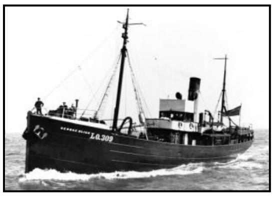
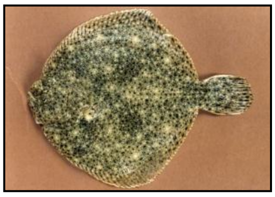
UK fisheries, climate change and North Sea fishes:

a long-term perspective

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Learning about the past is important

because it will help us determine our future

J. Jackson, J. Jacquet

(The shifting baselines syndrome: perception, deception, and the future of our oceans.
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Contents

Abstract

North Sea demersal fishes and fisheries have changed over the past 100 years. To detect the main factors driving these changes, long-term data are needed. Using historical fisheries data that extend throughout the 20th century, this thesis aims to assess drivers influencing developments in fisheries as well as changes in the distribution and abundance of commercially important fishes in the North Sea.

For English demersal fisheries, favourable political, technological and economical drivers were identified, inducing a vast rise in English fisheries in the first half of the 20th century; however, the same drivers, acting adversely, influenced the decline in recent decades and the emphasis of fisheries shifted from England to Scotland.

Different trends in distribution were observed for North Sea whiting, turbot and brill between the 1920s and 2000s. Whiting distribution shifted westward between the late 1940s and1960s, whereas turbot nearly disappeared from the northern North Sea from the 1970s onwards. Brill distribution remained rather stable in the central and southern North Sea. The reasons for the longitudinal shift of whiting remained unclear as the relationships to two potential drivers, climate change and fishing pressure, were not strong. For turbot, the cause for the near disappearance from the northern North Sea is inconclusive.

Commercial fisheries data were assessed reliable for distribution analysis when comparing commercial data of whiting, a commonly discarded species, and unbiased survey data. Whiting, compared to flatfish, is of secondary commercial importance. In areas where discrepancies occurred between commercial and survey data, higher discarding of whiting is suggested, as highly priced flatfish are caught there.

This thesis demonstrates past conditions of demersal fish populations and fisheries in the North Sea and presents the effects of different drivers on them. The documented changes in fishes and fisheries contain valuable information for resetting baselines and developing appropriate management strategies.

Acknowledgements

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Chapter 1

Introduction

Introduction

The North Sea represents a large marine ecosystem. Its bordering countries (Belgium, Denmark, France, Germany, Netherlands, Norway, England and Scotland) intensely utilise and exploit this ecosystem (e.g. fishery, oil, gas, and tourism) (McGlade, 2002). It is one of the world's most important fishing grounds (Rogers and Stocks, 2001) with fishing having a long history and being a well-established activity (e.g. Bruijn, 1996; Holm, 2005; Robinson and Starkey, 1996; Poulsen, 2010). Although humans have exploited North Sea fish stocks for many centuries, it was not until the late 19th century, that fisheries have expanded faster than ever before due to major technological advances in particular of demersal fishing vessels and gears (Engelhard, 2008). Since then, commercial fisheries have increasingly impacted North Sea fish stocks and the ecosystem.

Human activities affect the marine ecosystem and include impacts of fisheries and climate change on fish stocks, damage to seabed habitats as a results of bottom fishing practices, eutrophiciation in coastal areas caused by nutrient inputs, pollution with hazardous substances such as metals and persistent organic pollutants as well as increased quantities of litter and microscopic plastic particles occuring in the North Sea (OSPAR Commission, 2010). However, the understanding of the long-term changes and the extent of human impacts on North Sea fish populations caused by drivers such as fisheries or climate change and its interaction with other human impacts is not complete.

Gradual changes and degradations in fish abundances and distributions as well as changes in fisheries are often not perceived due to a phenomenon called ‘shifting baseline syndrome’ (Pauly, 1995). However, knowledge of such long-term changes potentially have implications for fisheries assessment. Without a better understanding of past developments in fish and fisheries, scientists, managers and politicians will not be able to improve current knowledge and future management decisions. Historical data therefore represents a valuable source of information helping to evaluate and assess former states of fisheries and fish stocks.

1.1 The North Sea

The North Sea is a relatively small basin (575,300 km^2) (ICES, 1983) situated on the continental shelf of north-western Europe. It is a semi-enclosed sea, delimited in the north by a line between Scotland and Norway, to the south by the English Channel, and connected in the east to the Baltic Sea via the Skagerrak and Kattegat (McGlade, 2002). The North Sea is a fairly shallow sea with depth ranges from approximately <50 m in the south-east to 200 m in the north-west, but exceeding 500 m at the Norwegian Trench (ICES, 2008). The substrate of the seabed is variable, consisting of mud, sand, gravel, and boulders. The oceanographic conditions in the North Sea are to a large extent determined by the inflow of saline Atlantic water through the north and, to a lesser degree, through the English Channel. The water in the coastal areas mixes with the freshwater from rivers and the inflow of Baltic low-saline water through the Kattegat. Salinity therefore ranges from 29‰ in the south-eastern to more than 35‰ in the north-western North Sea. Average bottom temperatures are between 5°C-8°C in the winter, and 8°C-18°C in the summer (ICES, 2008). The heterogeneous character of the North Sea, with large regional variations in depth, temperature and salinity, different natures of the sea bed and topographies along the coastline, influence the biology and ecology of the North Sea fish fauna (Daan et al., 1990).

Although the North Sea only represents less than 1% of all oceans, it is of major economic importance for its bordering countries. Not only extractive industries such as fisheries or gas and oil production depend on this ecosystem, the North Sea and the Dover Strait are also one of the most heavily utilised sea routes in the world supporting commercial ports. Further, the coastal areas are important for the tourism industry (McGlade, 2002).

Before the Industrial Revolution, human activity had relatively little impact on this ecosystem; only with growing industrial activity and an increased population, it has become clear that its resources are close to over-exploitation and under threat (McGlade, 2002). Further, in the past decades, human-induced global climate change impacted marine ecosystems, having implications for the economic and social systems that depend upon them (Harley et al., 2006).

1.2 North Sea fish

The North Sea is inhabited by around 224 fish species originating from three biogeographical regions: 66 Boreal species (e.g. cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*)), 110 Lusitanian species (e.g. sprat (*Sprattus sprattus*), grey gurnard (*Eutrigla gurnadus*)), and 48 Atlantic species (e.g. mackerel (*Scomber scombrus*)) (Yang, 1982). Boreal species are northern, cold-favouring fishes which extend northwards to the Norwegian Sea and Icelandic waters. They often have their southern limits of distribution around the British Isles or west of Brittany, although some may still occur further south, either in low numbers or as vagrants. Lusitanian species are southern, warm-favouring fishes and tend to be abundant from the Iberian Peninsula (including the Mediterranean Sea) to as far north as the British Isles, and may have northerly limits in the southern or central North Sea. Atlantic species are often pelagic or deep-water fishes that are widespread in the North Atlantic, and include many of the deeper-water or mesopelagic species that may be widely distributed along the continental slope (ter Hofstede et al., 2010) Considering biomass, the Boreal fauna represents the highest at 53.8% of total biomass, the Lusitanian fauna is represented by 36.6% and the Atlantic fauna by only 9.6% (Yang, 1982).

North Sea fish species can also be grouped into assemblages by their composition, abundance, and habitat (Figure 1). Three main groups are identified, with group 1 being associated with the shelf edge and northern North Sea and the dominance of gadoid species such as saithe (*Pollachius virens*), haddock, Norway pout (*Trisopterus esmarkii*), and whiting (*Merlangius merlangus*). Group 2 is found in the northern and central North Sea with e.g. haddock, whiting and cod. The community of group 3 is distributed in the southern and eastern North Sea where the species composition is mainly made up by e.g. dab (*Limanda limanda*), whiting, and grey gurnard (Harding et al., 1986).

Figure 1. The North Sea fish assemblages are divided into three groups: 1. shelf edge community, 2. north central community, and 3. south-eastern community (Harding et al. , 1986).

1.3 North Sea fisheries

North Sea demersal fisheries, the focus of this study, underwent major developments in the past 150 years (an in depth overview is provided in Chapter 2). With the Industrial Revolution in the 18th and 19th century, the power and range of fishing vessels rapidly increased. These advancements made trawling as well as seining by far the most efficient fishing method (Pitcher and Hart, 1993). Seiners are generally used to catch aggregating pelagic species (swimming freely in the water column, e.g. herring (*Clupea harengus*), mackerel or tuna (*Thunnus thynnus*)) by surrounding shoals, however, so called ‘Danish seiners’ use gear to target demersal species (FAO, 2001). Trawlers tow a net along the sea floor catching demersal fish (living close to the seabed, e.g. cod, haddock or plaice

(*Pleuronectes platessa*)). In contrast to pelagic fisheries fishing in the water column, towed gears can impact on the physical nature of the seabed and the communities of species that grow or live in or on it (MacMullen, 2007; Watling and Norse, 1998). Still, targeted or non-targeted species are generally impacted by fishing operations which may include: discarding (e.g. non-commercial species, non-marketable commercial species thrown back to sea (Catchpole et al., 2005)), bycatch (unintentional catch, e.g. undersized commercial species, marine mammals), mortality or damage of species that may escape from the gear, and general changes to the marine ecosystem (e.g. removal of larger fish potentially leads to changes in the age structure of the population) (MacMullen, 2007).

Fishing pressures in most of Europe's seas exceed sustainable levels. This has led to a decline in fish catches since 1985, which affects in particular demersal species such as cod (EEA, 2010). Further, the tendency over the past years has been that a decreasing proportion of stocks (from 47% in 2003 to 35% in 2012) can be classified according to safe biological limits (EU, 2012). Although improvements have been achieved in recent years, currently still 47% of the fish stocks in the North-East Atlantic and adjacent waters are overfished (EU, 2012). However, the term 'overfishing' is not constrained to recent decades with the introduction of modern trawlers and the exploitation of fish stocks on high levels. The problem of overfishing had already occurred before the industrialisation of fisheries (Anon., 1868).

