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The North Sea fish community: past, present and future

Background document for the 2011 National Nature Outlook

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Abstract

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Long-term changes in the North Sea fish community have been demonstrated both as trends in individual species, particular those subject to fishing pressure, as well as in the community as a whole. Trends in diversity, size structure, trophic level and size at maturation have been related to fishing pressure, whilst trends in diversity can also be driven by an increase in water temperature due to climate change. Areas of high diversity often relate to areas where rare species are found (coastal and northern North Sea). Vulnerable species appear mainly along the coast of the UK. The physical environment is a natural driver of the distribution and migrations of fish species, but human impacts through fishing, climate change, offshore construction and shipping can change the natural patterns through direct and indirect effects, making it difficult to predict future changes through multiple interacting impacts.

Key words: long-term trends, spatial and temporal distribution, human impact, diversity, climate change, anthropogenic drivers

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Woord vooraf

Dit onderzoek naar vissen en de visgemeenschap in de Noordzee is uitgevoerd in opdracht van het Planbureau voor de Leefomgeving (PBL) in het kader van de Natuurverkenning 2011. Het uitbrengen van een Natuurverkenning is een wettelijke taak, die onder verantwoordelijkheid valt van het PBL en waaraan Wageningen UR via de WOT Natuur en Milieu een belangrijke bijdrage levert.

De Natuurverkenning heeft tot doel een aantal mogelijke toekomstrichtingen voor natuur en landschap op lange termijn te schetsen, waarbij ingespeeld wordt op ontwikkelingen die op de samenleving kunnen afkomen. Naast het schetsen van die mogelijke ontwikkelingen geeft de Natuurverkenning ook handelingsperspectieven voor het beleid op korte en middellange termijn.

Om verschillende redenen staat het huidige natuurbeleid onder druk. Een van die redenen is dat ondanks inspanningen de biodiversiteitsdoelen niet gehaald worden. Daarnaast stuit het beleid op weerstand in de uitvoering ervan en is het beleid mogelijk niet bestand tegen ontwikkelingen als klimaatverandering. Ook groeit de aandacht voor het duurzaam gebruik van natuurlijke hulpbronnen en staan de zogenaamde ecosysteemdiensten in de beleidsdossiers. Vanuit de samenleving klinkt het geluid dat het natuurbeleid toe is aan een herijking. Natuurverkenning 2011 wil hierop inspelen en de maatschappelijke discussie rond het huidige natuurbeleid prikkelen en voeden.

Het onderzoek naar de visgemeenschap in de Noordzee heeft tot doel om de bestaande kennis samen te vatten over de langetermijntrends in de visgemeenschap, de sturende factoren te benoemen die op het patroon en de trends van vispopulaties van invloed zijn en vervolgens daarop verwachtingen voor de toekomst te baseren. Omdat visgemeenschappen alleen effectief kunnen worden bestudeerd op grote ruimtelijke en temporele schaal is de hele Noordzee in dit werkdocument beschouwd.

Tot slot wil ik mijn collega's Ralf van Hal, Henk Heesen & Wim Wiersinga bedanken voor het verstrekken van informatie of het kritisch doornemen van eerdere versies van dit document.

Lorna Teal

Natuurverkenning

Inhoud

Summary

In the context of the '2011 National Nature Outlook' (Natuurverkenning 2011), it is important to understand the drivers of past changes and long-term trends that have been observed in the North Sea fish community in order to make predictions on how these may affect the fish community in the future. The aim of this chapter was to summarise and highlight some long-term trends and the associated drivers on which future predictions may be based.

Although the 'Natuurverkenning 2011' deals with the Dutch section of the North Sea, fish communities can only be studied effectively at large spatial and temporal scales, and therefore the whole North Sea is considered here. Information was derived mainly from the peer-reviewed literature with some background information from the ICES-FishMap. Knowledge on long-term trends is based mostly on annual surveys (IBTS, BTS, DFS, Acoustic surveys, egg surveys).

Broad-scale biogeographical patterns show three main fish communities (shelf edge and northern North Sea, central North Sea and southern and eastern North Sea). Detailed spatial and temporal trends of four commercially important (plaice, sole, cod, herring) and three additional important prey species (whiting, sandeel, gobies) are presented.

Analysing trends in the diversity of North sea fish is shown to be problematic, although the most recent studies show an increase in species richness in relation to an increase in water temperatures. Equally, findings on changes in trophic structure of the fish community are not always in agreement, which is likely due to different approaches and interpretations of results. It is concluded that changes in size structure due to differential effects of fishing on species with different life histories are a stronger and more useful indicator of changes in the community in the North Sea. Size-selective fishing is also shown to lead to earlier maturation in some species.

Patterns of rare species match closely with patterns observed for species richness, where the coastal areas and northern boundary of the North Sea shower higher values than the central North Sea. Vulnerable species, referring in particular to the elasmobranch community, are distributed mostly along the western North sea down the eastern coast of the UK.

The physical environment is important as a natural driver of the distribution and migrations of fish species. Anthropogenic drivers such as fisheries, climate change, ocean acidification, eutrophication, offshore construction and shipping can all effect and change these natural patterns in numerous ways. Predicted future impacts and changes therefore relate strongly to how these drivers may change in the future and how multiple drivers may interact which each other. Many indirect effects will occur through a chain of interacting processes which hamper the ability to evaluate and predict future human impact.

1   Introduction

1.1 The content

Defining and characterising long-term changes within the North Sea fish community is of great interest in a biodiversity and conservation context, as such changes integrate the effects of natural variation as well as anthropogenic effects (e.g. fishing pressure, climate change, spatial use of the North Sea) on the structure and functioning of the North Sea ecosystem.

Distribution ranges of species are maintained by a species' ability to return to a specific habitat (homing). The quantitative population responses of a species at one location at a given point in time, however, are dependent on influences of the environment, including anthropogenic impacts, over the entire distribution range of the stock. Because both these external drivers and the distribution ranges vary depending on a species life history characteristics and the ecological niche occupied within the food web, the species composition of a community can show considerable spatio-temporal variability. Due to these complex dynamics, long term changes in fish communities can only effectively be studied at large spatial and temporal scales. For this reason, the focus of this chapter goes beyond the boundaries of the Dutch Exclusive Economic Zone (EEZ) and considers the wider North Sea.

This working document aims to present past changes in the North Sea fish community, highlighting some long-term trends and associated drivers (anthropogenic and environmental) on which future predictions may be based. The chapters are divided as follows.

Chapter 2 aims to summarise biogeographical patterns in species assemblages, present trends in space of time of some key species and relate long-term trends in the community to environmental and anthropogenic factors. Rare species and vulnerable species are also highlighted.

The North Sea fish community has been presented and analysed in the ICES-FishMap (2005) based on data available from the international bottom trawl surveys (IBTS). These findings are summarised in *Section 2.1*. As it is certainly not possible to discuss trends of ~230 North Sea fish species some selections were made for *Section 2.2*. on spatial and temporal trends. A first selection is based on available data, which is of course geared towards the more commercially interesting species which are surveyed regularly for stock assessment purposes and where time series of data are available. Data limitations are discussed in *Section 1.2*. Four key commercial species were therefore selected (plaice, sole, herring, cod) and three additional species (whiting, sandeel, gobies) that, as well as herring and cod, are known to be important prey items for sea birds and sea mammals. Changes in the rest of the community are considered more generally *Section 2.3*. in relation to species-specific life history traits and subsequent effects on the community via the food web, changes in size composition or genetic consequences. The distribution of rare species and of vulnerable species, mainly elasmobranchs, are also presented (*Section 2.4*. and *2.5*. respectively).

Chapter 3 aims to summarise the current driving forces shaping, or forcing changes to, the North sea fish community. These are split into the physical environment influences in *Section 3.1.* and anthropogenic impacts in *Section 3.2.* Focus is given to how these drivers may change in the future to shape the future North Sea fish community.

Chapter 4 then takes into account the relationships between the environmental and anthropogenic drivers summarised in *Chapter 2*, together with predicted changes in these drivers presented in *Chapter 3,* to make predictions on what changes can be expected in the North Sea fish community by 2040.

1.2   Data and limitations

Checklists of the total fish fauna present in an area are most commonly based on a variety of sources, including landings from commercial fleets, research vessel surveys, angler reports, sightings, beachings etc. Together, these sources contribute to a fairly complete picture of the fish fauna. However, due to the different sampling techniques (e.g. fishing gear) that effect the catchability of different species in different ways, quantitative estimates of abundance and species composition remain biased. Furthermore, it is important to consider that marine ecosystems are essentially open systems. Ocean currents move large bodies of water around that only gradually change their characteristics, such as temperature and salinity, allowing fish to move freely across large areas. It must be realized, therefore, that the North Sea provides an open system for fish, which cannot be considered in isolation from the west of Scotland shelf, Norwegian Sea, Channel, and Skagerrak (Daan *et al*. 1990). Although many commercial species are considered to represent self-sustaining stocks within the boundaries of the North Sea, others are only parts of a much larger stock complex (e.g. spurdog *Squalus acanthias*). Over 230 fish species have been recorded from the North Sea (Yang 1982a, b, Daan *et al*. 1990). These species originate from three zoogeographical regions, with approximately 30% of Boreal (northern) origin, 50% of Lusitanian (southern) origin and 20% of Atlantic origin (Yang 1982a, Harding *et al*. 1986).

Due to the lack of strict borders, defining what constitutes a 'fish community' can be problematic. The concept of a 'community' assumes some functional and structural coherence among the constituting species, such as inter- and intra-specific predation and competition. As a consequence of the openness of marine systems, organisms may easily cross defined borders, either due to seasonal migrations, or simply as vagrants occasionally entering the area. Whilst these vagrants contribute to the total fish fauna of an area, based on the above definition of a fish community, they do not contribute to the community due to their lack of interaction with other species as they pass through. The choice of including a species within a community is thus to a large extent arbitrary, although the criterion most commonly employed is whether or not a species occupies an important niche. As ecological importance cannot be directly measured, a guideline is used whereby a species is included if it is a permanent constituent of, or at least a regular and frequent visitor to, the area studied.

Although fisheries landings provide insight into the abundance and distribution of commercially important species, knowledge of the North Sea fish community, including the non-commercial species, is based mostly on annual fishing surveys (e.g. IBTS, BTS, DFS, Acoustic surveys, Egg surveys). Whilst these provide valuable information on long-term trends in community characteristics, there are some fundamental problems associated with the data. Firstly, these surveys are geared towards the commercially important species in order to provide data for stock assessment purposes. The gear used is therefore the gear most suitable for the targeted species and can be less reliable for data on non-targeted species. Secondly, information on the different catchability between various species, or even within the same species depending on size, depth and bottom characteristics, is lacking, but may severely affect quantitative estimates derived from catch rates. Thirdly, the fishing gear used in bottom trawl surveys (IBTS, BTS, DFS) is unsuitable for fishing rocky grounds as these cause severe damage to the nets. Species that preferentially inhabit rocky grounds are thus not represented

sufficiently within these survey data and due to the noise generated in the data by species with low catchability, these are also frequently discarded from subsequent analysis. Some analyses on the different catchability of different gears of the same species have been performed (ICES 2004) and may be used to estimate raising factors between gears to allow integration of different surveys. Such integration of data would allow better comprehensive atlas of community characteristics to be obtained, as well as a more comprehensive view of the distributions of individual species. It should also be noted that intertidal areas or even shallow coastal areas are not covered by all surveys, yet are known to be important nursery grounds for a number of species.

Another issue to consider is the reliability of species identification between reporting countries or individuals. Misidentifications can severely affect calculations of diversity indices for example, and may also not be easily detected. Some species (e.g. sandeels, gobies) are particularly difficult to separate, particularly under the conditions of the survey where identifying large numbers of similar species in a haul is impractical, and these may thus often be combined in higher taxonomic units. Further misinterpretations can come from differing definitions or terminology. In general 'demersal fish' are defined as those fish which live on ('groundfish') or near ('bentho-pelagic') the seabed. Groundfish have no swimbladder (e.g. flatfish), are negatively buoyant and can rest on the bottom, whereas bentho-pelagic fish do have a swimbladder, are neutrally buoyant and float in the water column just above the seabed. Because these terms are sometimes used interchangeably, we have always used the term given in the respective reference.

2 The North Sea fish community: past to present

2.1 Broadscale biogeographical patterns (text from ICES-FishMap 2005)

Three main fish assemblages have been defined in the North Sea (Harding *et al*. 1986, Callaway *et al*. 2002). The first is associated with the shelf edge and northern North Sea, the second group occurs in the central North Sea, and the third group is found in the southern and eastern North Sea (Figure 1). However, more discrete communities (e.g. those that occur on rocky grounds or in estuaries) are also present in the region. A rather sharp boundary may be found near the 200 m isobath between species assemblages of the Norwegian Deep and those of the shallow plateaus of the North Sea and Skagerrak. The communities found in the Norwegian Deep resemble those found in the areas along the outer shelf of the Northeast Atlantic and the deep fjords of Norway (Bergstad 1990).

The fish assemblages of the central and northern North Sea (ICES Divisions IVa-b) are very different to those assemblages further south (Callaway *et al*. 2002), and the division in fish assemblages corresponds with changes in water depth and temperature. The dominant fish species include demersal species (fish that live on or near the bottom) such as whiting *Merlangius merlangus* and haddock *Melanogrammus aeglefinus*, and pelagic species including mackerel *Scomber scombrus* and horse mackerel *Trachurus trachurus*. In shallower waters (50–100 m depth), populations are dominated by haddock, whiting, herring *Clupea harengus*, dab *Limanda limanda* and plaice *Pleuronectes platessa*, while at greater depth (100–200 m), Norway pout *Trisopetrus esmarki* dominate (Callaway *et al*. 2002). The northern North Sea also contains a number of boreoarctic species that are rarely found further south (e.g. Vahl's eelpout *Lycodes vahlii* and Esmark's eelpout *L. esmarkii*).

The southern North Sea (ICES Division IVc) is generally shallower than more northerly waters. Correspondingly, the dominant fish species are those that are more characteristic of inshore waters (<50 m deep). Plaice *Pleuronectes platessa*, sole *Solea vulgaris*, dab *Limanda limanda* and whiting *Merlangius merlangus* are some of the dominant commercial species, and non-commercial species such as lesser weever *Echiichthys viper*a, grey gurnard *Eutrigla gurnardus* and solenette *Buglossidium luteum* are also an important component of the fish assemblage (Callaway *et al*. 2002). Species such as sandeels (Ammodytidae) and sand gobies (*Pomatoschistus* spp.) are also abundant and are important prey species for many species of demersal fish (section 2.2.).

On a finer resolution, cluster analysis based on the numerical composition of IBTS catches by statistical rectangle (1° longitude * 30' latitude) has revealed that the North Sea fish community may be split into six sub-communities (Callaway *et al*. 2002). The divisions between these largely follow the 50, 100 and 200 m depth contours, with evidence of a separate sub-community in the southernmost area near the entrance to the Channel (Figure 2). The pattern is almost undistinguishable from the one observed in epibenthic species and also confirms earlier findings based on English Groundfish Surveys (Daan *et al*. 1990) which indicated the 50 m and 200 m isobaths as important boundaries. However, the species accounting for most of the similarities within these sub-communities overlap to a large extent (Table 1).
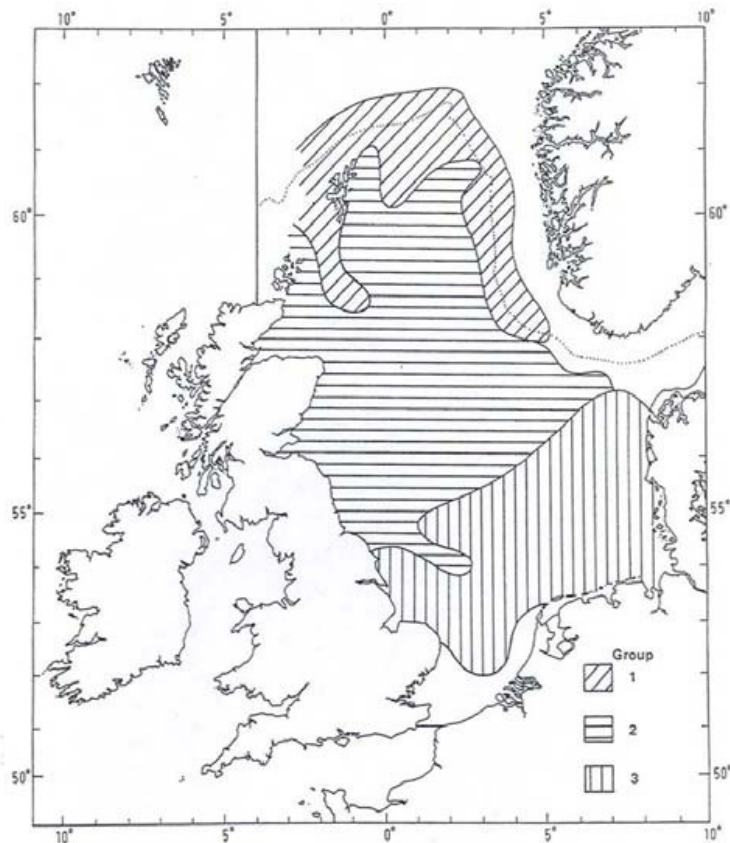
Figure 1: Distribution of three fish communities of the North Sea, based on average catches of the fifty most abundant species in the English Groundfish Survey in the years 1982 – 1986 (Harding et al. 1986): 1) Shelf edge community, 2) North Central community, and 3) Southeastern community.

