an increasing number of publications suggest a relationship between fish populations and climate change, through correlations with the North Atlantic Oscillation (NAO; Attrill & Power 2002, Henderson & Seaby 2005) or due to the effects of increasing water temperatures (Genner et al. 2003, Pörtner & Knust 2007, van Keeken et al. 2007, van Hal et al. 2009).

1.1 Trilateral Cooperation

Since 1978, The Netherlands, Denmark and Germany have coordinated their activities and measures for a comprehensive protection of the Wadden Sea, covering policy and management as well as monitoring and research. Important elements of this Trilateral Cooperation are the:

(i) Quality Status Report (QSR)
(ii) Trilateral Monitoring and Assessment Program (TMAP)
(iii) Trilateral Wadden Sea Plan (WSP)
(iv) Trilateral Governmental Conference (TGC)

The QSR is published every 5 years and it evaluates the status of the Wadden Sea based on various ongoing monitoring programs, including TMAP (Essink et al. 2005). The aim of TMAP is to provide a scientific assessment of the status and development of the Wadden Sea ecosystem, and to assess the status of implementation of the trilateral targets formulated in the WSP (Bakker et al. 1998). The WSP was adopted at the 8th TGC and it entails the common policies, measures, projects and actions of the countries for their joint efforts to fulfil the ecological targets (Stade Declaration, 1998). Wadden Sea Conferences at the ministerial level have been held regularly since 1978. The last one, the 10th TGC was held on Schiermonnikoog in November 2005 (Schiermonnikoog Declaration, 2006).

The importance of fish as an element of the Wadden Sea ecosystem has not been sufficiently acknowledged by the Trilateral Cooperation. Although a chapter on fish was included in the Quality Status Reports of 1999 (de Jong et al. 1999) and 2004 (Vorberg et al. 2005), fish is not included in TMAP, nor is fish mentioned (explicitly) in the WSP. Meanwhile, the need to include fish in the WSP and TMAP has grown because the Water Framework Directive recognizes fish as a biological quality element for transitional waters. In addition, selected fish species are listed in the Habitats Directive (e.g. twaite shad, river lamprey and sea lamprey), and characteristic fish species should be used to assess the status of the habitat types described in this Directive (e.g. submerged sandbanks, estuaries, 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 has been adopted and is now being implemented. In this Directive, fish again are one of the qualitative descriptors of the good environmental status.

1.2 Assignment

The omission of fish in the Trilateral Cooperation has been recognised; recommendations in the QSR 2004 (Vorberg et al. 2005) and those following from the 10th TGC (Schiermonnikoog Declaration, 2006) have led to the instigation of the TMAP ad hoc Working Group Fish. One of the mayor objectives of this group was to support the TMAP revision process. However, formulating (quantitative) targets for fish and evaluating the status of the Wadden Sea based in these targets within TMAP is severely hampered by the lack of knowledge on the processes causing changes in the fish assemblages of the Wadden Sea. This too was recognised at the 10th TGC, which has led to the current assignment.

The overall objective of this project, and of the future research requirements as identified within this project, is to obtain a better understanding of the processes and causal factors underlying trends observed in Wadden Sea fish fauna.

The work plan consisted of 3 components:

1. collate an inventory of long-term/ongoing fish monitoring programmes in the Wadden Sea
2. analyse trends in fish fauna based on data collected during the Dutch Demersal Fish Survey
3. identify future research needs

Part of the work was carried out in cooperation with international colleagues through the TMAP ad hoc Working Group Fish. This covered the inventory of fish monitoring programmes (component 1), elaborate quality controls of the basic data (pre-requisite for component 2), and trend analyses for 14 selected fish species and species composition (part of component 2). Hence, component 2 was elaborated in comparison to the original plan as German monitoring data were included in this part of the trend analyses. Furthermore a list of fish species presently occurring in the Wadden Sea and an overview of environmental data available for the Wadden Sea and adjacent waters were compiled. The current report (Trends in Wadden Sea Fish Fauna – Part I: Trilateral Cooperation) presents the results of the work carried out in international cooperation. A large part of these results have also been used in the QSR 2009 (Jager et al. 2009).

The rest of the work was based on Dutch data only and is presented in the follow-up report (Trends in Wadden Sea Fish Fauna – Part II: Dutch Demersal Fish Survey (DFS), Tulp & Bolle 2009). This comprised an elaboration of the trend analyses (component 2): the number of individual species included in the analyses was increased to 34, correlations between trends in fish fauna and environmental variables were explored, and trends were compared with other coastal waters and between groups of species to identify similar patterns that could give rise to hypotheses on the causes of the observed trends. The results of the trend analyses presented in follow-up report have been published in the peer-reviewed literature (Tulp et al. 2008).

Future research requirements (component 3) were identified based on the results presented in both reports. The 2 reports are stand-alone documents which can be read independently of each other.

2 Methods

2.1 Fish monitoring in the Wadden Sea

Several fish monitoring programmes have been carried out in the Wadden Sea and adjacent waters. Table 2.1.1 lists the most important monitoring programmes which specifically target areas within the Trilateral Wadden Sea Conservation Area as illustrated in Figure 2.1.1. These surveys vary in spatial coverage (1-120 stations), temporal coverage (2-49 years), and fishing gear (beam trawl, stownet, fyke net, cooling water intake).

Table 2.1.1 is not a comprehensive list of all fish sampling ever undertaken in the Wadden Sea. Numerous fish (larvae) surveys dedicated to specific research goals have been carried out by a.o. Wageningen IMARES, Royal NIOZ, National Institute for Coastal and Marine Management (RIKZ), von Thünen Institute (vTI), Alfred Wegener Insitute (AWI). Furthermore several ongoing North Sea surveys have some coastal stations which lie within the Trilateral Wadden Sea Conservation Area. These surveys include:

- the Sole Net Survey (since 1969, Wageningen IMARES)
- the Beam Trawl Survey (since 1985 Wageningen IMARES & von Thünen Institute)
- Fish monitoring in the German EEZ (since 1958, von Thünen Institute)
- the German Autumn Survey EEZ (von Thünen Institute)

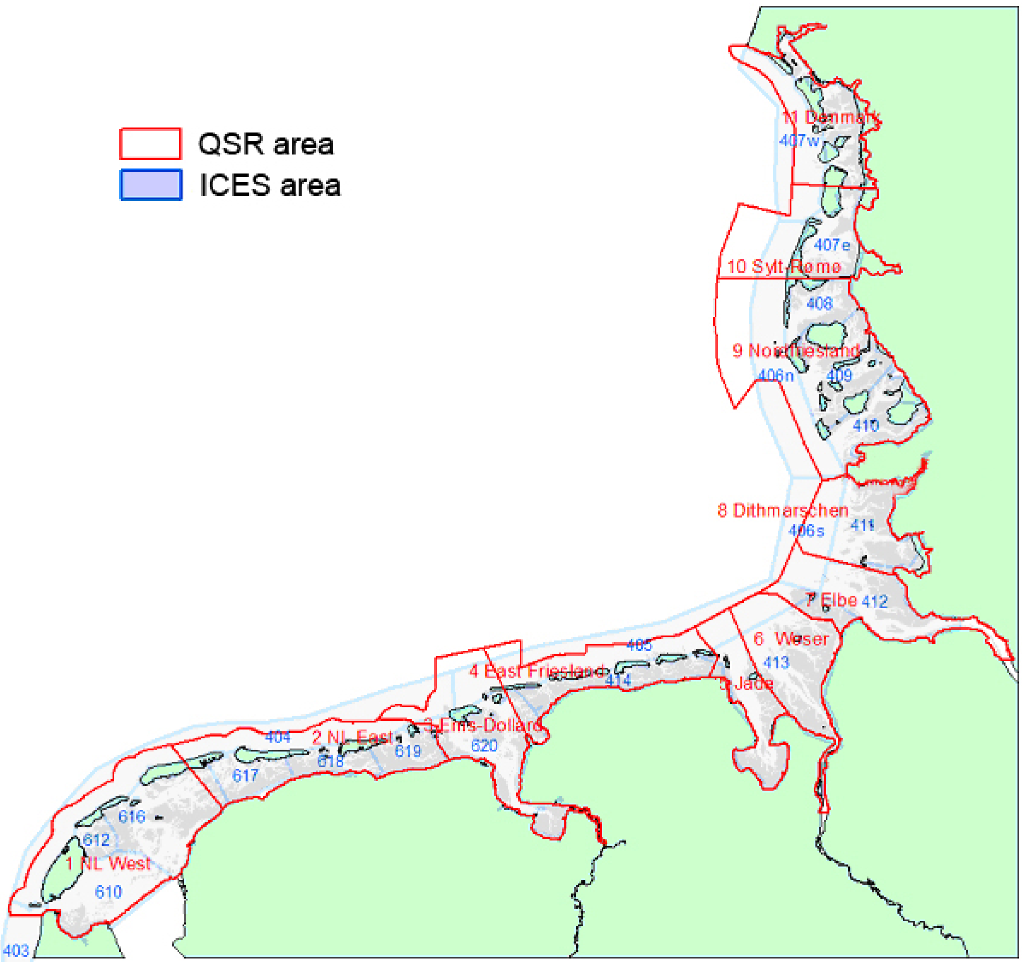

Figure 2.1.1. Trilateral Wadden Sea Conservation Area (red contour) subdivided into QSR areas as defined within the context of Quality Status Report, and ICES areas as defined in the original DFS/DYFS survey design.

Table 2.1.1. Overview of fish monitoring in the Wadden Sea

Survey	Country	Institute	Gear	Spatial coverage			Temporal coverage			
				[1] water body	[2] QSR area	nr. of stations	first year	last year	sampling period	sampling frequency
Demersal Fish Survey (DFS)	Netherlands	Wageningen IMARES	3m beam trawl	WS	1-3	± 120	1970	1986	Apr/May+Sep/Oct	2x per year
			3m beam trawl	WS	1-3	± 120	1970	ongoing	Sep/Oct	1x per year
			6m beam trawl	NS	1-11	± 70	1970	1986	Apr/May+Sep/Oct	2x per year
			6m beam trawl	NS	1-11	± 70	1970	ongoing	Sep/Oct	1x per year
Demersal Young Fish Survey (DYFS)	Germany	J.H. von Thünen Institute	3m beam trawl	WS,NS	4+7-9	± 120	1971-74	2004	Apr/May+Sep/Oct	2x per year
			3m beam trawl	WS,NS	4+7-9	± 120	1971-74	ongoing	Sep/Oct	1x per year
			3m beam trawl	WS,NS	5-6	± 30	2005	ongoing	Sep/Oct	1x per year
Schleswig-Holstein Survey (SHS)	Germany	Marine Science Service /	stownet	WS	8	3	1991	ongoing	Aug	1x per year
		National Park Agency	stownet	WS	9	3	2001	ongoing	Aug	1x per year
Seabird-Fish-Interactions Survey (SFIS)	Germany	Institute of Avian Research	stownet	WS	5	1	2005	2007	whole year	1x per month
			cooling water intake	WS	5	1	2005	2007	Mar-Sep	1x per 2 weeks
Balgzand tidal flat survey	Netherlands	Royal NIOZ	2m beam trawl	WS	1	36	1974	1982	Feb-Jun	1x per 2-4 weeks
			2m beam trawl	WS	1	36	1993	2002	Feb-Jun	1x per 2-4 weeks
Marsdiep fyke net survey	Netherlands	Royal NIOZ	kom-fyke	WS	1	1	1960	ongoing	Apr-Jun+Sep-Oct	1x per 1-3 days
Fish Monitoring East Frisian Wadden Sea	Germany	Alfred Wegener Institute	3m beam trawl	WS	4	± 25	1992	1997	whole year	6x per year
			3m beam trawl	WS	4	± 25	1998	ongoing	Mar+Jul/Aug	2x per year
BLMP/JAMP Elbe	Germany	Elbe River Water Quality Board	commercial beam trawl	WS,NS	7	14	1999	2005	Oct/Nov	1x per year
WFD fish monitoring Ems	Germany	Bioconsult	stownet	TW	3	3	2006	ongoing	May+Sep	2x per year
Weser	Germany	Voigt Consulting	stownet	TW	6	4	2007	ongoing	May/Jun+Sep/Oct	2x per year
Elbe	Germany	Elbe River Water Quality Board	stownet	TW	7	7-14	2000	ongoing	May/Jun+Sep/Oct	2x per year
Eider	Germany	Limnobios	stownet	TW	8	2	2006	ongoing	May+Aug/Sep	2x per year

[1] WS=Wadden Sea, NS=North Sea, TW=transitional waters

[2] Wadden Sea subareas as defined within the context of the Quality Status Report, see Figure 1

Data from three ongoing, long-term surveys have been used to analyse the trends in the Wadden Sea fish fauna:

- Demersal Fish Survey (DFS),
- Demersal Young Fish Survey (DYFS)
- Schleswig-Holstein Survey (SHS)

Data from these 3 surveys, together with data collected during a short-term monitoring programme:

- Seabird-Fish-Interactions Survey (SFIS)

have been used to compile a species list of the present-day Wadden Sea fish fauna.

The spatial and temporal coverage of the 3 surveys included in the trend analyses is summarised by the number of hauls per year and area (Table 2.1.2). The spatial resolution for the trend analyses was set at the level of the so-called QSR areas, i.e. the Wadden Sea sub-areas which were distinguished in the QSR 2004 (Essink et al. 2005). These QSR areas largely correspond to single or aggregated ICES areas as defined in the original DFS/DYFS survey design (Figure 2.1.1). A short description of the survey design of the DFS, DYFS and SHS is presented in the following sections. Further information on the beam trawl surveys (DFS and DYFS) and the coordination and standardisation hereof, is presented in several ICES working group reports (ICES 1985, ICES 2006, ICES 2007a).

Important note: The data presented here were made available exclusively for this report and the Wadden Sea Quality Status Report 2009 and may not be used for other purposes without consulting the institute contributing the data.

Table 2.1.2. The number of hauls by year, survey and area for the Demersal Fish Survey (DFS), Demersal Young Fish Survey (DYFS) and the Schleswig-Holstein Survey (SHS). See Figure 2.1.1 for the QSR and ICES area definitions.

survey	DFS	DFS	DFS	DYFS	DYFS	DYFS	DYFS	DYFS	DYFS	SHS	SHS
QSR area	1	2	3	4	5	6	7	8	9	8	9
ICES area	610-616	617-619	620	414, 405	413, 405	413, 405	412, 406s	411, 406s	408-410, 406n	411	408
1970	47	38	20								
1971	49	29	21	21							
1972	42	30	20	21	5	8	12				
1973	44	29	22	15	7	6	12				
1974	49	33	21				4	22	24		
1975	53	33	21				4	22	24		
1976	53	33	21				4	22	24		
1977	54	34	21	15	5	2	27				
1978	54	33	21				3	22	24		
1979	47	30	19	31			17	22	24		
1980	54	33	21	24			10	21	21		
1981	53	33	21	23			2	21	24		
1982	54	32	21	37			34	22	24		
1983	53	32	21	25			21	9			
1984	54	31	21	39			27	19	18		
1985	54	30	20	41					41		
1986	54	32	21	45			26	29	24		
1987	54	31	23	48			25	15	36		
1988	47	30	22	44			26	20	29		
1989	47	31	23	53			22	21	24		
1990	46	31	23	54			28	28	36		
1991	53	33	24	17			26	17	39	8	
1992	55	18	28	46			26	27	31	8	
1993	50	33	28	34			25	21	30	12	
1994	50	28	25				24	25	33	9	
1995	54	34	26	42				26	48	12	
1996	62	34	27	29			25	29	33	12	
1997	55	35	27	32			25	51	31	12	
1998	62	35	26	30			23	33	48	11	
1999	57	36	22	36			25	38	31	12	
2000	68	36	26	38			23	32	35	10	
2001	53	35	26	35			20	31	27	10	6
2002	53	33	26	27			24	32	35	10	12
2003	55	31	26	25			18	36	33	9	12
2004	61	32	25	19			24	29	25	12	11
2005	60	33	33	33	5	14	21	30	47	11	11
2006	62	32	29	29	6	20	28	28	38	11	11
total	**1972**	**1186**	**868**	**1008**	**28**	**50**	**661**	**800**	**961**	**169**	**63**

2.1.1 Demersal Fish Survey (DFS) – The Netherlands

The DFS was initiated in 1969 (Boddeke et al. 1970, 1972) and since 1970 covers the Dutch Wadden Sea, the Ems-Dollard estuary, the Scheldt estuary, and shallow coastal waters from the Dutch-Belgian border to Esbjerg, Denmark.

The DFS was originally designed to provide recruitment indices of commercial flatfish species (i.e. plaice and sole), but all fish and most benthic invertebrate species have always been recorded for each haul, thus providing valuable long-term data series on bottom-dwelling species in coastal and estuarine waters.

Initially the survey was carried out in spring (April-May) and autumn (September-October), but since 1987 only the autumn survey has been continued. Sampling is stratified by geographical area (ICES areas in Figure 2.1.1) and depth strata (5m depth classes). Sampling is restricted to water deeper than 2-3 m, because of the draught of the research vessels. Three different research vessels cover the survey area, one for the Scheldt estuary, one for the coastal waters and one for the Wadden Sea and Ems Dollard. Approximately 190 stations are located within the Trilateral Wadden Sea Conservation Area (Table 2.1.1). The gear used is either a 6m beam trawl (coastal waters) or a 3m beam trawl (Scheldt estuary, Wadden Sea and Ems Dollard). The beam trawls are rigged with a shrimp net, a roller chain ("bobbin rope"), one tickler chain and a fine-meshed cod-end (20 mm stretched).

The catches are processed by haul. Total catch volume is recorded before sorting out the catch. Fish are identified to the species level, with a few exceptions. The length frequency distributions of all fish species and brown shrimp, and the quantity of other invertebrates are recorded. Length stratified subsamples are collected by ICES area for all flatfish species. The fish from these subsamples are individually measured, weighed and otoliths are collected for subsequent age determinations.

Trawl data (geographical position, date, time, haul duration, haul distance, water depth, tidal phase, wind direction and wind speed) are recorded for each haul. Hydrographical data are also collected by haul. Prior to 2004 only basic hydrographical measurements (surface water temperature and visibility estimates using a secchi disc) were collected. Since 2004 a data-log CTD is attached to the net and depth profiles of temperature, salinity and turbidity data are available for each haul.

Only the DFS data collected within the Dutch Wadden Sea and the Ems Dollard (ICES areas 610, 612, 616-620 in Figure 2.1.1) were included in the trend analyses. The data collected in the coastal waters adjacent to the Wadden Sea (areas 404-407) were omitted from the trend analyses, but were included as a separate survey in the species list (Table 3.1.1). The DFS areas in the Wadden Sea correspond to tidal basins. In the QSR area definitions, the 6 tidal basins in the Dutch Wadden Sea have been combined into 2 larger regions (Figure 2.1.1).

Figure 2.1.2. Beam trawl deployed during the DFS in the Dutch Wadden Sea.

2.1.2 Demersal Young Fish Survey (DYFS) – Germany

From 1970 onwards Germany joined in with the Dutch initiative for an inshore beam trawl survey (Boddeke et al. 1972). At first only aggregated data were collected, but from 1971 onwards data are available by haul. The survey area was extended in the following years and since 1974 the East Frisia, Elbe and Schleswig-Holstein regions (QSR areas 4, 7-9) are covered consistently. The Jade-Weser region (QSR areas 5-6) has permanently been included in the monitoring programme since 2005, before it was only sampled occasionally.

The DYFS, like the Dutch DFS, was initially established entirely for fishery science and stock assessment purposes concerning commercial species, i.e. plaice, sole and brown shrimp. However, as all other fishes were recorded during the survey, this source contains valuable long-term data series for the Wadden Sea. Unfortunately, not all data are digitally available yet. At present the German scientists are in the process of checking and entering data, working backwards from the present. All data from 1996 onwards are digitally available and checked. For several species, catch rates (only) are available for the full time range but these data have not been checked yet and should therefore be treated with care.

The DYFS survey gear is almost identical to the Dutch DFS gear (ICES, 2006). Mayor difference is the use of a tickler chain in the Dutch DFS, which was omitted in the German DYFS because of the excessive catch of dead shells on many of the German stations (pers com Rauck). Campaigns were carried out in both spring (April-May) and autumn (September-October) until 2005, only the autumn survey has been continued since 2005. Sampling is stratified by area, but not by depth. The DYFS station grid differs compared to the DFS grid with respect to the area covered outside the chain of Wadden Sea islands. The DYFS samples only a small part of the ICES areas outside of the islands (405-406) in extension of the area sampled within the islands, whereas the DFS fully covers the ICES areas (405-407) outside the chain of islands. Sampling is carried out using chartered vessels. Different vessels are used for the 4 main segments of the DYFS, i.e. East Frisia, Jade-Weser, Elbe and Schleswig-Holstein. Although in principle the survey protocol was kept the same for all regions some differences inevitably occurred (Neudecker 2001). The most important difference, as this is expected to affect the catchability of fish, was that in some areas (Elbe and East Frisia) part of the sampling was carried out at dusk or night. Furthermore, changes in vessels over time have led to slight shifts in the area covered within the ICES areas, i.e. an offshore shift of the stations related to increased draught of the charted cutters.

The catches are processed by haul. Total catch weight (volume in the early days) is recorded before sorting out the catch. Fish are identified to the species level, with a few exceptions. The length frequency distributions of all fish species and brown shrimp are recorded. No otolith samples are collected, length frequency distributions are used to discriminate age groups in the case of commercial species.

Trawl data (geographical position, date, time, haul duration, haul distance, water depth, tidal phase, wind direction and wind speed) are recorded for each haul. Hydrographical data are collected at a limited number of stations and the data are extrapolated to stations in the near vicinity.

All DYFS data within QSR areas 4, 7, 8 and 9 were included in the trend analyses; no distinction was made between hauls inside and outside the chain of islands (as was done for the DFS). The data for QSR areas 5 and 6 were omitted from the trend analyses, because the time series was too short, but they were included in the species list (Table 3.1.1).

2.1.3 Schleswig-Holstein Survey (SHS) – Germany

In 1991, a fish monitoring program started in the Meldorf Bight (QSR area 8) using a stow net as standard sampling gear (Vorberg 2001). Since 2001, a second sampling location has been installed in the Hörnum Deep, a tidal basin between the North Frisian islands of Sylt, Amrum and Föhr (QSR area 9).