Recent studies have raised concerns about the ecological effects of industrialised fishing (e.g. Christensen et al., 2003; Myers and Worm, 2003; Pauly, 1998; Pauly et al., 2002; Tegner and Dayton, 1999), initiating a United Nations resolution on restoring fisheries and marine ecosystems to healthy levels (UN, 2002; 2012). However, a premise for bringing fish stock back to healthy levels is a general understanding of the composition, abundance and distribution of unexploited fish communities, relative to contemporary ones (Myers and Worm, 2003).

1.4 Factors affecting fish distributions

Fish communities are dynamic, continuously changing their structure, assemblage composition and distribution in response to different natural or human-induced drivers (ter Hofstede and Rijnsdorp, 2011). Traditionally these changes have been considered to be mainly fisheries-induced (Levin et al., 2006; Pauly, 1998; Rice and Gislason, 1996). For example, in the North Sea it was shown that the intense exploitation of fish in the 20th century has led to substantial reductions in the biomass of large fishes and the abundance of target species, and to changes in species composition (Daan et al., 2005; Greenstreet and Hall, 1996; Jennings and Blanchard, 2004; Rice and Gislason, 1996). However, with marine air and sea surface temperatures rising in the past 25 years over the north-east Atlantic and UK waters (MCCIP, 2010), various studies suggested that climate change also plays an important role in changing the structure of fish communities (e.g. Attrill and Power, 2002; Hiddink and ter Hofstede, 2008; Cheung et al., 2009; 2013). Further, it was demonstrated that species responded to rising temperatures by shifting in latitudes (Hedger et al., 2004; Hiddink and ter Hofstede, 2008; Perry et al., 2005) and depth (Dulvy et al., 2008). However, these studies have been based on survey data going back around three decades because older survey data are not available. Although fisheries and climate change have been identified as two important drivers for a species distribution, disentangling the effects of these factors is often difficult due to the relatively short time-span of these datasets. Longer time-series, covering periods of changing climate and different levels of fishing pressure, improve our ability to attribute observed changes in fish populations to climate change and/or fishing. Recent studies, that analyse time-series data that span over nine decades, demonstrated well that longer time-series offer greater insight into likely mechanisms influencing fish distributions than shorter time-series. Analysis of long-term commercial fisheries data revealed that north-westward shifts of North Sea plaice were attributable to climate change. The south-westward shifts of sole (*Solea solea*), and recent north-eastward shifts of cod in the North Sea, were related to both fishing pressure and climate change (Engelhard et al., 2011 a, b).

1.5 The shifting baseline phenomenon

Environmental changes, such as climate change, loss of biodiversity or shifts in species' distributions, tend to be a gradual and rather slow process. Unless a popular species is endangered as for example the Giant Panda (*Ailuropoda melanoleuca*) in China (WWF, 2013) or an acute incident occurs (e.g. oil spill), these changes receive relatively little recognition. Fisheries declines can be counted among these (Cudmore, 2009).

The underlying cause is that human nature has difficulties to recognise the gradual degradation of the environment. Each generation subconsciously perceives as 'natural' or 'normal' the environment they remember from their youth. Subsequent changes are compared against this 'baseline', masking the true extent of environmental degradation. Furthermore, anecdotes of past abundance or sizes of species may be disbelieved (Roberts, 2007). The phenomenon, coined 'shifting baseline syndrome' (Pauly, 1995), is based on the assertion that fisheries scientists are most familiar with those conditions that exist during their lifetimes. Unless being aware of historical fish stock conditions, recent levels of stocks are accepted as normal. Saenz-Arroyo et al. (2005), for example, demonstrated how rapid perceptions in environmental baselines can shift. Within just three generations of fishers from Mexico's Gulf of California, changes in perception of the state of the environment occurred. Although old fishermen remembered catching greater abundances and sizes of Gulf grouper (*Mycteroperca jordani*) few young fishers seemed aware that this species had ever been common.

As the state of the stock of each generation serves as a new baseline, the result is a gradual shift of the baseline perception, a gradual accommodation of the creeping disappearance of resource species (Pauly, 1995), and a failure to recognise the extent and consequences of past environmental modifications by humans (Cudmore, 2009). The consequences are inappropriate reference points for evaluating economic losses or for identifying targets for rehabilitation measures (Pauly, 1995). Counteracting the gradual shift of perception is only possible by the analysis of long-term data to "maximize the use of fisheries history [which] would help us to understand and to overcome - in part at least - the shifting baseline syndrome" (Pauly, 1995).

1.6 Historical fisheries data

1.6.1 Research initiatives

Resetting baselines and understanding the extent of change is only possible by reconstructing and understanding past states and conditions of fish populations. Although in principal a wide range of information is available to define historic marine population status (e.g. written evidence including anecdotes, archaeological remains), most fisheries assessments are less than three decades long (Pinnegar and Engelhard, 2008).

The growing interest in historical marine and fisheries data initiated in recent years several research initiatives. An ICES (International Council for the Exploration of the Sea) Working Group on the History of Fish and Fisheries (ICES WGHIST (former Study Group SGHIST (2009-2011) and Workshop on Historical Data on Fisheries and Fish WKHIST (2008); http://www.ices.dk) was set up, bringing together fisheries scientists, historians and marine biologists. The group is working on multidecadal to centennial changes in the marine environment and aims at improving the understanding of the long-term dynamics of fish populations, fishing fleets, and catching technologies. The results are used for setting baselines for management, restoration and conservation of marine resources and ecosystems. The History of Marine Animal Populations project (HMAP, http://hmapcoml.org/about/) is an international, interdisciplinary research initiative studying the past ocean life and human interaction with the sea and marine organisms. HMAP, initiated in 2000, forms the historical component of the Census of Marine Life (www.coml.org) and aims to improve our understanding of ecosystem dynamics, specifically with regard to long-term changes in stock abundance, the ecological impact of large-scale harvesting by man, and the role of marine resources in the historical development of human society. The Sea Around Us Project (SAUP, http://www.seaaroundus.org/), initiated in 1999, is an international research group as well utilising historical data to study the impact of fisheries on the world's marine ecosystems. The project assembles global databases of fisheries information, including catches, prices, distribution of commercial marine species and marine protected areas. It documents human impacts and aims to offer mitigating solutions to a range of stakeholders.

In recent years, various research institutes undertook great effort to search their archives for historical fisheries data (e.g. Centre for Environment, Fisheries and Aquaculture Science (Cefas) (UK), Swedish Board of Fisheries (Sweden), Flanders Marine Institute (Belgium)). Recovered material was analysed and helped to reconstruct e.g. population dynamics of plaice and turbot (*Scophthalmus maximus*) in the Kattegat–Skagerrak over the past century (Cardinale et al., 2009; 2010), Belgian fleet dynamics of the past 180 years (Lescrauwaet et al., 2012), or fish distribution patterns of North Sea sole, plaice and cod between the 1920s and 2000s (Engelhard et al., 2011a, b).

1.6.2 Cefas

Founded in 1902, Cefas is one of the world's longest-running fisheries research bodies, holding unique UK fisheries data going back around 100 years. From 1906 onwards, data on weight and the value of landed species, but as well information of the visited fishing grounds and the number of days absent was recorded. Between the 1920s and 1960s, monthly and annual British North Sea trawlers' landings and effort data were collected per ICES rectangle (1° longitude x 0.5° latitude) and documented on statistical charts (Figure 2). This was carried out for 29 commercially exploited species in this time-period; thereafter only 12 different species were recorded. For the years 1923 to 1966, concordant Scottish data were collected by the Scottish Home Department (SHD), Edinburgh, now Marine Scotland. Data until 1980 were processed, compiled and hand-written on blank paper charts at the Directorate in Lowestoft (Engelhard, 2005).

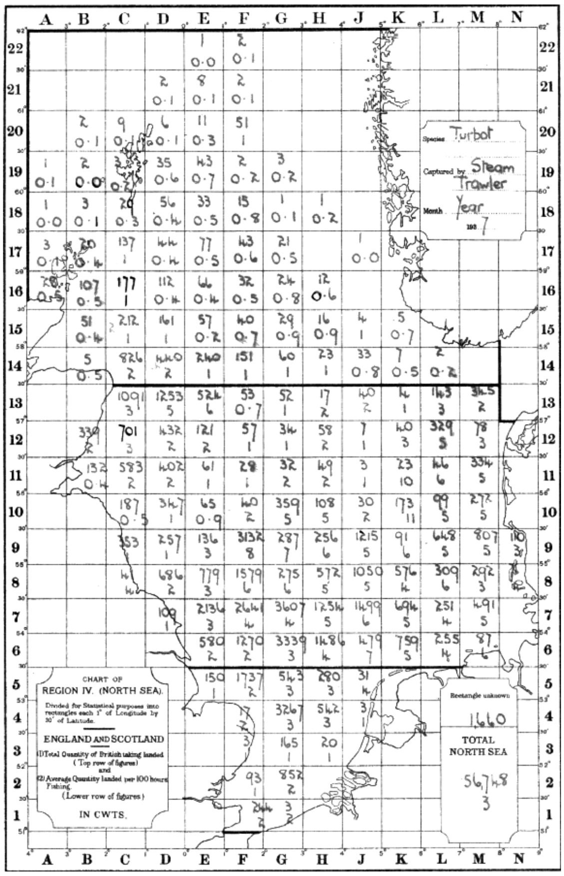

Figure 2. Example of statistical chart for the North Sea, showing landings and catch rates of turbot by British steam trawlers in 1937. Upper figures in each rectangle show the landed quantities in hundred-weight (cwt, 1 cwt = 0.05080 metric tonne), lower figures show the average quantity landed per 100 hours fishing. The bottom right-hand corner of the graph shows the global values for the entire North Sea and, under 'Rectangle unknown', the quantity landed that could not be assigned with reasonable confidence to any one rectangle.