Table 1: Species composition of three North Sea fish communities as described in (Harding et al. 1986)

Shelf edge community	Percentage weight	North Central community	Percentage weight	Southeastern community	Percentage weight
Saithe	43.6	Haddock	42.4	Dab	21.8
Haddock	11.6	Whiting	13.9	Whiting	21.6
Norway pout	10.7	Cod	9.2	Grey gurnard	12.8
Whiting	9.1	Norway pout	4.7	Horse mackerel	10.1
Horse mackerel	7.6	Saithe	4.5	Plaice	6.3
Blue whiting	4.1	Dab	3.7	Cod	5.5
Remainder	13.3	Remainder	21.6	Remainder	21.9
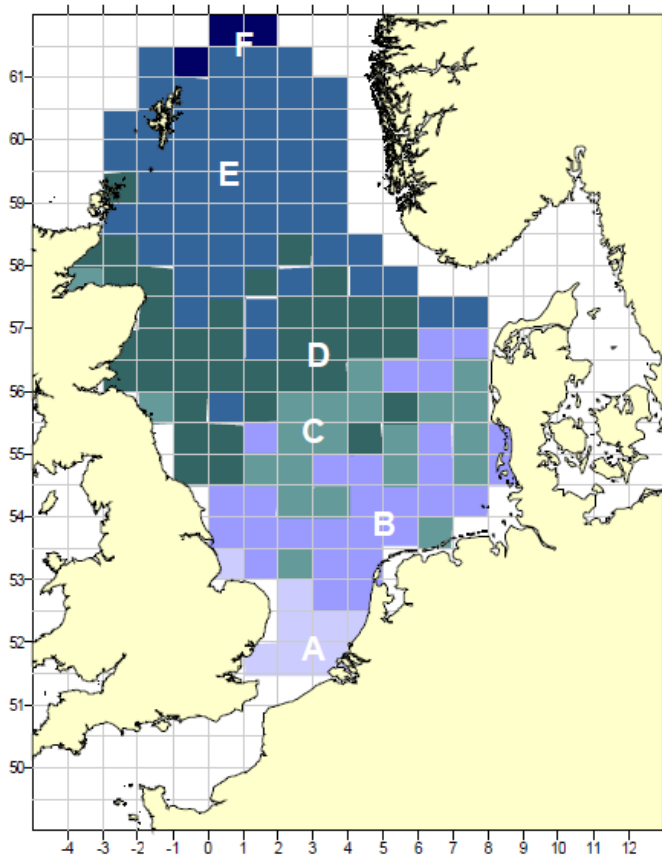
Figure 2: Sub-division of the North Sea fish community based on cluster analysis of similarities in the species composition of IBTS catches (redrawn from (Callaway et al. 2002).
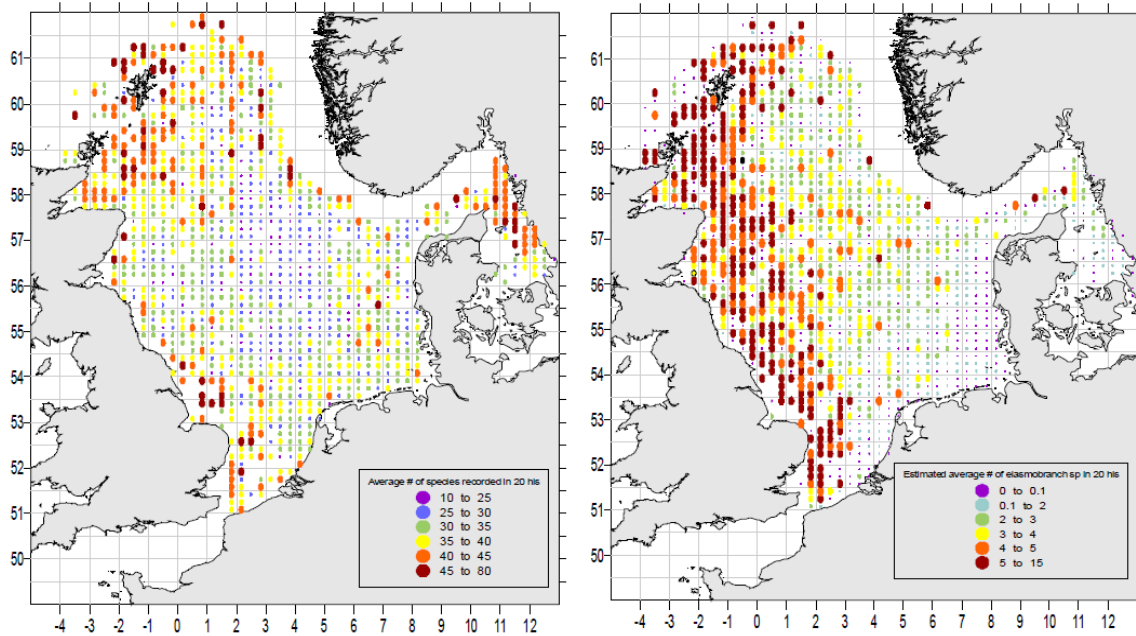
Figure 3: Spatial variation in species richness, expressed as average number of species recorded in 20 hauls, based on IBTS (all quarters, 1977-2004): A (left panel) – entire fish community; B (right panel) – elasmobranchs only (sharks and skates). From ICES-FishMap (2005).

The central North Sea is clearly an area with relatively low species richness (Figure 3a), where rarely more than 30 species have been recorded after 20 half-hour hauls. The continental coast is somewhat richer, but the real hotspots of species richness lie around the borders (Figure 3a). The reasons for these differences are still obscure, but high numbers of species might reflect regular occurrence of species that have their normal distribution largely outside the North Sea.

This might explain the hotspots in Scottish waters, particularly around Shetland, and along the Norwegian Deep. Another explanation could be more variable habitat characteristics at a local scale. For instance, the high species richness along the English coast might be related to the variable topography including deeper pits and hollows, and shallower banks. Another hotspot is the Kattegat, but why this would be so seems less clear. Similar analyses may be carried out for groups of species. Figure 3b provides an example for the elasmobranch (sharks and skates) community. In this case, there is a clear east-west gradient, with a much higher diversity all along the British coast compared to continental waters.

2.2 Spatial distribution and temporal trends of selected species

2.2.1 General

Due to the limitations on data outlined in section 1.2, it is not possible to look at spatial and/or temporal trends of all North Sea fish species. North Sea fish surveys are mostly designed for species of commercial importance in order to provide numbers for stock assessment and management purposes. However, species that are not commercially important may have a high ecological importance as they can provide food for higher trophic levels, also birds and sea mammals, or themselves be important predators in the system. Here we have chosen to select a couple of species which are important commercial species and/or important prey items for larger predators (birds, mammals). The four most important commercial species for the Dutch fishing sector are: Plaice, Sole, Cod and Herring. Important prey items for seabirds and/or sea mammals are: Cod and other gadoids, herring, sandeel and gobies. The roundfish areas referred to in the text are depicted in Figure 4.

2.2.2 Plaice (Pleuronectes platessa)

Plaice is an important commercial species in European waters, especially for the Dutch Beam trawl fleet and has been exploited for centuries. It is therefore also one of the best studied species in the North Sea. Although, plaice is managed as a single stock in the North Sea, in reality there is evidence for geographically separated sub-stocks with high gene flow (Horeau *et al*. 2002). The distribution of plaice ranges from the western Mediterranean Sea, along the coast of Europe as far north as the White Sea and Iceland, with occasional occurrences off Greenland (Nielsen 1986). Plaice is a demersal boreal species that can reach a maximum length of a meter (Yang 1982a, Ellis *et al*. 2002), however the common length is around 40 cm. Maturity is reached at an age of 2 to 5 years; males mature earlier than females (Rijnsdorp 1989). Plaice is a determinate batch spawner, which spawns pelagic eggs and shows seasonal migration from feeding areas to spawning areas.

The spatial distribution of plaice changes with life-stage as the juveniles utilise shallower coastal waters as nursery areas, moving offshore into deeper cooler waters as they grow. The importance of the Dutch EEZ for plaice therefore also varies in time and for different life stages (Table 2; Teal *et al*. 2009).
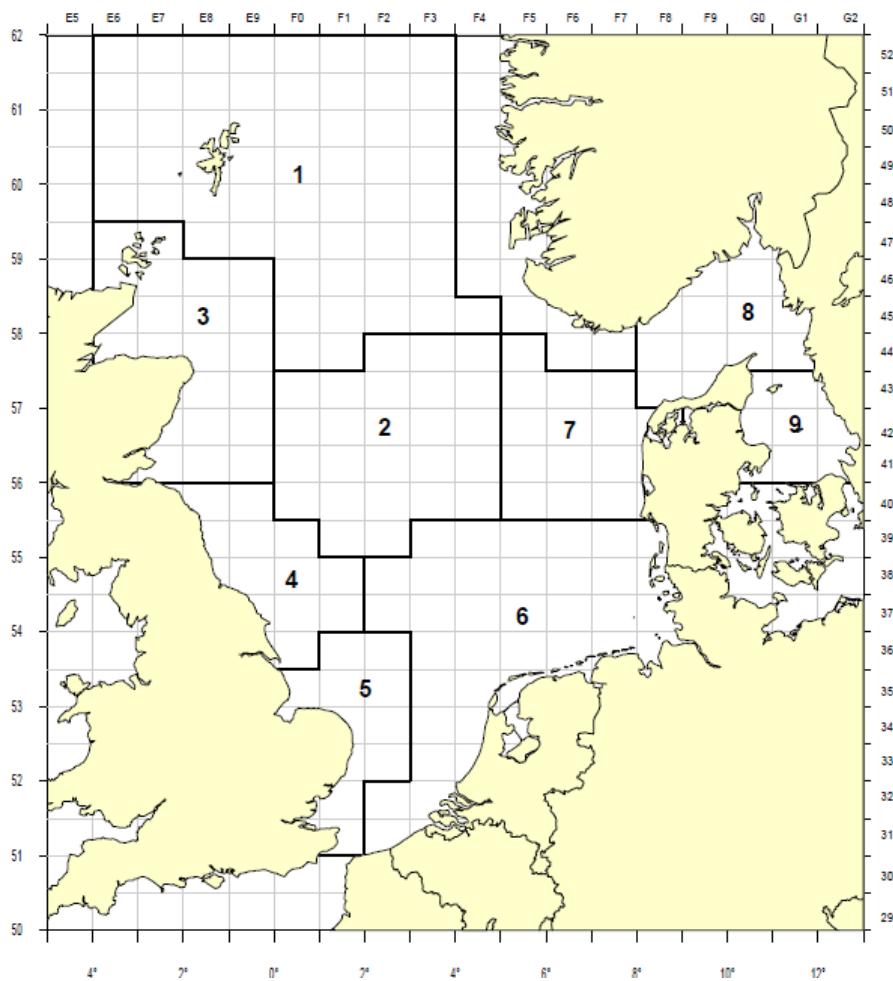
Figure 4: North Sea Roundfish Areas. In the text they are referred to as 1) north, 2) central, 3) north-west, 4) central-west, 5) south-west, 6) south-east, 7) east, 8/9) Skagerrak/Kattegat (from (Heessen & Ter Hofstede 2005)

Survey catches show the highest abundance of plaice in the south-eastern North Sea (area 6, Figure 5). Catches increased from 1977 to 1987, dropped steeply the following 4 years, and are more or less stable since. The total long-term trend of the North Sea shows an increase until 1987 followed by a steep decline until 1991, after which catches remain stable (Figure 5; Heessen *et al*. 2005).

Table 2: Summary of the importance of the Dutch EEZ for different life stages of plaice at different times of the year. Eggs and larvae information is provided on a monthly basis, juvenile and adults on a quarterly basis. Importance levels (none or close to none = white; low = yellow; medium = orange; high = red; grey = unknown) relate to the extent of the distribution of each life stage within the Dutch EEZ and are based on best estimates from current knowledge (from: (Teal et al. 2009)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Eggs	Med	Med	Med									
Larvae		Med	Med	Med								
Juveniles	Med			High			High			Med		
Adults	Med			Med			Med			Med		

Figure 5: Time series data of plaice by North Sea roundfish area (see Figure 4) shown as average catch in numbers per hour for all length classes combined. Catch rates are plotted on a log-scale for roundfish areas and on a linear scale for the total North Sea (lower panel). The smallest value indicated on the log scale (0.0001) stands for 'no specimens caught'. 9 plots are presented: for areas 1 to 7 separately, for areas 8 and 9 combined, and for the average North Sea value (for area 1 to 7). The plots are arranged approximately in the same way as they are situated in the North Sea (from (Heessen & Ter Hofstede 2005) and the solid line shows the North Sea average in all panels.

2.2.3 Common Sole (Solea solea)

Sole is a popular consumption fish and of great commercial importance. Sole tend to occupy shallow, sandy and sandy/muddy habitats which are widespread in the North Sea. Due to its preference for burying into sandy or muddy bottoms, fishing for sole requires either heavy bottom trawling gear , or if timed when sole are active, gill and tangle nets can be used. As for plaice, older and bigger individuals tend to occur in deeper waters than the juveniles, but they remain largely restricted to waters < 50 m deep (ICES FishMap 2005b). Due to their diurnal feeding behaviour, sole are easier to catch at night. As North Sea surveys are exclusively carried out during the daytime, catch rates may therefore underestimate absolute abundances. Within the North Sea

several different sub-populations have been distinguished based on egg distribution and tagging experiments. However, these are, to a large extent, mixed during the feeding season. Assessments examine the North Sea sole as one stock unit, with the stocks in the eastern Channel and the Skagerrak/Kattegat being assessed separately (ICES FishMap 2005b).
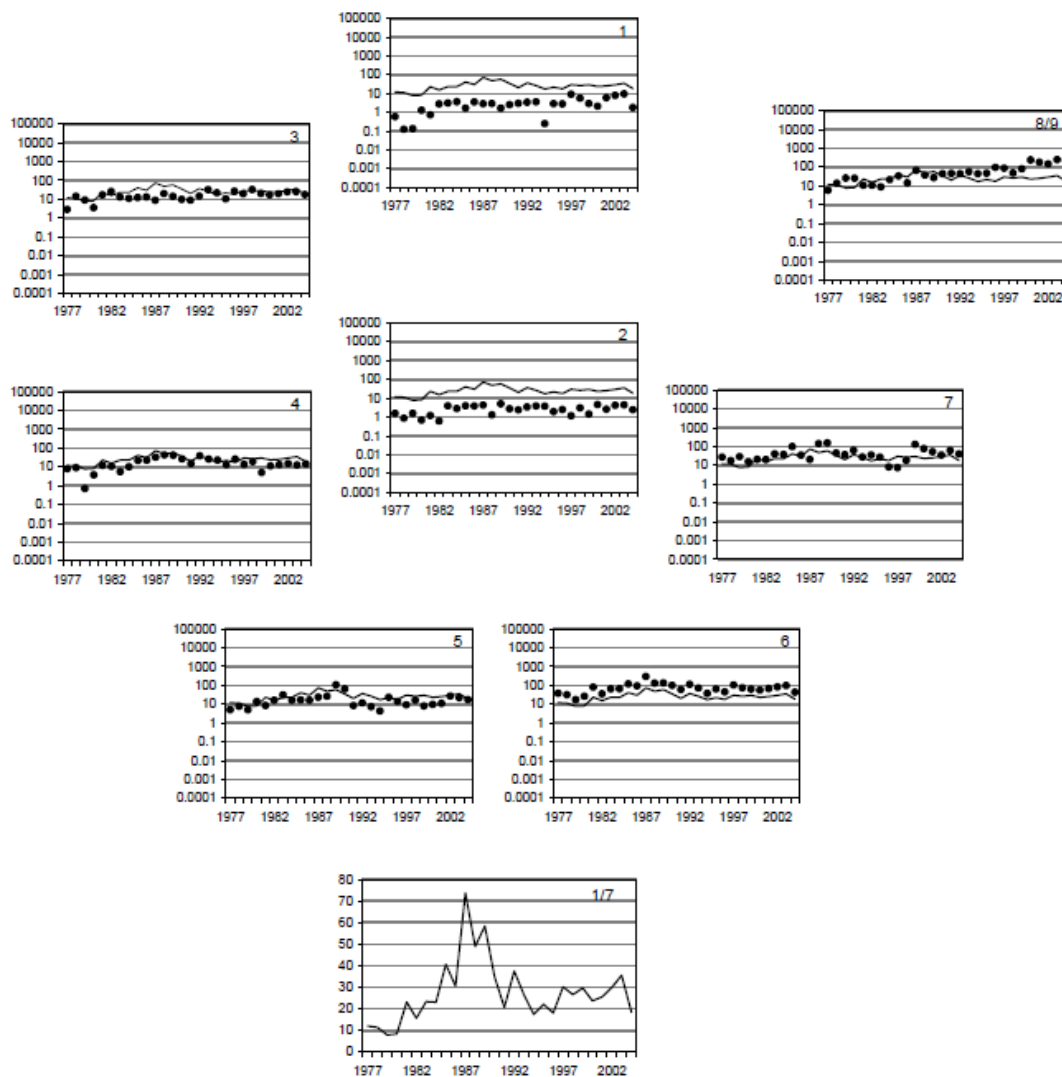

Figure 6: Time series data of common sole by North Sea roundfish area (see Figure 4) shown as average catch in numbers per hour for all length classes combined. Catch rates are plotted on a log-scale for roundfish areas and on a linear scale for the total North Sea (lower panel). The smallest value indicated on the log scale (0.0001) stands for 'no specimens caught'. 9 plots are presented: for areas 1 to 7 separately, for areas 8 and 9 combined, and for the average North Sea value (for area 1 to 7). The plots are arranged approximately in the same way as they are situated in the North Sea (from (Heessen & Ter Hofstede 2005) and the solid line shows the North Sea average in all panels.