The stow net, with a 9x10m net opening, reached from the water surface down to the bottom. The net was operated from an anchored vessel. This gear is considered to be suitable to obtain quantitative data for pelagic fish (Breckling & Neudecker 1994). Standard sampling takes place once a year in August. At each site three sampling stations have been installed, and at each station up to four hauls were done, resulting in a maximum of 24 hauls per year (Table 2.1.2). Additional sampling was carried out in June in 1997-2001, but these data were not included in the trend analyses.

The catches are sorted out by haul and fish are identified to the species level. Length frequency distributions and total catch weights are recorded by haul for all fish species. Trawl data (geographical position, date, time, water depth, current speed, wind direction and wind speed) and hydrographical data (temperature, salinity, oxygen) are collected by haul.

2.2 Wadden Sea fish fauna

2.2.1 Present-day species list

Catch data from 2 beam trawl surveys (DFS & DYFS) and 2 stownet surveys (SFS & SFIS) were used to compile a list of the present-day Wadden Sea fish fauna. Both beam trawl surveys have a large spatial coverage, together these 2 surveys cover the entire Dutch and German Wadden Sea and the adjacent coastal waters (Table 2.1.2). The spatial coverage of the stownet surveys was limited to 1-3 stations in QSR areas 5, 8 and 9.

Different survey gears need to be used to obtain a complete overview of all fish species occurring in the Wadden Sea as no gear exists which is equally selective for all fish species. The beam trawl is considered to be the most suitable gear to catch demersal fish species, whereas the stownet is considered to be better suited to catch pelagic species. The beam trawl does catch pelagic fish in the water column while it is lowered and hauled up, but the quantitative value of these catch rates is doubtful. Likewise the stownet does catch demersal fish but it will only do so if these fish are actively swimming. A third gear type, the fyke net, would probably provide a valuable addition to the species list as this gear catches certain species frequently, which are not caught well by the other 2 gears (e.g. grey mullet, *Chelon labrosus*, pers com Hans Witte, NIOZ).

Only species caught in recent years were included in the present-day species list. The period chosen to represent the present-day was:

- 2001-2005 for the DFS, DYFS and SHS
- 2005-2006 for the SFIS (as no data prior to 2005 are available, see Table 2.1.1).

All species caught in this recent period were listed. The presence (abundance and occurrence) was listed per survey, in which the DFS in coastal waters outside the Wadden Sea islands was treated as a separate survey (see section 2.1.1). Abundance and occurrence were rated in 3 classes:

Abundance	Occurrence
– = absent	– = occurred in <10% of hauls
+ = present	+ = occurred in 10-90% of hauls
++ = in top 10	++ = occurred in >90% of hauls

2.2.2 Selection of priority species

A limited number of 'priority species' was selected from the present-day species list of the Wadden Sea fish fauna. These priority species were included in the trend analyses presented in this report and are considered to be suitable candidates for further monitoring and research. Selection of the priority species was partly based on the present-day abundance and occurrence of these species and partly based on specific selection criteria which addressed the following topics:

1. Ecology

Objective was to select species representing different ecological niches. Therefore 3 parameters were listed to describe the habitat use of each fish species:

- 1.1 Functional guild: this classification (Elliott & Hemmingway 2002) characterises the role of the Wadden Sea in the life history of a fish species (e.g. nursery area for so-called marine juveniles)
- 1.2 Stratification: demersal or pelagic species
- 1.3 Benthic habitat: the habitat preference of demersal species (e.g. sandy bottoms)

2. Relevance for management

Several fish species are directly or indirectly relevant for management through the EU directives

- 2.1 Habitats Directive (HD): Annex II, IV & V species
- 2.2 Water Framework Directive (WFD): species included in transitional water (Ems) monitoring
- 2.3 Endangered or vulnerable species according to Dutch, German or trilateral Red Lists
- 2.4 Species which are important food items for birds or mammals and as such are protected under the Habitat and Bird Directives (Natura 2000 network).

3. Sensitivity to driving forces

The potential sensitivity of each species was evaluated (based on expert judgement) for the following driving forces:

- 3.1 climate change
- 3.2 nutrient enrichment
- 3.3 habitat degradation
- 3.4 fishing mortality
- 3.5 local pressures

2.3 Species richness and composition

Species richness and composition were calculated for each year, QSR area and survey. Species richness was defined as the total number of species observed. Mayor drawback of this parameter is that it is dependent on the number of hauls (in a non-linear way). Therefore species richness can not be compared between regions if the number of hauls differ. Furthermore, temporal trends in species richness within a region should be treated with care if the number of hauls varies between years.

In principle all fish were recorded at the species level, but due to identification problems a higher taxonomic level was chosen for some groups of species (Table 2.3.1). Although some of the identification problems did not occur in all surveys, the grouping listed in Table 3 was applied to all data to enable a better comparison between the surveys. Freshwater species were excluded from the species counts due to the coincidental nature of these catches (e.g. discharges from sluices). The aggregation of species as listed in Table 2.3.1 and the exclusion of fresh water species was only applied for the analyses of species richness and composition.

Table 2.3.1. Species grouped in species richness analyses

Scientific name	English name	guild
Ammodytes sp. + Hyperoplus sp.	Sandeels	ER
Callionymus sp.	Dragonets	MA+MS
Mugilidae	Mullets	MA+MS
Liparis sp.	Sea snails	ER
Pomatoschistus sp.	Gobies	ER
Syngnathus sp.	Pipefishes	ER
Triglidae	Gurnards	MA+MS

Species composition was defined as the total number of species per functional guild, for which the classification into guilds as proposed by Elliott & Hemmingway (2002) was used. The guilds considered to be most relevant for the Wadden Sea are CA (diadromous), MJ (marine juvenile) and ER (estuarine resident). Freshwater species (FW) were excluded from the present analyses. The remaining categories (i.e. MS=marine seasonal and MA=marine adventitious) were combined. The number of species per guild was calculated for each year and region.

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 defined species that are resident in the Wadden Sea (i.e. they spend the majority of their life span in the Wadden Sea) as ER. Whether or not the species also occurs (abundantly) outside of the Wadden Sea is irrelevant for the classification ER.

The aggregation of species because of identification problems sometimes troubled the calculation of the number of species per guild. Greater sandeel (*Hyperoplus lanceolatus*) is considered to be a MJ species, but it was grouped with the *Ammodytes* species which were classified as ER (Table 2.3.1).

2.4 Abundance

The catch rates per haul were converted into standardized abundance estimates. For the stow-net data, catch rates were converted into numbers per $10^6 m^3$ based on the volume of water fished (size net opening x flow). For the beam trawl data, catch rates were converted into numbers per $1000 m^2$ based on the area swept (haul distance x beam trawl width). If haul distance was missing (e.g. in the early DYFS data) an average haul distance corresponding to the haul duration was used.

These standardised abundance estimates by haul were then averaged by year, QSR area and survey. In the case of the beam trawl data (DFS & DYFS) the averages were weighted by the surface area of the depth class (Table 2.4.1). No weighting was carried out for the stownet data (SHS).

Table 2.4.1. Surface areas of the different subareas and corresponding area-based weighting factors for beam trawl surveys.

Region	QSR	ICES	Surface area by depth class *						Weight by depth class					
	area	area	0-5m	5-10m	10-15m	15-20m	>20m	total	0-5m	5-10m	10-15m	15-20m	>20m	total
western Dutch Wadden Sea	QSR1	610-616	1222.9	134.6	70.1	31.7	23.8	1483	0.825	0.091	0.047	0.021	0.016	1
eastern Dutch Wadden Sea	QSR2	617-619	535.7	49.6	12.4	5.4	1.7	605	0.886	0.082	0.021	0.009	0.003	1
Ems-Dollard	QSR3	620	304.9	89.7	78.6	33.5	6.1	513	0.595	0.175	0.153	0.065	0.012	1
East Frisia Wadden Sea	QSR4	414	83.8	9.4	3.6	0.6	0.0	97	0.861	0.096	0.037	0.006	0.000	1
Jade-Weser Wadden Sea	QSR5-6	413	325.8	161.2	106.6	50.7	13.6	658	0.495	0.245	0.162	0.077	0.021	1
Elbe Wadden Sea	QSR7	412	126.2	93.9	46.0	24.5	5.8	296	0.426	0.317	0.155	0.083	0.019	1
Dithmarschen Wadden Sea	QSR8	411	220.3	56.8	21.3	1.3	0.0	300	0.735	0.190	0.071	0.004	0.000	1
North Frisia Wadden Sea	QSR9	408-410	386.5	106.1	58.3	21.5	7.3	580	0.667	0.183	0.101	0.037	0.013	1

* ICES, 2007

2.5 Size composition

We chose to use mean length as proxy for size composition for practical reasons, i.e. fish length is generally recorded for all fish species during all surveys (contrary to fish weight) and the mean is easily calculated. It was calculated as follows:

Mean length = $\Sigma(N*\text{length}) / \Sigma N$, in which N is number of fish by year, QSR area and survey.

In effect, this equals the average of the mean lengths by haul weighted by the number of fish in each haul.

Mean length estimates based on less than 5 fish were excluded from further analyses to reduce random error. The German DYFS data collected prior to 1996 were also excluded, because these data have not been quality controlled yet (see section 2.1.2) and apparently many length records are missing (not yet available digitally) or incorrect. Furthermore, the German DYFS data for herring and sprat were excluded because the results were obviously incorrect (too small by a factor 2).

Mean length was calculated for each year, QSR area and survey. The results of only one QSR area in each survey are presented because of the lack of evident trends and evident differences between areas within a survey.

2.6 Trend analyses

Temporal trends in abundance were analysed for all priority species in each QSR area and survey separately. Temporal trends in mean length were examined for all priority species in one QSR area for each survey: QSR area 1 for the DFS and QSR area 8 for the DYFS and the SHS. In some cases the number of observations was too small to be able to carry out reliable trend analyses (e.g. the SHS data in QSR area 9).

The time series were analysed using TrendSpotter, an analytical method based on structural time-series models in combination with a Kalman filter (Visser 2004). The advantage of this method is that it takes account of serial correlation and provides confidence limits that enable to statistically test changes in abundance. Classic statistical methods (e.g. linear regression) assume independence of the observed values for the response variable, but this assumption is violated if serial correlation occurs and P-values will be inflated (i.e. insignificant trends may seem significant, Zuur et al. 2007). TrendSpotter estimates smoothed values for the response variable for a time series with N equidistant measurements over time. It also estimates the confidence limits for the modelled values and for the differences between consecutive time points (increments). The confidence limits of the increments were used to assess the statistical significance of changes in time.

Abundance data were 4^{th} root transformed to stabilise the variance. The effect of this transformation is comparable to a log transformation, which is often applied to log-normally distributed catch data, but the advantage of 4^{th} root transformation is that it can deal with zero catch observations. The observed and modelled values for abundance were transformed back and plotted on a log-scale in the graphs in section 3.3 to facilitate the interpretation of the results. No transformation was carried out for the mean length data (normally distributed).

2.7 Environmental data

A first step in understanding which factors cause variations in fish populations and communities is to correlate fish parameters (e.g. abundance, size composition, species richness and species composition) with environmental data. Although correlative research is a first logical step which may provide important clues on driving forces, it does not prove causality and may sometimes even be confounded by collinearity between explanatory variables.

In the first part of the project (trilateral cooperation) we compiled an overview of environmental data available for the Wadden Sea and adjacent waters (Appendix 1). This overview is presented on meta-data level; it provides a description of what is available in terms of variables measured, spatial and temporal resolution, geographic area and time span covered, accessibility of the data). The overview is not all-inclusive and further elaboration is required with regard to additional data sources as well as more detail on the data collected. Originally we aimed at doing correlative research for all surveys included in the trend analyses of this report (DFS, DYFS and SHS), however, due to the amount of time lost because of data problems in the German data, this proved to be impossible. The topic is re-addressed in the second part of this project (Dutch Demersal Fish Survey).

3 Results

3.1 Wadden Sea fish fauna

The species list presented in Table 3.1.1 reflects the present-day Wadden Sea fish fauna based on their presence in four monitoring programs in recent years (see section 2.1). Two species were not caught in this period in these surveys, but were nevertheless considered relevant for the Wadden Sea: houting (*Coregonus oxyrinchus*), because it is a Habitats Directive species, and thick-lipped grey mullet (*Chelon labrosus*), because it is regularly caught in fyke nets (pers. com. Hans Witte, NIOZ).

The objective of Table 3.1.1 was not only to list the typical Wadden Sea fish species, but also to select a limited number of species as candidates for further analyses. The first part of the table (monitoring) presents the occurrence and abundance of each species in recent years (2001-2005 for the ongoing surveys and 2005-2006 for the SFIS) and the suitability of different gears to catch these species. The second part of the table (selection criteria) provides information on the ecology of the species, it's relevance to management and it's sensitivity to important driving forces. The parameters presented in the table are described in detail in section 2.2.

A scoring system was developed in an attempt to provide an objective quantitative tool to select priority species. For each fish species a total score was calculated for the selection criteria and for the monitoring parameters separately. For this, each column received a weighting factor indicating the relative importance of each '+' within the column. These weighting factors were based on expert judgement and elaborate discussions between the co-authors of this report. The group considered the selection criteria based on the Habitats Directive (HD) and the Water Framework Directive (WFD) to be important, therefore these criteria received a high weighting factor (2). Both scores (i.e. one for the selection criteria and one for the monitoring parameters) are a summation of each '+' multiplied by the weighting factor which is listed at the top of the table. Table 3.1.1 has been sorted by these scores. The fourteen species which have a score of above 2 for both the selection criteria as well as the monitoring results, were selected as priority species (Table 3.1.2). This selection contained common (e.g. plaice and herring) and less common species (e.g. twaite shad and river lamprey). It also contained representatives of all functional guilds considered to be important for the Wadden Sea (CA, ER, MJ and MS). As the catchability of these species differs between the gear-types, either beam trawl or stownet data, and in some cases both, were used in the trend analyses (Table 3.1.2).

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 very rare or not covered by the current monitoring methods and programs. Therefore, despite their relevance, they could not be taken further into the analyses.

Table 3.1.1. Present-day Wadden Sea fish fauna based on the presence (abundance and occurrence) in 4 surveys (DFS, DYFS, SHS, SFIS) in recent years and criteria for the selection of priority species. The table also indicates the suitability of both gear-types for quantitative abundance estimates of each species. Further explanation of the parameters is given sections 2.2 and 3.1.

		Monitoring												
		Abundance					Occurrence					Suitability		
		DFS outer area (beamtrawl, 2001-2005)	DFS inner area (beamtrawl, 2001-2005)	DYFS (beamtrawl, 2001-2005)	SHS (stownet, 2001-2005)	SFIS (stownet, 2005-2006)	DFS outer area (beamtrawl, 2001-2005)	DFS inner area (beamtrawl, 2001-2005)	DYFS (beamtrawl, 2001-2005)	SHS (stownet, 2001-2005)	SFIS (stownet, 2005-2006)	Beamtrawl	Stownet	**Score**
	weight of each "+" for score	*0.5*	*0.5*	*1*	*1*	*0*	*0.5*	*0.5*	*1*	*1*	*0*	*n.a.*	*n.a.*	
Pleuronectes platessa	Plaice	++	++	++	++	++	++	++	+	++	+	+	-	**11**
Clupea harengus	Herring	++	++	++	++	++	+	+	+	++	++	-	+	**10**
Syngnathus rostellatus	Nilsson's pipefish	++	++	++	++	++	+	+	+	++	++	+	-	**10**
Osmerus eperlanus	Smelt	+	++	++	++	++	+	+	+	++	++	-	+	**9.5**
Platichthys flesus	Flounder	+	++	++	++	+	+	+	+	++	+	+	-	**9.5**
Pomatoschistus minutus	Sand goby	++	++	++	++	++	+	+	+	+	++	+	-	**9**
Pomatoschistus microps	Common goby	(1)	(1)	(1)	+	++	(1)	(1)	(1)	-	++	+	-	**(1)**
Sprattus sprattus	Sprat	+	+	+	++	++	+	+	+	++	++	-	+	**8**
Solea vulgaris	Sole	+	++	+	++	++	+	+	+	+	++	+	-	**7.5**
Limanda limanda	Dab	++	++	++	+	+	++	+	+	-	-	+	-	**7.5**
Merlangius merlangus	Whiting	++	+	++	+	+	+	+	+	+	+	+	+	**7.5**
Myoxocephalus scorpius	Bull rout	+	++	++	+	+	+	+	+	+	-	+	-	**7.5**
Agonus cataphractus	Hooknose	++	+	++	+	+	+	+	+	+	+	+	-	**7.5**
Ciliata mustela	Five-bearded rockling	+	++	+	+	+	+	+	+	+	+	+	-	**6.5**
Alosa fallax	Twaite shad	+	+	+	++	++	-	-	-	++	+	-	+	**6**
Gadus morhua	Cod	+	+	+	+	+	+	+	+	+	+	+	+	**6**
Zoarces viviparus	Eelpout	+	+	+	+	+	-	+	+	+	-	+	-	**5.5**
Trachurus trachurus	Horse mackerel	+	+	+	++	++	+	-	-	+	+	-	+	**5.5**
Liparis liparis	Sea snail	+	+	+	+	+	+	+	+	-	+	+	-	**5**
Psetta maxima	Turbot	+	+	+	+	+	+	-	-	+	-	+	-	**4.5**
Trigla lucerna	Tub gurnard	+	+	+	+	+	+	-	-	+	-	+	-	**4.5**
Lampetra fluviatilis	River lamprey	+	+	+	+	+	-	-	-	+	+	-	+	**4**
Ammodytes sp.	Sandeel	+	+	+	+	+	+	+	-	-	+	-	-	**4**
Anguilla anguilla	Eel	+	+	+	+	+	-	-	-	+	-	-	-	**4**
Scophthalmus rhombus	Brill	+	+	+	+	-	-	-	-	+	-	+	-	**4**
Eutrigla gurnardus	Grey gurnard	+	+	+	+	-	-	-	-	+	-	+	-	**4**
Callionymus lyra	Dragonet	++	+	+	-	+	+	-	+	-	-	+	-	**4**
Gasterosteus aculeatus	Stickleback	+	+	+	+	+	-	-	-	+	-	-	+	**4**
Pholis gunnellus	Butterfish	+	+	+	+	+	-	+	-	-	+	+	-	**3.5**
Cyclopterus lumpus	Lumpsucker	+	-	+	+	+	-	-	-	+	-	+	-	**3.5**
Engraulis encrasicolus	Anchovy	-	-	+	+	+	-	-	-	+	+	-	+	**3**
Liparis montagui	Montaguis sea snail	-	-	+	+	+	-	-	-	+	+	+	-	**3**
Belone belone	Garfish	+	+	-	+	+	-	-	-	+	+	-	+	**3**
Scomber scombrus	Mackerel	+	+	-	+	+	-	-	-	+	-	-	+	**3**
Arnoglossus laterna	Scaldfish	++	+	+	-	-	+	-	-	-	-	+	-	**3**
Buglossidium luteum	Solenette	++	+	+	-	+	+	-	-	-	-	+	-	**3**
Syngnathus acus	Greater pipefish	+	+	+	-	-	+	-	-	-	-	+	-	**2.5**
Echiichthys vipera	Lesser weever	+	+	+	-	-	+	-	-	-	-	+	-	**2.5**
Hyperoplus lanceolatus	Greater sandeel	+	+	+	-	+	+	-	-	-	+	-	-	**2.5**
Trisopterus luscus	Bib	+	+	+	-	-	-	+	-	-	-	+	+	**2.5**
Salmo salar	Salmon	-	-	-	+	-	-	-	-	+	-	-	+	**2**
Mullus surmuletus	Striped red mullet	+	+	+	-	-	-	-	-	-	-	+	-	**2**
Entelurus aequoraeus	Snake pipefish	+	+	+	-	+	-	-	-	-	+	+	-	**2**
Microstomus kitt	Lemon sole	+	+	+	-	+	-	-	-	-	-	+	-	**2**
Gymnocephalus cernuus	Ruffe	-	+	+	-	-	-	-	-	-	-	+	+	**1.5**
Atherina presbyter	Sand smelt	+	-	+	-	+	-	-	-	-	-	-	+	**1.5**
Callionymus reticulatus	Reticulated dragonet	+	-	+	-	-	-	-	-	-	-	+	-	**1.5**
Stizostedion lucioperca	Pikeperch	-	+	+	-	-	-	-	-	-	-	+	+	**1.5**
Gaidropsarus vulgaris	Three-bearded rockling	+	-	+	-	-	-	-	-	-	-	+	-	**1.5**
Alosa alosa	Allis shad	-	-	+	-	-	-	-	-	-	-	-	+	**1**
Dicentrarchus labrax	Bass	+	+	-	-	-	-	-	-	-	-	-	+	**1**
Callionymus maculatus	Spotted dragonet	-	-	+	-	-	-	-	-	-	-	+	-	**1**
Nerophis ophidion	Straight-nosed pipefish	-	-	+	-	-	-	-	-	-	-	+	-	**1**
Enchelyopus cimbrius	Four-bearded rockling	+	-	-	-	-	+	-	-	-	-	+	-	**1**
Trisopterus minutus	Poor cod	+	+	-	-	-	-	-	-	-	-	+	+	**1**
Petromyzon marinus	Sea lamprey	+	-	-	-	+	-	-	-	-	-	-	+	**0.5**
Perca fluviatilis	Perch	-	+	-	-	-	-	-	-	-	-	+	+	**0.5**
Galeorhinus galeus	Tope	+	-	-	-	-	-	-	-	-	-	+	+	**0.5**
Pollachius pollachius	Pollack	-	+	-	-	-	-	-	-	-	-	+	+	**0.5**
Chelon labrosus	Thick-lipped grey mullet	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Coregonus oxyrinchus	Houting	-	-	-	-	-	-	-	-	-	-	-	+	**0**
Number of species		48	45	49	34	38	48	45	49	34	38			
Number of hauls		295	582	1185	53	19	295	582	1185	53	19			