In total, the Cefas archive holds over 37,000 statistical charts that provide detailed information on locations of catches landed by British fishing vessels (Engelhard, 2005). Unfortunately, data for 1981 are incomplete. Since 1982, fishing effort and landings data are electronically stored and are available from the Fisheries Activity Database (FAD), held at the Marine Management Organisation (MMO) and accessible to Cefas.

1.6.3 ICES

1.6.3.1 Commercial fisheries data

International commercial fisheries statistics, covering around 100 years, are held at the International Council for the Exploration of the Seas (ICES; prior to 1955 referred to as the International Council or the Council), founded in 1902 (Rozwadowski, 2002). In 1904, the International Council decided to publish annual fisheries statistics in the Bulletin Statistique des Pêches Maritimes (renamed ICES Fisheries Statistics in 1988; the series has been discontinued) with the first volume presenting data for 1903. The main objective was to create a database allowing the comparison of landings from different countries (Lassen et al., 2012).

Until recent years, an electronic database of catch statistics maintained by ICES and Eurostat contained data only from 1973 onwards. Great effort was undertaken by ICES to extend the database to include all landings data available from volumes of ICES Bulletin Statistique des Pêches Maritimes covering the period 1903-1972. Specifically, two datasets were produced: (1) Excel files for the time period 1903-1949 and only available on the ICES website, and (2) an electronic database covering the time period 1950 to present and available for downloading from the Eurostat and ICES websites (D. Cross, pers. comm.; Lassen et al., 2012).

For the years 1903-1949, for each country data were compiled not as time-series but as separate annual Excel worksheets. Data were broken down by ICES subareas and, in some cases, further to ICES divisions. The main species herring , cod, haddock, and plaice were reported throughout the period, with further 20-30 species or species groups being reported in the statistics. Very few data exist on shellfish. However, over time, the number of species included in the reports increased significantly (Lassen et al., 2012).

Data for 1950-1972 combined with those for 1973 to present are formatted in the FAO FishStat Plus format. The database is a coherent time-series of commercial landings per country per species per area and year. It comprises around 155 invertebrate and 558 marine fish species and species groups, respectively. The geographical breakdown is according to the ICES system of subareas, divisions and subdivisions (FAO, 2011).

1.6.3.2 Research survey data

As commercial fisheries only provide information on the exploitable component of the stocks and landings data are influenced by e.g. discarding or underreporting, fisheries-independent surveys are necessary to gain unbiased data. Research surveys aim to provide ICES assessment and science groups with consistent and standardised data for examining spatial and temporal changes in (a) the distribution and relative abundance of fish and fish assemblages; and (b) of the biological parameters of commercial fish species for stock assessment purposes (ICES, 2012).

The longest running survey is the North Sea International Bottom Trawl Survey (NS-IBTS; formerly the International Young Fish Survey (IYFS) and International Young Herring Survey (IYHS)), commencing in 1960/61. Countries bordering the North Sea collect basic data of the caught species (lengths, weights, and of particular species otoliths for age determination) and the amount of fishing effort expended to these fish. The surveys are coordinated by the ICES International Bottom Trawl Survey Working Group (IBTSWG). The main objectives are to determine distribution and abundance of pre-recruits, to monitor changes in stocks of commercial fish species independently of commercial fisheries data, and to collect hydrographical information (temperature, salinity, nutrients) (ICES, 2012; ICES-FishMap).

Since 1985, the Beam Trawl Survey (BTS), commencing with the RV '*Isis'* from the Netherlands, is included as part of the North Sea survey. This survey mainly collects information about plaice and sole in the North Sea. However, since the beginning of the survey all caught species were measured and recorded. Currently, five countries are participating in the ICES Working Group on Beam Trawl Surveys (WGBEAM). This survey is not as homogeneous as the IBTS, as the surveys covered by WGBEAM have all their own origins and were not set up as one survey. Due to that, no standardisation in gears has taken place. The different countries all have their own sampling area and because the gears used vary, it is not possible to change sampling locations from one country to the other without any thorough scientific study beforehand. However, efforts are made by the WGBEAM to increase standardisation in this survey (ICES, 2009). Data for the IBTS and BTS surveys are available from the ICES DATRAS website (http://datras.ices.dk/Home/default.aspx).

In this thesis, the unique historical databases from Cefas and ICES, covering around 100 years of commercial fisheries in the North Sea, and around four decades of ICES surveys, constituted the basis for the research.

1.7 Thesis outline

1.7.1 Research context

This study was conducted within the context of a 3.5 year Defra (Department for Environment, Food and Rural Affairs) research project MF 1108: "100 Years of Change in Fish and Fisheries", aiming to make use of so far not utilised historical fisheries data held at Cefas, Lowestoft. Defra is a UK governmental department responsible for policy and regulations on environmental, food and rural issues, striving to develop sustainable fisheries exploitation strategies.

As part of this research project, this thesis contributed to the digitisation process of historical commercial fisheries records (1903-1981) and statistical charts (1923-1981), the latter containing information of fishing effort and landings at the spatially detailed level of ICES rectangles (0.5° latitude by 1° longitude). Both time-series were completed up to present with the electronic database FAD. Further, commercial and survey data were extracted from the ICES database and prepared for subsequent analysis.

Findings were made available by publications, presentations, as well as reports to Defra. Resulting information from this thesis will potentially be useful to marine managers in setting restoration and recovery targets as it provides insights into past conditions of North Sea fishes and fisheries.

1.7.2 Objectives of the thesis

The objective of this thesis is to reveal and understand long-term changes and developments in North Sea demersal fishes and fisheries. By compiling and analysing historical fisheries data extending throughout the 20th century, this thesis aims to identify drivers affecting developments in UK demersal fisheries and to interpret findings in the historical context. So far, the knowledge on spatial distribution on North Sea fish species dates back around three to four decades. This thesis examines fisheries data, covering nine decades, aiming to extend knowledge by revealing long-term distribution changes of whiting, turbot and brill, and assessing drivers influencing the species' distribution. In addition, the thesis intends to deliver new insights on former stock levels of turbot and brill by presenting long-term abundance trends dating back to the 1920s. As commercial landings data are potentially influenced by discarding, this study aims to assess whether commercial data is reliable for distribution analysis. In this thesis, North Sea whiting, a commonly discarded species in the North Sea, is used as a case study to compare whiting distribution based on both commercial and survey data.

1.7.3 Thesis structure

The four principal chapters (Chapters 2 - 5) are written in the form of peer-reviewed papers. At the time of submission of this PhD thesis, three chapters were published (Chapter 2: (Kerby et al., 2012); Chapter 3: (Kerby et al., 2013a); Chapter 5: (Kerby et al., 2013b)).

Chapter 2 synthesises and reviews over 100 years of international North Sea demersal fish landings data, with trends interpreted in the historical context. Focusing in this thesis on the UK, the developments in demersal fisheries since the late 19th century are described, and the main technological, economical and political drivers are presented, affecting the UK fishing industry. Further, the different developments in English and Scottish fisheries are described, explaining why the dominance in demersal fisheries shifted within Great Britain.

In Chapter 3, nine decades of North Sea whiting distribution are analysed. As this time span covers periods of warming and cooling and different levels of fishing pressure, I examined whether distribution shifts could be explained by variables related to climate change and/or fishing pressure. I further describe the trends of international whiting fisheries in the North Sea by compiling and analysing over 100 years of landings data of European nations as well as recent quota uptake rates (1980 to present).

The reliability of commercial fisheries data for distribution analysis is assessed in Chapter 4 by a comparison of commercial and survey data of whiting between 1970 and 2009. This species was chosen as it is a commonly discarded species in the North Sea which potentially influences commercial landings data. Discrepancies between both datasets are evaluated, identifying areas in the North Sea where whiting is possibly more commonly discarded. As whiting reaches lower market prices compared to plaice and sole as well as cod and haddock, I examined if fishermen might discard more whiting in areas where they catch higher priced fish.

In Chapter 5, distribution changes of turbot and brill over the past nine decades are analysed. To assess the abundance dynamics of both species, abundance trends based on commercial data and two North Sea surveys are compared. Further, to understand the developments in brill and turbot fisheries, long-term landings data of European countries were collated and interpreted in the historical context.

Finally, Chapter 6 synthesises the key findings of this research, discusses the main conclusions and suggests directions for future research.

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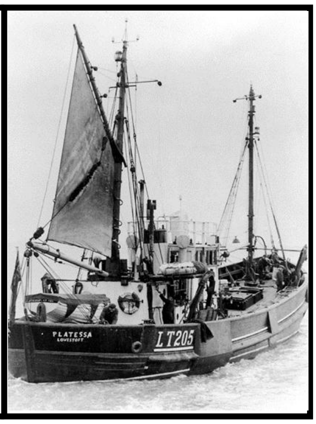
Chapter 2



The United Kingdom’s role in North Sea demersal fisheries: a hundred year perspective

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2.1 Abstract

This study compiles 100 years of North Sea demersal landings, focusing on the UK, and relating them to historical events and political, technological and economical drivers that influenced demersal fisheries. In the early twentieth century, aided by technological advances, the UK, and in particular England, had unchallenged dominance in North Sea demersal fisheries. Since then, the two World Wars and other political developments have had a great impact on British fisheries. Between the 1920s and 1960s, English ports shifted their interests away from the North Sea towards highly profitable distant waters, whereas the Scottish fleet relied less on these fishing grounds. Meanwhile, especially in the 1960s, other European countries expanded their fisheries, undermining Britain's lead. In the 1970s and 1980s, Scotland benefitted from mainly fishing in the North Sea. Firstly, the assertion of 200 nautical miles Exclusive Economic Zones made the distant waters inaccessible to English fleets at a time when England's fisheries were highly dependent on them. Secondly, the relatively minor activity in the North Sea by the English compared to the Scottish fleets coincided with the establishment of the Common Fisheries Policy. This had implications when total allowable catches were first implemented because quota allocations to countries were based on their recent catches from the North Sea. Thus, after the loss of fishing opportunities in distant waters, the North Sea once more became an important fishing ground for Britain, just as in the early twentieth century, however, the emphasis of fisheries had shifted from England to Scotland.