Sole is a southern species and due to the preference for relatively warmer waters inhabits only the southern parts of the North Sea. The shallow coastal areas from the English Channel up to Denmark, of which the Dutch areas form a large part, are particularly important spawning and nursery grounds. Dutch waters are thus important particularly during the early life stages (eggs, larvae, juveniles) before sole move

further offshore and become more evenly distributed throughout the southern North Sea. Seasonal migrations do occur in relation to temperature, but are not as extensive as in other species and the southern North Sea remains inhabited throughout the year. Juveniles and adults can be found in the Dutch EEZ throughout the year (Table 3; (Teal *et al*. 2009).

Table 3: Summary of the importance of the Dutch EEZ for different life stages of sole at different times of the year. Eggs and larvae information is provided on a monthly basis, juvenile and adults on a quarterly basis. Importance levels (none or close to none = white; low = yellow; medium = orange; high = red; grey = unknown) relate to the extent of the distribution of each life stage within the Dutch EEZ and are based on best estimates from current knowledge (from (Teal et al. 2009)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Eggs			Med	Med	Med							
Larvae				Med	Med	Med						
Juveniles	Med			Med			Med			Med		
Adults	Med			Med			Med			Med		

Highest survey catches are made in the south-western and south-eastern North Sea (areas 5 and 6, Figure 6), and these areas determine the overall North Sea trend. Relatively high catches are also made in Skagerrak/Kattegat (areas 8/9, Figure 6). No long term trend for the total North Sea is evident and the irregularity of high catch rates most likely reflect strong year-classes (Heessen & Ter Hofstede 2005).

2.2.4 Herring (Clupea harengus)

Herring is a boreal pelagic species (Yang 1982a, Ellis *et al*. 2002) and is widely distributed in the north-west and north-east Atlantic, from the northern Bay of Biscay to Greenland and east into the Barents Sea. Herring are mostly found in continental shelf seas to depths of ~200 m (Whitehead *et al*. 1986), however, the Atlanto-Scandian herring disperses widely over the abyssal plains during its feeding migrations between Norway, Iceland and Greenland. The North Sea herring stock is made up of a number of components (sub-populations) of fish that show different physical characteristics, spawning strategies and migration behaviour (Zijlstra 1958). Variability in their environment (particularly temperature) during spawning, hatching and the first year of life is thought to create the differences between component parts of the stock by influencing growth and physical development (Hulme 1995, McQuinn 1997). Herring can reach a maximum length of 40 cm (North Sea adults range from 20-30 cm) and a maximum reported age of 22 years (most North Sea herring are younger than 7 years). Herring are iteroparous determinate spawners and have sticky demersal eggs that attach to coarse sand, gravel, shells and small stones during spawning.

Herring show a strong shoaling behaviour, which makes them an easy target for directed fisheries (purse seine and trawls) that can use echo-sounding equipment to locate the shoals. Herring is caught for human consumption but also by industrial fisheries to extract fish meal and oil.

Herring is a very abundant species and occurs throughout the North Sea, although distribution varies in space and time. Most juveniles are distributed in the coastal waters of Denmark, Germany and the Netherlands.
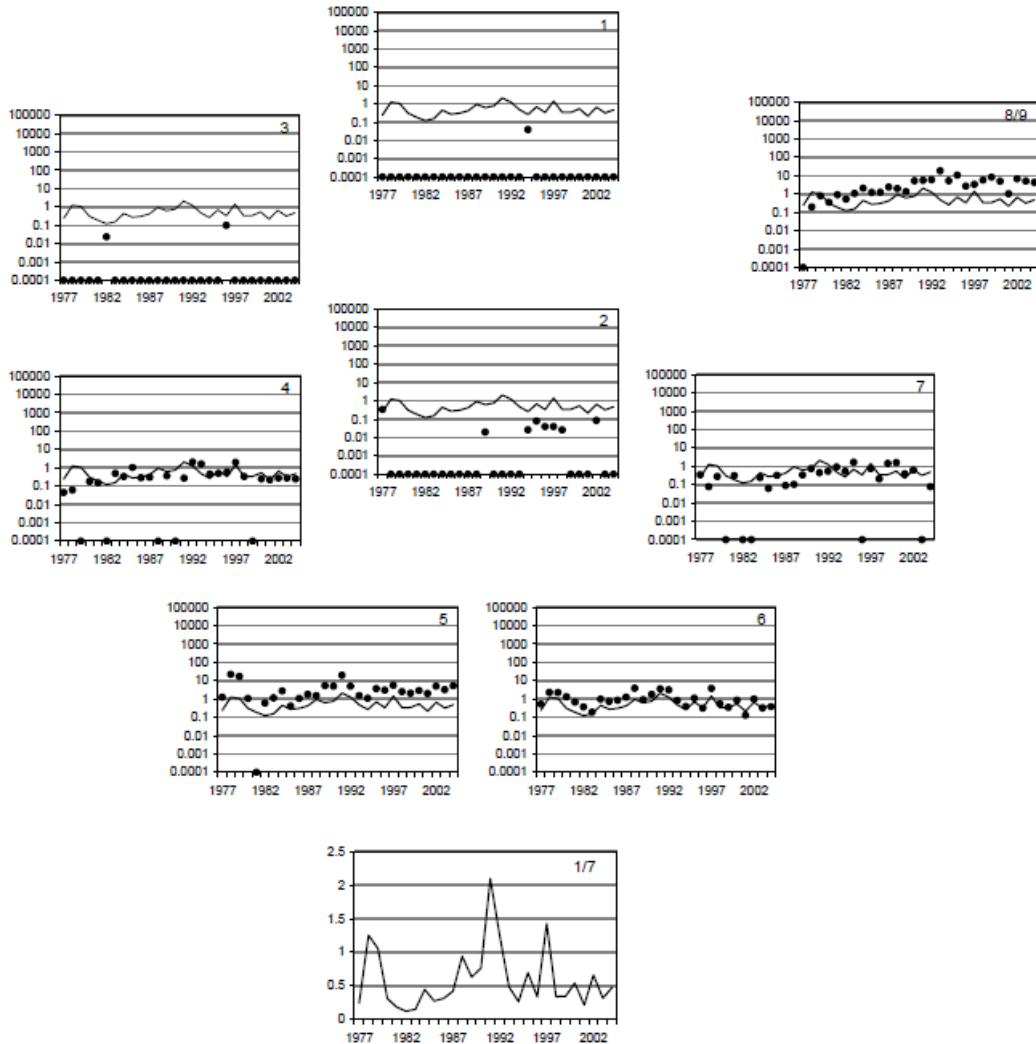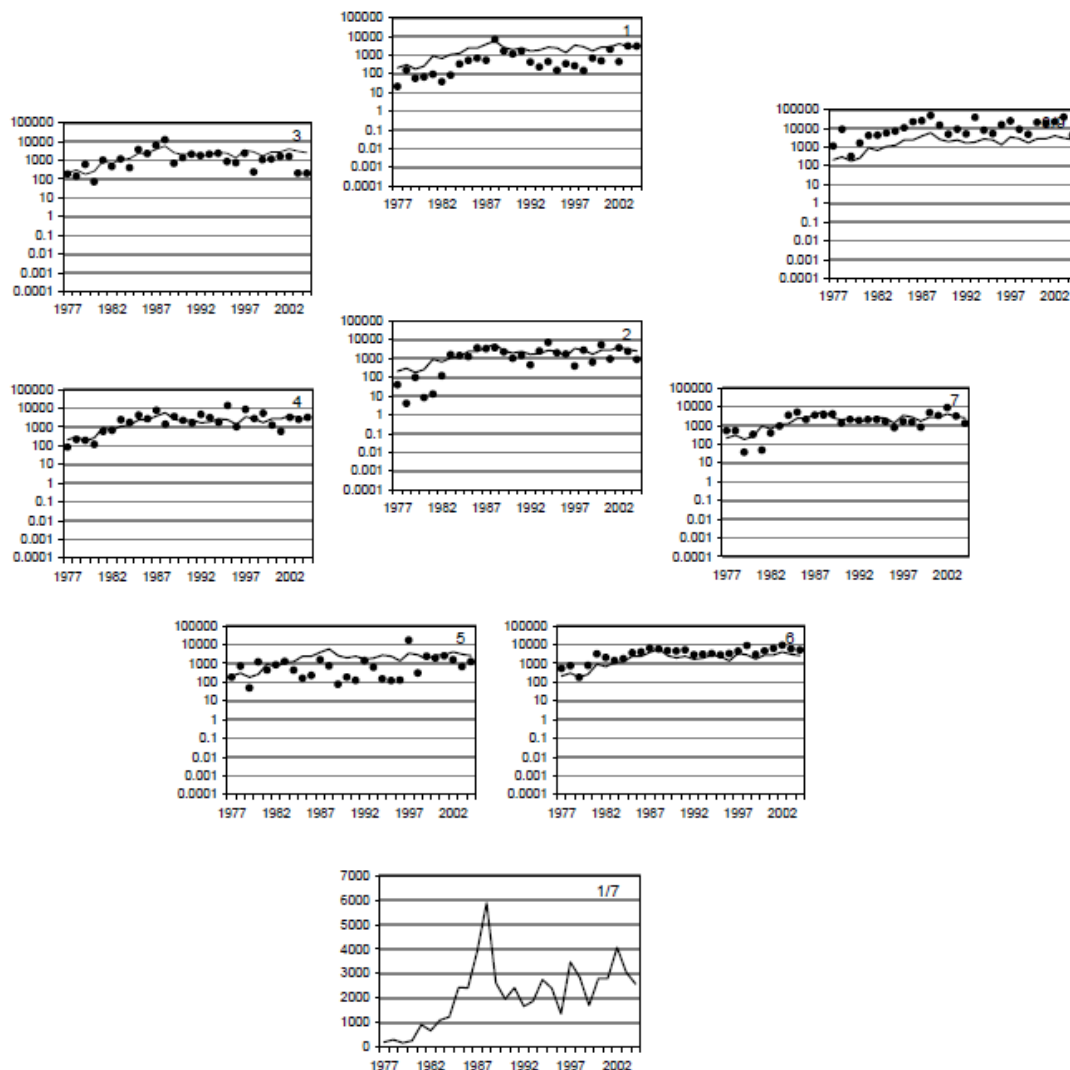
Figure 7: Time series data of herring by North Sea roundfish area (see Figure 4) shown as average catch in numbers per hour for all length classes combined. Catch rates are plotted on a log-scale for roundfish areas and on a linear scale for the total North Sea (lower panel). The smallest value indicated on the log scale (0.0001) stands for 'no specimens caught'. 9 plots are presented: for areas 1 to 7 separately, for areas 8 and 9 combined, and for the average North Sea value (for area 1 to 7). The plots are arranged approximately in the same way as they are situated in the North Sea (from (Heessen & Ter Hofstede 2005) and the solid line shows the North Sea average in all panels.

In Dutch waters, the Wadden Sea is an important area for the juveniles (Table 4; (Teal *et al*. 2009), but they are also found in the estuaries of Zeeland. At the end of the summer, juveniles migrate to deeper waters, and during the following spring the 1-group herring are found in the south-eastern North Sea. Survey catches show that the temporal trend in abundance is similar in all areas (Figure 7). Catches increased sharply from 1977 to the end of the 1980s and have remained more or less stable since then. The total long-term North Sea trend shows an increase until mid-1980s and no clear trend since (Figure 7; (Heessen & Ter Hofstede 2005).

Table 4: Summary of the importance of the Dutch EEZ for different life stages of herring at different times of the year. Eggs and larvae information is provided on a monthly basis, juvenile and adults on a quarterly basis. Importance levels (none or close to none = white; low = yellow; medium = orange; high = red; grey = unknown) relate to the extent of the distribution of each life stage within the Dutch EEZ and are based on best estimates from current knowledge (from (Teal et al. 2009)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Eggs												
Larvae	Med	High	High									
Juveniles	Med			Med			Med			Med		
Adults	Low									Low		

The herring stock is assessed annually by ICES, where the spawning stock biomass, catches, fishing mortality and recruitment are calculated (ICES 2010a). The collapse of the herring stock in the 1970s is evident and although the stock recovers following management measures, a recent low recruitment is evident (Figure 8).

In addition to their commercial importance, herring are considered a major prey item by the majority of North Sea seabirds. Many can only feed on the smaller juvenile herring, but some larger birds, such as gannets, *Morus bassanus,* and guillemots, *Uria aalge,* (but not razorbills, *Alca torda*) can handle the larger herring. Some marine mammals, such as the harbour porpoise, *Phocoena phocoena*, and minke whales, *Balaenoptera acutorostrata*, also prey on herring.
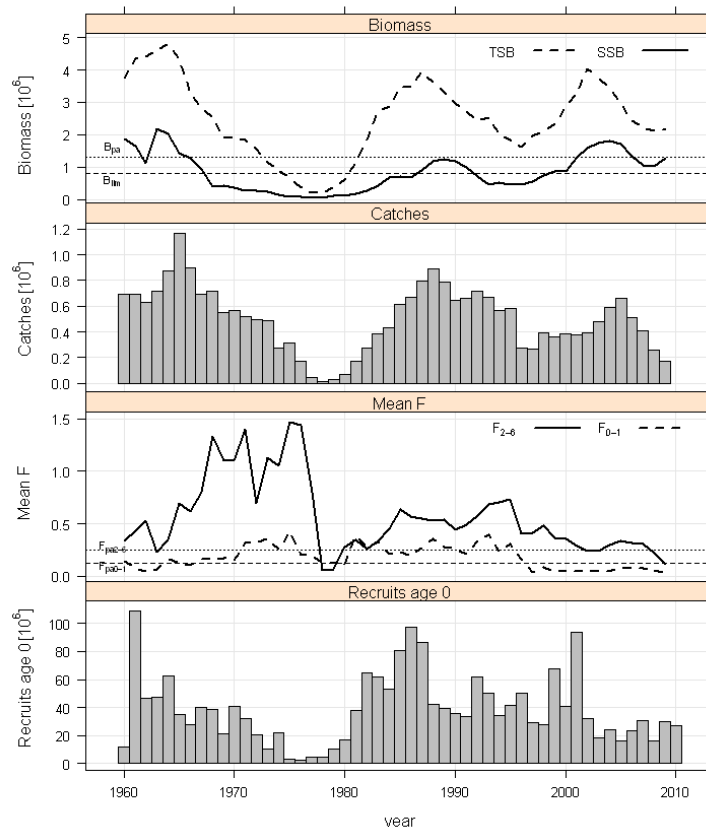

Figure 8: North Sea herring. Stock summary plot for Spawning Stock Biomass (SSB), recruitment and mean F on ages 2-6 (from (ICES 2010a).

2.2.5 Gadoids

Gadoids contain both commercially important species (e.g. Cod) as well as being a major prey item for harbour porpoise (whiting), minke whales and white-beaked dolphins (larger gadoids). The two main gadoid species of the southern North sea are cod and whiting. Haddock is another important gadoid species, but less so in the southern North Sea and Dutch waters and is therefore not considered here.

Cod (Gadhus morhua)

Cod is a demersal species that occurs throughout the boreal region of the North Atlantic: in the west from North-Carolina to Labrador, around Iceland and Greenland, and in the Northeast Atlantic from the Bay of Biscay up to Svalbard (Spitsbergen) and Novaya Zemlya. Cod is recognised as one of the most important commercial species of the North Atlantic of all times and has played a crucial role in both economy and politics of Iceland, Norway, Spain and Newfoundland (Kurlansky 1997). In recent years however, due to significant declines in abundance and biomass, Atlantic cod is now classified as 'vulnerable' by the IUCN (www.iucn.org).

In the North Sea, cod may be found from shallow coastal waters to the shelf edge (200 m depth), although catches have even also been reported from the deepest parts of the Norwegian Deeps at 500 m (Bergstad 1991). Both juvenile and adult cod are found throughout most of the North Sea and apart from the adult shift northwards during the summer months, cod show neither a particularly strong migration pattern nor a strong segregation between spawning grounds and feeding grounds (Teal *et al*. 2009). The importance of the Dutch EEZ for the different life stages is summarised in Table 5.

Table 5: Summary of the importance of the Dutch EEZ for different life stages of cod at different times of the year. Eggs and larvae information is provided on a monthly basis, juvenile and adults on a quarterly basis. Importance levels (none or close to none = white; low = yellow; medium = orange; high = red; grey = unknown) relate to the extent of the distribution of each life stage within the Dutch EEZ and are based on best estimates from current knowledge (from: (Teal et al. 2009)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Eggs	Low	Med	Low									
Larvae												
Juveniles		M			M			M			M	
Adults		M			L			L			L	

The North Sea wide distribution of cod is reflected in survey catches (Figure 9). The irregularity of catch rates between years is due to large variation in recruitment. Catches are gradually declining over time and have been especially poor since 1999 (Figure 9; Heessen & Ter Hofstede 2005).