(1) Identifications unreliable, *P. microps* and *P. minutes* pooled

Table 3.1.1. Continued

		Selection criteria: Ecology			Relevance for management				Sensitivity to driving forces					
		Functional guilds [1]	Stratification [2]	Benthic habitat [3]	HD species	WFD species for Eems	Endangered or vulnerable	Food for birds or mammals	Climate change	Nutrient enrichment	Habitat degradation	Fishing mortality (commercial species)	Local pressures	Score
	weight of each "+" for score	*n.a.*	*n.a.*	*n.a.*	*2*	*2*	*1*	*0.5*	*1*	*1*	*1*	*1*	*1*	
Pleuronectes platessa	Plaice	MJ	D	m-s		+		+	+	+	+	+		**6.5**
Alosa fallax	Twaite shad	CA	P		+	+	+	+			+			**6.5**
Clupea harengus	Herring	MJ	P			+		++	+		+	+		**6**
Osmerus eperlanus	Smelt	CA	P			+		++			+	+		**5**
Solea vulgaris	Sole	MJ	D	m-s				+	+	+	+	+		**4.5**
Zoarces viviparus	Eelpout	ER	D	m-p		+					+		+	**4**
Platichthys flesus	Flounder	ER/CA	D	m-s		+		+			+			**3.5**
Limanda limanda	Dab	MJ	D	s				+		+	+	+		**3.5**
Gadus morhua	Cod	MJ	D					+	+		+	+		**3.5**
Lampetra fluviatilis	River lamprey	CA	P		+		+							**3**
Ammodytes sp.	Sandeel	ER	DP	s				++			+	+		**3**
Sprattus sprattus	Sprat	MS	P					+			+	+		**2.5**
Merlangius merlangus	Whiting	MJ	D					+			+	+		**2.5**
Engraulis encrasicolus	Anchovy	MS	P				+	+	+					**2.5**
Alosa alosa	Allis shad	CA	P		+		+				+			**4**
Coregonus oxyrinchus	Houting	ER	P		+		+				+			**4**
Gymnocephalus cernuus	Ruffe	FW	D			+					+			**3**
Petromyzon marinus	Sea lamprey	CA	P		+		+							**3**
Myoxocephalus scorpius	Bull rout	ER	D	m-p							+		+	**2**
Liparis liparis	Sea snail	ER	D	m-h			+				+			**2**
Anguilla anguilla	Eel	CA	D	m-s			+					+		**2**
Pholis gunnellus	Butterfish	ER	D	m-p			+				+			**2**
Cyclopterus lumpus	Lumpsucker	MS	D	h-p			+				+			**2**
Liparis montagui	Montaguis sea snail	ER	D	h			+				+			**2**
Syngnathus acus	Greater pipefish	ER	D	s-p			+				+			**2**
Echiichthys vipera	Lesser weever	MA	D	m-s			+				+			**2**
Syngnathus rostellatus	Nilsson's pipefish	ER	D	s-p				+			+			**1.5**
Pomatoschistus minutus	Sand goby	ER	D	s				+			+			**1.5**
Pomatoschistus microps	Common goby	ER	D	s				+			+			**1.5**
Trachurus trachurus	Horse mackerel	MA	P					+				+		**1.5**
Psetta maxima	Turbot	MJ	D	s-g				+				+		**1.5**
Scophthalmus rhombus	Brill	MJ	D	s-g				+				+		**1.5**
Belone belone	Garfish	MS	P					+			+			**1.5**
Hyperoplus lanceolatus	Greater sandeel	MJ	DP	s				+			+			**1.5**
Agonus cataphractus	Hooknose	ER/MS	D	m-s							+			**1**
Ciliata mustela	Five-bearded rockling	ER/MS	D	m-s							+			**1**
Eutrigla gurnardus	Grey gurnard	MS	D	m-s			+							**1**
Callionymus lyra	Dragonet	MA	D	m-s							+			**1**
Scomber scombrus	Mackerel	MA	P									+		**1**
Gasterosteus aculeatus	Stickleback	CA	P					+						**0.5**
Trigla lucerna	Tub gurnard	MJ	D	m-s										**0**
Arnoglossus laterna	Scaldfish	MA	D	m-s										**0**
Buglossidium luteum	Solenette	MA	D	m-s										**0**
Trisopterus luscus	Bib	MJ	D											**0**
Salmo salar	Salmon	CA	P		(+)		+					+		**2**
Mullus surmuletus	Striped red mullet	MA	D	s-h					+		+			**2**
Atherina presbyter	Sand smelt	MJ	P				+				+			**2**
Callionymus reticulatus	Reticulated dragonet	MA	D	m-s			+				+			**2**
Stizostedion lucioperca	Pikeperch	FW	D								+	+		**2**
Dicentrarchus labrax	Bass	MJ	D				+					+		**2**
Perca fluviatilis	Perch	FW	D								+	+		**2**
Entelurus aequoraeus	Snake pipefish	ER	D	s-p			+							**1**
Microstomus kitt	Lemon sole	MA	D	s-g								+		**1**
Gaidropsarus vulgaris	Three-bearded rockling	MA	D	m-s			+							**1**
Callionymus maculatus	Spotted dragonet	MA	D	m-s							+			**1**
Galeorhinus galeus	Tope	MA	D				+							**1**
Pollachius pollachius	Pollack	MA	D									+		**1**
Nerophis ophidion	Straight-nosed pipefish	ER	D											**0**
Enchelyopus cimbrius	Four-bearded rockling	MA	D	m-s										**0**
Trisopterus minutus	Poor cod	MA	D											**0**
Chelon labrosus	Thick-lipped grey mullet	MA	P											**0**

[1] ER = estuarine resident
MJ = marine juvenile
MS = marine seasonal migrant
MA = marine adventitious
CA = diadromous
FW = fresh water

[2] D = demersal
P = pelagic
DP = sandeels: pelagic or buried

[3] m = mud
s = sand
g = gravel
h = hard substrate (rocks, musselbeds etc.)
p = plants

Table 3.1.2. Priority species selected for the spatial and temporal trend analyses (CA=diadromous, ER=estuarine resident, MJ=marine juvenile, MS=marine seasonal). X denotes which data (beam trawl or stownet) are considered to give the best quantitative estimates of abundance, (X) denotes the cases in which data from both gear-types were included in the analyses.

Species		Guild	Stratification	Beamtrawl	Stownet
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.	Sandeel	ER	Pelagic & Burried	x	-
Pleuronectes platessa	Plaice	MJ	Demersal	x	-
Solea vulgaris	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

3.2 Species richness and composition

The number of species encountered by year and QSR area ranged from 18 to 33 in the DFS, from 12 to 29 in the DYFS (excluding 1995) and from 18 to 29 in the SHS. Comparisons between areas is however hampered by the fact that species richness, expressed as the number of species, is sensitive to the number of samples taken. In principle, the number of species will increase curvilinearly with the number of samples until a certain maximum. Figure 3.2.1 clearly shows that the number of species encountered in the Dutch DFS increased with the number of hauls.

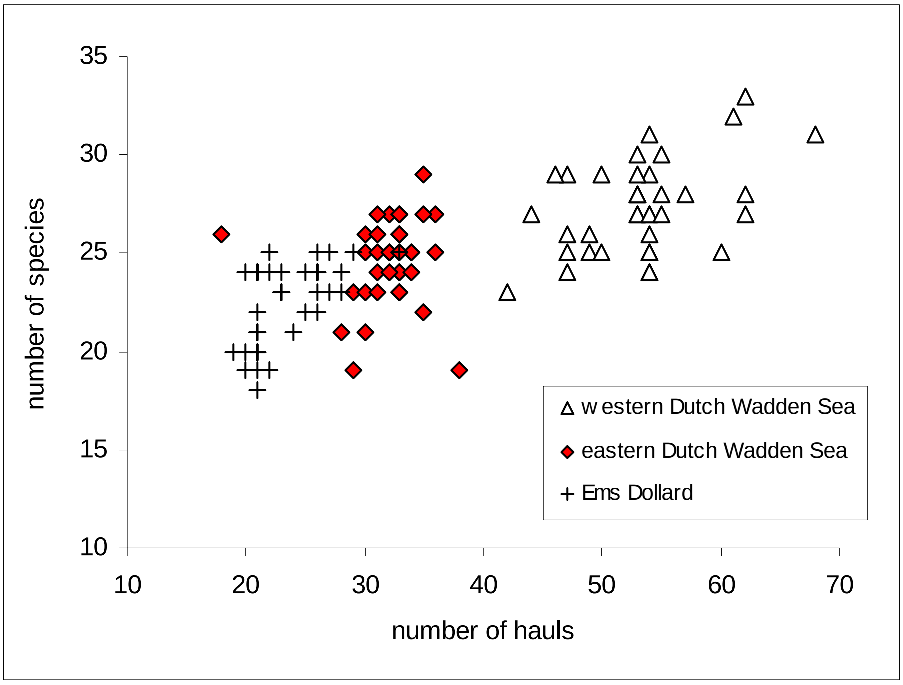

Figure 3.2.1. Number of species per year and region in relation to the number of hauls per year and region.

A strange dip in species richness is observed in 1995 in the North Frisian area for the DYFS (number of species = 4). Although this result can not be explained by an exceptionally low number of hauls (see Table 2.1.2), it seems suspect and may be related to the fact that the German DYFS data prior to 1996 have not been (sufficiently) quality controlled yet.

Overall there appears to be no clear temporal trend in species richness nor in species composition in terms of functional guilds (Figure 3.2.2). The number of estuarine residents (ER) is remarkably stable, especially in the western and eastern Dutch Wadden Sea. Not much variation is observed in the number of marine juveniles (MJ) either. Most of the variation in species richness is caused by the number of diadromous species (CA) and by the number of marine adventitious + marine seasonal species (MA + MS).

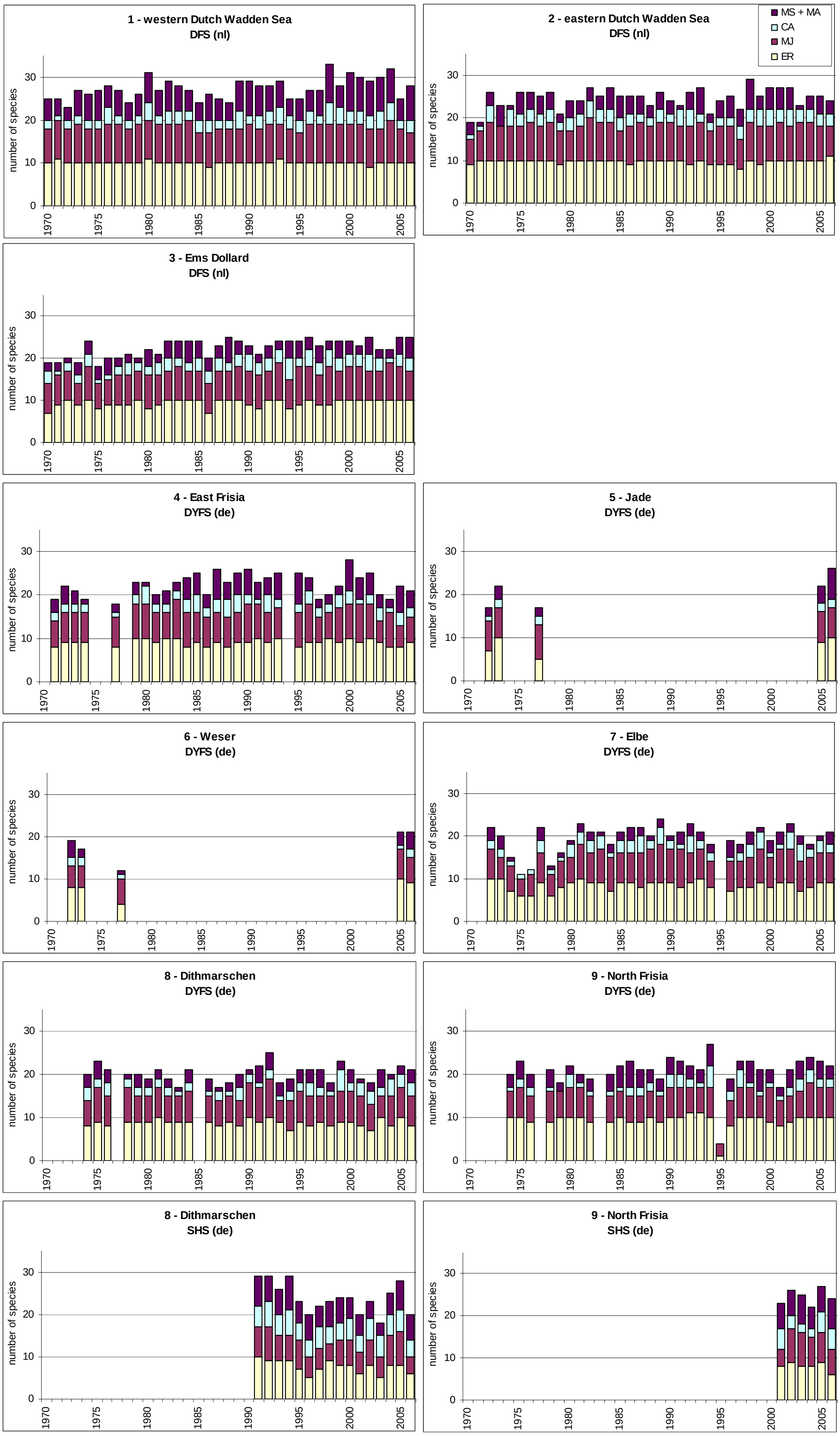

Figure 3.2.2. Number of species per year and guild for each region and survey

3.3 Abundance

Temporal and spatial trends in abundance were examined for all priority species by plotting the mean abundance by year and the long-term average (arithmetic mean) for each QSR area and survey (left panels in Figures 3.3.1–3.3.14). The Y-axis of these graphs is on a log-scale, therefore zero-values have been converted into a small value corresponding with the lowest observed value. These graphs also show the smoothed trend as estimated by the TrendSpotter analyses (see section 2.6). TrendSpotter analyses were not available for the SHS in North Frisia (QSR area 9), because the time series was too short. The significance of a trend was assessed by the confidence limits of the increment estimates (right panels in Figures 3.3.1 – 3.3.14). An increase in abundance corresponds with a positive increment, likewise a negative increment indicates a decrease in abundance. An increase or decrease is considered to be significant if 0 is not within the confidence limits. The modelled increments and their confidence limits reflect the significance of a trend for consecutive time steps (in this case from year to year). TrendSpotter also enables a statistical comparison of the last value in the time-series with any value in the past. This 'retrospective' analyses makes it possible to assess if the abundance in the last year of the time series (in this case 2006) is significantly higher or lower than at the beginning of the survey. The results of the retrospective analyses are not presented in graphs, but are described in the text. The trends by year, area and survey are summarised in Tables 3.3.1 – 3.3.14, in which the significance of a trend is indicated by colour codes. Tables 3.3.1 – 3.3.14 also give an overall description of the trend for the full time span of the survey based on the statistical analyses (both the trend and retrospective analyses), or in the case of the SHS data for QSR area 9 (for which TrendSpotter analyses were not available) on a visual inspection of the graphs. This overall description is the basis for the colour codes used in the left panels of Figures 3.3.1 – 3.3.14.

The time span of the SHS was relatively short compared to the DFS and DYFS, especially for North Frisia (QSR area 9). Furthermore, the area coverage of the SHS within a QSR area was limited to 3 stations. Therefore caution should be taken when comparing trends between the SHS and the beam trawl surveys. What appears to be a downward trend in the SHS may be part of an overall upward trend if a longer time span or larger area is examined (see for example the results for herring in section 3.3.11).

The observed trends differed between species and regions. Often the trends were only significant during a few years, or more pronounced in one area or period than in another (Tables 3.3.1 – 3.3.14). Overall more downward trends than upward trends were observed. A pattern that emerged in several species and regions is an increase in abundance in the 1970s and early 1980s followed by a decrease. This pattern cannot be ascribed to a survey effect because it is observed in both the DFS and DYFS which are 2 completely independent surveys. Comparison of present (2006) catch rates with those at the beginning of the survey period showed an overall increase in the abundance of smelt, flounder and herring, an overall decrease in the abundance of eelpout, plaice, sole, dab, cod, whiting and river lamprey, and no significant changes for twaite shad, sandeel, sprat, anchovy.

3.3.1 Twaite shad (*Alosa fallax*)

Catch rates of twaite shad were low and highly variable in the beam trawl surveys (DFS and DYFS). The long-term average ranged from 0.01 in North Frisia to 0.2 $*10^{-3}m^{-2}$ in the eastern Dutch Wadden Sea (Figure 3.3.1). Catch rates were also low in SHS in North Frisia (18 $*10^{-6}m^{-3}$). Higher catch rates were observed in the SHS in Dithmarschen (520 $*10^{-6}m^{-3}$).

The presence of twaite shad in the beam trawl catches in the western Dutch Wadden Sea and in the German Wadden Sea (QSR areas 4-9) seemed to have increased after 1980. Similarly, the abundance of twaite shad in the SHS in Dithmarschen, appeared to have increased since the onset of this survey in 1991 (Figure.3.3.1). However, none of these trends were significant (Table 3.3.1) and present catch rates are not significantly higher than at the beginning of the surveys (statistics not presented).

Table 3.3.1. Twaite shad. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available for SHS in QSR area 9.

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									no significant trend
DFS (nl)	2									no trend
DFS (nl)	3									no trend
DYFS (de)	4									no significant trend
DYFS (de)	7									no significant trend
DYFS (de)	8									no significant trend
DYFS (de)	9									no significant trend
SHS (de)	8									no significant trend
SHS (de)	9									no trend

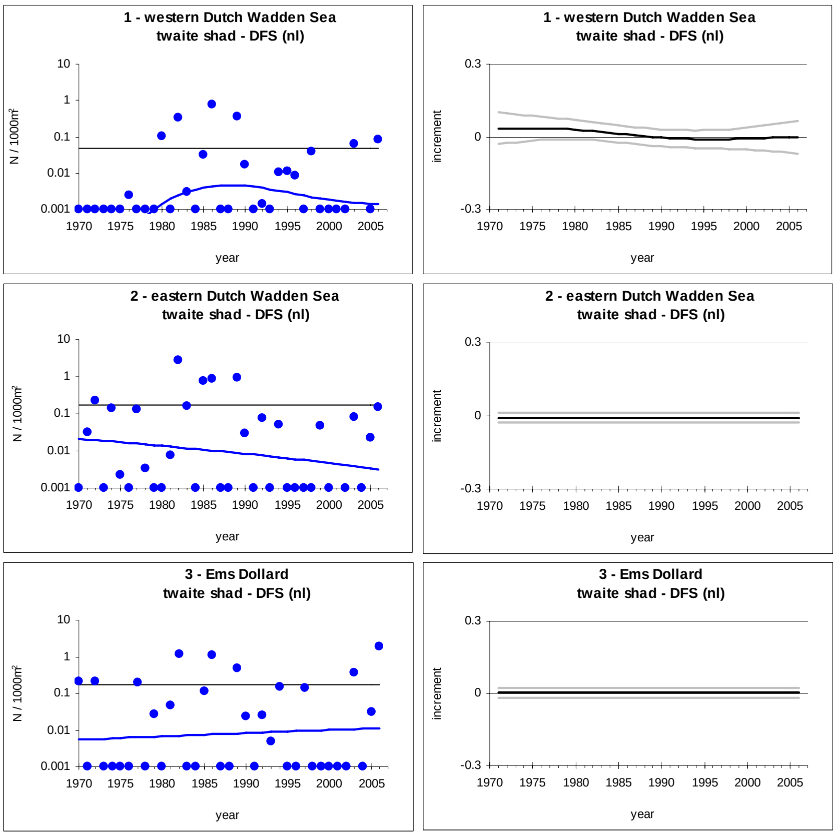

Figure 3.3.1. Twaite shad. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$ (DFS & DYFS) or $n/10^6m^3$ (SHS). Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

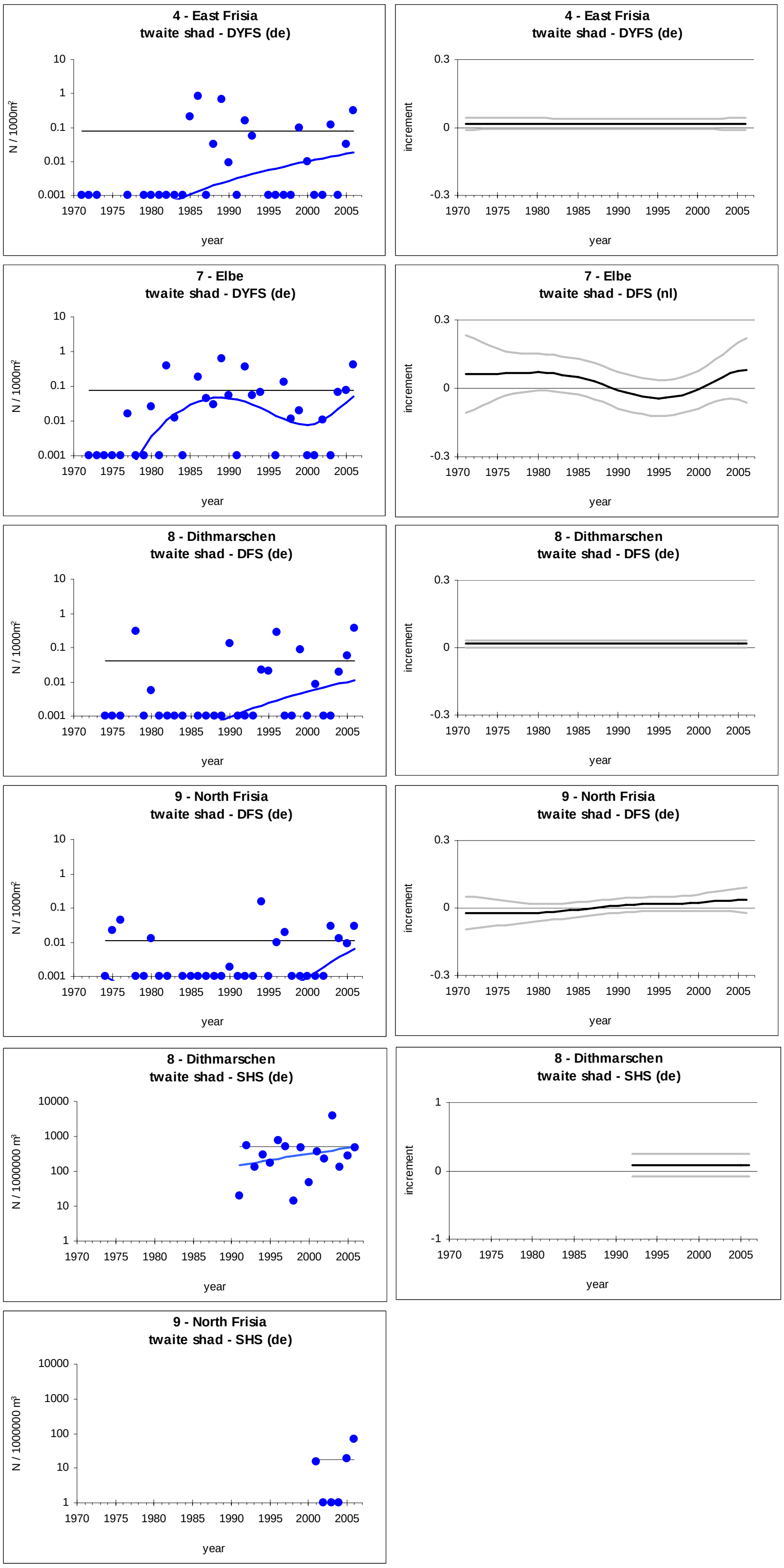

Figure 3.3.1. continued.