2.2 Introduction

Recovered historical records of fisheries landings represent a valuable source of information on long-term changes in marine ecosystems and can help to counteract the 'shifting baseline syndrome' (Pauly 1995). Still, as fisheries scientists often need to interpret changes in fish stocks and in ecosystems, it is necessary to understand the underlying changes and developments in the fishing fleets and industry itself. Commercial landings can fluctuate due to natural variations in the abundance of fish stocks (e.g. Cushing 1984; Beverton and Holt 1993; Cushing and Horwood 1994), but when analysing trends in landings human-induced factors have to be taken into account as well (e.g. Garstang 1900; Beare et al. 2010). Such factors include not only the direct effects of fishing on stock levels, but also technological developments improving the efficiency of capture methods (e.g. vessel or gear improvements), economical factors (e.g. increased demand), political events (e.g.

wars) and fishery regulations (e.g. catch quotas) influencing the fishing industry over time. Therefore, to accurately interpret available landings data, one needs to consider the historical context so that the changes and influences of the drivers on these data can be clearly understood. This enables a more accurate interpretation of fisheries data to reveal the trends in fisheries, and the subsequent formulation of appropriate management actions.

In the history of North Sea demersal fisheries, the influence of technological, political and economical drivers particularly applies to the development of the demersal fisheries of the United Kingdom[1]. In the nineteenth century, industrialised fisheries had their origins in England, which became the leading country in North Sea demersal fisheries. In this era, England took commercial exploitation of fish stocks to a new dimension through the development of a large mechanised trawling fleet. The situation gradually reversed over the course of the twentieth century, and the once most powerful sovereign in the North Sea demersal fishery gradually lost its dominance and developed into a fishing nation 'amongst others'. Favourable terms of political, technological and economical drivers initially brought about England's rapid rise. These same drivers, acting adversely, also influenced the decline of English North Sea fisheries in the second half of the twentieth century (e.g. Roberts 2007; Robinson 2000a, b). In contrast, Scotland, despite being so close to England, underwent a different development in North Sea demersal fisheries regarding the influence of these drivers (Coull 1996). This resulted in the prevalence of the Scottish demersal fisheries over the English in the North Sea in recent decades.

This paper analyses 100 years of demersal fish landings from the North Sea and tries to interpret the trends in a historical context. It documents major technological, economical and political drivers influencing the British fishing industry since the late nineteenth century, and shows how these drivers affected English and Scottish demersal fisheries. Furthermore, the paper aims at understanding why England not only lost its dominance in North Sea fisheries within Europe but also how the emphasis shifted within Great Britain from England to Scotland.

2.3 Data

Demersal landings data for all European countries fishing in the North Sea were obtained from ICES statistics (ICES 2010a, b). Individual countries' catch statistics for 1903–1949 were available as Excel files, and data for 1950–2008 were extracted with the FishStat Plus programme (FAO 2010). For England, Wales and Scotland, more detailed fisheries data

[1] United Kingdom (England, Scotland, Wales and Northern Ireland); Great Britain (England, Wales and Scotland). Landings from Wales and Northern Ireland played a minor role in North Sea fisheries.

(e.g. landings distinguished by vessel type, number of registered vessels) were obtained from annual ‘Sea Fisheries Statistical Tables’ of England and Wales and of Scotland. English and Welsh data were available from the Board of Agriculture and Fisheries (1904–1912, 1913–1915, 1920), the Ministry of Agriculture and Fisheries (1921–1939, 1946, 1948–1951, 1952–1954) and the Ministry of Agriculture, Fisheries and Food (1955–1982). Data were digitised up until 1981; thereafter data were available from the Fisheries Activity Database (FAD) held at the UK Department for Environment, Food and Rural Affairs (Defra). Scottish data were available from the Fishery Board for Scotland (1890–1918, 1919–1930, 1931, 1932–1939), Scottish Home Department (1951, 1952a, 1952b–1959) and the Department of Agriculture and Fisheries for Scotland (1960–1977). For landings data it is acknowledged that, over time, fisheries statistics became more detailed regarding the amount of recorded species. This, in particular, applies to the electronically available data from ICES (ICES 2010b) and English FAD data from 1982 onwards.

2.4 North Sea demersal landings in the twentieth century

The quantities of demersal fish landed from the North Sea have shown major changes over the course of the past 100 years (Fig. 1). In the first half of the twentieth century, total North Sea landings were relatively constant at a level of around 400,000 tonnes. Exceptions to this were two remarkable dips in landings caused by the two World Wars (1914–1918 and 1939–1945), each followed by temporary increases shortly after the wars. Landings then rose sharply within a period of 20 years, from around 338,000 tonnes in 1950 to around 1.5 million tonnes in 1970. Thereafter, landings declined continuously until the 1990s, remaining relatively constant for a decade, before decreasing again at the beginning of the twenty-first century.

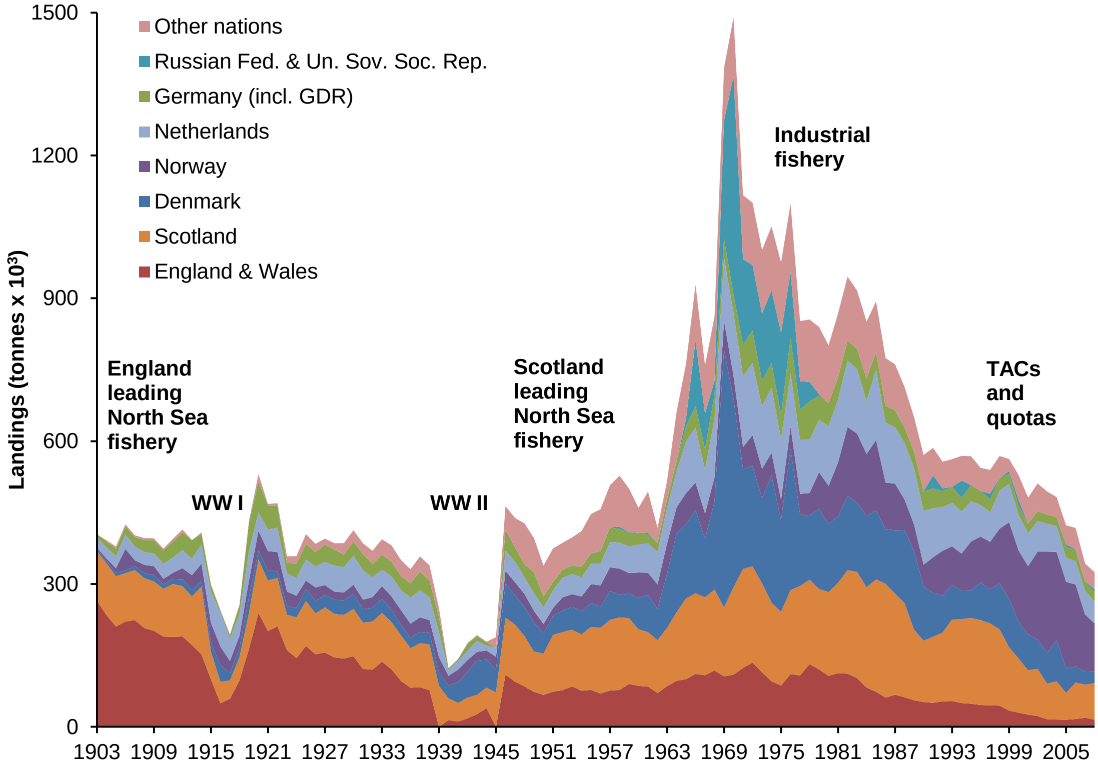

Figure 1. Long-term changes in demersal fish landings from the North Sea, shown separately by country. ''Other nations'' represent the combined landings for Belgium, Faroe Islands, France, Greenland, Iceland, Ireland, Lithuania, Poland, Portugal, Spain and Sweden.

Clearly the United Kingdom dominated the North Sea demersal fisheries throughout most of the first half of the century, with the combined landings into England and Scotland, on average, accounting for approximately 65% of all demersal fish taken from the North Sea. This proportion was highest in the years before the First World War, ranging from 70 to 90% between 1903 and 1914. Although the UK was leading the North Sea fishery, landings were declining until the Second World War. In the post-war years, landings showed an upward trend and the UK still landed on average around 47% of the total North Sea fish until 1960. However, especially in the 1960s, the fisheries of other European countries within the North Sea progressed and expanded; in particular those of Denmark, Norway and the Soviet Union. This resulted in a diminishing dominance of the British fisheries and, between 1961 and 2008, the share of British landings decreased from 40 to 28%. In recent years, the Norwegian fishery in the North Sea has gained in importance: its share increasing from 12 to 31% in the same time period, with a peak of 43% in 2003 and 2005.