Cod is not only an important commercial species, but due to its size (max. length ~ 1.5 m) cod is also almost at the top of the food chain and thus plays a major role within the ecosystem, feeding on other commercial species as well as predating its own kind. In turn, cod is predated on by other fish eating species and marine mammals such as grey seals and white-beaked dolphins. Because of its importance as a high trophic level predator in marine ecosystems, as well as its value to fisheries, rebuilding the depleted stocks in the NE Atlantic remains a key policy aim in Europe, the USA and Canada (Christensen *et al*. 2003).

Although the current Spawning Stock Biomass (SSB) and fishing mortality are uncertain, the stock is said to have begun to recover from the low levels to which it was reduced in early 2000, at which recruitment was impaired and the biological dynamics of the stock difficult to predict. In recent years, emergency measures have been taken and a recovery plan implemented with the aim of reversing the declining trend in SSB and increasing the spawning stock above B_{lim}. These measures have contributed to a reduction in fishing mortality and a rebuilding of SSB. There is a need to reduce fishing induced mortality on North Sea cod further, particularly for younger ages, in order to allow more fish to reach maturity and increase the probability of good recruitment (Figure 10; ICES 2010b).
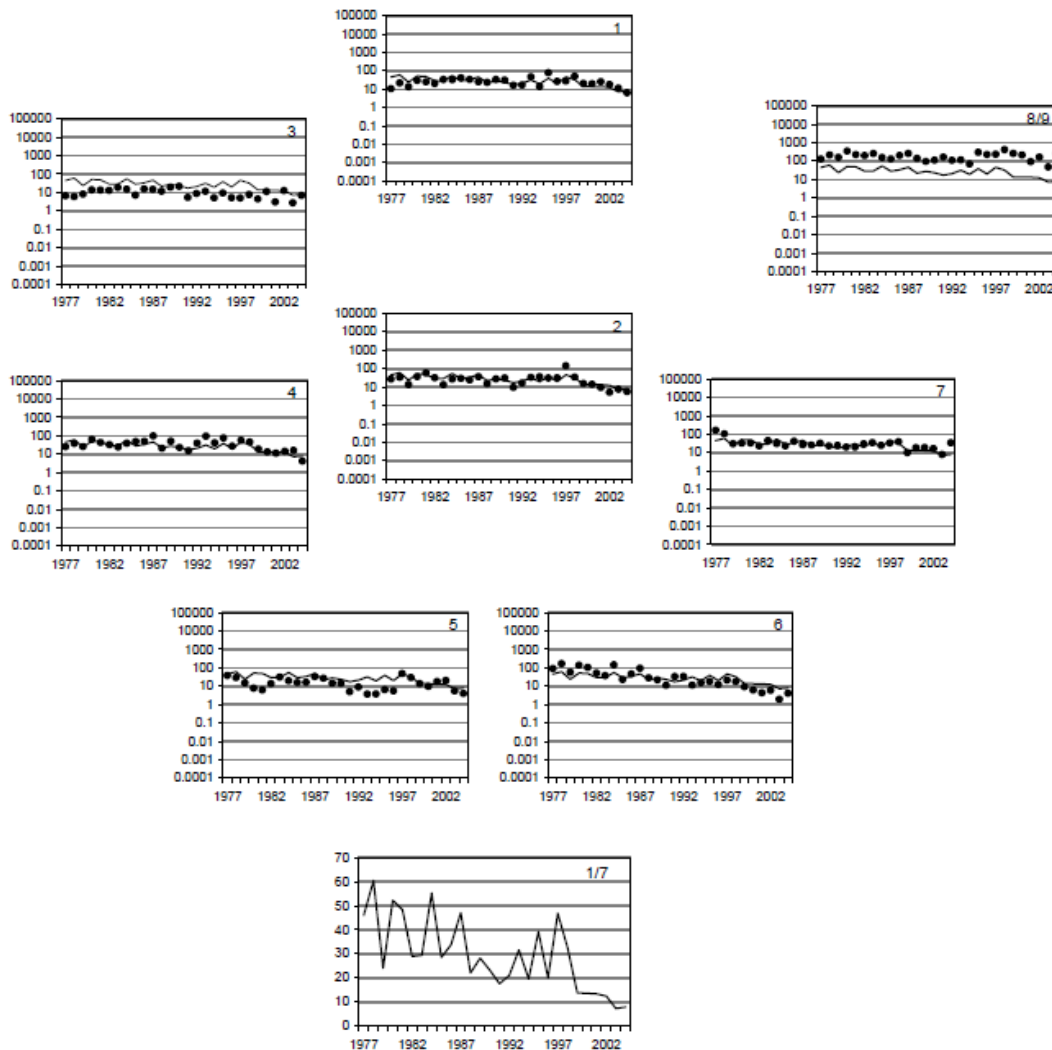
Figure 9: Time series data of cod by North Sea roundfish area (see Figure 4) shown as average catch in numbers per hour for all length classes combined. Catch rates are plotted on a log-scale for roundfish areas and on a linear scale for the total North Sea (lower panel). The smallest value indicated on the log scale (0.0001) stands for 'no specimens caught'. 9 plots are presented: for areas 1 to 7 separately, for areas 8 and 9 combined, and for the average North Sea value (for area 1 to 7). The plots are arranged approximately in the same way as they are situated in the North Sea (from (Heessen & Ter Hofstede 2005) and the solid line shows the North Sea average in all panels.
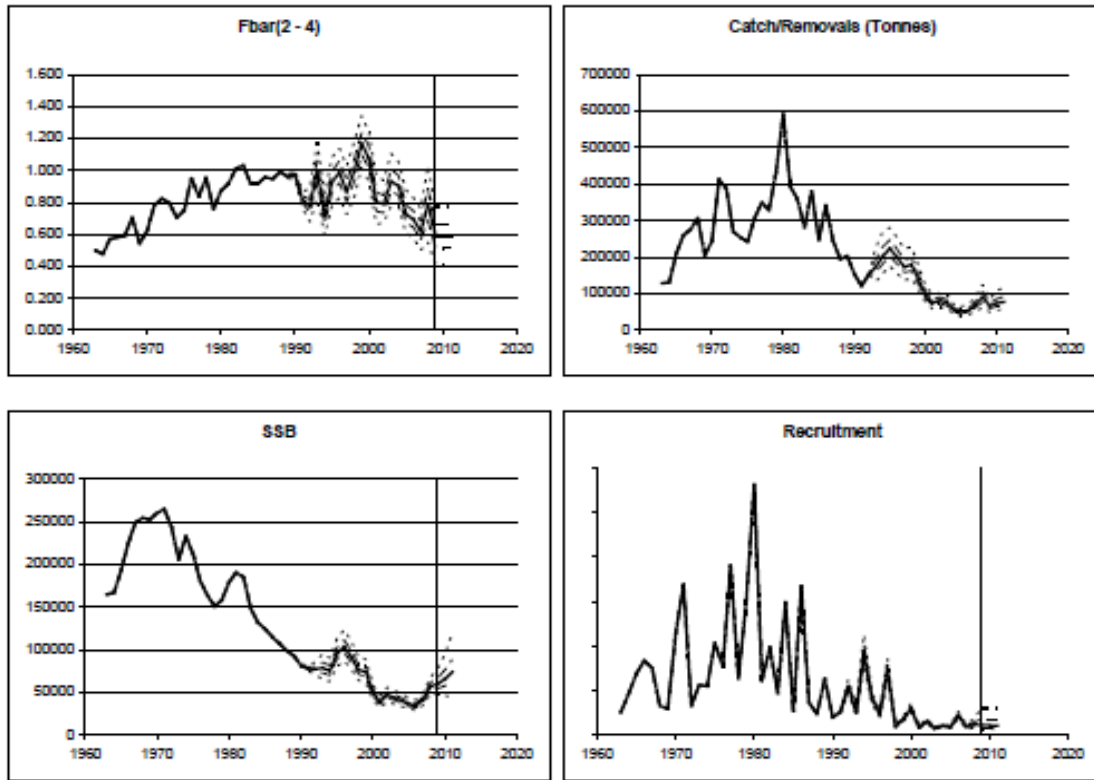
Figure 10: Cod. Stock summary plot fishing mortality (Fbar), catches, SSB and recruitment (from (ICES 2010b).
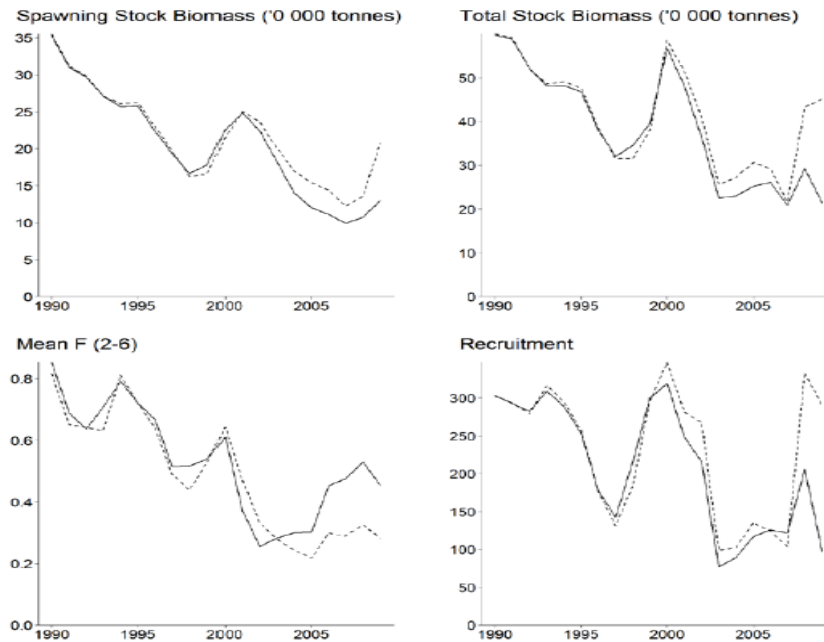
Figure 11: Whiting. Comparison of spawning stock biomass, total stock biomass, mean fishing mortality F2-6) and recruitment. Solid line: IBTS Q1; dotted line: IBTS Q3 (from ICES 2010b).

Whiting (Merlangius merlangus)

Whiting is widely distributed in the North Sea and is commonly found near the bottom in waters less than 200 m deep, where it feed on benthos. High numbers of whiting are found throughout the North Sea, except on the Doggers Bank (Heessen *et al*. 2005), which may reflect a north-south divide between two subpopulations (Hislop & MacKenzie 1976). Whiting is the preferred prey of harbour porpoises.

In the absence of defined reference points, the state of the stock cannot be evaluated. An analytical assessment estimates SSB in 2009 as being near the lowest level since the beginning of the time-series in 1990. Fishing mortality has declined from 2000-2004, but increased in recent years. Recruitment has been very low since 2002, with an indication of a modest improvement in the 2007 year class (Figure 11; ICES, 2010).

2.2.6 Sandeel

In many ecosystems sandeel is a key prey fish linking trophic levels (Furness 1990, Hain *et al*. 1995, Furness 2002, Frederiksen *et al.* 2007). The lesser sandeel, *Ammodytes marinus*, constitutes the vast majority of sandeels in the North Sea and one of the largest fish biomasses (Temming *et al.* 2004, ICES 2005a). As a consequence, variability in the abundance of lesser sandeels is likely to have broad effects on the entire ecosystem, as well as the fisheries (Van Deurs *et al* 2009). Sandeels are an important prey item for a range of seabirds and form an important part of the grey seal diet.

Besides Norway pout, *Trisopterus esmarki*, sandeel is one of the main target species of industrial fisheries in the North Sea (Figure 12), which are predominantly practised by Denmark and Norway. The Danish industrial sandeel fleet has changed through time, with a tendency towards fewer and larger vessels. This change was especially apparent in 2005, when only 98 Danish vessels participated, compared to 200 vessels in 2004.
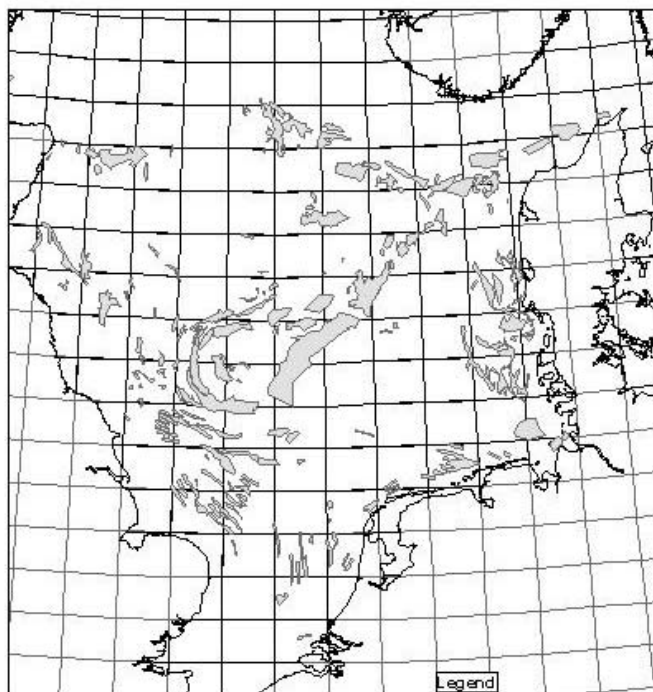
Figure 12: Spatial distribution of sandeel fishing grounds (INEXFISH 2008)

Following a historically low recruitment in 2002 (Figure 13), the spawning stock biomass of sandeel reached critically low levels and the development of new forecast methods and identification of factors affecting sandeel population dynamics was given high priority (ICES 2007). Van Deurs *et al*. (2009) studied the recruitment of sandeel in relation to density-dependence and zooplankton abundance. Both density-dependence (abundance of age 1 sandeel) and abundance of *C. finmarchicus* were shown to affect recruitment. They argue that early egg production in *C. finmarchicus* supports the survival of larvae, and that climate-generated shifts in the *Calanus* species composition lead to a mismatch in timing between food availability and the early life history of lesser sandeels.