3.3.2 Smelt (*Osmerus eperlanus*)

Smelt was frequently caught in all surveys. The long-term average ranged between 0.5 and 12 $*10^{-3}m^{-2}$ for the beam trawl surveys (DFS and DYFS), with the highest abundance in western Dutch Wadden Sea and the lowest abundance in North Frisia (Figure 3.3.2). The long-term average for the SHS was much higher in Dithmarschen (2900 $*10^{-6}m^{-3}$) than in North Frisia (200 $*10^{-6}m^{-3}$).

In the western Dutch Wadden Sea, Ems Dollard and Elbe, the abundance of smelt increased in the 1970s and early 1980s followed by a decline since 1985 (Figure 3.3.2). However, the negative trend was not significant (Table 3.3.2) and present catch rates are significantly higher than at the beginning of the survey (statistics not presented). No clear trends were observed in the eastern Dutch Wadden Sea and East Frisia. In Dithmarschen and North Frisia, the DYFS catches significantly increased during the full time span of the survey, whereas in the SHS no trend or a significant decrease in the most recent years was observed (Table 3.3.2).

Table 3.3.2. Smelt. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available for SHS in QSR area 9.

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									increase>decrease
DFS (nl)	2									no significant trend
DFS (nl)	3									increase>decrease
DYFS (de)	4									no significant trend
DYFS (de)	7									increase>decrease
DYFS (de)	8									increase
DYFS (de)	9									increase
SHS (de)	8									decrease
SHS (de)	9									no trend

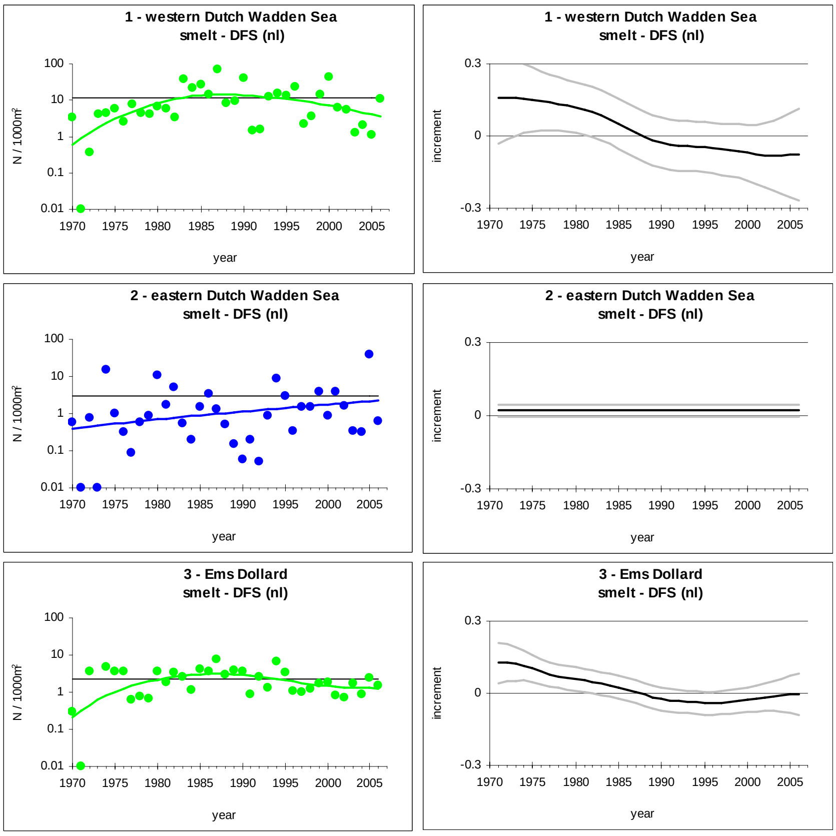

Figure 3.3.2. Smelt. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$ (DFS & DYFS) or $n/10^6m^3$ (SHS). Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

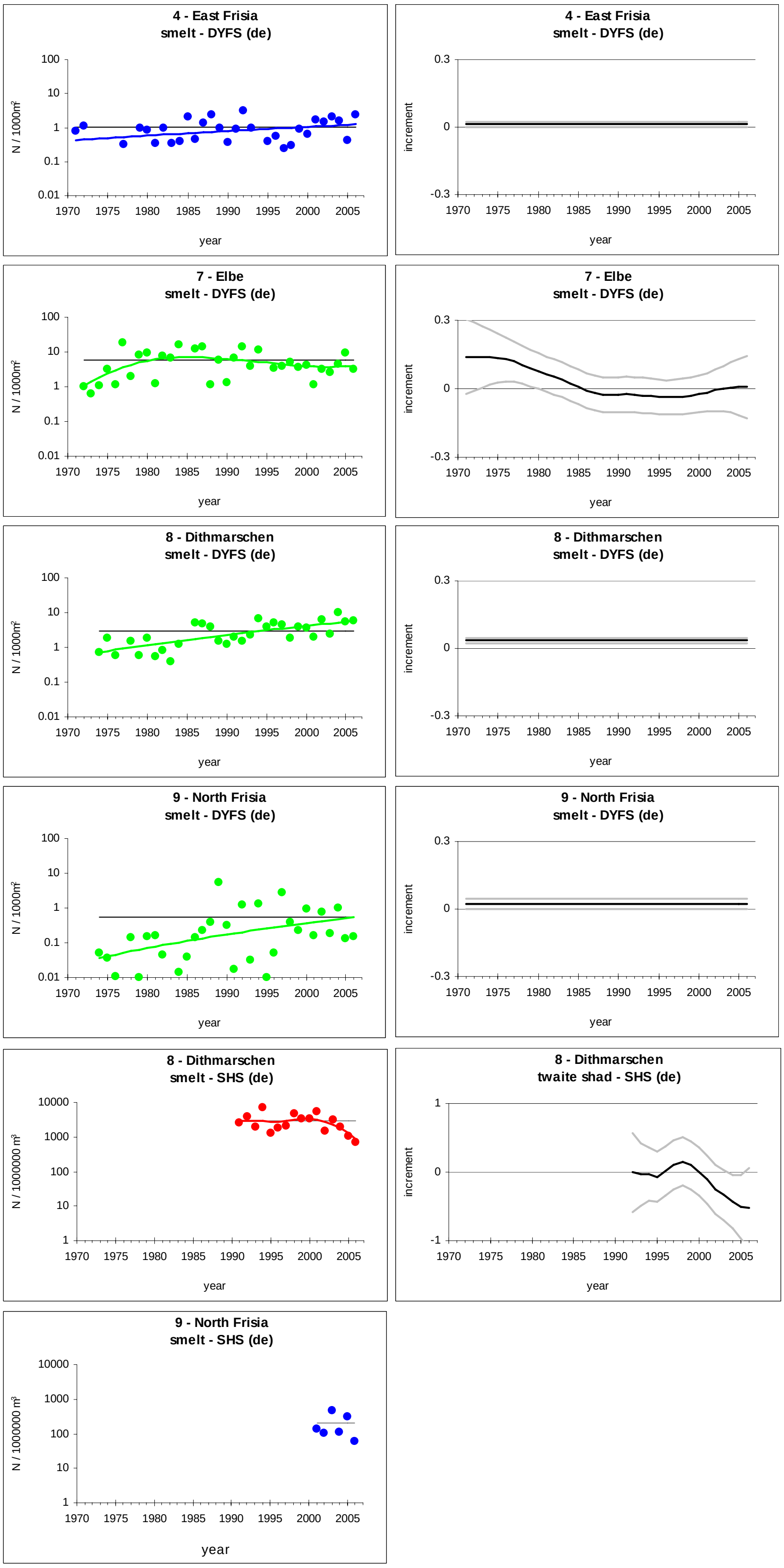

Figure 3.3.2. continued.

3.3.3 Flounder (*Platichthys flesus*)

Flounder was frequently caught in beam trawl surveys (DFS and DYFS) and in the SHS in Dithmarschen, but was less abundant in the SHS samples in North Frisia (Figure 3.3.3). The long-term average for the beam trawl surveys ranged from 0.3 in North Frisia to 3 $*10^{-3}m^{-2}$ in the Elbe. The long-term average for the SHS was much higher in Dithmarschen (1400 $*10^{-6}m^{-3}$) than in North Frisia (2 $*10^{-6}m^{-3}$).

The beam trawl surveys showed a significant increase in the abundance of flounder in the Ems Dollard, Elbe and Dithmarschen (Figure 3.3.3). However, the period of increase differed between the areas; it occurred between 1995 and 2005 in the Ems Dollard, between 1974 and 1985 in the Elbe, and during the whole time series in Dithmarschen (Table 3.3.3). No significant trends were observed in the other areas of the beam trawl surveys, nor in the SHS.

Table 3.3.3. Flounder. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available for SHS in QSR area 9.

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									no trend
DFS (nl)	2									no trend
DFS (nl)	3									increase
DYFS (de)	4									no significant trend
DYFS (de)	7									increase
DYFS (de)	8									increase
DYFS (de)	9									no significant trend
SHS (de)	8									no significant trend
SHS (de)	9									no trend

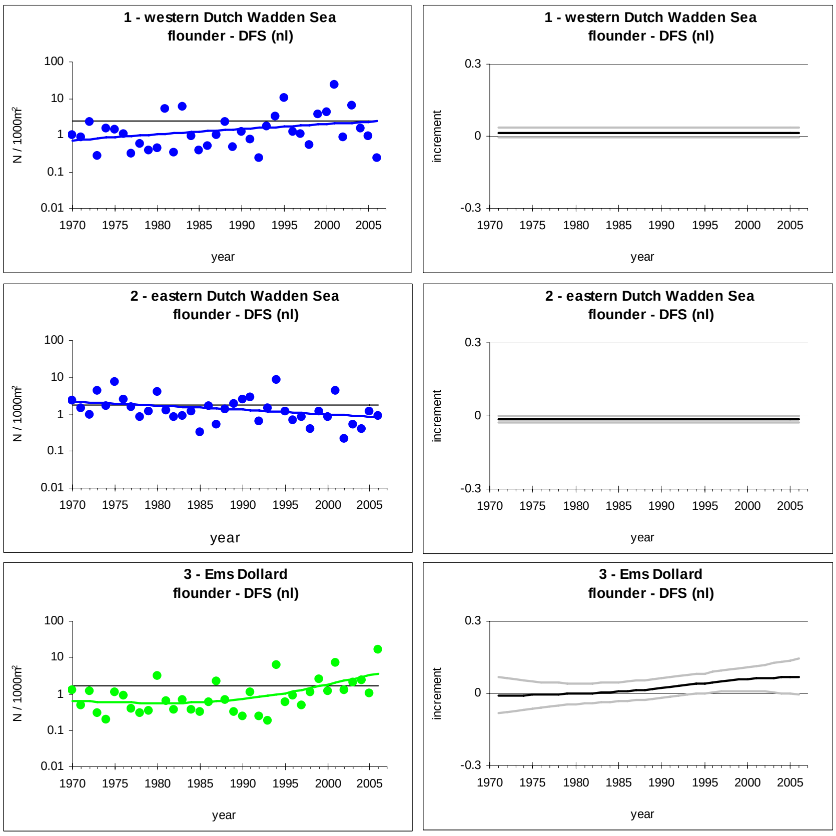

Figure 3.3.3. Flounder. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$ (DFS & DYFS) or $n/10^6m^3$ (SHS). Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

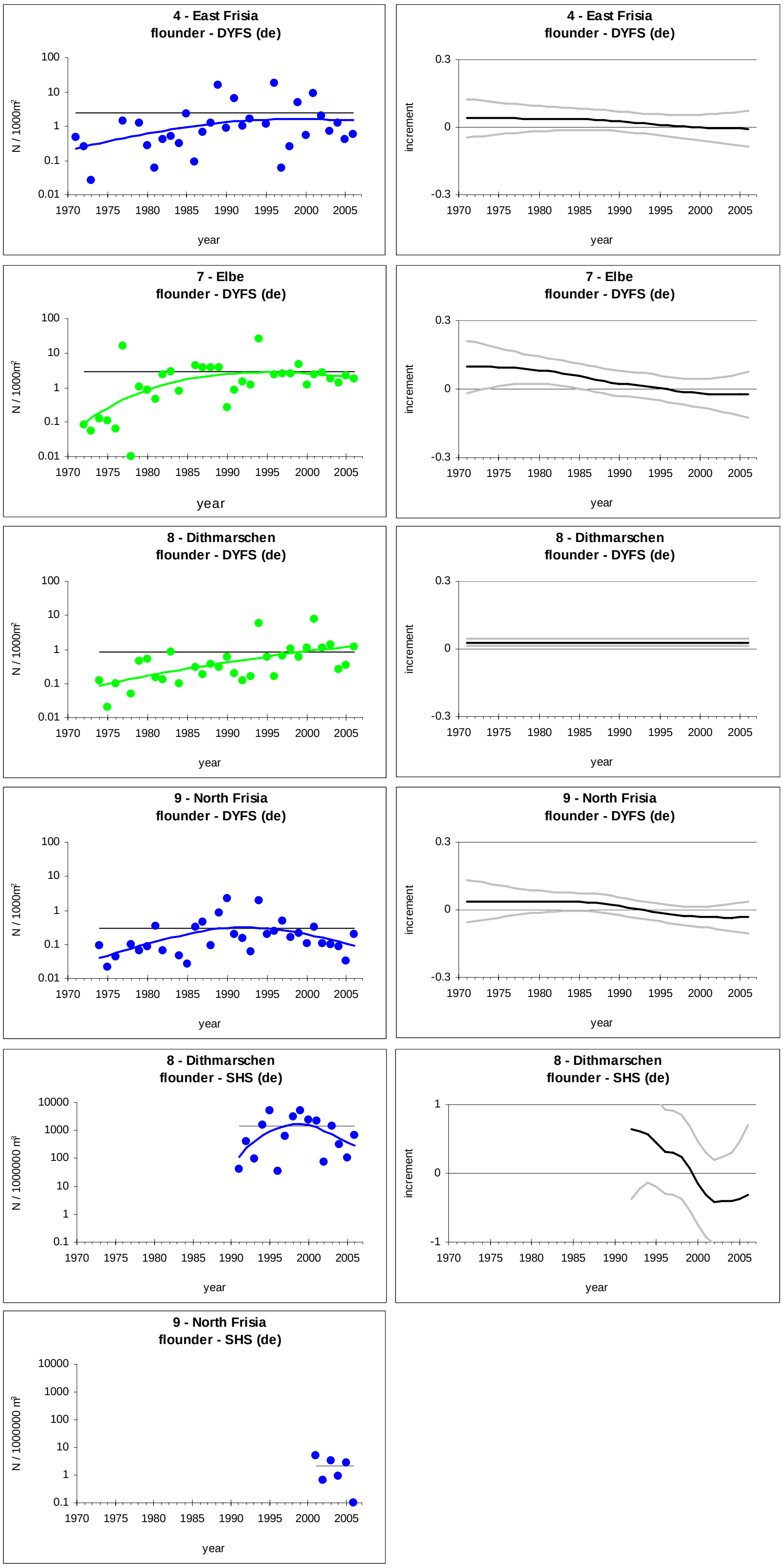

Figure 3.3.3. continued.

3.3.4 Eelpout (*Zoarces viviparous*)

Eelpout was frequently caught in all areas of the beam trawl surveys (DFS and DYFS). The long-term average ranged between 0.4 and 4 $*10^{-3}m^{-2}$, with the highest abundance in western Dutch Wadden Sea and the lowest abundance in the 3 northernmost areas (QSR areas 7-9; Figure 3.3.4).

The abundance of eelpout fluctuated (Figure 3.3.4). For all areas except the Elbe, the overall trend observed was a decline (Figure 3.3.4 and Table 3.3.4), with significantly lower catch rates at present than at the beginning of the beam trawl surveys (statistics not presented). The fluctuations in abundance were more pronounced in some areas than in others, nevertheless a similar pattern can be detected with relatively high catch rates in the (early) 1980s and relatively low catch rates in the early 1990s (Figure 3.3.4).

Table 3.3.4. Eelpout. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available).

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									decrease
DFS (nl)	2									increase<decrease
DFS (nl)	3									increase<decrease
DYFS (de)	4									increase<decrease
DYFS (de)	7									no significant trend
DYFS (de)	8									increase<decrease
DYFS (de)	9									decrease

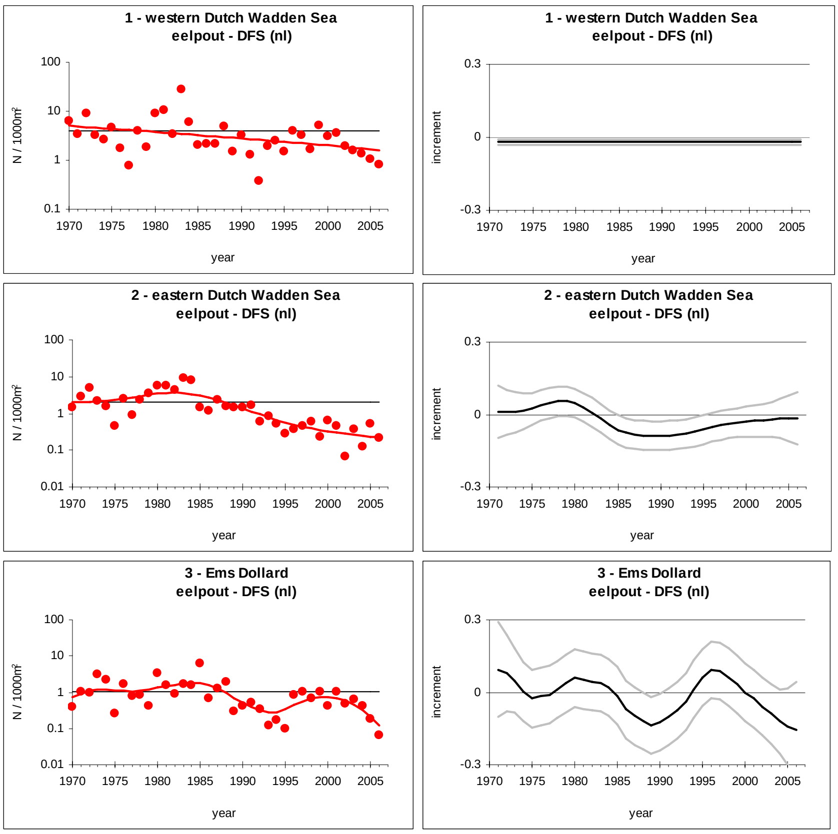

Figure 3.3.4. Eelpout. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

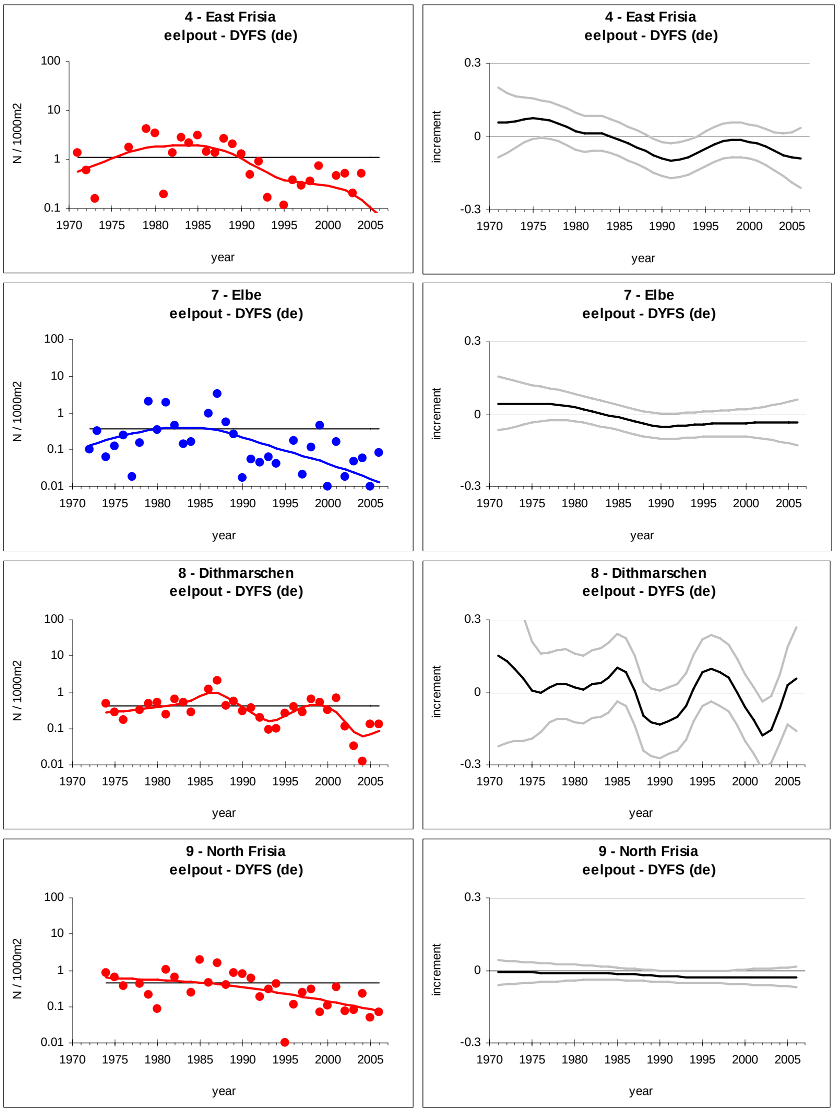

Figure 3.3.4. continued.

3.3.5 Sandeel (*Ammodytes sp.*)

Catch rates of sandeel were low and highly variable in the beam trawl surveys (DFS and DYFS). The long-term average ranged from 0.01 in Dithmarschen to 0.2 $*10^{-3}m^{-2}$ in the western Dutch Wadden Sea (Figure 3.3.5).