Assessing British landings separately reveals that in the years before the First World War, England (including Wales) on average accounted for 65% and Scotland for 35% of the total British demersal landings from the North Sea. In the inter-war period, Scottish landings remained stable, while English landings declined from around 163,000 tonnes in 1919 to around 77,000 tonnes in 1938. Shortly before the Second World War, Scotland recorded higher landings than England, taking over the lead in North Sea demersal fisheries. After the war, the increasing trend in Scottish landings lasted until the mid-1980s, dropping thereafter. English landings remained stable in the 1950s, increasing slightly between 1960 and 1980. Thereafter, landings decreased gradually and remained low until the present. In 2008, the demersal landings from the North Sea into Scotland were more than five times higher than those into England.

2.5 Technological drivers

Two of the most important drivers for changes in British fisheries are found in the technological developments of fishing vessels and fishing gears. In particular during the nineteenth century, within a relatively short time period, major technological innovations and developments allowed fisheries to expand to previously inaccessible areas in distant and deeper waters (Alward 1932).

2.5.1 Vessel improvements

In the era of the Industrial Revolution in the eighteenth and early to mid-nineteenth century, a trawl fishery was carried out by sailing vessels using beam trawls. Although sailing vessels had already been proved capable of trawling the deeper grounds, which gradually opened up unexploited fishing grounds in the North Sea (Alward 1932), the first major leap forward in the demersal fishing industry was in 1881 with the introduction of the first purpose-built steam trawler in England (Robinson 1998). Unlike sailing trawlers, steam trawlers were not dependent on wind and tides for propulsion and these vessels could tow larger nets and longer beams. Furthermore, hauling the trawl net by steam winch also accelerated fishing (Collins 1889). Within a short time period, a great number of steam trawlers were built. In particular Hull and Grimsby, located on England’s east coast, became the main ports for the steam-trawling industry in terms of registered steam trawlers (Fig. 2) and landings (e.g. Board of Agriculture and Fisheries 1904). These large ports had the best marine engineering support available, a prerequisite for building up such an enormous trawling fleet. Furthermore, they were integrated in the recently constructed railway network, connecting fishing ports to inland towns and cities and consequently new markets for fish were established (Alward 1932).

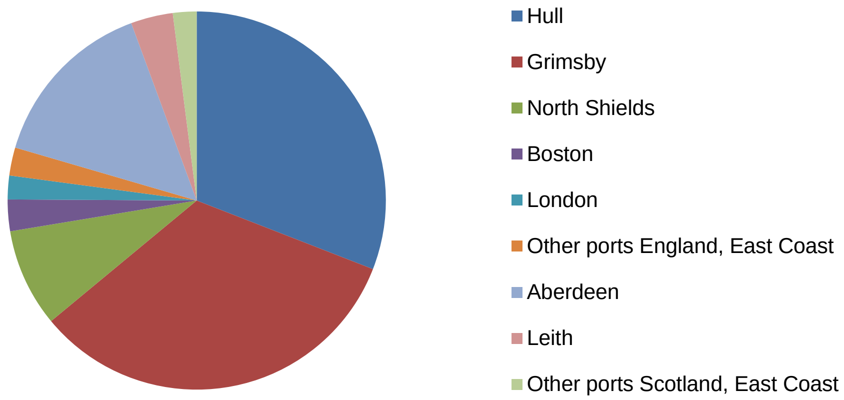

Figure 2. Numbers of steam trawlers registered in 1903 in main English and Scottish ports, highlighting the importance of the ports of Hull and Grimsby.

Throughout the 1880s, the technology of marine steam engines improved, notably in engine performance and fuel consumption, which at that time was coal (Robinson 2000b). As a result, the steam trawlers were concurrently expanding their operating range within the North Sea (Graham 1956) (Fig. 3).

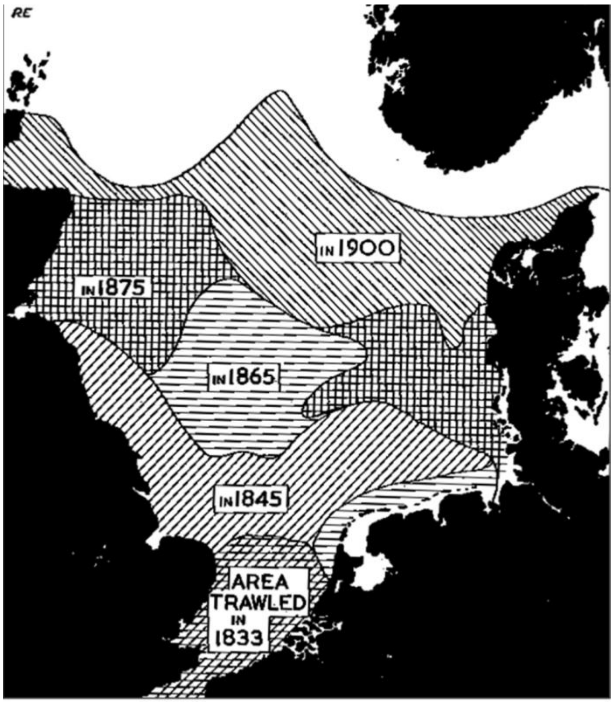

Figure 3. Spread of the English trawling fisheries during the nineteenth century (from Wimpenny (1953), shown with permission from the Trustees of the Buckland Foundation).

At the end of the nineteenth century, signs of overfishing were already apparent, and English landings discernibly decreased at the beginning of the twentieth century. To maintain an adequate supply of fish, new fishing grounds were being explored. Steam trawlers, especially from the important ports of Hull and Grimsby, began to shift their trawling activity to more distant areas further north and landed large quantities of fish from the waters off Iceland, the Faroe Islands, Newfoundland and Greenland; in 1905 the Barents Sea was also opened up by English trawlers. Enormous catches were brought back from these distant grounds, making these enterprises highly profitable. Furthermore, English trawlers began to operate on southern fishing grounds, such as the Bay of Biscay and the waters off the coasts of Spain, Portugal and North Africa; and these vessels landed a considerable portion of their catches in Portugal and elsewhere (Fulton 1911). During this time period, the English steam trawling sector was perceived to be at the leading edge of the fishing industry, and this encouraged other European countries to establish similar operations (Robinson 2000b).

In Scotland the development of trawling at this time was different to that of England due to the isolation of the Scottish fishing ports from the developing centres of trawling in England. Furthermore, Scotland was already a leader in the herring fishery (Coull 1996), and beam trawling was of no importance in Scotland (Alward 1932). At that time white fish was mainly caught using long-lines (Coull 1996). In the 1860s, however, the expansion of the English trawl fisheries and their search for new fishing grounds brought English sailing trawlers into Scottish waters, and trawling in Scottish waters began to increase (Coull 1996). Scottish line and drift-net fishermen were strongly prejudiced against trawling (Alward 1932). They were concerned about the large amounts of fish being taken, the destructive nature of the gear on the stocks and damage done by trawls to lines and nets shot at sea. With the introduction of the more powerful and efficient steam trawlers in the 1880s, these conflicts intensified and the intrusion of steam trawling in Scotland, originating mainly from England, created additional resentment (Coull 1996). Due to the success of trawling, however, this innovation became regarded as being essential to any progress in demersal fishing. Aberdeen in particular, invested rapidly in building up a fleet of steam trawlers and became the most important fishing port in Scotland during the first half of the twentieth century (Alward 1932). Still, the scale of Scottish fisheries remained distinctly smaller than that of England in terms of total number of steam trawlers (Fig. 4) and demersal landings (Fig. 5).

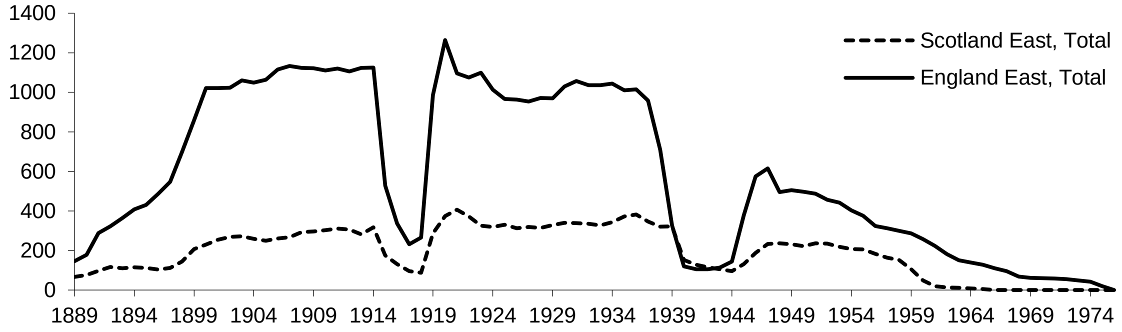

Figure 4. Total number of steam trawlers registered in ports along the east coast of England and Scotland.

Trawling in Scotland was first concentrated on inshore waters leading to local depletions of these grounds in the early twentieth century. As more and bigger trawlers were built, the fishing areas were expanded beyond the North Sea and Scottish trawlers followed the English initiative in extending their operations to the more distant waters of, for example, the Faroe Islands and Iceland (Coull 1996). Yet, the North Sea still provided the bulk of all Scottish demersal landings; for example, around 70% in 1914 compared to around 20% from the distant fishing grounds (Barents Sea and Murman Coast, Northward of the Norwegian Coast, Iceland and Faroes, East Coast of Greenland). For Scotland, these distant fishing areas never attained the same importance as they had for England (Figure 5). Although Scottish demersal catches were relatively small compared to those of England, they contained on average a higher percentage of more valuable marketable species, and shorter voyages from Scotland to the fishing grounds meant that the fish was often in better condition when landed (Graham 1956).