According to recent estimates of SSB (ICES 2009), ICES classifies the stock as being 'at risk of reduced reproductive capacity'. Fishing mortality (F) decreased between 2001 and 2007 and increased in 2008 and 2009 (Figure 13, Figure 14), but the present absolute level is uncertain. In the absence of an F reference point, the state of the stock cannot be evaluated with regard to sustainable harvest.
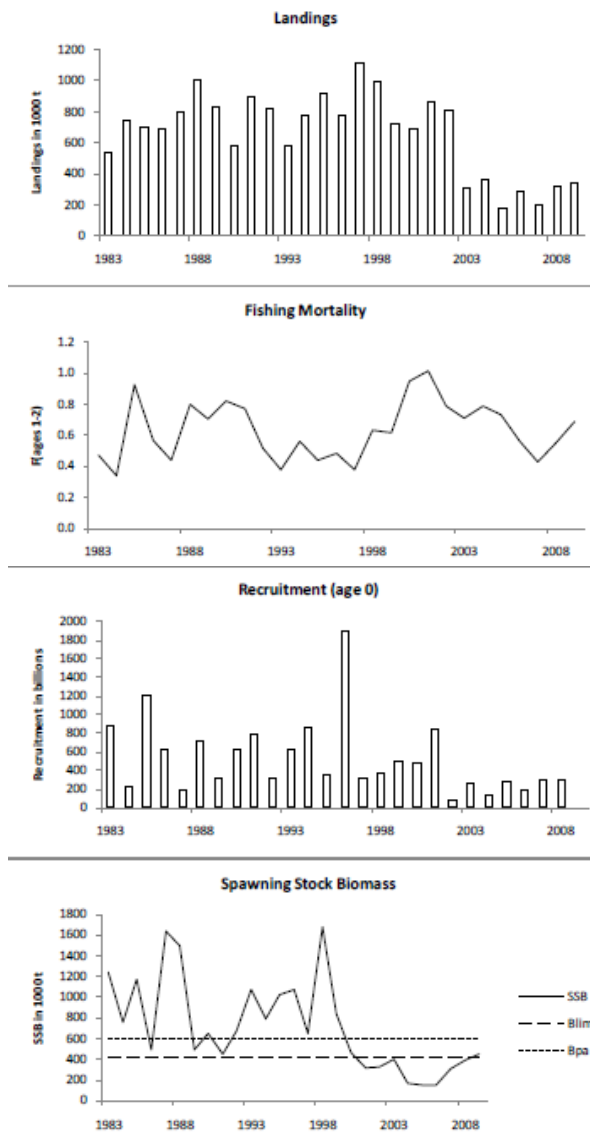
Figure 13: Lesser sandeel. Stock summary plot for landings, recruitment, fishing mortality and SSB (from ICES 2009).
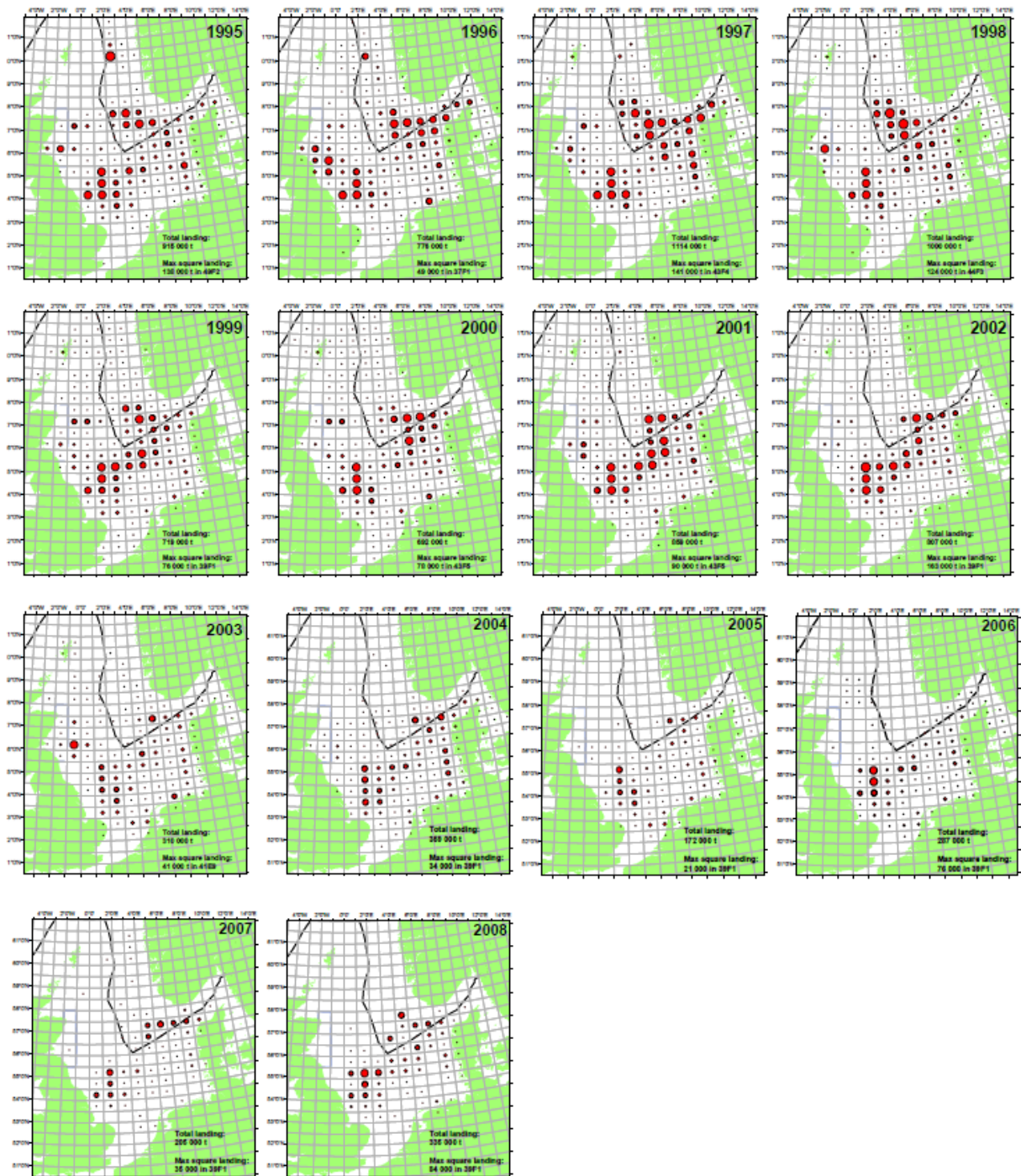
Figure 14: Landings (tonnes, Danish and Norwegian) of sandeel by year and ICES' rectangles for the period 1995–2008. Scottish landings are included from 1997 onwards; Swedish landings are included from 1998. Landings from other countries are negligible. The area of the circles corresponds to landings by rectangle. All rectangle landings are scaled to the largest rectangle landings shown in the 1995 map. The boundary between the EU EEZ and the Norwegian EEZ are shown on the map (from ICES WGNSSK 2008b).

2.2.7 Gobies

The Gobiidae are a large group of fish and up to 18 species are found in saline, brackish and fresh waters of Northern Europe (Wheeler 1978). In the North sea, Gobies are distributed predominantly in southern waters and coastal areas, often living in untrawlable areas close to the coast (Wheeler 1978). Due to their lack of economic importance and difficulty in species determination, very little information is available on species-specific population trends. Because of their small size (2 – 11 cm), gobies escape through survey nets and available survey data does not adequately represent the gobies abundance and distribution.

Gobies are considered an important prey item of harbour porpoise.

2.3 General species trends

A summary of some general trends of North Sea fish species is given by Heessen & Ter Hofstede (2005) and summarised here. These can be split up as follows:

1. Species that have showed a considerable increase over the investigated period 1977 – 2004:
    Quite a number of species have shown a remarkable increase over the years 1977 to 2004: Scyliorhinus canicula (lesser-spotted dogfish), Enchelyopus cimbrius and Ciliata mustela (4- and 5-bearded rockling), Scomber scombrus (mackerel) and Trachurus trachurus (horse mackerel), Echyichthus vipera (lesser weever), possibly Callionymus maculatus (spotted dragonet), Aspitrigla cuculus and Eutrigla gurnadus (red and grey gurnard), and the flatfish species Limanda limanda (dab), Hippoglossoides platessoides (long rough dab), Microstomus kitt (lemon sole) and Buglossidium luteum (solenette). Except for mackerel and horse mackerel, these are mainly species for which no directed fishery exists.

2. Species that have showed an increase since approximately 1990 (stable between 1977-1990):
    A few species only have shown an increase since approximately 1990. These are *Mustelus asterias* (starry smooth hound), *Alosa fallax* (twaite shad), *Mullus surmuletus* (red mullet) and Arnoglossus laterna (scaldfish). Engraulis encrasicolus (anchovy) has increased since the mid 1990ies.

3. Species that have shown a decrease since 1977:
    The few species that have shown a decrease are *Gadus morhua* (cod; see above), *Squalus acanthias* (spurdog) and *Anarhichas lupus* (catfish). All three are large-sized species, the first one a major commercially important species while the latter two are landed as a by-catch and have a relatively low fecundity.

Over the period (1977 – 2004) investigated by Heessen & Ter Hofstede (2005), considerable changes have taken place in the composition of the fish community of the North Sea. In a number of species no long-term trend can be detected, but several others have increased over the observed period and some species have shown a decrease. Most of the species that increased have no or a rather low commercial value. The observed decreases are most likely due to a considerable fishing pressure, and some of the increases may be attributed to species that have filled gaps in the ecosystem. But also the effect of gradual climate changes may play a role, both regarding declining and increasing species. (Heessen & Ter Hofstede 2005).

2.4 Fish community trends in relation to anthropogenic and environmental drivers

2.4.1 General

The North Sea is a heavily exploited system, with the quantity of fish taken from the North Sea estimated to be around 1 million tonnes around 1900, growing to 3.5 million tonnes during the 1970s, and currently estimated around 2.5 million tonnes (Daan *et al*. 1990, ICES 1995). As the total biomass of the North Sea has been estimated at approximately 10 million tonnes (Sparholt 1990), these large catches cause concern over the wider impacts on the North Sea fish community and ecosystem (ICES 1995, Greenstreet & Hall 1996).

The structure of an exploited community can change in a number of ways due to the selective removal of target species and larger size-classes of the respective species. The number of species and their relative abundance within the community may vary. Exploited species may be replaced by ecologically similar species that are less sensitive to fishing disturbance (Pimm & Hyman 1987), causing systems to switch between alternate stable states (e.g. (Beddington 1984). The size composition of individuals may also change (e.g. (Pope *et al*. 1988), which may subsequently lead to changes in the trophic structure of the system (Greenstreet & Hall 1996). Whilst differential effects of fishing on species with contrasting life histories can lead to gross changes in community structure (Jennings *et al*. 1999a, Greenstreet & Rogers 2006), environmental forces may contribute to these changes (O'Brien *et al*. 2000) further influencing the fish community and also mediating its response to fishing pressure. In light of recent changes in climate, it is important to consider the interactions of both anthropogenic and environmental drivers on the fish community.

2.4.2 Trends in diversity

Temporal trends in fish diversity have been detected in the North Sea. (Rijnsdorp *et al*. 1996), for example, compared survey catches of demersal species in the south-eastern North Sea between 1906-1909 and 1990-1995 and concluded that, although the more recent surveys had caught more species in total, the diversity of the demersal fish assemblage had decreased between the early and late 20th century (Table 6). Furthermore, the analysis showed that the recent catch composition within the area compared was dominated by a single species (either whiting or dab depending on the survey gear used), which made up over 50% of the catch (Figure 15).

Table 6: Community parameters for the demersal fish species caught in the South-eastern North Sea (roundfish area 6 in (Rijnsdorp et al. 1996) by gear. OT = 6m Otter trawl, GOV = Grand Ouverture Vertical, BT = 8m Beam trawl (from Rijnsdorp et al. 1996).

	1906-1909 (OT)	1990-1995 (GOV)	1990-1995 (BT)
No of species	29	48	42
SW diversity (H')	2.1	1.23	1.68
Evenness	0.62	0.32	0.45
Simpson diversity	0.83	0.58	0.67

A similar comparison of old and recent survey data was carried out for the northern North Sea groundfish assemblage by (Greenstreet & Hall 1996), where Scottish research survey data were compared between 1929-1953 and 1980-1993. Weak evidence was found for a decline in groundfish diversity over time and *k* - dominance curves showed highly significant differences between the two time periods, whereby the community in the more recent period is dominated by a few species. However, when

species targeted by a directed fishery were removed from the analysis, no change in diversity over time could be detected and the *k* - dominance curves remained similar between both periods. Greenstreet & Hall (1996) concluded that species diversity in Scottish North Sea waters was fairly robust over time, with changes in dominance curves being mostly due to a decline in commercially targeted species.
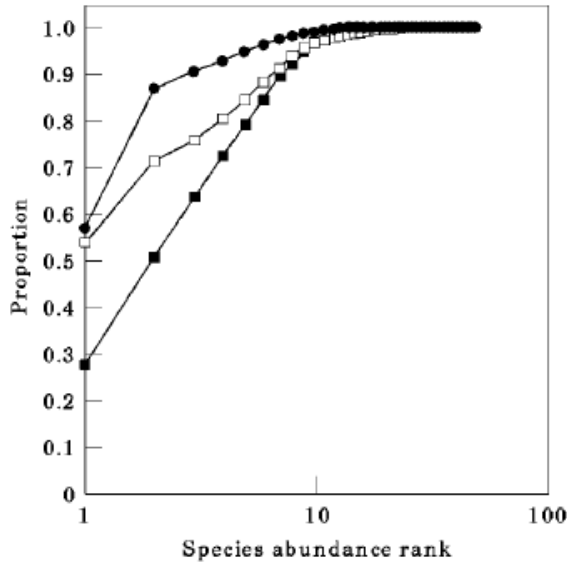

Figure 15: Dominance plot showing the cumulative catch rates against species rank for 1906-1909 (OT, ■), and 1990-1995 (GOV, ●; BT, □) (from Rijnsdorp et al. 1996).

However, when species identity was taken into account, rather than considering just univariate indices of diversity, a more complex picture emerges. The multidimensional scaling plot present in Figure 16 shows how similar observations (denoted by squares and circles) are based on the catch composition: The greater distance between points, the less similar the catches. Highly significant differences are detected in species composition between the time periods (Figure 16). These changes were driven by a decline in spur-dog, *Squalus acanthias*, which are vulnerable to exploitation due to their low fecundity, an increase in Norway pout, *Trisopterus esmarki*, and declines in both long rough dab, *Hippoglossoides platessoides*, and grey gurnard, *Eutrigla gurnardus* (Figure 17). The latter two are dominant among the non-target species. The declines of these two species are balanced by an increase in lemon sole, *Microstomus kitt*, and common dab, *Limanda limanda* (Figure 17). Due to the lack of a plausible hypothesis, the changes in these four species were concluded to be the result of a stochastic drift in population growth (Greenstreet & Hall 1996).

When analysed closely, it appears that many of the detected differences are due mainly to changes in the abundant commercially targeted species, or in the very rare species, leading to the conclusion that in the North Sea, assemblage types are persistent, despite the impact of fisheries (Greenstreet & Hall 1996).

It should be noted however that comparisons across surveys, such as the ones made by Rijnsdorp *et al*. (1996) and Greenstreet & Hall (1996) are impeded by the different survey gears used, which affect the catchability of certain species, and thus the comparability of catch rates, as well as the fact that some surveys may not sufficiently record the smaller species (Rijnsdorp *et al*. 1996). Although in the comparison of Scottish research data, the gear was consistent (otter trawl, same size and net dimensions, minor modification to the design in the more recent survey), the increase in

vessel power lead to an increase in towing speed from 2-2.5 to 3.5-4 knots, which in turn increased the catchability of faster swimming pelagic species, such as mackerel and herring. Although this was taken account of in the study by removing pelagic species from the analysis, it highlights again the difficulty of assessing long-term trends in diversity.
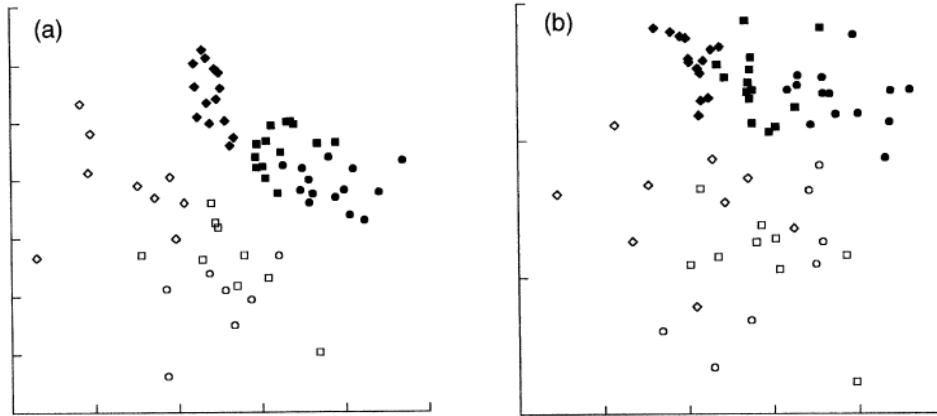
Figure 16: Multi-dimensional scaling ordination plots: (a) for both the whole groundfish assemblage and (b) for the non-target species subset. Points closer together are more similar in catch composition. The filled symbols indicate recent samples, unfilled symbols are archive data; circles show data for East Shetland, squares show data for Northwest Central, and diamonds show data for Scottish East Coast (from Greenstreet & Hall 1996).

Figure 17: Between-data-set variation in the relative abundance of the key species (within-group typifying and between-gro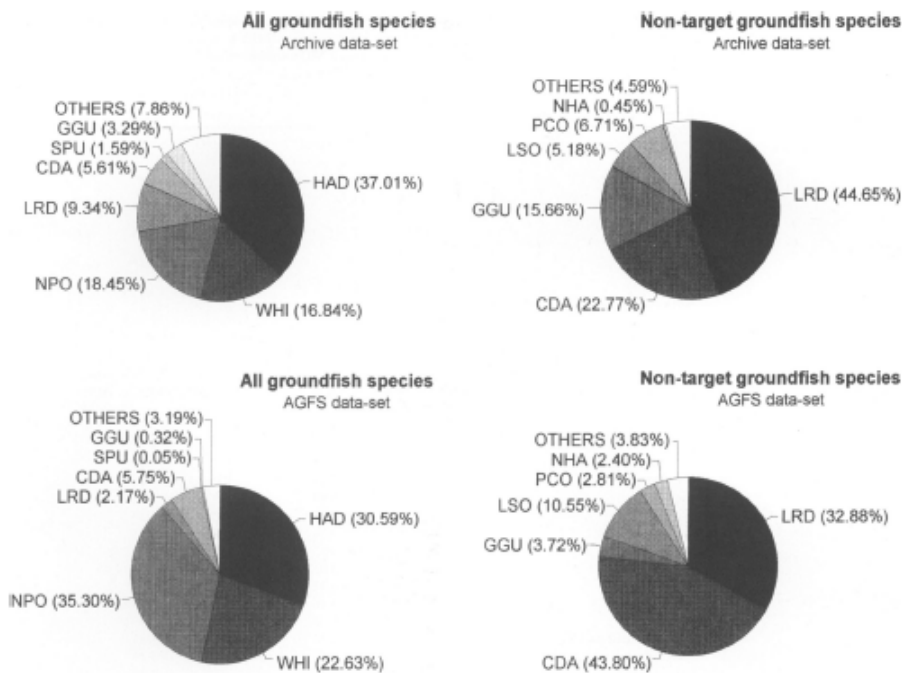up discriminating) in both the whole groundfish assemblage and the non-target species subset. HAD = haddock, WHI = Whiting, NPO = Norway pout, LRD = Long rough dab, CDA = common dab, SPU = spur-dog, GGU = grey gurnard, LSO = lemon sole, PCO = poor cod, NHA = Norway haddock (from Greenstreet & Hall 1996).