No clear trends in the abundance of sandeel were observed (Figure 3.3.5), with the exception of an increase in the Elbe between 1982 and 1987 (Table 3.3.5). This increase, however, was driven by 8 years of zero catches in 1974-1981, which might be suspect taking into account the fact the DYFS data collected prior have not yet been quality controlled (see section 2.1.2). For all areas including the Elbe, present catch rates were not significantly different from the catch rates at the beginning of the surveys (statistics not presented).

Table 3.3.5. Sandeel. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available).

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									no trend
DFS (nl)	2									no trend
DFS (nl)	3									no trend
DYFS (de)	4									no significant trend
DYFS (de)	7									increase=decrease
DYFS (de)	8									no trend
DYFS (de)	9									no trend

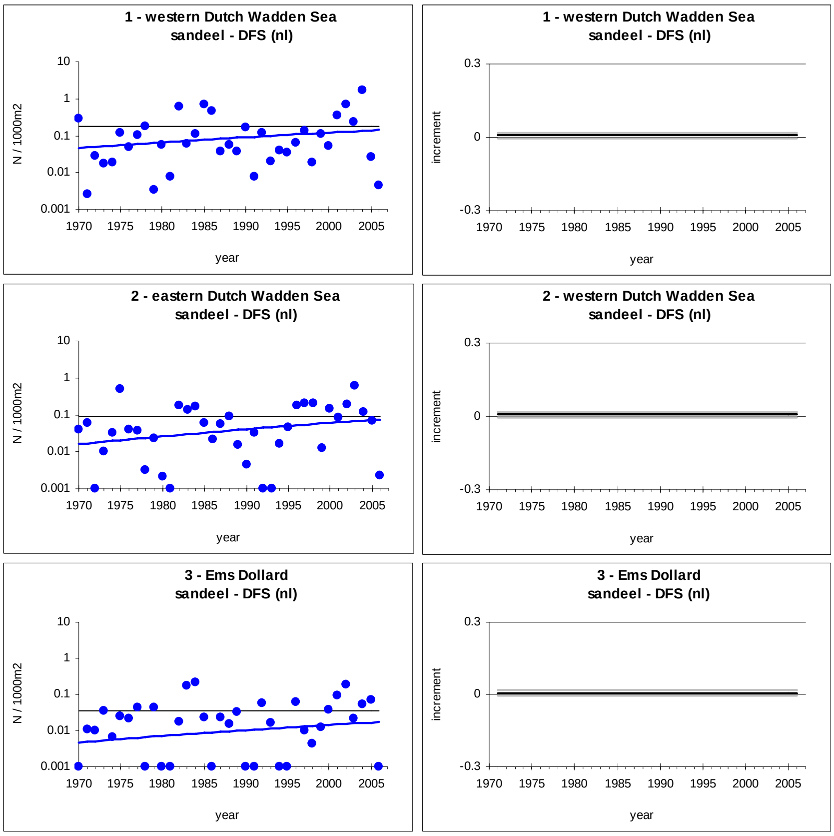

Figure 3.3.5. Sandeel. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

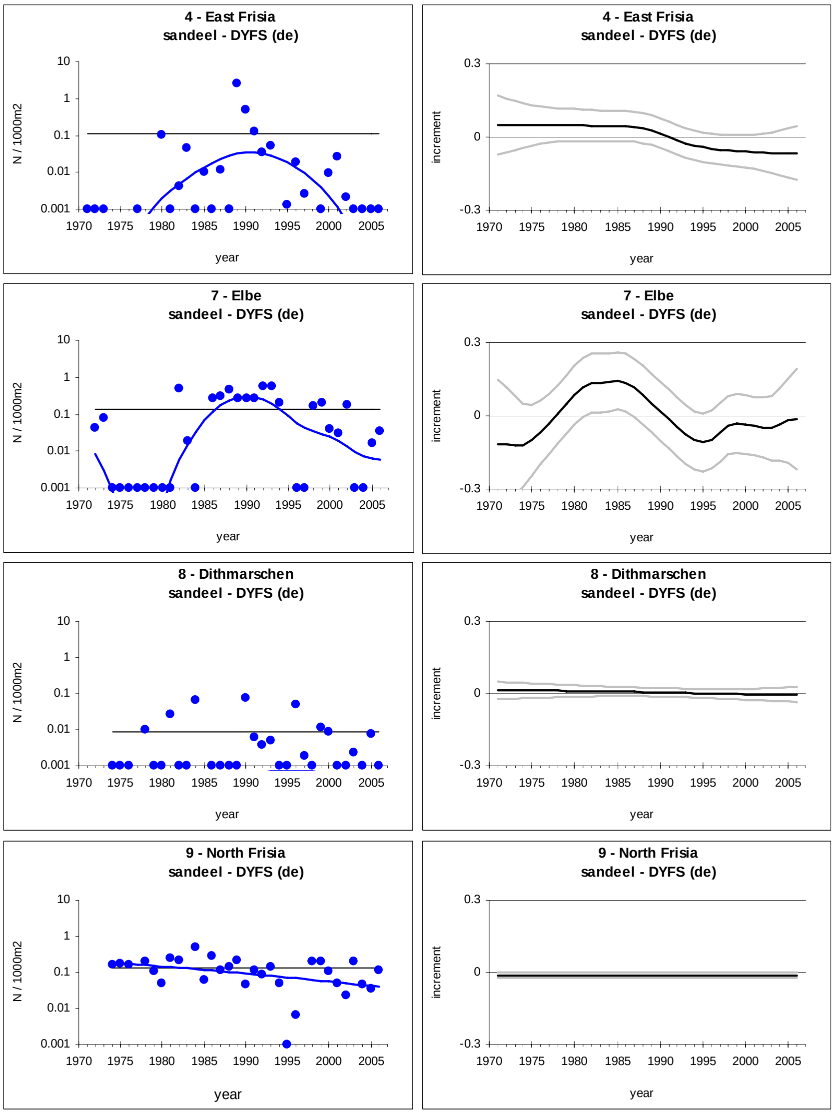

Figure 3.3.5. continued.

3.3.6 Plaice (*Pleuronectes platessa*)

Plaice is an abundant species in the Wadden Sea. The long-term average catch rate in the beam trawl surveys (DFS and DYFS) ranged between 11 and 43 $*10^{-3}m^{-2}$, with the highest abundance in western Dutch Wadden Sea and the lowest abundance in North Frisia (Figure 3.3.6).

In the southern Wadden Sea (QSR areas 1-4), the abundance of plaice increased until the mid-1980s and declined thereafter (Figure 3.3.6). These trends were significant except for the increase in the eastern Dutch Wadden Sea and the decrease in the Ems Dollard (Table 3.3.6). Over the whole time series, the increase more or less equalled the decrease, except in the eastern Dutch Wadden Sea, where present catch rates were significantly lower than at the beginning of the survey (statistics not presented). No clear trends were observed in the northern Wadden Sea (QSR areas 7-9; Figure 3.3.6).

Table 3.3.6. Plaice. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available).

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									increase=decrease
DFS (nl)	2									increase<decrease
DFS (nl)	3									increase=decrease
DYFS (de)	4									increase=decrease
DYFS (de)	7									no significant trend
DYFS (de)	8									no significant trend
DYFS (de)	9									no significant trend

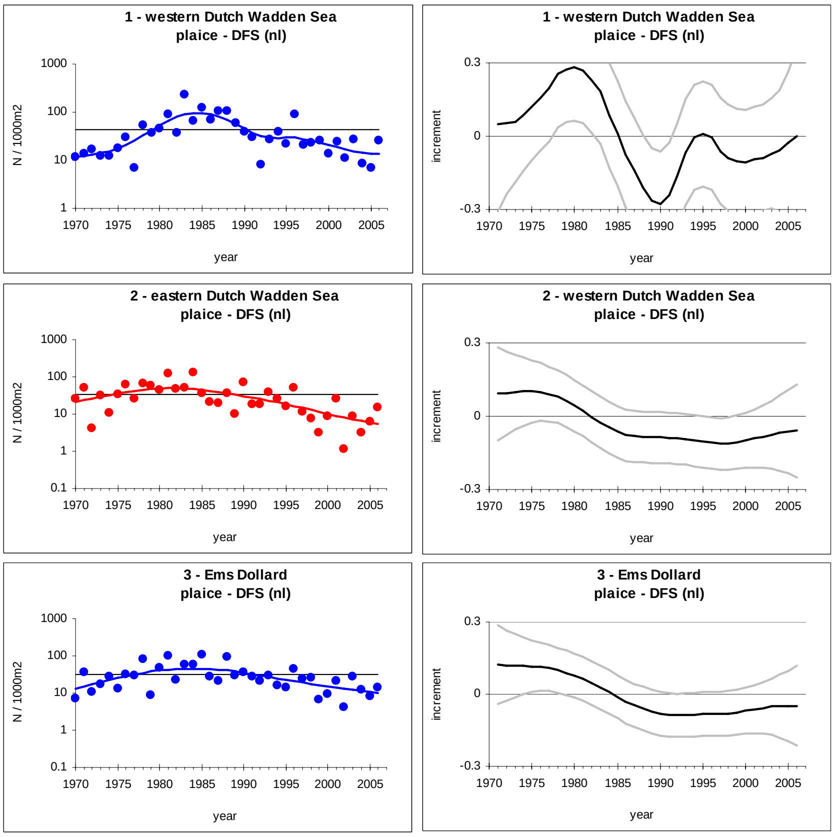

Figure 3.3.6. Plaice. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

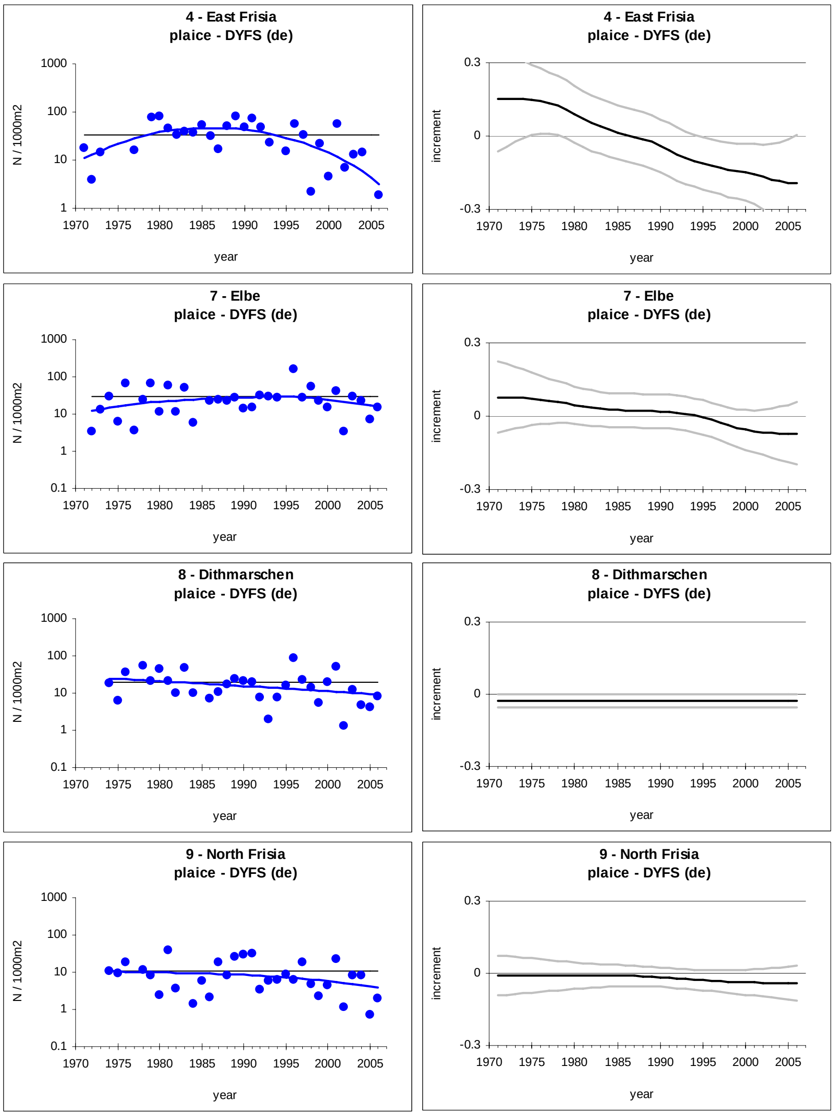

Figure 3.3.6. continued.

3.3.7 Sole (*Solea solea*)

Sole was frequently caught in all areas of the beam trawl surveys (DFS and DYFS). The long-term average ranged from 0.4 in North Frisia to 9 $*10^{-3}m^{-2}$ in the Ems Dollard (Figure 3.3.7).

In all areas except the Ems Dollard, the abundance of sole significantly decreased (Table 3.3.7) and present catch rates are significantly lower than at the beginning of the surveys (statistics not presented). The smoothed trends indicated a gradual decline in the western and eastern Dutch Wadden Sea and in North Frisia, whereas they indicated a marked decline in the 1980s or 1990s preceded by an increase for East Frisia, Elbe and Dithmarschen (Figure 3.3.7). Although it was not always detected by the trend analyses, a pattern of relatively high catch rates before 1990 and relatively low catch rates after 1990 can be observed in all areas.

Table 3.3.7. Sole. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available).

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									decrease
DFS (nl)	2									decrease
DFS (nl)	3									no significant trend
DYFS (de)	4									increase<decrease
DYFS (de)	7									increase<decrease
DYFS (de)	8									increase<decrease
DYFS (de)	9									decrease

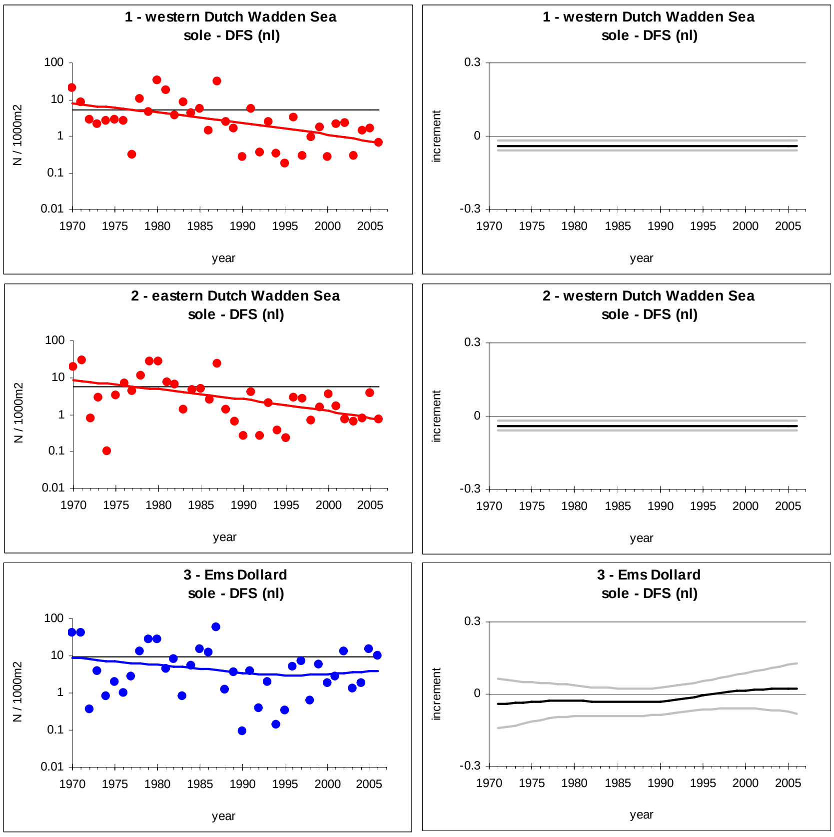

Figure 3.3.7. Sole. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

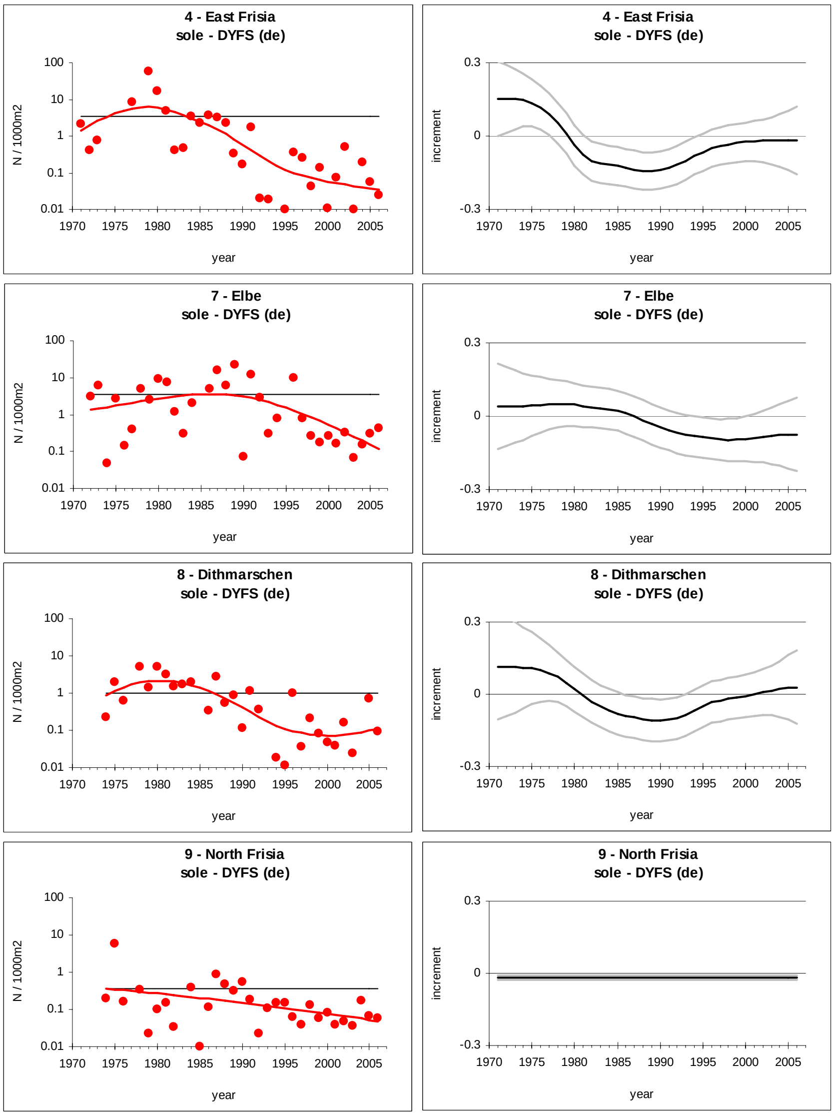

Figure 3.3.7. continued.

3.3.8 Dab (*Limanda limanda*)

Dab used to be abundant in the Wadden Sea, with an average catch rate in the period 1970-1989 ranging from 18 in the Elbe to 64 $*10^{-3}m^{-2}$ in East Frisia. Present day catch rates (average 2000-2006) are much lower ranging from 0.1 in eastern Dutch Wadden Sea to 5 $*10^{-3}m^{-2}$ in the western Dutch Wadden Sea (Figure 3.3.8).

The abundance of dab has strongly decreased in all Wadden Sea areas. In the period before approximately 1990 a slight decrease (QSR areas 2, 8 and 9), no decrease (QSR areas 1, 3, 7) or even a slight increase (QSR area 4) was observed, but since 1990 the catch rates have dropped dramatically in all areas (Figure 3.3.8).

Table 3.3.8. Dab. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available).

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									decrease
DFS (nl)	2									decrease
DFS (nl)	3									decrease
DYFS (de)	4									increase<decrease
DYFS (de)	7									decrease
DYFS (de)	8									decrease
DYFS (de)	9									decrease

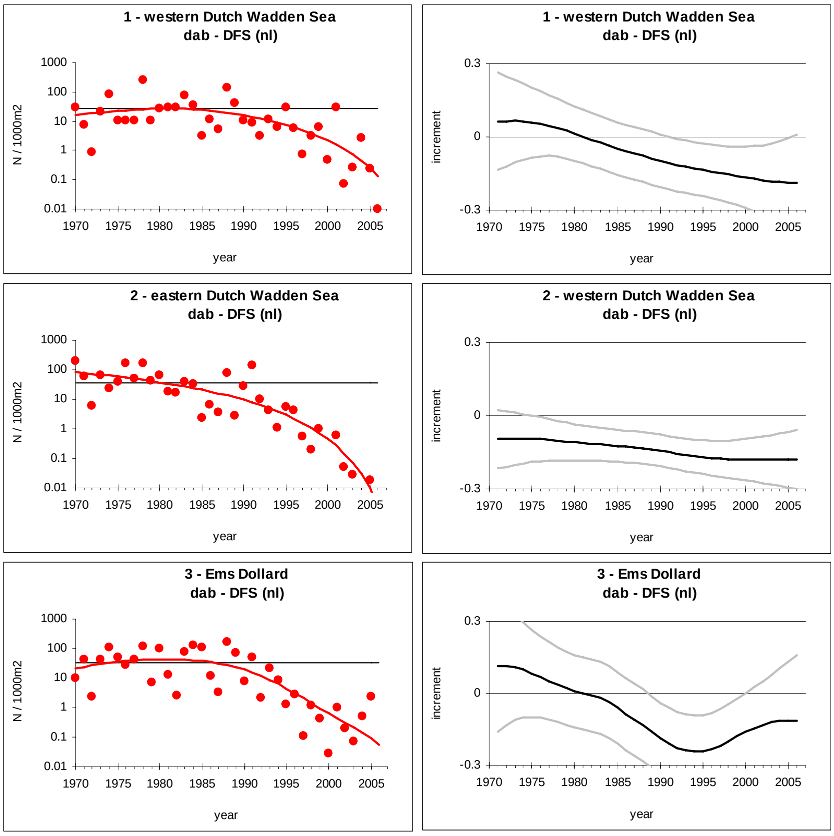

Figure 3.3.8. Dab. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

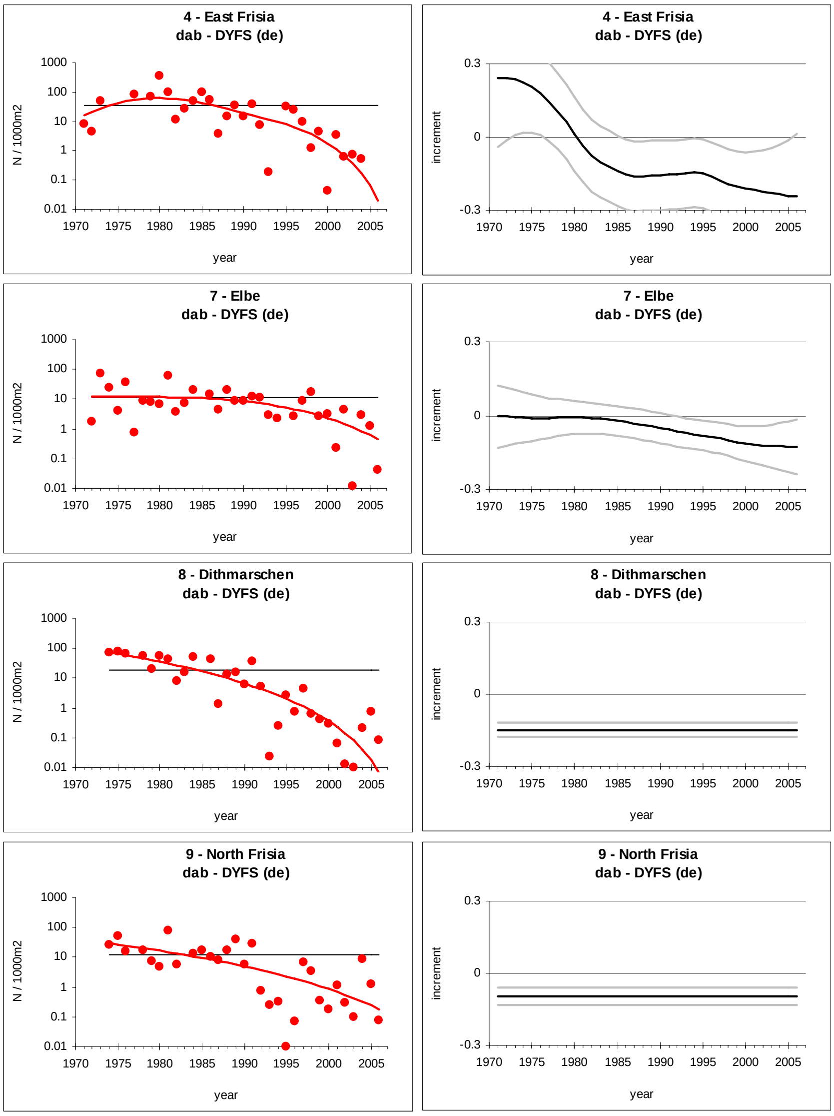

Figure 3.3.8. continued.