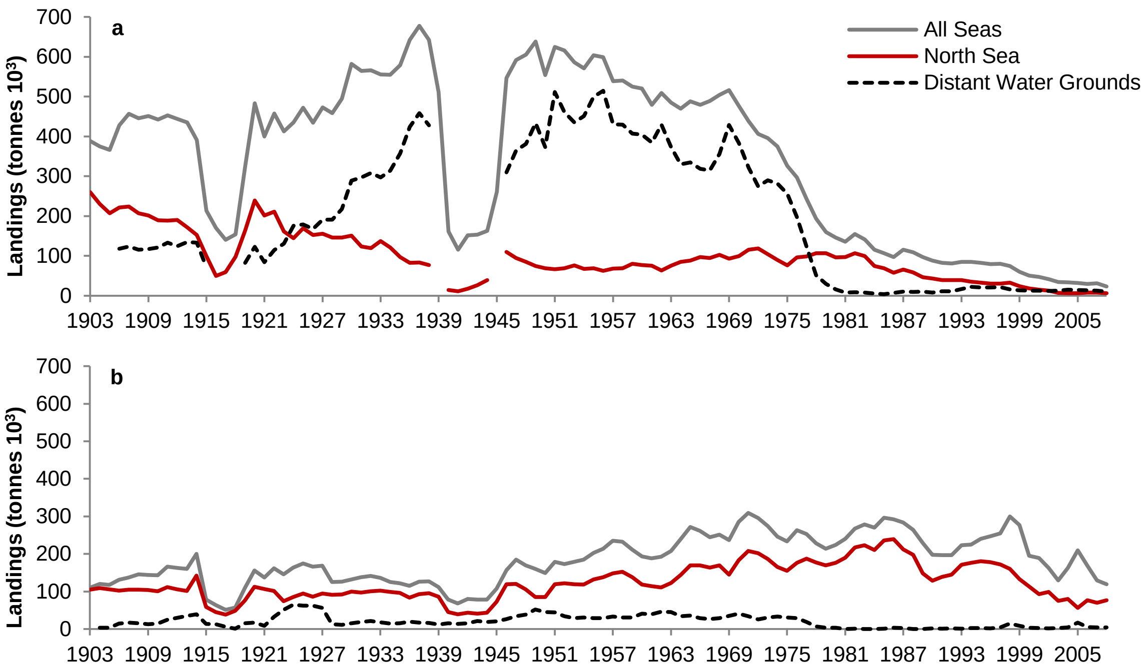

Figure 5. The quantities of (a) English and Welsh and (b) Scottish demersal landings from the North Sea (ICES area IV) and the distant water grounds, comprising ICES area I (Barents Sea and Murman Coast), II (Northward of the Norwegian Coast), V (Iceland and Faroes), and XIV (East Coast of Greenland). The total demersal landings from all fishing grounds combined are also indicated.

The shift in dominance of North Sea demersal fisheries between the two countries began shortly before the Second World War. Scotland became the country with the highest demersal North Sea landings, displacing England from its leading position. Multiple interacting factors were responsible for this shift. Firstly, the fleets of the English east coast ports, especially Hull and Grimsby, were relocating from the North Sea to the more prolific distant waters. In the mid-1920s, English landings from the North Sea were distinctly decreasing, while distant water landings were rapidly increasing (Fig. 5a). Secondly, during the years between the two World Wars, the successful herring fishery of Scotland, as well as that of England, underwent a process of contraction. During this period, international herring trade with the main consumer countries such as Germany and Russia was disrupted. Combined with these problems, several countries were catching up and challenging the lead that Britain had in the herring trade. The result was 20 years of diminution and readjustment of the herring fisheries in Scotland. After the Second World War, the ageing Scottish fleet was renewed with government help, and many dual-purpose boats were built that could be used for both demersal and pelagic fisheries. Herring, however, continued to decrease in importance, whereas the white fish sector increased in relevance (Coull 1996; Coull 2003).

2.5.2 Large scale modern fisheries

After the Second World War, most fishing boats were still using steam-powered engines fuelled by coal. Shortly after the war, oil-fired boilers had been introduced and were soon widely adopted on steam trawlers. Although this fuel was more expensive, its benefits were the great savings in bunker space (Robinson 2000b). Meanwhile, purpose-built motor trawlers driven by marine diesel were introduced, gradually replacing steam trawlers. As the motor trawlers were equipped with compact engines this again allowed significant savings on space (Robinson 2000b). By the 1960s, steam trawlers were outcompeted both in numbers (Engelhard 2005) and total landings (Fig. 6).

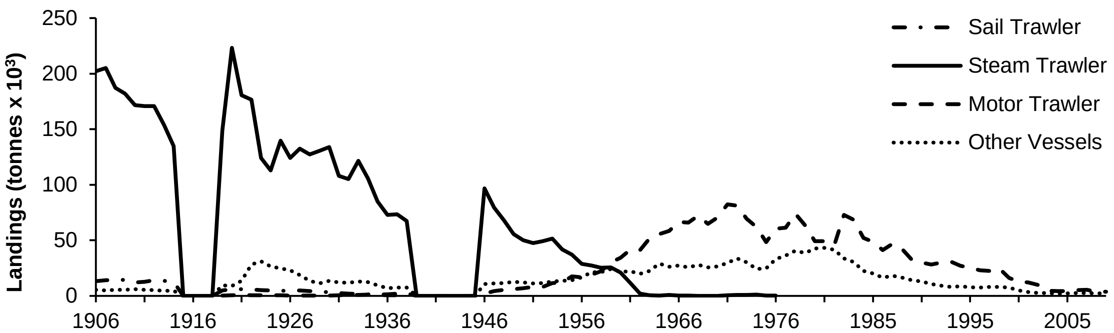

Figure 6. Total demersal landings from the North Sea into England and Wales by sailing, steam, and motor trawlers, and other vessel types. The latter include steam and motor seiners, sail, steam and motor liners, and other vessels.

The international demersal fishery in the North Sea expanded significantly from the 1950s to 1970s, with various countries becoming heavily involved in the exploitation of fish stocks (Fig. 1). During this period, the focus of English trawlers was on the distant grounds of, for example, Iceland, Bear Island, Spitsbergen and the Barents Sea, with trips lasting up to three weeks. In the late 1950s, catches from these northern grounds were falling and the fishing industry had to go as far as the waters around Greenland. As voyage durations were constrained by the durability of iced fish and the amount of fuel a conventional vessel could carry, periods of actual fishing in these far-off areas were 4–5 days shorter than those around Iceland, for example (Robinson 2000b). Thus, large stern freezer trawlers were constructed. These trawlers were able to gut, fillet and freeze fish and store hundreds of tonnes of fish in their holds, therefore enabling the storage of catch for much longer periods and so permitting longer fishing voyages. It was mainly the companies based in Hull and Grimsby that deployed these trawlers for their operations in the distant waters (Thompson 1988). Eastern European nations, especially the former Soviet Union, also adopted this design and built up considerable distant-water fleets in the 1960s, made up of a diversity of trawling vessels fitted with processing units for freezing, canning, and reduction. Furthermore, large transporting vessels and mother ships were constructed, serving as supply and storage units at sea. Fishing trawlers therefore were able to largely reduce their steaming time to and from landing ports and extend their fishing time (Borgstrom 1961). The Russian fishing fleet was fishing extensively in distant waters as well as in the North Sea; during the period 1966–1976, for example, a total of 1,800,000 tonnes of demersal fish were taken by the Russian fleet from the North Sea.

From the 1960s onwards, nations fishing in the North Sea were benefiting from the 'gadoid outburst' that led to remarkable increases in landings. Over a time-span of about two decades, various gadoid fish species, such as cod, haddock and whiting produced many exceptionally large year classes (Cushing 1984; Hislop 1996). Coinciding with this, various European countries expanded their fishing fleets, and this was reflected in remarkable increases in the total landings from the North Sea. The period of high productivity of gadoid fish stocks came to an end in the 1980s. Since then, a combination of reduced productivity with high fishing pressure by the large international fishing fleet in the North Sea has contributed to overexploitation. The large decline in stock abundance resulted in fishing restrictions and a marked decrease in landings (Fig. 1).

2.5.3 Fishing gear

Technological advancement also brought about development of more efficient fishing gear. An important improvement of gear-efficiency in trawl fisheries was introduced in 1894. The previously widely used beam trawl was being rapidly discarded and replaced by a beamless trawl constructed on the principle of the otter trawl (Cunningham 1896). The new gear was more efficient in capturing a larger quantity of fish than the beam trawl, and within a few years beam trawls were hardly in use on either English or Scottish steam trawlers (Fulton 1902; Kyle 1903). At that time, the otter trawl was 37% more efficient than the beam trawl (Garstang 1900). In the early 1920s, the Vigneron- Dahl modification of the otter trawl was introduced, which further improved the efficiency of the otter trawl (Hickling 1931), and the modified gear had become widely used from 1926 onwards (Beverton and Holt 1993).

In the period after the Second World War, several technological developments allowed fishermen to catch more fish at less cost. Amongst other new tools, echo sounding equipment was used for navigational purposes and fish detection. Furthermore, echo sounder transducers were developed, being attached to the headline or footrope, showing the depth and the vertical opening of the trawl, making the fishing process more precise and efficient. With the advent of synthetic fibres, fishing nets gained superior quality (e.g.

higher breaking strength, lower towing resistance) compared to the conventional cordage made from cotton, manila or sisal (Burgess 1961; Kristjonsson 1959; Kristjonsson 1971).