Whilst Rijnsdorp *et al*. (1996) and Greenstreet & Hall (1996) focus on fishery impacts on community assemblages, recent warming of the North Sea as a result of climate change may also effect species diversity. (Hiddink & Ter Hofstede 2008) used data from the International Bottom Trawl Survey (IBTS) to show that average species richness of fish in the North Sea has increased from 1985 to 2006, both at the scale of the ICES rectangle and for the whole North Sea (Figure 18, 18a and 18c). They tested the hypothesis that: "if the relationship between temperature and species richness was found to be stable in time, changes in temperature can be assumed to explain observed changes in species richness. If the relationship was found to be different for two periods, it means that species richness has changed at a different rate than could be predicted from temperature changes alone".

Species richness was significantly positively correlated to average winter bottom temperature over the previous 5 years (Figure 18, 18b and 18d). Fish species whose distribution range expanded, contributed to the increase in local species richness. Such fish species were generally small-sized and close to their northern latitudinal boundary (i.e. southerly species), while fish that decreased their range were large species and far from their northern latitudinal boundary (Figure 19).
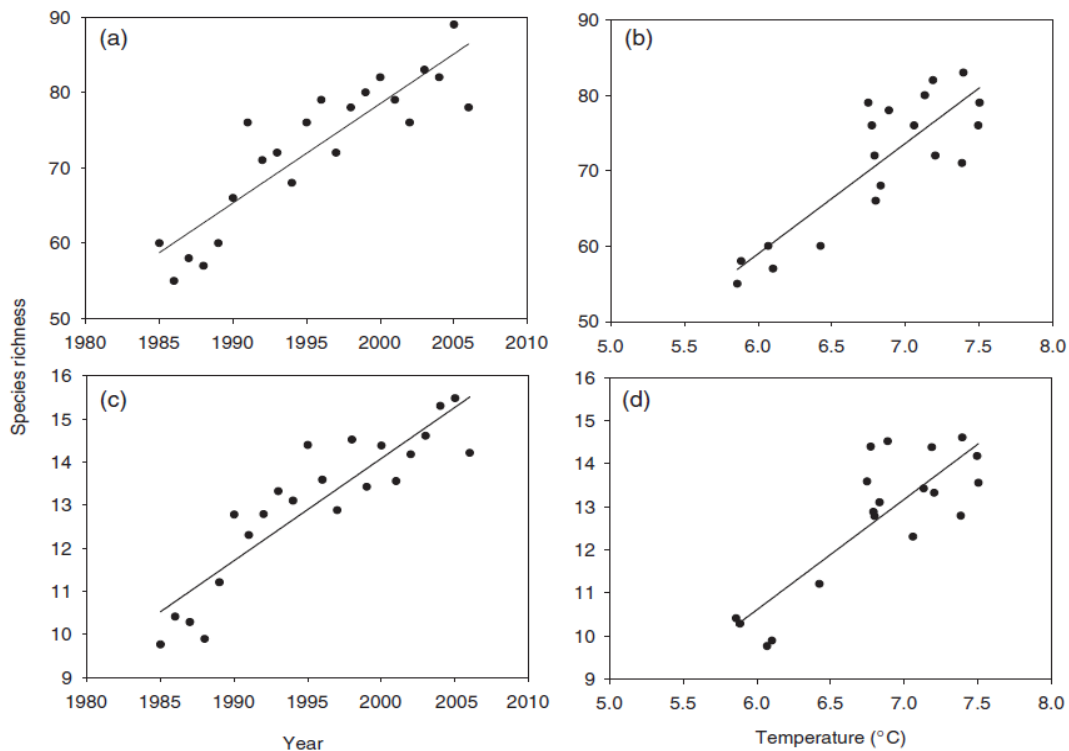
Figure 18: Change in North Sea fish species richness over time and with temperature. (a) Total number of species recorded per year ($R^2 = 0.80$, $F_{1,20} = 577.7$, $P < 0.001$). (b) Total number of species recorded vs. average temperature over the previous 5 years ($R^2 = 0.72$, $F_{1,17} = 44.8$, $P < 0.001$). (c) Average number of species recorded per rectangle ($R^2 = 0.81$, $F_{1,20} = 82.7$, $P < 0.001$). (d) Average number of species recorded per rectangle vs. average temperature over the previous 5 years $R^2 = 0.70$, $F_{1,17} = 39.8$, $P < 0.001$) (source: IBTS – data from ICES DATRAS). IBTS, International Bottom Trawl Survey (from Hiddink & Ter Hofstede 2008)
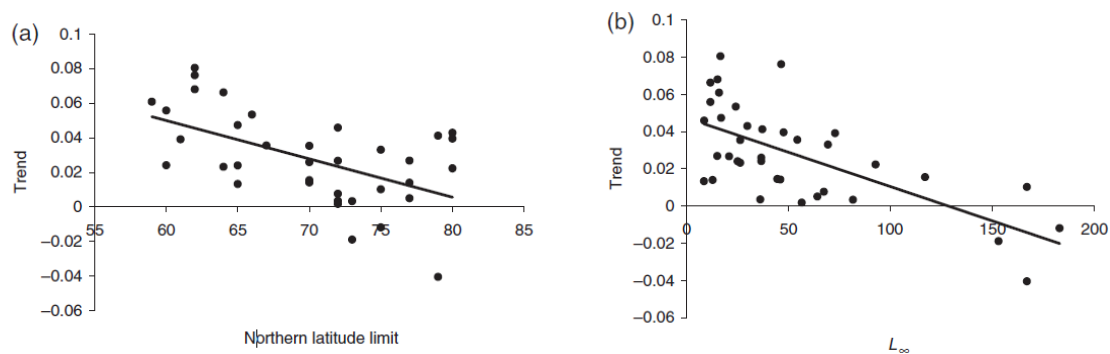
Figure 19: Effect of (a) latitude limit and (b) life-history on distribution trends of fish species in the North Sea (R250.53, latitude limit: $F_{1,\ 34}$ = 6.2, P < 0.017, L_∞: $F_{1,\ 34}$ = 32.8, P < 0.0001) (from Hiddink & Ter Hofstede 2008)

Over eight times more fish species displayed increased distribution ranges in the North Sea (mainly small-sized species of southerly origin) compared with those whose range decreased (primarily large and northerly species). Only three species showed decreased range sizes: the catfish, *Anarhichas lupus*, the spurdog, *Squalus acanthias* and the ling, *Molva molva*; all three large species have a high northern latitudinal boundary (> 73∘N). Thirty –four species displayed significant increases in distribution ranges. The five fish whose ranges expanded most were anchovy, *Engraulis encrasicolus*, red mullet, *Mullus surmuletus*, scaldfish, *Arnoglossus laterna*, solenette *Buglossidium luteum* and lesser weever, *Echiichthys vipera*. These are all small species with a northern latitudinal boundary at a relatively low latitude (59–64∘N).

Hiddink & Ter Hofstede (2008) conclude that the interaction between large-scale biogeographical patterns and climate change may lead to increasing species richness at temperate latitudes. However, they also state that species richness increased more than predicted by temperature alone, which indicates that other factors besides climate may contribute to the increase in species richness. A possible factor is the improvement of identification accuracy of the fish species during the surveys, but more likely it can be put down to an increase in small species due to a release from predation by large commercial fish given the overexploitation of these larger species Jennings & Blanchard (2004). Although there is no theoretical basis to predict the effect of fishing on species richness Rochet & Trenkel (2003) but nevertheless, the reduction in abundance of target species and the possible increase in abundance of non-target species due to release from competition and predation are likely to have effects on local species richness (Hiddink & Ter Hofstede 2008).

2.4.3 Size composition and trophic structure

Due to the selective removal of larger, and older, individuals by fisheries, it can be expected that the size structure of a fish stock/community changes. The reasons for this are two-fold; (1) the fishery can directly impact the targeted stock by removing older and larger individuals, causing a decrease in relative abundance of older and larger individuals within a stock, and/or (2), the overall size composition of the community can decrease due to an increase in abundance of small-bodied species and/or a decrease in abundance of large-bodied species. Thus, as fishing mortality rises, the mean size of individuals in the community falls, and species with larger body sizes form a smaller proportion of community biomass (Jennings *et al*. 2002). These effects have been demonstrated in fisheries from the tropics to the Arctic (for reviews see: (Gislason 1994, Jennings & Kaiser 1998, Hall 1999, Gislason & Sinclair 2000).

Fisheries only directly affect the targeted stocks, but the fish community as a whole will integrate the subsequent indirect effects, e.g. removal of larger predators. Global landings have shown a shift in the last 50 years from large piscivorous fish to smaller planktivorous fishes and invertebrates, especially in the northern hemisphere. These changes, often described as 'fishing down the marine food web' (Pauly *et al*. 1998), may have major consequences for the marine food web. Although gross changes in community structure are primarily due to the differential effects of fishing on species with contrasting life-histories (Jennings *et al*. 1999a, Dulvy *et al*. 2000, Rogers & Ellis 2000, Greenstreet & Rogers 2006), climate change has undoubtedly affected some species (O'Brien *et al*. 2000).

In the North Sea, clear changes have occurred in the 20th century, both in the size and species composition of the fish community (Rice & Gislason 1996). Drastic decreases have been observed in the abundance of primary target species, such as cod (Pope & Macer 1996, Cook *et al*. 1997), and other larger species with low intrinsic rates of increase (Rijnsdorp *et al*. 1996, Walker & Heessen 1996, Walker & Hislop 1998). Many smaller species, on the other hand, have increased in abundance, despite intense fishing activity (Greenstreet & Hall 1996, Heessen & Daan 1996, Greenstreet *et al*. 1998).

Comparisons of recent survey data with demersal trawl catches of research vessel surveys conducted in the south-eastern North Sea during the first decade of this century, have shown a marked decrease in the relative contribution of larger fish to both roundfish and flatfish assemblages (Figure 20, (Rijnsdorp *et al*. 1996). Rijnsdorp *et al*. (1996) found that smaller-sized species, such as whiting (roundfish) and dab (flatfish) increased in relative abundance compared to the larger-sized species, such as cod and plaice.

Aggregate fishing-induced changes in the size-composition of multispecies communities have been described using size-spectra (relationships between abundance and body mass; (Rice & Gislason 1996, Gislason & Rice 1998, Bianchi *et al*. 2000). The effects of fishing on the size composition within a fish community has been demonstrated by a positive correlation between the slopes of size-spectra and fishing intensity (Pope *et al*. 1988, Rice & Gislason 1996, Bianchi *et al*. 2000).
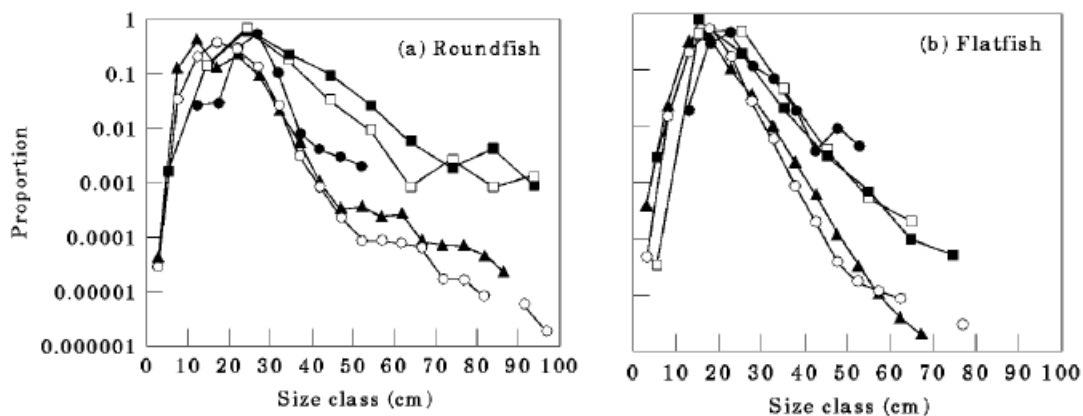

Figure 20: Size frequency distribution of (a) roundfish and (b) flatfish by trawl survey in 1906-1909 (■ = Beam Trawl survey, □ = Otter trawl survey (English), ● = Otter trawl survey (Dutch) and 1990-1995 (O = GOV, ▲ = Beam trawl) (from Rijnsdorp et al. 1996).

Because of the change in size composition and decrease in abundance of larger predatory fish, changes in the mean trophic level of the fish community can be expected. (Yang 1982b) examined the mean trophic level of the North Sea between 1947 and 1977 by assigning a trophic level to each of 34 fish species based on feeding habits available in the literature and calculating the mean. Despite increasing catches, the mean trophic level of the nominal catch was found to remain stable (between 3.62 and 3.76) across the time period (Figure 21a). Drastic changes in individual species catches, for example herring (Figure 21b), do not appear to have affected mean trophic level, as these species have been replaced by a similar trophic level species (Figure 21b). (Yang 1982b) therefore concluded that, as generally speaking, the catch should approximately reflect the abundance in a well-exploited sea, and assuming that the trophic levels of the 34 species were similar during 1947-77, fishing did not appear to have upset the fundamental ecological balance of the North Sea, or, in other words, the influence of fishing has not yet surpassed the self-regulatory capacity of the North Sea ecosystem (Yang 1982b).
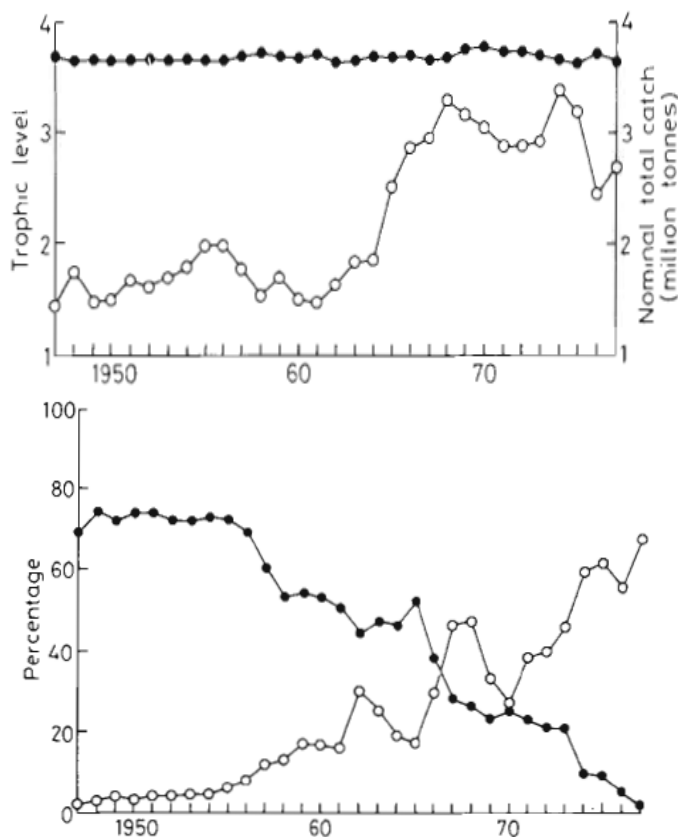
Figure 21: a) Mean trophic level of nominal catch (filled circles) and nominal total catch (open circles) of North Sea fish during 1947-77, b) Percentage of herring (filled circles) and of other plankton feeding fishes (open circles) in the nominal total catch of fish from the North Sea during 1947-77 (from Yang 1982b).

However, the critical assumption that the trophic level of a species remains stable is not necessarily correct, particularly in view of the changes in size composition of species populations. Many species switch feeding habits as they grow (Cushing 1975) and it is therefore conceivable that trophic levels can decrease with increasing body size. In a later study on long-term trends in the trophic structure of North Sea fish, Jennings *et al*. (2002) took account of the size-spectra of the community. The trophic level of the North

Sea demersal fish community was then found to decline between 1982 and 2000 (Figure 22), although the decline was only significant when the size structure of the community was taken into account. The decline was also small compared to changes found elsewhere (e.g. Celtic Sea, (Pinnegar *et al*. 2002).

The analysis done by Jennings *et al*. (2002) suggests that impacts of fishing on the trophic structure of fish communities are extremely complex, partly due to the fact that sampled communities do not reflect all the pathways of energy transfer in a marine system and partly because historical, as well as temporal and spatial changes, in the trophic levels of individuals are not available. Within the North Sea, changes in size structure due to the differential effects of fishing on species and populations with different life histories appear to be a stronger and more universal indicator of changes in the structure of the community.
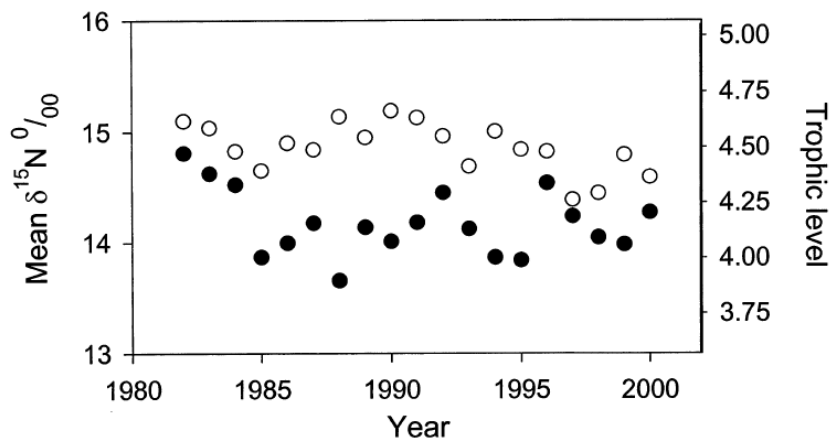
Figure 22: Long-term trends in the mean $\delta^{15}N$ and equivalent trophic level of the North Sea fish community, as sampled by the International Bottom Trawl Survey. Filled circles Pelagic and demersal species; open circles demersal species (from Jennings et al. 2002).