3.3.9 Cod (*Gadus morhua*)

Cod was frequently caught in all areas of the beam trawl surveys (DFS and DYFS). The long-term average ranged between 0.1 and 2 $*10^{-3}m^{-2}$, with the lowest abundance in the western Dutch Wadden Sea and the highest abundance in the Elbe (Figure 3.3.9).

In QSR areas 1-7, the beam trawl surveys recorded low catch rates in the early 1970s and relatively high catch rates in the late 1970s (Figure 3.3.9). This increase was significant in QSR areas 2, 4 and 7 (Table 3.3.9). In Schleswig-Holstein (QSR areas 8-9) no increase in the 1970s was observed as no sampling was carried before 1974 (Figure 3.3.9). In all areas the abundance declined since 1980 (Figure 3.3.9) and this decrease was significant in all areas except the western Dutch Wadden Sea and the Elbe (Table 3.3.9). Present catch rates were significantly lower than at the beginning of the survey for all areas except the western Dutch Wadden Sea, East Frisia and the Elbe (statistics not presented).

Table 3.3.9. Cod. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available).

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									no significant trend
DFS (nl)	2									increase<decrease
DFS (nl)	3									increase<decrease
DYFS (de)	4									increase=decrease
DYFS (de)	7									increase=decrease
DYFS (de)	8									decrease
DYFS (de)	9									decrease

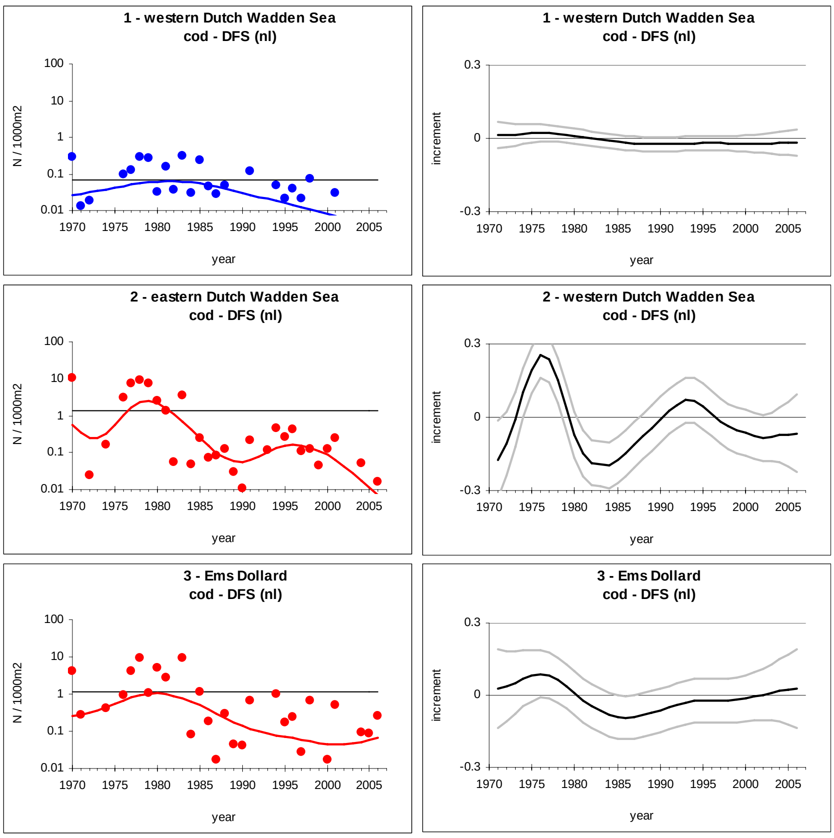

Figure 3.3.9. Cod. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

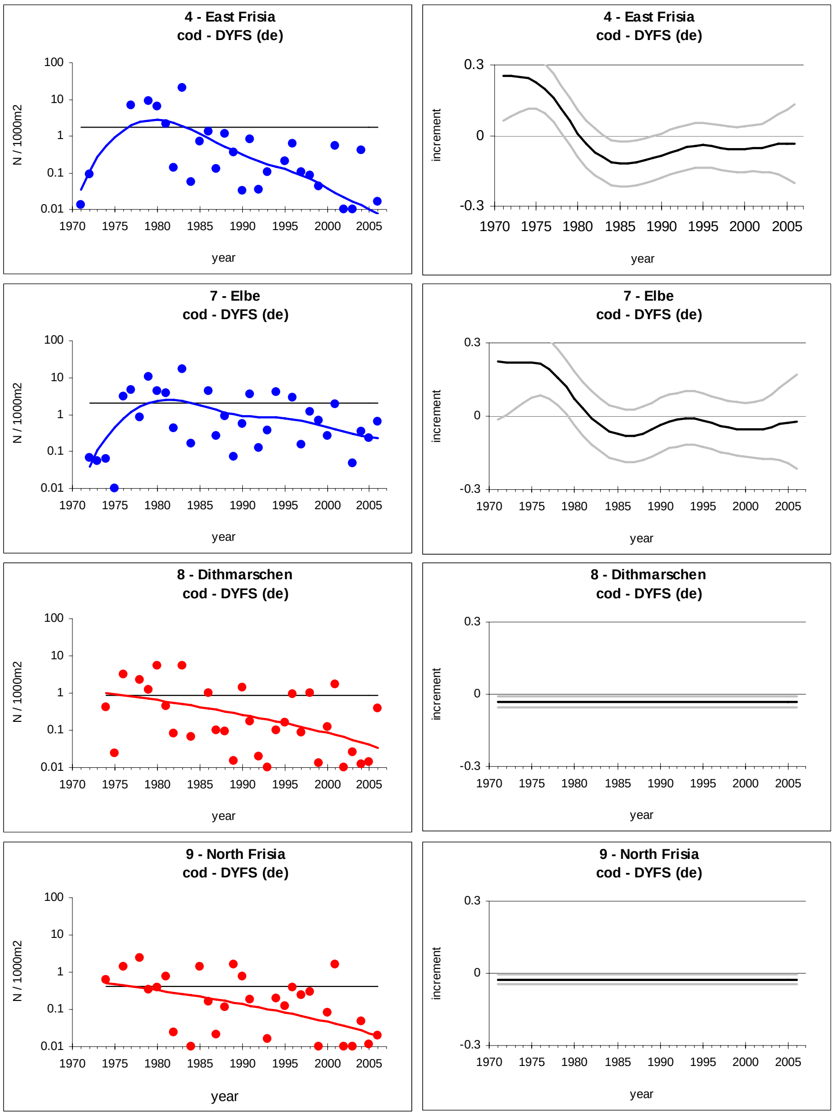

Figure 3.3.9. continued.

3.3.10 Whiting (*Merlangius merlangus*)

Whiting was frequently caught in all areas of the beam trawl surveys (DFS and DYFS). The long-term average ranged between 0.8 and 3 $*10^{-3}m^{-2}$, with the lowest abundance in the western and the highest abundance in the eastern Dutch Wadden Sea (Figure 3.3.10).

In QSR areas 1-7, the abundance of whiting appeared to increase until the mid 1980s, followed by a decrease (Figure 3.3.10). In the Dutch Wadden Sea (QSR areas 1-3) the negative trend was significant (Table 3.3.10) and present catch rates were significantly lower than at the beginning of the survey (statistics not presented). In East Frisia the positive trend was significant, but only in 1 year (Table 3.3.10) and present catch rates did not differ significantly from those at the beginning of the survey (statistics not presented). In the other areas (QSR areas 7-9), no significant trends were observed (Table 3.3.10).

Table 3.3.10. Whiting. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available).

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									increase<decrease
DFS (nl)	2									increase<decrease
DFS (nl)	3									increase<decrease
DYFS (de)	4									increase=decrease
DYFS (de)	7									no significant trend
DYFS (de)	8									no significant trend
DYFS (de)	9									no trend

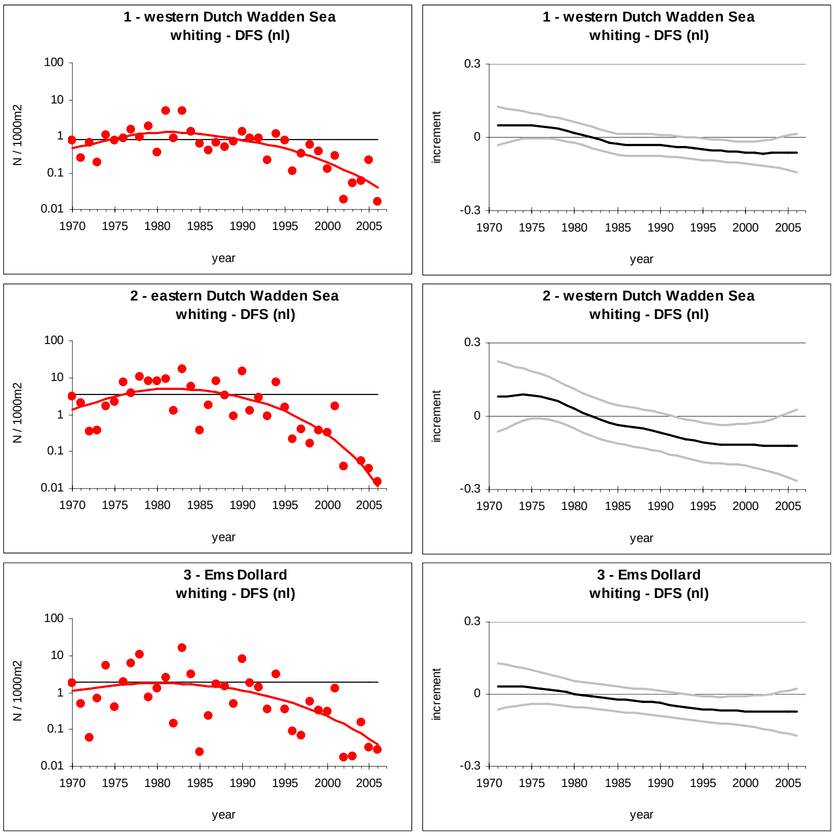

Figure 3.3.10. Whiting. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

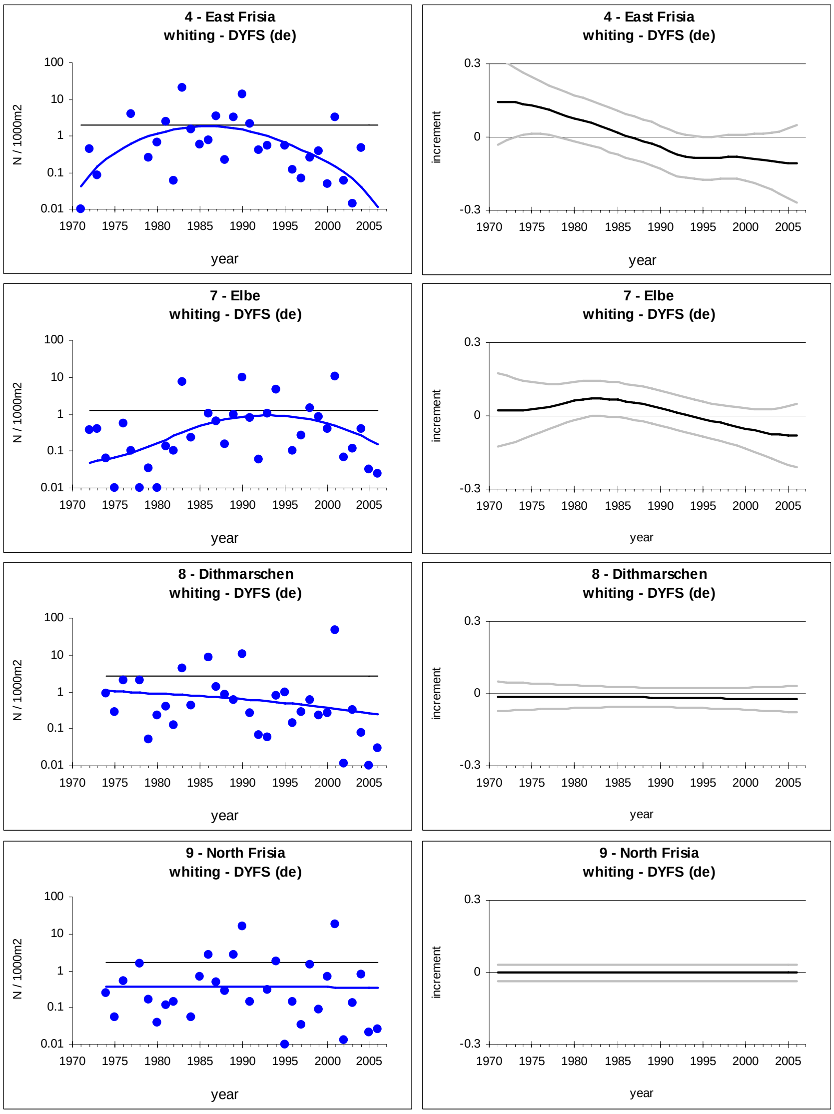

Figure 3.3.10. continued.

3.3.11 Herring (*Clupea harengus*)

Herring was frequently caught in all areas of the beam trawl surveys (DFS and DYFS). The long-term average ranged from 0.7 in Schleswig-Holstein (QSR areas 8-9) to 12 $*10^{-3}m^{-2}$ in the western Dutch Wadden Sea (Figure 3.3.11). Herring was very abundant in the SHS catches (24000 - 68000 $*10^{-6}m^{-3}$).

In QSR areas 1-7, the abundance of herring significantly increased in the 1970s and early 1980s (Table 3.3.11). This increase appeared to be followed by a decrease (Figure 3.3.11), but the downward trend was only significant in East Frisia (Table 3.3.11) and present catch rates were higher than at beginning of the survey for all of these areas except East Frisia (statistics not presented). A similar pattern was observed in the DYFS in QSR areas 8-9 and in the SHS in QSR area 8 (Figure 3.3.11), but here none of the trends were significant (Table 3.3.11). No trend was observed in SHS time-series for QSR area 9 (Figure 3.3.11).

Table 3.3.11. Herring. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available for SHS in QSR area 9.

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									increase>decrease
DFS (nl)	2									increase>decrease
DFS (nl)	3									increase>decrease
DYFS (de)	4									increase=decrease
DYFS (de)	7									increase>decrease
DYFS (de)	8									no significant trend
DYFS (de)	9									no significant trend
SHS (de)	8									no significant trend
SHS (de)	9									no trend

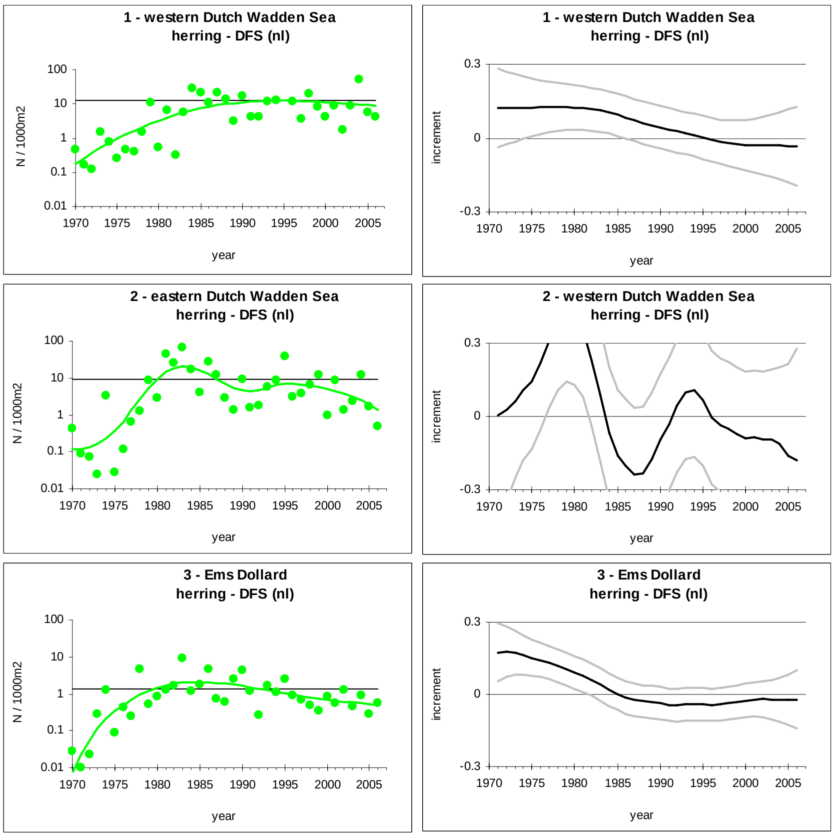

Figure 3.3.11. Herring. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$ (DFS & DYFS) or $n/10^6m^3$ (SHS). Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

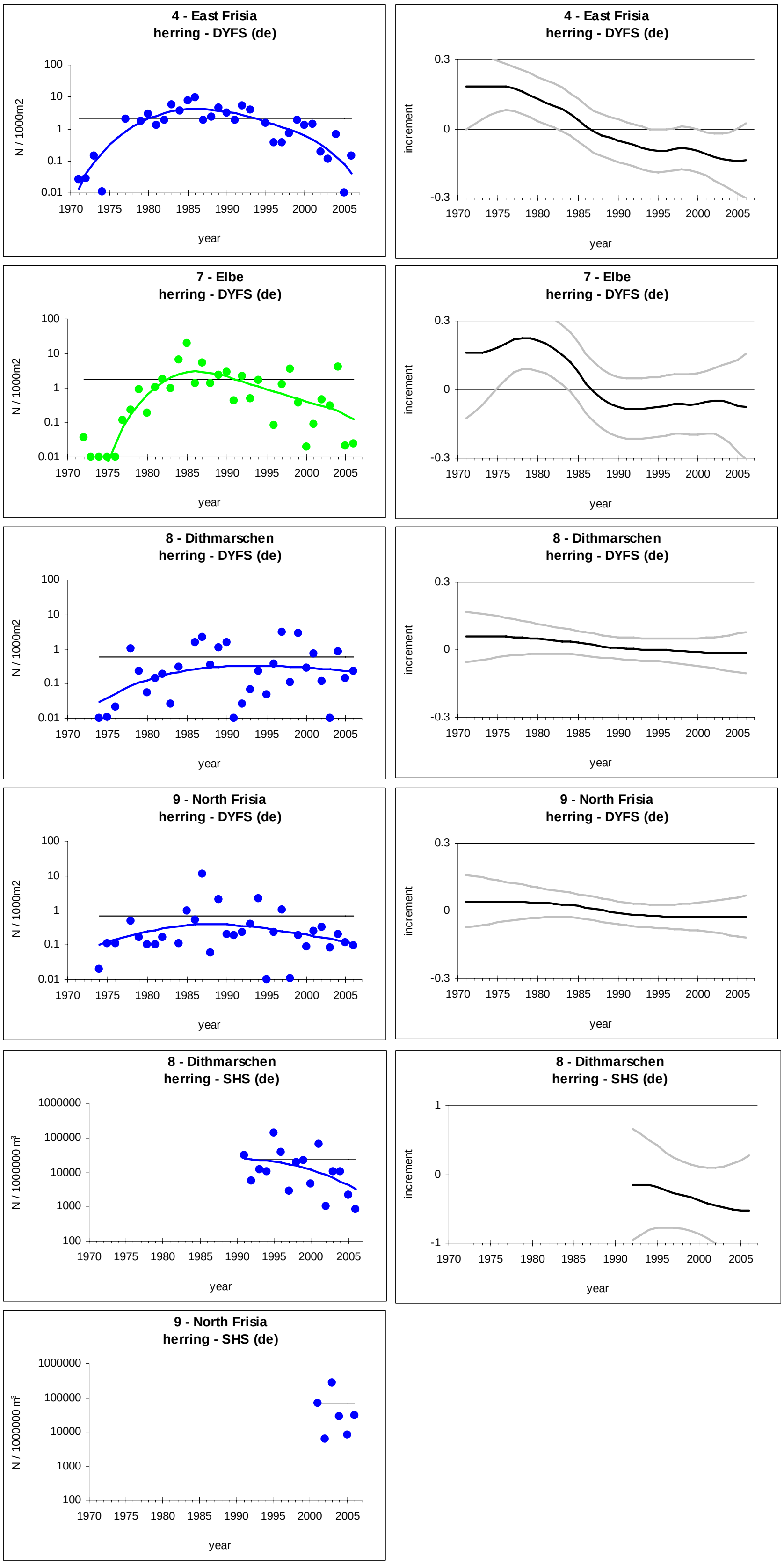

Figure 3.3.11. continued.