2.6 Economical drivers: demand and supply of seafood

Consumer products are mainly regulated by two drivers: demand and supply. In the seventeenth and early eighteenth century, transportation, mainly by horse or by boat on rivers and canals, limited the delivery of fresh fish to inland markets. Fish is a perishable product, and fishermen in this era only had a specific time window for catching and selling their fish. Hence, the markets that could be supplied through trade in fresh fish were relatively limited, being restricted mainly to the villages and countryside close to the fishing ports (Anonymous 1921). This situation changed substantially with the advent of the Industrial Revolution in the UK in the eighteenth and nineteenth centuries. Firstly, the demand for food increased with an increasing population. Due to improvements in agricultural productivity, rising living standards, and improved sanitation, the British population grew rapidly between 1801 and 1901. In England, the population increased from 8.3 to 30.5 million, and in Scotland from 1.6 to 4.5 million in this period (Jefferies 2005). Secondly, the supply of commodities within the country made a leap forward with the development of a rail transport system from the 1820s onwards. The creation of a national railway network provided the fishing industry with new marketing opportunities for fresh fish, as inland markets could now be reached, and fresh fish became an item of cheap mass consumption in the growing towns and cities throughout the country (Robinson 1998). Furthermore, in the 1850s, the widespread use of ice, imported from Norway and North America, allowed better preservation of catches. This extended the distances to the fishing grounds, and enabled the transportation of fresh fish to inland markets which previously were not accessible (Anonymous 1921). Consequently, fishermen were now able to land large volumes of fish and sell it at a profit. It was the conjunction of these two circumstances - the railway allowing a quicker supply of goods, and the increased food demand - that paved the way for a dramatic expansion in the fishing sector.

Soon after, the fish and chip shop trade emerged and grew in popularity among the British working class (Walton 1992). The increase in domestic demand for white fish exceeded the supply in the waters surrounding the British Isles, allowing a profitable distant water fishery (Ashcroft 2000). Though fish landed from these distant fishing grounds was regarded as coarser than North Sea fish, it was ideal for the fish and chip shop trade, which started to flourish in the years before the First World War (Robinson 2000b; Walton 1992). It was estimated that the fish and chip shop trade consumed around 20% before the First World War, and later in the 1930s around 60% of all white fish landed in Britain (Walton 1992).

Changing patterns of seafood consumption contributed to the changes in fish trade for the North Sea demersal fisheries. Due to the availability of cheap white fish before 1914, fish consumption rose per capita. During the inter-war years, white fish consumption (exclusive of fried fish) declined slightly while fish and chip consumption increased by about one-fifth. However, from the 1950s onwards, the overall fish consumption per capita declined continuously (Reid 2000).

Other factors influencing the demand for fish include changes in consumers' income, affecting their expenditure on fish, and changes in consumers' choice of fish, which currently is strongly influenced by the media and the recommendations of celebrity chefs (e.g. see 'Delia-Effect' in Bell and Hollows 2005). Moreover, in recent years public awareness of environmental issues is growing. Environmental organisations (e.g. Marine Stewardship Council (MSC), Seafood Watch) research and evaluate the sustainability of seafood, informing consumers about their choices when buying these products. The aim of consumer-based schemes is to positively influence the demand for seafood by, for example, eco-labelling, thus leading to the promotion of sustainable fisheries (e.g. Wessells et al. 1999; Jaffry et al. 2004; Jacquet and Pauly 2007).

2.7 Legislation and political events

Developments in the North Sea demersal fisheries have been strongly driven by changes in fishing restrictions and regulations, and political events including wars and conflicts. The English trawl fishery in particular, suffered severely from the consequences of legislation amendments in the 1970s and 1980s, which redefined access to formerly open fishing grounds.

2.7.1 Fishing without restrictions and the effects of two wars

In the United Kingdom, the Sea Fishing Act of 1866 laid the foundation for unrestricted fishing (Anonymous 1868). This was in the era of sailing vessels, when trawl fisheries were rapidly growing (Alward 1932), and the prevailing opinion that fish stocks could not be depleted (Anonymous 1868). The expansion of trawl fisheries was not a welcome development to many fishers using lines, nets and traps, who complained that trawlers were wasteful, destructive and wiping out fish stocks. The Royal Commission on Sea Fisheries, however, rejected the contention that the supply of fish was diminishing, concluding that the allegations of trawling being wasteful and destructive were unproven, and finally advised the continuation of unrestricted freedom of fishing (Anonymous 1868). Although fisheries were, in principle, unrestricted, the two World Wars between 1914–1918 and 1939–1945 nearly brought the North Sea fishery to a standstill and had great impacts on the fishing sectors in the UK and Europe, as landings markedly dipped (Fig. 1). During both wars, fishing was constrained, notably in the central and southern North Sea, owing to waters being closed due to mines and enemy action, and fishing vessels being called up for naval service. Many fishermen were also called up for the armed forces. The impact of the wars on the English trawling industry was severe. For instance, before the Second World War, the English trawling fleet was estimated to have 1,132 trawlers. During the war years, about 856 vessels were requisitioned for naval service, leaving England only a fraction of its trawling fleet. Hull and Grimsby, being the leading ports in trawl fisheries, were most affected with their trawling fleet reduced to nearly one-fifth of its size by the end of the war. As England's biggest and best ships were called up for naval service, leaving fishing to the older and less efficient vessels, catching capacity declined even more than fleet numbers (Ashcroft 2000; Ministry of Agriculture and Fisheries 1946).

2.7.2 The 'Cod Wars' and fishing limits

The prolific waters around Iceland were of particular interest to English trawl fisheries during much of the twentieth century. By the 1950s, several other nations sent considerable fishing fleets to the waters surrounding Iceland, overall taking about half of the Icelandic catch (e.g. Gilchrist 1978; Jonsson 1982; Thor 1995). As a result, Iceland was concerned about the depletion of the fish stocks along its coast as its fishing industry contributes largely to the economy of the country. In 1958, Iceland declared that it had extended its territorial waters from 4 to 12 nautical miles. A wave of European protests followed; however, the UK refused to respect Iceland's decision and declared the extension illegal. British vessels continued fishing in Icelandic territorial waters causing the first of three subsequent Anglo-Icelandic disputes, the so called 'Cod Wars', dealing with the extension of Icelandic territorial waters (1958–1961: 4–12 nautical miles; 1972–1973: to 50 miles; 1975–1976: to 200 miles). In all three conflicts Iceland achieved its overall aims and the 'Cod Wars' ended with the successive expulsion of British trawlers from Icelandic territorial waters. With the agreement of more than a hundred nations to the creation of 200 nautical mile Exclusive Economic Zones (EEZ) in 1975 it was clear that the previous governing principle of open access to the seas belonged to the past (Robinson 1996). The impact on the English distant-water fishing industry was severe, as the grounds around Iceland and the Faroe Islands, the Norwegian coast, the Barents Sea and the East Coast of

Greenland in 1975 accounted for 80% of the total English and Welsh landings, but were now off-limits and landings dramatically decreased thereafter (Fig. 5a). Scotland, however, had a much smaller dependence on distant water fishing grounds as only around 13% of the total landings into Scotland came from these waters in 1975, whereas catches from the North Sea contributed no less than 65% of the total Scottish landings (Fig. 5b).

2.7.3 Sharing resources: the European Union and the Common Fisheries Policy

With the foundation of the European Economic Community (EEC) in 1957 [now European Union (EU)], the fisheries of Europe became increasingly politicised. The demands and needs of the various member states had to be reconciled in a joint policy: the Common Fisheries Policy (CFP). Initially the CFP was linked in the Treaty of Rome to the Common Agricultural Policy (CAP), with fisheries products being defined as ‘agricultural products’ (EEC 1957). It was not until 1970 that the Council adopted legislation to establish a common organisation of the market for fisheries products and put in place a community structural policy for fisheries. The principle of ‘equal access’ was established for European Community vessels to member state waters, with the exception of a narrow coastal band reserved for local fishermen with a tradition of fishing in that area (House of Lords 2008). In January 1973, the accession of the United Kingdom, Denmark and Ireland to the EEC (1972), whose combined catches represented more than twice those of the six founding members, prompted a review of the principle of equal access. At that time, international maritime law gave countries jurisdiction out to 12 nautical miles from their coastline, beyond which lay international waters (House of Lords 2008). Coastal states such as Iceland, Norway and the USA, supported the assertion of the 200 nautical mile EEZ principally to be able to manage, utilise and conserve their own waters in times of increased overfishing. As a result, the declaration of EEZs led to a reshape of the political geography not only in European fisheries but worldwide (Wise 1984).

As the Community’s resources in the North Atlantic and the North Sea were under serious threat from overfishing, a European policy to conserve fishery resources was considered necessary. A further milestone was set in 1983 when, after several years of negotiation, the adoption of a Council Regulation formally established the Common Fisheries Policy (EC 1983), organised around four components: market policy, structural policy, conservation policy and relations with third countries (House of Lords 2008). Conservation measures included a total allowable catch (TAC) for exploited fish stocks, surveillance measures (e.g. fleet controls, surveillance activities) and technical management (e.g. minimum mesh sizes for nets, closed areas and seasons, minimum landing sizes) (Moussis 2008). The TAC is annually renegotiated by the EU Council of Fisheries Ministers for the main commercial species of Europe's seas, and each member state receives a quota, or share of the TAC, and is responsible for policing this quota. The quota allocation is based on three criteria: traditional fishing patterns, the needs of regions especially dependent on fishing, and loss of catch potential in third-country waters (Wise 1984). Under the 200 nautical miles EEZ regime, European vessels lost fishing rights outside the EU when international boundaries were expanded. To compensate losses, agreements were concluded between the EU and third countries for fishing activities of European vessels outside EU waters and the access of third country vessels (e.g. Norway) to EU waters (Moussis 2008).