2.4.4 Maturity

The combinations of ages and sizes at which maturation of a fish occurs, strongly influence an individuals expected reproductive success. The evolution of reaction norms for age and size at maturation is determined by environmental conditions such as size-dependant mortality rates (Heino & Kaitala 1999) and resource availability (Siems & Sikes 1998). Because, in general, ecological settings with low survival survival and growth rate among potentially reproducing individuals favours high reproductive effort at early ages (Hutchings & Myers 1993, Reznick 1993, Reznick *et al*. 1993), removal of large individuals from a population by selective fishing is expected to select for genotypes with a lower age and size at maturation (Grift *et al*. 2003).

A significant decrease in age and length at maturation of North Sea plaice has been observed during the 20th century. The age at which 50% of the females were mature (A_{50}) has decreased by 2 year between the early (1904 to 1911) and late (1960 to 1990) 20th century, whereas for Age group 4 the length at which 50% of the females were mature (L_{50}) has decreased by 5.8 cm (16%) in the same period (Rijnsdorp 1993). Although the implications of resource availability for life-history characteristics are as yet less well understood, based on statistical analysis, Rijnsdorp (1993) suggested that phenotypic plasticity could explain about 2.7 cm of this decrease and concluded that fisheries-induced evolution could account for the remaining 3.1 cm.

The proposed evolutionary changes in North Sea plaice maturity were further investigated by Grift *et al*. (2003). Phenotypic and evolutionary changes were disentangled using the probabilistic reaction-norm method (Heino *et al*. 2002), which allows for a refined test of the hypothesis that the observed decrease in age and length at maturation is partly caused by fisheries induced adaptive change. Although less obvious for lengths, both age and length at 50% maturity showed a significant decline over time (Figure 23), with A_{50} decreasing by around 1yr and L_{50} by around 1 cm over a 40 year period (Grift *et al*. 2003). The reaction norms showed that over the whole period and for all ages, the length at which fish had a certain probability to mature decreased (Figure 24). (Grift *et al*. 2003) concluded that the significant gradual downward trend in probabilistic reaction norms over cohorts of 1955 to 1995 strongly supports the hypothesis that fisheries-induced evolution has changed the maturation process in North Sea plaice towards maturation at earlier age and length. An acceleration on growth rates over the same period is thought to have driven this trend further (Rijnsdorp 1993, Grift *et al*. 2003).

Similar trends towards earlier maturation have also been shown for North Sea sole (Mollet *et al*. 2007) and cod (Rowell 1993). Mollet *et al*. (2007) found the reaction norm for age and size at first maturation of sole has significantly shifted towards younger age and smaller size. Size at 50% probability of maturation at Age 3, for example, decreased from 28.6 cm (251 g) to 24.6 cm (128 g) (Figure 25).
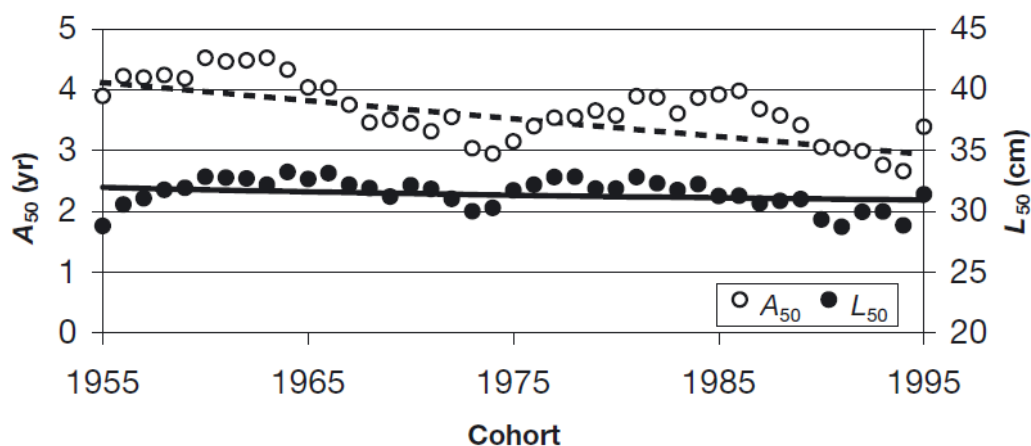
Figure 23: Plaice (<u>Pleuronectes platessa</u>). Trends in the age (A_{50}) and length (L_{50}) at which 50% of fish are mature in each cohort. Data from logistic models with cohort either as a factor (open and filled circles; R^2 = 0.34 and 0.42 for age and length at maturation, respectively) or as a variate (dashed and continuous lines; R^2 = 0.30 and 0.40, respectively). In both cases, the decline of A_{50} and L_{50} with time (cohort) is significant (p < 0.0001) (from Grift et al. 2003).
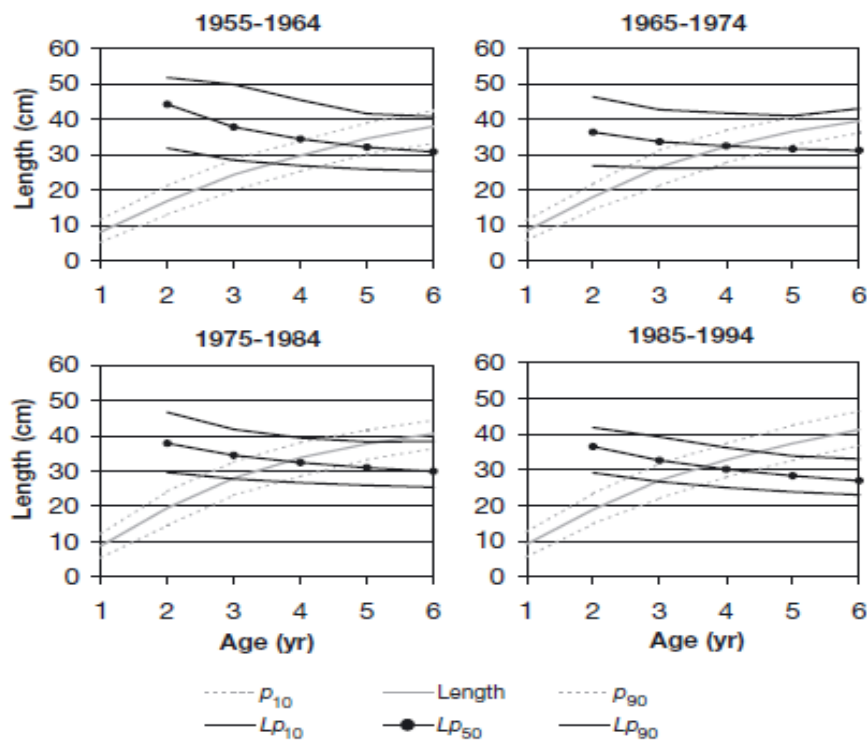
Figure 24: Plaice (*Pleuronectes platessa*). Maturation reaction norms and growth curves. Lengths at which the probability to mature reaches 10, 50, and 90% (LP10, LP50, and LP90) are shown as continuous curves. Distributions of growth trajectories are depicted in terms of arithmetic mean length-at-age together with 10 and 90% percentiles (Length, p10, and p90). All values are averages over 10-cohort periods (from Grift et al. 2003).
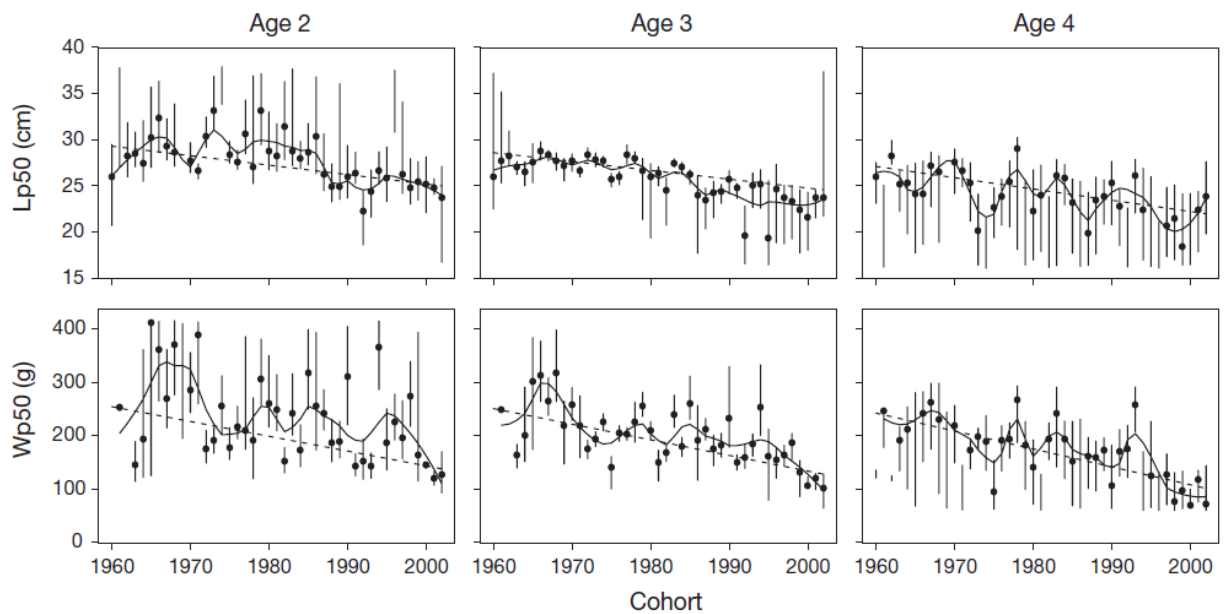
Figure 25: Sole (*Solea solea*). Reaction norm midpoints Lp50 and Wp50 over time (d), bootstrapped 95% percentiles (vertical bars), trend regression weighted by the inverse bootstrap variances (---) and fit with a non-parametric smoother (--). All trends are significant on a level of $a = 10^{-4}$ (from Mollet et al. 2007).

2.5 Rare species

Species rarity encompasses two aspects: low population density and a restricted area of distribution. Based on data from IBTS survey, Daan (2001) calculated 'rarity values' for a 10 × 10 nm grid of the North Sea (Figure 26; Daan 2001). The rarity value considers three aspects: the geographical area considered, the numerical abundance and the extent of the area occupied. Because rare species are caught in smaller numbers and/or in fewer rectangles, the percentage contribution of squares where these are caught is relatively high compared to species that are numerically abundant over large areas. Summing these values over all species thus provides an appropriate index of the relative contribution of each square to the catch of rare species, without having to specify *a priori* which species are to be considered rare.
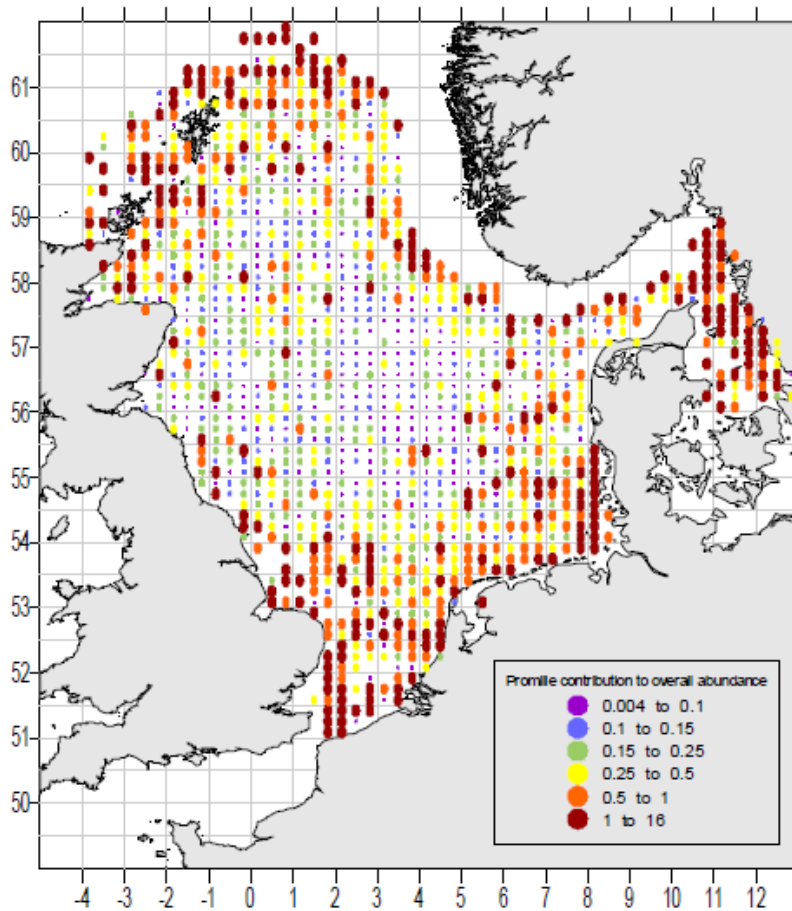
Figure 26: Spatial variation in the 'rarity value', expressed as the cumulative promille contribution to the average abundance of all species caught during the IBTS (all quarters, 1977-2004; from ICES 2008).

The resulting pattern bears broad similarities with the map for species richness (Figure 3). The central North Sea can be identified as an area that is of very limited significance to rare species, with much higher values found around the North Sea coasts. In contrast, however, the zone around the continental coast emerges as a clear hotspot in terms of rarity value. The reason for this appears to be that, although the number of species is relatively low, many of these are typical of near-shore waters and do not occur elsewhere. Considering rare species and their spatial patterns in occurrence is of great importance from a conservation point of view.

2.6 Vulnerable species

The North Sea elasmobranch community is considered vulnerable as they are susceptible to overfishing (Stevens et al. 2000) due to their life-history traits (slow-growing, low fecundity). Specific management advice was therefore drafted by ICES in 1997 (ICES 1998), page 171) indicating that the common skate, Raja batis, was almost extirpated and that stocks of thornback rays, Raja clavata, and spotted rays, Urobatis maculatus, were outside safe biological limits (Daan et al. 2005). However, as elasmobranchs are landed as bycatch in mixed fisheries targeting teleost species, conservations measures were sought to limit the impact of these fisheries in those areas where the most vulnerable ray species still occur. So far, EC management measures have been attempted through implementation of an overall total allowable catch (TAC) for all rays caught in EU waters of ICES areas IIa and IV. The effectiveness of this measure, however, has been questioned (Daan et al. 2005), as a large part of the ray bycatch is discarded and a global TAC does not restrict catches of individual species in an mixed fishery. Marine protected areas (MPAs), whilst a potential option to protect rays, have, as yet, not been established.

Not a lot is known about the North Sea elasmobranch community, but it has been established that the diversity of elasmobranch species increases from east to west (Figure 27), with higher diversity encountered all along the British Coast (Daan et al. 2005).

Figure 27: Estimated average number of elasmobranch species caught after 20 hauls during IBTS (all quarters), based on 20 Monte-Carlo simulations and fitted regression lines of nr of species vs nr of hauls (1977-2004; from Daan et al. 2005).

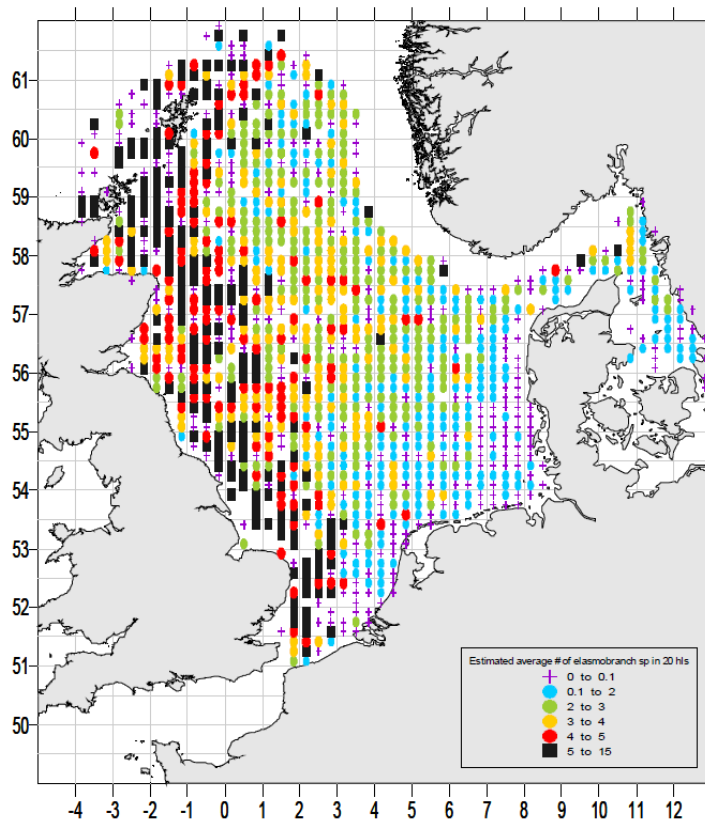# 3 Current pressures and driving factors

3.1 The physical environment (from ICES-FishMap 2005)

The physical environment of the North Sea (and changes therein) is described in Van Hal *et al*. (2011). Here it is important to mention that the physical environment is also a natural driver of the distribution and migrations of fish species (Table 7).