3.3.12 Sprat (*Sprattus sprattus*)

Sprat was frequently caught in all areas of the beam trawl surveys (DFS and DYFS). The long-term average ranged from 0.5 in the Elbe to 3 $*10^{-3}m^{-2}$ in the western Dutch Wadden Sea (Figure 3.3.12). In the SHS, sprat was very abundant in Dithmarschen (16000 $*10^{-6}m^{-3}$), but less abundant in North Frisia (2000 $*10^{-6}m^{-3}$).

In QSR areas 1-7, the abundance of sprat appeared to increase until approximately 1985 followed by a decline (Figure 3.3.12). However, although the upward trend in QSR areas 2, 4 and 7 was significant (Table 3.3.12), present catch rates were not significantly different from the catch rates at the beginning of the surveys (statistics not presented). In Schleswig-Holstein (QSR areas 8-9), no clear trends were observed in the DYFS data, whereas a strong decline in the most recent years was observed in the SHS data (Figure 3.3.12 and Table 3.3.12).

Table 3.3.12. Sprat. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available for SHS in QSR area 9.

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	1									no significant trend
DFS (nl)	2									increase=decrease
DFS (nl)	3									no significant trend
DYFS (de)	4									increase=decrease
DYFS (de)	7									increase=decrease
DYFS (de)	8									no significant trend
DYFS (de)	9									no significant trend
SHS (de)	8									decrease
SHS (de)	9									decrease?

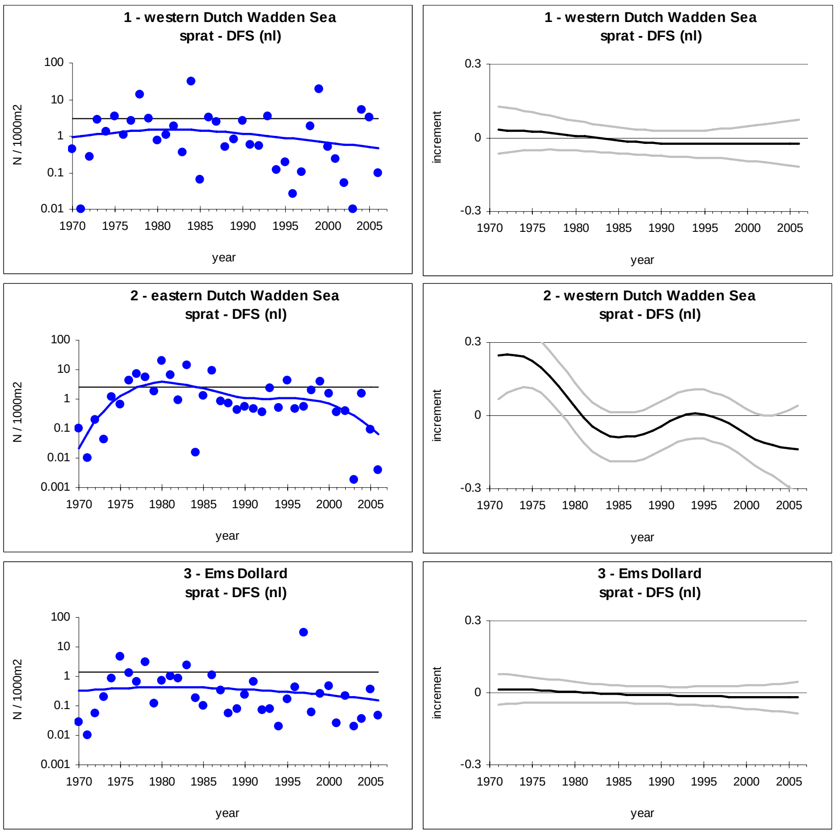

Figure 3.3.12. Sprat. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^3m^2$ (DFS & DYFS) or $n/10^6m^3$ (SHS). Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

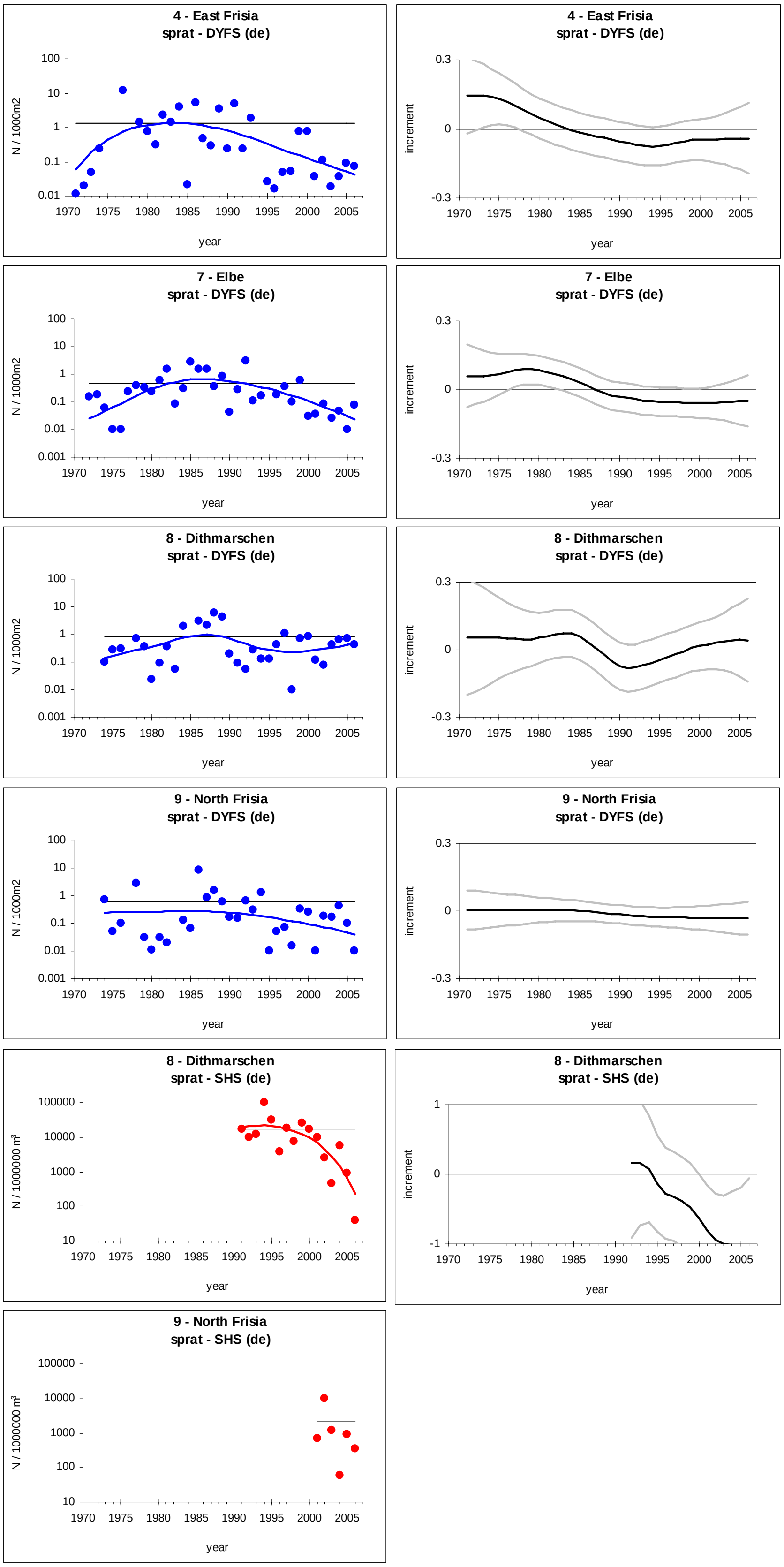

Figure 3.3.12. continued.

3.3.13 Anchovy (*Engraulis encrasicolus*)

Anchovy was caught sporadically during the beam trawl surveys (DFS and DYFS), therefore only the SHS was included in the trend analyses. In the SHS, anchovy was caught in several years, with a long-term average of 160 $*10^{6}m^{-3}$ in Dithmarschen and 510 $*10^{6}m^{-3}$ in North Frisia.

The presence of anchovy in the SHS catches in Dithmarschen appeared to increase, but the trend was not significant (Figure 3.3.13 and Table 3.3.13). No trend was visible in the SHS data for North Frisia (Figure 3.3.13).

Table 3.3.13. Anchovy. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available for QSR area 9.

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
SHS (de)	8									no significant trend
SHS (de)	9									no trend

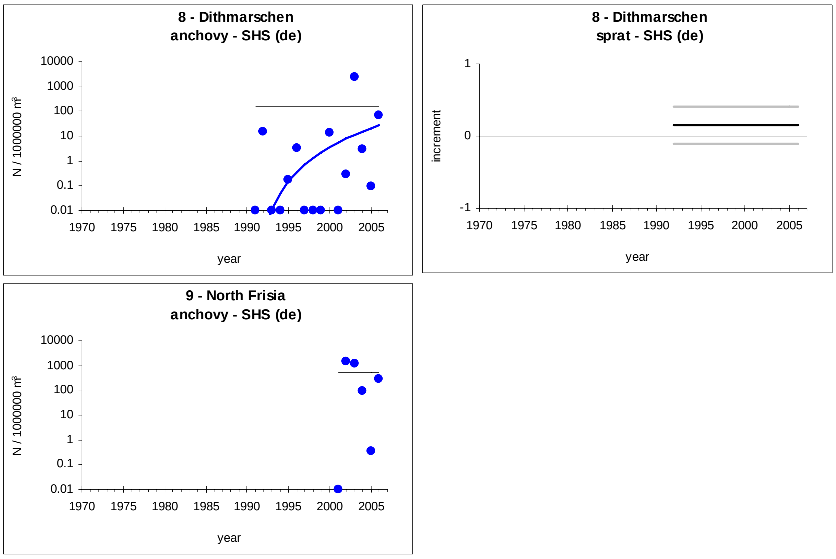

Figure 3.3.13. Anchovy. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^{6}m^{3}$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

3.3.14 River Lamprey (*Lampetra fluviatilis*)

River lamprey was caught sporadically during the beam trawl surveys (DFS and DYFS), therefore only the SHS was included in the trend analyses. Catch rates were low in Dithmarschen (4 $*10^{-6}m^{-3}$) and even lower in North Frisia (0.7 $*10^{-6}m^{-3}$; Figure 3.3.14).

A decline in the abundance of river lamprey was observed in the most recent years (Figure 3.3.14). This decline was significant for Dithmarschen; no statistical trend analysis was available for North Frisia (Table 3.3.14).

Table 3.3.14. River Lamprey. Trends in abundance by year, survey and QSR area (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available for QSR area 9.

Survey	QSR area	1970	1975	1980	1985	1990	1995	2000	2005	overall description
SHS (de)	8									decrease
SHS (de)	9									decrease?

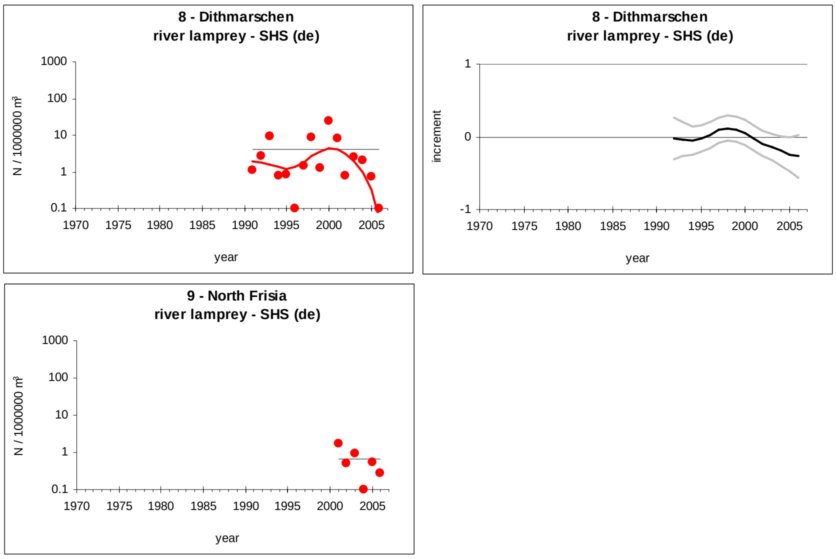

Figure 3.3.14. River lamprey. Left panels: Mean abundance by year (symbols), modelled trend (coloured line) and long-term average (black line) for each QSR area and survey. Abundance in $n/10^6m^3$. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). Right panels: Modelled trend increments with 2 δ confidence limits (transformed data).

3.4 Size composition

Temporal and spatial trends in size composition were examined using mean length as a proxy for size composition (see section 2.5). The mean length by year and the long-term average were plotted for one QSR area in each survey (Figure 3.4.1). Annual means were only included if these were based on at least 5 observations. Furthermore the DYFS data for herring and sprat and for all other species prior to 1996 were unreliable and therefore not included (see section 2.5). Thus, the number of mean length observations in the time-series was often lower than the number of abundance observations, and in some cases too low to allow a statistical analysis of the trend. If TrendSpotter analyses were available, the smoothed trend is plotted in Figure 3.4.1. The significance of a trend was assessed by the confidence limits of the increment estimates, as was done in the abundance analyses (see section 3.3). The trends by year (for the one area in each survey presented in Figure 3.4.1) are summarised in Tables 3.4.1, in which the significance of a trend is indicated by colour codes. An overall description of the trend for the full time span of the survey is given based on the statistical analyses, if available. This overall description is the basis for the colour codes used in Figure 3.4.1.

For most species, no significant changes in mean length occurred and in some cases the smoothed trend even coincided with the long-term average (e.g. smelt in the western Dutch Wadden Sea). The only species which showed a significant trend were flounder, eelpout and plaice (Figure 3.4.1 and Table 3.4.1). The mean length of these 3 species declined in the western Dutch Wadden Sea and a declining trend for flounder was also observed in the SHS. In the DYFS, however, no significant trend was observed for flounder and eelpout and the mean length of plaice significantly increased. This discrepancy between the DFS and DYFS may be a consequence of the fact that the temporal coverage of the DYFS data for mean length was limited to the period 1996-2006, which is after the period in which the greatest decline was observed in the DFS (Figure 3.4.1).

Table 3.4.1. Trends in mean length by year for one QSR area in each survey (green=significant increase, red=significant decrease, grey=no data available). No statistical trend analysis available if number of observations was too small, this is indicated in the overall description.

Twaite shad		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									# observations too small
DYFS (de)	QSR area 8									# observations too small
SHS (de)	QSR area 8									no significant trend

Smelt		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no trend
DYFS (de)	QSR area 8									no significant trend
SHS (de)	QSR area 8									no significant trend

Flounder		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									decrease
DYFS (de)	QSR area 8									no trend
SHS (de)	QSR area 8									decrease

Eelpout		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									decrease
DYFS (de)	QSR area 8									no trend

Sandeel		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no trend
DYFS (de)	QSR area 8									# observations too small

Plaice		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									decrease
DYFS (de)	QSR area 8									increase

Sole		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no significant trend
DYFS (de)	QSR area 8									no trend

Dab		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no significant trend
DYFS (de)	QSR area 8									no trend

Cod		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no significant trend
DYFS (de)	QSR area 8									# observations too small

Whiting		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no significant trend
DYFS (de)	QSR area 8									# observations too small

Herring		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no significant trend
SHS (de)	QSR area 8									no trend

Sprat		1970	1975	1980	1985	1990	1995	2000	2005	overall description
DFS (nl)	QSR area 1									no trend
SHS (de)	QSR area 8									no trend

Anchovy		1970	1975	1980	1985	1990	1995	2000	2005	overall description
SHS (de)	QSR area 8									# observations too small

River lamprey		1970	1975	1980	1985	1990	1995	2000	2005	overall description
SHS (de)	QSR area 8									no trend

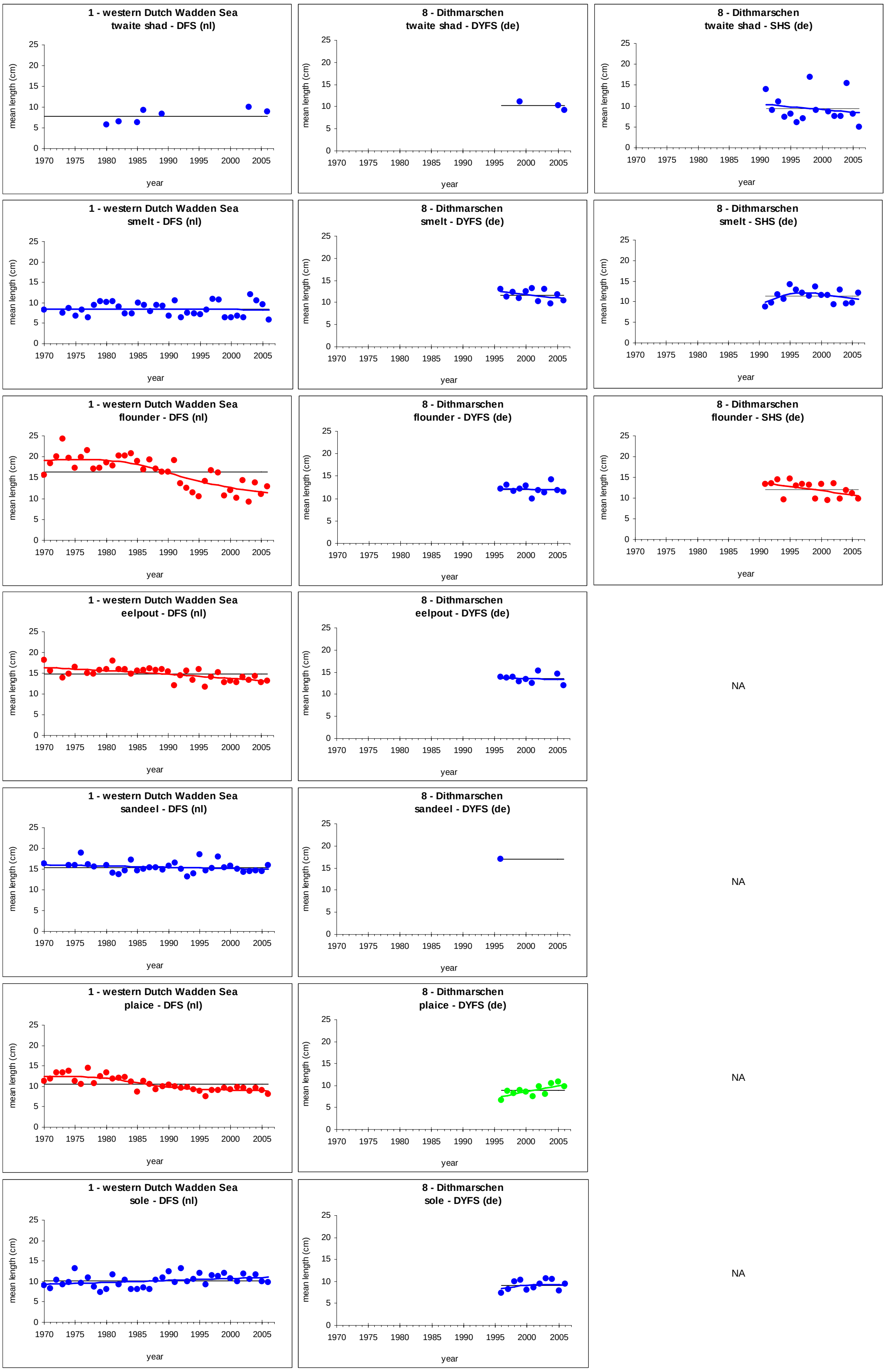

Figure 3.4.1. Mean length (cm) by year (symbols), modelled trend (coloured line) and long-term average (black line) for one QSR area in each survey. Colours indicate interpretation of overall trend (blue=no trend, green=increase, red=decrease). NA = not available.

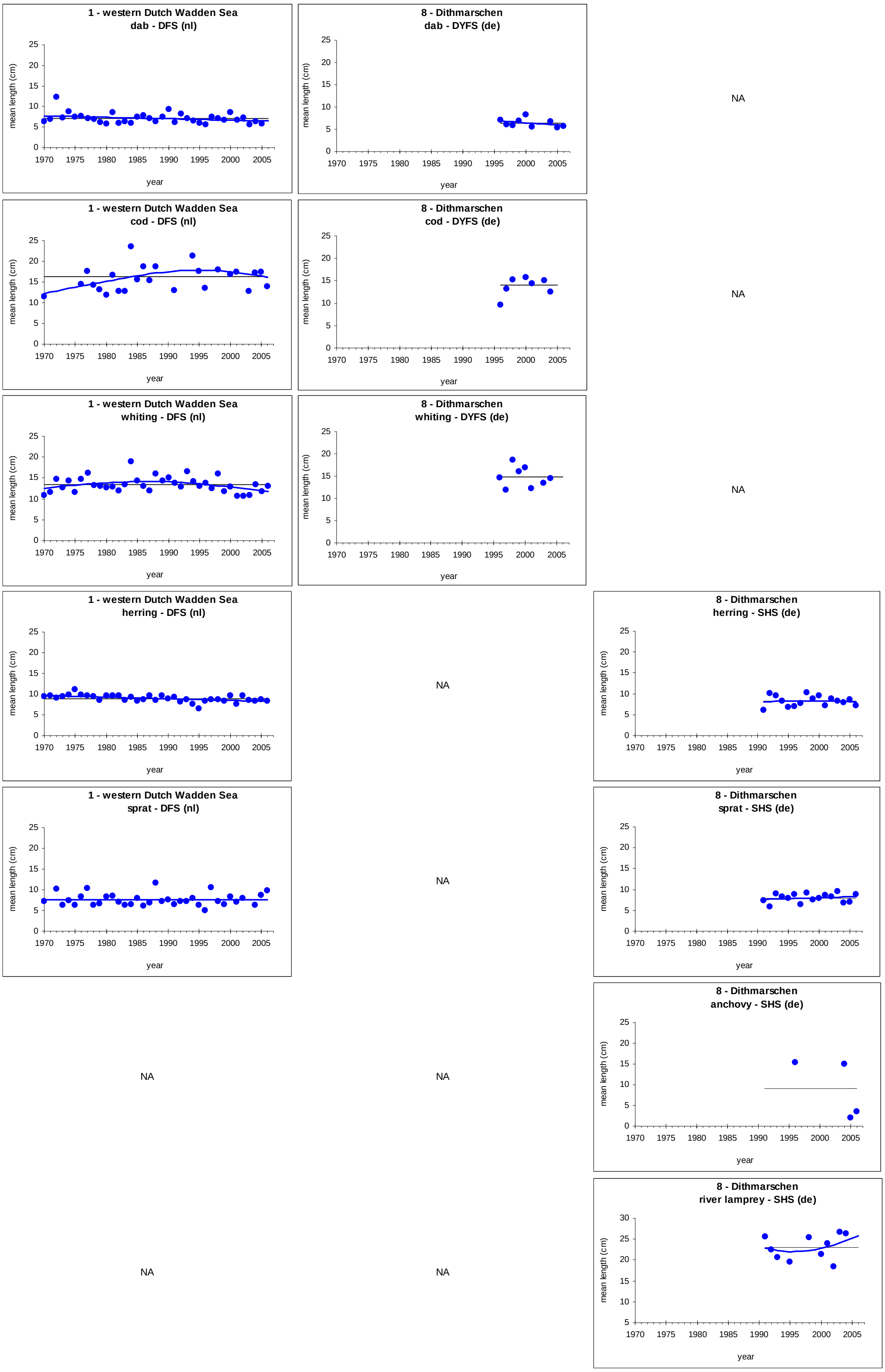

Figure 3.4.1. continued

4 Discussion

4.1 Fish monitoring in the Wadden Sea

Demersal fish sampling in the Wadden Sea by means of beam trawl surveys is quite extensive; at present approximately 300 hauls are done each year covering the Dutch and German Wadden Sea to the isle of Sylt (Figure 2.1.1, Table 2.1.2). The Danish Wadden Sea is not sampled and only the coastal waters bordering the Danish Wadden Sea are sampled during the Dutch Demersal Fish Survey (Table 2.1.1). From a trilateral fish monitoring perspective, this gap in demersal monitoring is regretted.