The variation in the physical environment is, of course, reflected in the flora and fauna. The different substrata support very diverse communities of bottom-living animals and, similarly, each water mass supports a different group of planktonic organisms (for review papers see: Heip *et al*. 1990, Reid *et al*. 1990, Duineveld *et al*. 1991, Fransz *et al*. 1991, Jennings *et al*. 1999b, OSPAR 2000, Zühlke *et al*. 2001, Callaway *et al*. 2002).

The Channel is generally considered to represent a biogeographical boundary between the northerly boreal province and the more southerly Lusitanean province. Some boreal species are widespread throughout much of the North Sea (e.g. cod, herring), although many tend to be more abundant in northern parts of the North Sea such as haddock, *Melanogrammus aeglefinus*. Species such as catfish, *Anarhichas lupus*, and Norway pout, *Trisopterus esmarki* , reach their southern limits in the central North Sea. Several of the Lusitanian species are largely restricted to the Southern Bight such as lesser weever, *Echiichthys vipera*, greater weever, *Trachinus draco*, striped red mullet, *Mullus surmuletus*, and bass, *Dicentrarchus labrax*.

Owing to the oceanic circulation of the North Atlantic, a warm current (North Atlantic Drift) runs northwards along the western coasts of the British Isles, and this enables some southerly species to occur further north along the western seaboard of the British Isles than in the North Sea. Those southerly species of fish that occur along the edge of the continental shelf (ca. 200 m depth) will also occur at more northern latitudes in the westerly North Sea, for example blue-mouth redfish, *Helicolenus dactylopterus*, while more broadly distributed deepwater species such as rabbitfish, *Chimaera monstrosa*, may be found all along the northern shelf edge and the Norwegian Deep. During some years, when there is an influx of oceanic Atlantic water into the northern North Sea, there can be increased numbers of particular species (Heessen *et al*. 1996, Iverson *et al*. 2002).

Other physical factors (e.g. salinity, hydrodynamics and substrate type) and biological interactions (e.g. predator-prey relationships) will also affect the distribution and relative abundance of fish on more local scales. Some species have specific habitat requirements, for example witch, *Glyptocephalus cynoglossus*, tend to occur on muddy grounds. In addition to sediment type, the structure and topography of the seabed (e.g. the presence of sand ripples, sessile invertebrates and wrecks) will also affect the local distribution of fish, as such complex habitats can provide cover, and therefore reduce natural mortality. However, the habitats favoured by any given species of fish may vary both with age and time of year. Though the overall biogeographical distribution of fishes is well documented in ichthyological literature (Wheeler 1969, 1978, Whitehead *et al*. 1984), there is less information on the distribution and relative abundance of fishes, and their various life history stages, using contemporary data on spatial scales relevant to fisheries management (Knijn *et al*. 1993).

Table 7. Overview of (autonomous) natural processes, their trends and their effects on the ecosystem component fish and the fish community (demonstrated effect with reference and hypothesized effect without reference)

Autonomous developments			
Natural processes	**Lead to changes in**	**Trends**	**Demonstrated effects (with reference) and hypothesised effects (no reference)**
1. Physical processes in de water column	Currents: speed/direction, bottom stress, transport sediment, larvae Waves: bottom stress, stratification Temperature; stratification, growth rate Salinity Fronts: upwelling, food availability Wind: water currents, waves, stratification Precipitation: salinity, nutrients Water depth	Stable? Cycles? Temperature: increase; sometimes step-wise shift in temperature Wind: variable Precipitation: seasonal increase	General effects: maintain natural variation in species biomass, composition and distribution, create broad-scale bio geographical – patterns in fish communities (ICES-Fishmap, Callaway 2002) Currents: determine distribution/survival of eggs/larvae; may affect success of egg/larval drifts to nursery areas Waves/winds: influences degree of stratification which can affect food resources (plankton) Temperature: direct effects on physiology determine species distribution ranges, indirect effects on food resources Fronts: affect food availability
2. Physical processes at the seabed	Sedimentation Particle size Hard/soft substrate Sludge percentage	Stable	Particle size: strong influence on composition of benthic community (Lavaleye, 2000; Craey-meersch *et al*., 2008), which in turn determines food availability for benthivores; influence on species with specific habitat requirements, e.g. spawning grounds of herring (Blaxter & Hunter, 1982; Maravelias *et al*., 2000), settlement of plaice larvae (Zijlstra *et al*., 1982)
3. Biological processes	Primary production Food web: predation, competition Regime shifts Population dynamics Keystone species/ecosystem engineers	Dynamic: populations of prey species (fish) have strong annual and seasonal dynamics	Primary production: any changes will translate through the food chain having consequences for the ecosystem, including fish

3.2 Anthropogenic drivers

3.2.1 Fisheries

Fisheries impact on the North Sea fish community both directly through removal of biomass (e.g. Rijnsdorp *et al*. 1996, Cook *et al*. 1997), size-selective removal of biomass (e.g. Jennings *et al*. 2002, Pinnegar *et al*. 2002) and consequences thereof (e.g. genetic changes, Grift *et al*. 2003, Mollet *et al*. 2007), and through discards (Table 8). Indirect effects occur through top-down (e.g. Branch *et al*. 2010, Pauly *et al*. 1998) and bottom-up effects through the food-web (e.g. through impacts of trawling on benthic communities, Table 8). The direct effects on fish populations are described in more detail above (section 2.4) and effects on the food availability (benthic production) are described in more detail in the benthos report (Van Hal *et al*., 2011).

Table 8. Overview of (steerable) anthropogenic influences on and activities in sea, their trends and their effects on the ecosystem component fish and the fish community (demonstrated effect with reference and hypothesized effect without reference)

Steerable developments			
Anthropogenic influences on and activities	**Physical/ecological influences(Pressures)**	**Trends**	**Demonstrated effects (with reference) and hypothesised effects (no reference)**
1. Fisheries (pelagic, demersal fisheries; passive, active)	Removal of biomass/fish stock Size-selective removal of biomass Selective removal predator species Genetic changes By-catch Discards Bottom stress	Reduction in effort of the largest segments of the fleet; Potential increase in various 'new' methods (e.g. pulse fisheries, sumwing, twin-rigs); Increase in passive techniques (standing rigging); Reduction of discards (ban on discards?)	Removal of biomass: direct decrease in abundance of targeted and non-targeted species (by-catch), extent of effect dependant on life-history of species (e.g. Rijnsdorp *et al.* 1996; Cook *et al.*, 1997) Size-selective removal of biomass/species: changes in size composition of a species population or community as a whole (e.g. Jennings *et al.* 2002; Pinnegar *et al.*, 2002) Genetic changes: earlier maturation due to selective removal of large individuals (Grift *et al.* 2003; Mollet *et al.*2007) Food web: *Top-down effects*: removal of target species and changes in size-composition can have cascading effects through the ecosystem (Christensen *et al.*, 2003), e.g 'fishing down the food web' (Branch *et al.* 2010; Pauly *et al.* 1998); *Bottom-up effects*: changes in food availability, e.g. by removal of prey species or indirect effects (positive or negative) through changes in benthic communities (see chapter on benthos) and therefore food availability
2. Oil and gas exploration and exploitation	Exploration: blasts Construction: noise Oil spills Drilling-mud disposal Soil subsidence Restricted area fisheries Increase hard substrate Underwater noise	General: decreasing in number; discharges are already reduced since 1990	Pollution: can have strong negative effects on organism health (Duineveld *et al.* 2007) Increase hard substrate: Can act as artificial reefs on which organisms settle and grow, can increase food for fish; fish attracted to structures, e.g. monopiles of wind farms (Couperus *et al.* 2010); potential accumulation of predator species which may impact on prey species Restricted area for fisheries: Unknown if areas are large enough to have a positive influence on North sea populations, may enhance survival locally although some fishing practises are still allowed Underwater noise: possible effect on survival of fish larvae

Steerable developments			
Anthropogenic influences on and activities	Physical/ecological influences(Pressures)	Trends	Demonstrated effects (with reference) and hypothesised effects (no reference)
3. Shipping	Gas emissions Oil spills Ballast water: introduction exotics Waste Discharges of TBT (antifouling) Underwater noise	General: intensity (noise) is increasing; measures against pollution/discharges decrease since 1990 Oil spills: sporadic/unpredictable Ballast water: stricter measures expected to reduce problems Waste discharges:? TBT: declining (Evans et al., 1996) Underwater noise: ?	Pollution: can have strong negative effects on organism health (Duineveld et al. 2007) Underwater noise: possible effect on survival of fish larvae Waste: e.g. 'plastic soup' – can be ingested and cause ill-health/mortalities
4. Wind parks	Habitat change Barrier effect Increase hard substrate Restricted area fisheries Underwater noise (notably during pile construction)	Increase in number of parks; major developments particularly since 2000	Increase hard substrate: Can act as artificial reefs on which organisms settle and grow, can increase food for fish; fish attracted to structures, e.g. monopiles of wind farms (Couperus et al. 2010); potential accumulation of predator species which may impact on prey species Restricted area for fisheries: Unknown if areas are large enough to have a positive influence on North sea populations, may enhance survival locally although some fishing practises are still allowed Underwater noise: possible effect on survival of fish larvae; especially drilling
5. Dredging fairways and ports	Substrate removal (sludge) in coastal sea Water depth Sight Discharge sludge	Stable or increasing (depending on development of ports)	Reduction in food and quality of habitat?
6. Emissions (to coastal waters, estuaries, open sea or through the atmosphere; from urban area, industry or agriculture)	Input nutrients Input toxic chemicals Plastics	Decreasing?	Input nutrients: changes in benthic community, i.e. food resources (Philippart et al. 2007) Input toxic chemicals: effects not well known
7. CO_2-emissions	Climate change: temperature increase and storm frequency Acidification by CO_2	Temperature: increasing Storm frequency: increasing? Water pH: decreasing?	Temperature: changes in species distribution depending on temperature tolerance of organism and changes in habitat quality (e.g. Teal et al. 2008; Van Hal et al. 2010); changes in diversity due to increase in southern species (e.g. Hiddink & Ter Hofstede, 2008); direct physiological effects on organisms interact with changes in food availability to affect habitat quality, organism growth and ultimately survival

Steerable developments			
Anthropogenic influences on and activities	Physical/ecological influences(Pressures)	Trends	Demonstrated effects (with reference) and hypothesised effects (no reference)
			Water pH/acidification: effects on abundance of food resources (Hendriks et al. 2010); effect on development/survival of eggs and larvae, effects on fish behaviour (Munday et al. 2009); effects on biogeochemical processes (Blackford & Gilbert, 2007) which can translate through the food chain to fish
8. Aquaculture (algae, MZI's, shellfish, worms and/or fish)	Habitat destruction Introduction alien species (invasive)	Increasing (shellfish transports increase)	Habitat destruction culture of predatory fish species requires industrial fisheries for fish food which impacts targeted species (e.g. sand eel)
9. Sand extraction	Substrate removal Water depth Seabed scaping Decreased sight Disturbance	Increasing (increased demand of sand at land as for coastal defence)	Substrate removal possible reduction in food and quality of habitat Seabed scaping variation in relief and depth offers opportunities for greater diversity fish fauna
10. Sand nourishment	Cover benthos Sediment composition Decreased sight Disturbance	Increasing	Cover benthos possible temporary reduction in food and quality of habitat
11. Recreational use coastal zone, water tourism	Disturbance Pollution	Increasing	Minor influence on fish
12. Military use (ammunition cleaning, flying, shooting etc.)	Disturbance (noise) Input toxic chemicals	Decreasing?	Effects not well known
13. Nature protection policies, management and areas	Aim to decrease human impact on ecosystem	Increasing	Fisheries management aim to keep commercial stocks within biologically safe limits, ecosystem approach to management to be implemented, Closed areas aim to enhance diversity

3.2.2 Climate change

Changes in the climate and what can be expected in the future are described in detail in Van Hal et al (2011). Climate can affect the environment of the fish community by changes in sea temperature, currents and waves, precipitation (salinity and river run off) and pH (Table 8). Of these factors, the effects of temperature are perhaps best studied, not only because temperature is an easy variable to measure and is commonly recorded, but also because temperature can directly affect the organisms physiology. Responses to changes in sea temperatures are therefore expected in terms of changes in species distribution relating to species temperature tolerance ranges and changes in distribution of habitat quality (eg. Van Hal et al. 2010, Teal et al. 2008). As temperatures in the North Sea are rising, an influx of southern species has been observed in relation to the increase in temperature, which in turn has led to an increase in diversity (Hiddink & Ter Hofstede, 2008).

In addition to the direct effects of temperature on organisms physiology, temperature can also effect the availability of food (both plankton and benthic food) which further affects the habitat quality of fish and therefore ultimately their potential for growth, reproduction and survival (Teal *et al*. 2010).

Climate change related changes in wind force and direction can have an impact on the strength and direction of currents, which can affect the success of eggs and larvae in reaching their nursery grounds.

3.2.3 Ocean Acidification

Ocean acidification is perhaps less intuitive to link directly to fish and current studies of the effects of a lower pH focus more on calcifying organisms (e.g. corals, bivalves, molluscs), which are directly affected. However, indirect effects on abundance of food resources can be expected (Hendriks *et al*. 2010), particularly when biogeochemical processes are affected which translate through the food chain (Blackford and Gilbert 2007). Direct effects may also occur on the development and survival of eggs and larvae or by affecting the behaviour of fish (e.g. Munday *et al*. 2009). Knowledge on the effects of ocean acidification on North Sea fish species is, however, still lacking.

3.2.4 Primary productivity (eutrophication)

Changes in primary production in the North Sea are described in the systems chapter as well as the climate chapter. Any changes in primary production will translate through the food chain having consequences for the ecosystem, including the fish (Table 7 and Table 8). Inflow of nutrients through rivers can cause eutrophication and can influence the benthic communities and thus food of fish in coastal areas.

3.2.5 Offshore construction

Offshore construction can interact with the fish community in multiple ways (Table 8). The spatial use of the North Sea for oil and gas platforms, as well as offshore wind parks has the potential to provide positive effects on fish species by providing closed areas from fisheries. However, this is not always the case as in some areas a range of fishing practises are still allowed and it is not certain whether these areas are in fact large enough to provide a refugium. The increase in hard substrate through structures on the seabed and through the water column may allow organisms to settle and grow, providing artificial reef structures and increase in food for fish. Fish are also known to be attracted to structures in the water column (Couperus *et al*. 2010). The effect of underwater noise caused by construction practices on fish and fish larvae is currently being studied.

3.2.6 Shipping

The distribution and use of North Sea shipping lanes may impact on fish communities by effects of pollution on organisms health, as well as effects of underwater noise (Table 8). Neither of these impacts however is well studied. Indirect effects through discharge of ballast waters and the introduction of invasive species may occur as well as effects of pollution on organisms health.

4 The North Sea fish community: future

4.1 Predicted future impacts

Fisheries will continue to effect the North Sea fish community, although it can be expected that with new management approaches (e.g. the Ecosystem Approach to Fisheries Management, EAFM) overall impacts will be closely monitored and minimised where possible. The steps already taken towards a different approach, whereby the objective is to keep all fish stocks above MSY (maximum sustainable Yield) reference levels, will lead to higher abundances of larger commercial fish species. It can also be expected that the management of the North Sea fish stocks will become stricter, especially by applying Good Environmental Status and implementing the various Natura 2000 protected areas. This green approach, which will be implemented in coming years and is expected to prevail on the longer term, will be beneficiary for the fish stocks and size/age structure of the populations.

Climate change can be expected to cause changes to the North Sea fish community on the longer term, both through increases in water temperature and acidification of the oceans. These changes to the fishes environment will have direct and indirect effects (Rijnsdorp *et al*. 2009). Considering the climate scenarios outlined in Van Hal *et al* (2011), it is unlikely, that major changes will occur prior to 2040.

The utilisation of the North Sea area by oil and gas platforms and shipping will remain and an increased number of offshore wind farms can be expected, impacting the spatial use of the North Sea.

4.2 Predicted future recovery possibility

Recovery possibilities for the North Sea community may arise through:
- Changes in Fisheries management;
- Implementation of marine protected areas (MPAs);
- Closed areas for fisheries (e.g. through construction of wind parks).

Predicting the effect these will have on the current community in a quantitative manner, however, is extremely complex.

4.3 The North Sea fish community in 2040?

Even when detailed information is available, the assessment of anthropogenic changes is difficult because of the complex nature of the system in which natural processes and human activities interact, and because of the paucity of time-series data needed to test hypotheses. Commercial fish stocks represent an exception, because they are continuously and extensively monitored, and at least the rates of mortalities inflicted by fisheries are well understood. However, for many other biota, including non-commercial fish species, reliable long-term time series are sparse. This hampers the evaluation of the impact by man (Rijnsdorp, 1996).

In the shorter term it can be expected that human activities will continue to modify the North sea fish community through direct and indirect impacts. Climate change can be considered an impact over the longer term , where the main direct effects of warmer sea temperatures can be expected show an increase in southern species from the western English Channel or Bay of Biscay (e.g. Van Hal *et al*. 2010) and a decrease in northerly species. However, many more indirect effects will occur through a chain of interacting processes which are difficult to predict.

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IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. 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 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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

Approved: Prof.Dr. H.L. Lindeboom
                     Director Science

Signature:

Date: September 2011

Approved: F.C. Groenendijk MSc
                     Head of Department

Signature:

Date: September2011

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