Although the spatial coverage of the beam trawl surveys are high, the seasonal coverage is presently limited to autumn (September-October). Consequently these surveys are inadequate for sampling seasonal migrants who visit the Wadden Sea at other times of the year. Furthermore the annual means may be biased due to changes in the seasonal distribution of fish.

Pelagic species are recorded during the demersal surveys, but the beam trawl is not considered to be optimal for quantitative abundance estimates of pelagic species. Surveys targeting pelagic species (e.g. stow net surveys) are limited in their spatial and temporal coverage (Table 2.1.1). The coverage of stow net surveys has recently improved for the Wadden Sea estuaries (Ems, Weser, Elbe and Eider, see Table 2.1.1) as a result of the EU Water Framework Directive (WFD) for transitional waters. Within the WFD, the Wadden Sea is categorised as a coastal water and fish is not considered as a WFD biological quality element for coastal waters.

4.2 Species richness and composition

Examination of spatial patterns in species richness was hampered by the fact that the number of species observed is related to the number of samples (Figure 3.2.1). Rogers et al. (1998) also showed that the number of species that are recorded within an area depends on the intensity of the sampling within that area. A greater effort is required to catch the infrequent species.

Assuming that annual variations in sampling intensity within an area were negligible, temporal trends in species richness could be examined. No clear temporal trends in species richness were observed in any of the areas or surveys included in the present study.

Species richness alone does not effectively describe the biodiversity of a fish community. Biodiversity is a joint construct of species richness and species evenness: the actual number of species in a given area and the distribution of the individuals among the species. A higher number of species as well as a more even distribution among the species points towards higher biodiversity. As species richness or species evenness on its own cannot fully describe the diversity of a community, a combination of the two is used. The most common indicators used to describe diversity in the North Sea fish community are Hills N_0, N_1 and N_2 (Piet & Jennings 2005, Greenstreet & Rogers 2006, Indeco 2006). Hills N_0 is an indicator of species richness: it is a simple count of the number of species in the community. Hills N_1 is an indicator of species evenness: effectively the number of abundant species. Hills N_2 is also an indicator of species evenness: effectively the number of very abundant species.

Species composition of a fish community can be addressed in various ways. In this study we focused on species composition in terms of functional guilds. Guilds refer to the grouping of species according to similarities in their functional characteristics. As fish use the Wadden Sea for different purposes, they can be divided into groups based on the function of the Wadden Sea for these groups. This approach was first adopted by Zijlstra (1978) and further developed by Elliott & Dewailly (1995), Elliott & Hemmingway (2002) and Elliott et al. (2007).

No clear temporal trends in species composition were observed in the present study. The number of estuarine residents and marine juveniles was stable and the number of diadromous, marine seasonal and marine adventitious species was highly variable without any clear trends. The variability for these last 3 guilds can partly be attributed to a limited seasonal coverage of the surveys.

Species composition in terms of functional guilds has been proposed as indicator for the ecological quality of estuarine waters (e.g. Jager & Kranenbarg 2004, Bioconsult 2007, Breine et al. 2007). Various other parameters, besides classification into functional guilds, can be used to describe the species composition of a fish community or as indicator for changes in the ecosystem. These include (i) the number of rare species (Dulvy et al. 2006); (ii) the proportion of Boreal (preferring cold water) and Lusitanian (preferring warm water) species (Daan 2000, Tulp et al. 2008); (iii) trophic structure (Jennings et al 2002, Nicholson & Jennings 2004, Piet & Jennings 2005, Greenstreet & Rogers 2006); and (iv) life history characteristics such as K- versus r-strategists, age and length at maturity, growth rate and mean maximum length (Jennings et al 1999, Nicholson & Jennings 2004, Piet & Jennings 2005, Perry et al. 2005, Greenstreet & Rogers 2006).

4.3 Abundance

The temporal trends in abundance varied widely among individual species and often also varied between areas for a single species. A general pattern that emerged for a number of species and areas was an increase in the 1970s and early 1980s followed by a decline. All marine juvenile and marine seasonal species (except anchovy) showed a decline in abundance since approximately 1985, but this negative trend was not always significant. The trends differed among species for the estuarine residents (decrease for eelpout; no trend or an increase for flounder and sandeel), and for diadromous species (decrease for river lamprey, no trend or an increase for smelt and twaite shad).

The selected priority species included 3 species (twaite shad, anchovy, river lamprey) with the status endangered or vulnerable according to Dutch, German or trilateral Red Lists (Table 3.1.1, Fricke et al. 1994, Berg et al. 1996, von Nordheim et al. 1996). Despite their Red List status, twaite shad was regularly caught during the SHS in the Meldorf Bight (QSR area 8), and anchovy was regularly caught in both areas of the SHS. In the DFS and DYFS, twaite shad was caught in low numbers and river lamprey and anchovy were almost absent. River lamprey was also rare in the SHS and catch numbers are declining.

Twaite shad is a diadromous species which spawns in the estuaries. Although the Weser and Elbe still sustain twaite shad populations (Bioconsult 2005, Gerkens & 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 2006). Bottlenecks are found in the upstream parts of the Ems estuary, where unfavourable conditions during summer (oxygen deficits and fluid mud) hamper successful reproduction.

The spawning grounds of smelt 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 and high concentrations of suspended matter (Turnpenny et al. 2006, Maes et al. 2007, Scholle et al. 2007). The very pronounced summer oxygen deficits in the Ems since 2000 are clearly outside the fish tolerance ranges specified for estuaries (Turnpenny et al. 2006, Scholle et al. 2007). Substantial differences between the Ems and the Weser, Elbe and Eider estuaries indicate the involvement of Ems-related problems (Scholle et al. 2007).

Catch rates of sandeel were highly variable. This may partly be caused by the fact that quantitative sampling is complicated by the combined benthic (buried) and pelagic lifestyle of sandeel.

Herring and sprat are pelagic species, which are not sampled well by the beam trawl 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 2007b). The initial increase in herring abundance during the 1970s reflects a period of recovery of the collapsed North Sea herring populations after the closure of the fishery between 1977 and 1983.

Eelpout, which is an estuarine resident species, 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 & Knust 2007). 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, hooknose (*Agonus cataphractus*, not analysed in this report), fluctuations in 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 abundance of hooknose (Power & Attrill 2002).

Plaice is a marine juvenile species who uses the Wadden Sea as nursery area. An offshore shift in the spatial distribution of young plaice appeared to occur in the 1990s. This shift is primarily attributed to a response to increased summer temperatures. At the same time, a decrease in predation risk and competition in the offshore areas allowed 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 towards deeper as well as further offshore areas (Schmidt 2008). This indicates that throughout the Wadden Sea young plaice have either changed their habitat preference or that a shift in the timing of emigration to deeper waters has occurred.

Sole and dab, both marine juvenile species, showed pronounced decreases in abundance. These trends concerned all age groups, since the mean length in the demersal surveys remained more or less constant. Juvenile dab, unlike plaice and sole, are not confined to coastal nurseries, but can occur over a wide depth range (Bolle et al. 1994). In autumn, the 0-group migrate inshore and enter the Wadden Sea. 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 visibility (>1 m). Increasing catch rates of 1-group dab in the BTS (beam trawl survey, North Sea) indicate that the decrease in juvenile dab abundance in the Wadden Sea may be the consequence of a distribution shift towards offshore waters (Bolle et al. 2001).

Distribution shifts of juvenile flatfish indicate changed conditions in the Wadden Sea nursery, which may have become less favourable due to higher water temperatures during summer. However the rising seawater temperature may also have a positive effect on the nursery quality of shallow coastal waters for warm-water species like sole (Teal et al. 2008). Increased summer temperatures coincided with increased growth rates in 0-group sole and to a lesser degree in 0-group plaice, until food limitation occurred. Furthermore, increased winter temperatures prolonged the first growing season of sole (not of plaice) due to earlier spawning (Teal et al. 2008).

The increasing trends in cod abundance in the Wadden Sea until the early 1980s reflects the 'gadoid outbursts' that occurred in the North Sea in the 1960s and 1970s (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 larval 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 patterns.

Correlations between trends in fish abundance and environmental variables have not yet been explored in this part of the project. This topic is re-addressed in the follow-up report (Tulp & Bolle 2009). Several environmental drivers may play an important role in changes in the fish community of the Wadden Sea. Climate change reflected by temperature rise or changes in the North Atlantic Oscillation can affect the distribution and abundance of fish species (Purps et al. 1999, Attrill & Power 2002, Genner et al. 2003, Roessig et al. 2004, Rose 2005, Henderson & Seaby 2005, Harley et al. 2006, Pörtner & Knust 2007, van Keeken et al. 2007, van Hal et al. 2009). It may also affect larval transport patterns, growth rates and spawning (Teal et al. 2008, Bolle et al. 2009). It has been hypothesized that changes in nutrient loads in the Wadden Sea has caused changes in the primary and secondary production and hence may affect food availability for fish (Beukema & Cadee 1988, Rijnsdorp & van Leeuwen 1996, Colijn et al. 2002, Cadee & Hegeman 2002, van Raaphorst & de Jonge 2004, Philippart et al. 2007, Teal et al. 2008, Kuipers & van Noort 2008). Fisheries may influence the Wadden Sea fish community directly (bycatch mortality in shrimp fisheries) or indirectly (removal of top predators or benthic prey) (Piersma et al. 2001, Hiddink 2003, Daan et al. 2005, Kraan et al. 2007). Habitat degradation (e.g. loss of sea grass and hard substrates) and local anthropogenic pressures such as dredging and contaminations may also affect fish populations (Essink 1989, de Boer et al. 2001, Sturve et al. 2005, Polte & Asmus 2006a, 2006b). All these environmental variables and others may cause changes in fish populations on a local or regional scale. Wide-scale changes in the environment may even have caused regime shifts in the entire North Sea and Wadden Sea ecosystems (Weijerman et al. 2005).

4.4 Size composition

Changing environmental conditions may affect the growth and recruitment of fish species and hence lead to changes in the size composition. Changing environmental conditions may also affect the distribution and habitat use of different life stages, which may lead to changes in the size composition within a particular area such as the Wadden Sea.

Various indicators can be used to describe the size composition of a fish population. These are: (i) slope of the size spectra, (ii) mean length, (iii) mean weight, (iv) the proportion of large fish (Rice & Gislason 1996, Nicholson & Jennings 2004, Piet & Jennings 2005, Daan et al. 2005, Greenstreet & Rogers 2006). In the present study we chose mean length to describe the size composition.

The only species which showed a significant trend in mean length were plaice, eelpout and flounder. For plaice, a decrease in mean length in the Dutch Wadden Sea was expected based on the fact that particularly the abundance of the 1 year old plaice had decreased (Vorberg et al 2005, unpublished IMARES data), because of an offshore shift in the distribution of 1 year old plaice (van Keeken et al. 2007, Grift et al. 2004). No decrease in mean length of plaice was observed in the German areas. This can partly be attributed to the limited time series for mean length in the DYFS (1996-2006), but it may also be caused by the fact that 1 year old plaice have always been scarce in the German areas (pers. com. Uli Damm).

Like plaice, sole and dab also showed a decline in their abundance within the Wadden Sea, which is probably related to a shift in distribution. However, for these 2 species the decline in abundance did not coincide with a decrease in mean length, thus indicating that the shift in distribution occurred in all age groups.

Although flounder spawns in the North Sea, it is classified as an estuarine resident because it spends the major part of it's life cycle in the Wadden Sea or in the estuaries. Contrary to plaice, the decrease in mean length observed for flounder did not coincide with a decrease in abundance. Nevertheless, this change in mean length may be related to a shift in the distribution of the older age groups. It may also indicate decreased growth rates within the Wadden Sea.

Eelpout is a true resident species; it inhabits the Wadden Sea during it's entire life cycle. Therefore the decrease in mean length observed for this species can not be explained by shifts in distribution. It indicates reduced growth rates or reduced survival of the older/larger fish.

5 Recommendations on future research

5.1 Monitoring

Two mayor limitations of the current monitoring programs in the Wadden Sea are evident. Firstly, the spatial coverage of surveys targeting pelagic species is limited. Secondly, the seasonal coverage of the beam trawl surveys (DFS & DYFS) is limited. Improved spatial and seasonal coverage will provide more insight in the dynamics of fish populations in the Wadden Sea.

5.2 Trend analyses

The next step in the trend analyses is to correlate environmental variables with fish parameters (e.g. abundance, size composition, species richness and species composition) with environmental data. This approach can be used to test *a priori* postulated hypotheses based on existing knowledge, or it can give rise to new hypotheses which can further be examined in detailed research. Although correlative research is the next logical step to take at this stage in the process of understanding the causes of variations in fish populations, it does not prove causality and may sometimes be confounded by collinearity between explanatory variables. Therefore, detailed (experimental) research is also required to identify mechanisms underlying observed trends.

In the second part of this project, correlations between environmental variables and the abundance 34 fish species was explored (for the DFS data only), using a multivariate statistical method (dynamic factor analysis). This method also enabled to estimate common patterns for each of 3 regions. The results are presented in the follow-up report (Tulp & Bolle 2009).

Changes in the population structure occur if trends differ between life stages or age groups. Mean length was used in the present study as proxy for the size structure of the population. However, this parameter only indirectly detects changes in the population structure. A better approach for the Wadden Sea, which has different functions during the life-cycle of different species, would be to make a distinction between juvenile and adult fish, or in the case of marine juvenile species, between 0 group and 1+ group fish.

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Quality Assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 December 2009. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2009 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation, with the last inspection being held on the 5th of October 2007.

Justification

Rapport C108/08

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen IMARES.

Approved: Dr. Ingrid Tulp
Scientist

Signature:

Date: 29 December 2009

Approved: Dr. Floris Groenendijk
Head of Ecology Department

Signature:

Date: 29 December 2009

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Number of appendix attachments:	1

Appendix 1. Environmental data

Temperature

Source: Bundesamt für Seeschifffahrt und Hydrographie (BSH), Germany
Variables: temperature estimates (°C) based on both satellite and ship observations
Region: North Sea and Wadden Sea
Time span: 1968 – present (monthly data),
1995 – present (weekly data)
Temporal resolution: monthly or weekly averages and anomalies
Spatial resolution: ?
Accessibility maps: www.bsh.de/en/Marine_data/Observations/Sea_surface_temperatures/index.jsp
Accessibility data: ?

Source: Royal Netherlands Institute for Sea Research (Royal NIOZ), The Netherlands
Variables: temperature measurements (°C)
Region: western Dutch Wadden Sea
Time span: 1861 – present
Temporal resolution: monthly averages
Spatial resolution: 1 station in Marsdiep inlet
Accessibility data: www.nioz.nl/nioz_nl/ccba2464ba7985d1eb1906b951b1c7f6.php

Source: Rijkswaterstaat (RWS), The Netherlands
Variables: temperature measurements (°C)
Region: Dutch coastal waters
Time span: varies between stations, most stations approx. 1988 – present
Temporal resolution: varies between stations from daily observations to monthly observations
Spatial resolution: 37 stations
Accessibility data: www.waterbase.nl

Salinity

Source: Bundesamt für Seeschifffahrt und Hydrographie (BSH), Germany
Variables: ?
Region: German Bight
Time span: 1975 – present
Temporal resolution: monthly mean, min, max, standard deviation
Spatial resolution: ?
Accessibility data: ?

Source: Royal Netherlands Institute for Sea Research (Royal NIOZ), The Netherlands
Variables: salinity measurements (pss-78)
Region: western Dutch Wadden Sea
Time span: 1861 – present
Temporal resolution: monthly averages
Spatial resolution: 1 station in Marsdiep inlet
Accessibility data: www.nioz.nl/nioz_nl/ccba2464ba7985d1eb1906b951b1c7f6.php

Source: Rijkswaterstaat (RWS), The Netherlands
Variables: chloride measurements (mg/l)
Region: Dutch coastal waters
Time span: varies between stations, most stations approx. 1988 – present
Temporal resolution: varies between stations from daily observations to monthly observations
Spatial resolution: 37 stations
Accessibility data: http://www.waterbase.nl/

Oxygen

Source:	Bundesamt für Seeschifffahrt und Hydrographie (BSH), Germany
Variables:	?
Region:	German Bight
Time span:	1975 – present
Temporal resolution:	monthly mean, min, max, standard deviation
Spatial resolution:	?
Accessibility data:	?

Nutrients & Chlorophyll

Source:	QSR/TMAP data units, Common Wadden Sea Secretariat (CWSS)
Variables:	?
Region:	Wadden Sea (Netherlands, Lower Saxony, Schleswig-Holstein, Denmark)
Time span:	Nutrients in water: NL 1971-2003; LS 1999-2006; SH 1990-2006; DK 1986-2006 Phytoplankton: NL 1971-2006; LS 1999-2005; SH 1999-2002; DK 1990-2006
Temporal resolution:	?
Spatial resolution:	?
Accessibility data:	limited to QSR/TMAP purposes

NAO

The North Atlantic Oscillation (NAO) is a well known and key parameter for the climate in our northern hemisphere. Data on the air pressure difference between Iceland and the Azores are gathered daily since 1864 at different stations and are readily available via internet e.g. as monthly means. The Winter (December through March) index of the NAO is based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland. The SLP anomalies at each station were normalized by division of each seasonal mean pressure by the long-term mean (1864-1983) standard deviation. Normalization is used to avoid the series being dominated by the greater variability of the northern station. Positive values of the index indicate stronger-than-average westerlies over the middle latitudes. A link to various sources is also available through www.cgd.ucar.edu/cas/jhurrell/indices.info.html#naopcdjfm.

Musselbeds

Source:	QSR/TMAP data units, Common Wadden Sea Secretariat (CWSS)
Variables:	GIS data on location, size, shape of blue mussel beds
Region:	Wadden Sea (Netherlands, Lower Saxony, Schleswig-Holstein, Denmark)
Time span:	subtidal: NL 1999-2003; LS 1999-2006; SH 1999-2006; DK 1999 intertidal: NL 2003
Temporal resolution:	n.a.
Spatial resolution:	n.a.
Accessibility data:	limited to QSR/TMAP purposes

Source:	IMARES, The Netherlands
Variables:	Biomass estimates based on quantitative sampling and GIS data
Region:	Dutch Wadden Sea (subtidal & intertidal areas)
Time span:	1992 – present
Temporal resolution:	bi-annual estimates (spring & autumn)
Spatial resolution:	GIS: n.a. quantitative sampling: varies between years, grid in 2009= 0.25Nm x 0.5-2Nm
Accessibility data:	limited to joint research programmes

Dumping sites

Source: QSR 2004 & QSR 1999, Common Wadden Sea Secretariat (CWSS)
Variables: Amounts of dumped dredged material (tons dry weight)
Region: Wadden Sea
Time span: 1998 – 2003 (QSR 2004)
1989 – 1997 (QSR 1999)
Temporal resolution: n.a.
Spatial resolution: n.a.
Accessibility data: www.waddensea-secretariat.org/QSR/chapters/QSR-02.6-2.11-human-activities.pdf
www.waddensea-secretariat.org/news/documents/Qsr99/2-Activities.pdf

Source: OSPAR Commission
Variables: Several (e.g. dry weight dumped material, contaminants)
Region: North Sea & NW Atlantic
Time span: 1995 – 2007
Temporal resolution: n.a.
Spatial resolution: n.a.
Accessibility reports: www.ospar.org/v_publications/browse.asp?menu=00080800000000_000000_000000
Accessibility data: ?

Fishing pressure

Source: ICES-WGNSSK
Variables: Landings, effort and fishing mortality for plaice and sole (beam trawl fishery)
Region: North Sea
Time span: 1957 – present
Temporal resolution: annual estimates
Spatial resolution: n.a.
Accessibility data: www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=31

Source: von Thünen Institute (vTI), Bundesforschungsanstalt für Fischerei (BFA)
Variables: Fishing effort (e.g. fishing days, nr of vessels) by German shrimp trawlers
Region: German-Danish Wadden Sea
Time span: 1952-1958, 1966, 1976, 1986, 1996, 2000-2006
Temporal resolution: annual estimates
Spatial resolution: >2000: ICES rectangles (logbook obligation)
<2000: ?
Accessibility data: ?

Source: ICES-WGCRAN
Variables: Landings, effort, VMS (vessel monitoring through satellite) for shrimp fishery
Region: North Sea
Time span: 1970 – present (landings)
1988 – present (effort)
2006 – present (VMS)
Temporal resolution: annual estimates
Spatial resolution: n.a.
Accessibility data: www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=178