2.7.4 Adjustment and change in the fishery of the United Kingdom

With the accession of the UK in 1973 to the European Union (EC 1972) and the implementation of the EEZs two years thereafter, the British fishing industry had to adjust as the fishing areas were now largely confined to Community waters and inshore areas and the fleet was too large and overcapitalised for these waters (Thompson 1988). Furthermore, the industry had to adapt to the management of fish catches through the TAC system, restricting catches for the UK and the other EU member states, as they receive a fixed percentage share of these TACs. Owing to this principle of relative stability, the UK suffered from the introduction of the TACs, which were based on historical fishing patterns, because England's catches in the North Sea had declined and the fixed percentage therefore was low.

At present, the North Sea has regained importance in Britain's fisheries as, for example, in 2009 it provided 63% of the demersal fish landed by UK vessels into the UK and abroad (Marine Management Organisation 2009). The British fishing industry, however, is no longer able to satisfy the domestic market due to the loss of access to the distant water grounds, reduced catching capacity and its share of the Community's resources (Symes 1992). British vessels landing cod and haddock into the UK amounted to 39% of the total catch in 2009, whereas the import of these species into the UK accounted to 28% of the total imports (Marine Management Organisation 2009). In England, formerly successful ports struggled with these restrictions. In the 1970s, the port of Hull, with a high level of specialisation in stern freezer trawling and a heavy dependency upon access to distant water grounds, experienced the most serious cutback in fishing activity amongst all fishing ports. Between 1975 and 1986, Hull slipped from first to sixth in port rankings in the UK. In 1975 the ports of Hull and Grimsby accounted for 40% of the total demersal landings into the UK; this was reduced to only 5% in 1986 because of quota allocations. The emphasis of the UK fishing industry shifted markedly northwards to the north-east and north-west of Scotland. Peterhead became the leading UK port with a landings increase of 159% between

1975 and 1986 (Symes 1992), and in 2009 Peterhead remained the port with the largest quantity (112,000 tonnes) and value (£101 million) of fish landed (Marine Management Organisation 2009).

Table 1. Number of registered UK fishing vessels in 1973 and 2009. No information available for the 'under 40ft' capacity (gross tonnage, GT) in 1973.

	Vessels		England & Wales	Scotland
1973 [a]	under 40ft [c]	No.	2,410	1,516
		GT	-	-
	40ft and over	No.	1,202	1,173
		GT	214,059	71,252
2009 [b]	10m and under	No.	3,045	1,498
		GT	10,355	5,461
	over 10m	No.	605	695
		GT	57,485	120,554

[a] Ministry of Agriculture, Fisheries and Food: Sea Fisheries Statistical Tables 1973

[b] Marine Management Organisation: UK Sea Fisheries Statistics 2009

[c] 40 feet ≈ 12m

This northward shift in the British fishing industry is clearly seen in the development of its fishing fleets (Table 1). In terms of vessel numbers, the fleets of 'over 10 m' (~ 40ft and over) vessels in England and Wales, and Scotland were reduced by 50% and 40% respectively since accession to the EU. In terms of capacity (gross tonnage) however, the Scottish fleet of 'over 10 m' vessels increased by 70% in this time period, whereas the English and Welsh fleet suffered a 70% decrease. The '10 m and under' sector increased in this time period in England and Wales by 25% whereas in Scotland it remained nearly the same (Marine Management Organisation 2009).

2.8 Conclusions

The present study gives an overview of 100 years of North Sea demersal landings for England (including Wales), Scotland, and other European countries. The compilation and analysis of the dataset highlight the importance of understanding the historical context in interpreting fisheries data. In the case of England, it is shown that political, technological and economical drivers have had a great effect on the developments of its fisheries. Benefiting from its technological lead in the nineteenth and first half of the twentieth century and with a large domestic market, England's demersal fisheries in the North Sea were on a much larger scale than those of Scotland and other European countries. England then redirected much of its fishing effort away from the North Sea towards the distant fishing grounds as the demand of the home market made the distant water fisheries profitable. However, with the introduction of EEZs in the 1970s, the emphasis on distant waters disadvantaged the English trawl fisheries. Scotland in contrast, which had retained its fleets mainly in the North Sea and other waters adjacent to Scotland, benefited from these legislations resulting in a shift of the British fishing industry to Scotland.

This study shows that, for a more comprehensive understanding of changes in fisheries landings, all factors influencing the fisheries should be taken into account. Therefore, besides the biological responses of fish stocks to fishing and environmental changes, political, economical and technological factors have to be incorporated into analyses. For instance, as demonstrated in this paper, the decline of England's fisheries to some extent only reflects stock declines (e.g. end of the gadoid outburst), with much of it being reflected by political developments. This should be taken into account when interpreting fisheries statistics. In this regard, the loss of distant water fisheries should be considered when interpreting changes in landings per unit of fishing power in Britain as an indicator of fish abundance. Such consideration should make previous estimates of declines in fish abundance around the UK using landings-per-unit-effort (e.g. Thurstan et al. 2010) more conservative.

The recovery of historical fisheries data is of importance as long-term data are a prerequisite to the interpretation of long-term changes and dynamics in ecosystems and fish populations. Pinnegar and Engelhard (2008) pointed out that most time-series used for fishery assessments are less than three decades long and therefore long-term datasets would help to improve assessments. Furthermore, an underestimation of the potential abundance and diversity of marine species and the productive capacity of ecosystems without references from a historical perspective (Rosenberg et al. 2005) is likely, leading to the 'shifting baseline syndrome' (Pauly 1995). In recent years, interest has grown in the recovery of historical data and their analysis and interpretation have improved our knowledge of past ocean ecosystems and the impact of humans on these systems (e.g. Pitcher 2001; Sadovy and Cheung 2003; Cheung and Sadovy 2004; Rosenberg et al. 2005; Pinnegar and Engelhard 2008; Lescrauwaet et al. 2010; Poulsen 2010). Thus, data presented here can serve as a basis for further research for the analysis of long-term changes in fish stocks and can help to improve ecological models evaluating ecosystem effects of fishing.

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Chapter 3

Wondering about wandering whiting: distribution of North Sea whiting between the 1920s and 2000s

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3.1 Abstract

The responses of fish populations to anthropogenic and environmental drivers are of growing interest. In commercial fisheries attention is increasingly directed to species historically being of secondary importance and potentially being influenced by these drivers. We present long-term commercial fisheries data of North Sea whiting (*Merlangius merlangus*), comprising international catches (1903–2010), quotas (1980–2010), and British otter trawler data (landings-per-unit-effort (lpue) for 1923–2009 at the spatial scale of ICES rectangles). Based on lpue data, we tested the possible effects of climate change and fishing pressure on whiting distribution. Results showed no distinct latitudinal and deepening shifts, but a ~1° westward shift between the late-1940s and 1960s. Relations to climate change and fishing pressure were not strong. The lack of clear latitudinal and deepening shifts contrasts with recent studies on other North Sea species reporting such shifts related to temperature change. The North Sea is at the centre of the distribution range of whiting, and the temperature changes might still fall well within the physiological tolerance limits of this species, hence not affecting the distribution. The drivers for the longitudinal shift remain unclear. However, whiting is also commonly discarded by fisheries; if levels of discarding differ spatially, our results may not represent the true picture of whiting distribution and need to be interpreted with caution. This highlights the challenge in detection and attribution of climate change effects on exploited fish stocks with commercial data only.

3.2 Introduction

In recent years, North Sea whiting (*Merlangius merlangus*) has gained increased attention from fisheries management agencies, science and advisory organisations and the fishing industry. The status of the stock is considered unknown with respect to biological reference points as these are not defined (e.g. ICES, 2012). This has implications for stock management, increasing the demand for more information on this species. Further, lately the distribution and abundance of whiting became a matter of debate as findings of annual research surveys were not always corresponding with fishermen’s perception (e.g. ICES, 2011a). In addition, the interest in whiting fisheries, historically of secondary commercial relevance (ICES-FishMap, http://ices.dk/marine-data/maps/Pages/ICES-FishMap.aspx), has increased. Despite whiting being one of the most abundant and widely distributed North Sea gadoids (Knijn et al., 1993), and undergoing a substantial decline in SSB since the 1980s (ICES, 2012), it is not as well studied compared to other commercially important gadoids such as Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (Web of Knowledge[1]).

High densities of both small and large whiting can be found in the entire North Sea, with the exception of the Dogger Bank, generally showing lower abundance (ICES-FishMap). On the basis of vertebral counts, tag-recapture data, and genetic analysis it has been suggested that two distinct whiting populations are distributed to the north and the south of the Dogger Bank (Charrier et al., 2007; Gamble, 1959; Hislop and MacKenzie, 1976; Williams and Prime, 1966). In the North Sea, whiting is caught in three areas (northern zone, off the eastern English coast, and the southern area extending into the English Channel) (ICES, 2008) and as part of the mixed demersal roundfish fisheries, fisheries targeting flatfish and *nephrops*, and as bycatches in the industrial sandeel and Norway pout fisheries (ICES, 2011a). It is caught in large numbers, however, large quantities of the catch are discarded due to e.g. high-grading or once the species quota is reached (Catchpole et al., 2005; Cotter et al., 2002; Enever et al., 2009; Stratoudakis et al., 1999).

For commercial fisheries, distribution shifts of fish populations may have implications for the catchability of fish species. Fish stocks may move out of operating range for a country's fishing fleet or into areas with fishing restrictions (Pinnegar et al., 2010; Sumaila et al., 2011). A shift, expansion or contraction of a species' distribution can be caused by long-term changes in temperature (Brander et al., 2003; Cheung et al., 2009; Dulvy et al, 2008; Engelhard et al., 2011a; Keeken et al., 2007; Perry et al., 2005). However, not only climate change but also fishing pressure can influence long-term shifts of fish migration patterns, spawning grounds or a species' distribution (Engelhard et al., 2011b; Holst et al., 2002; Opdal, 2010). Long time series have been demonstrated to be useful for disentangling climate and fishing effects. Short time series have the disadvantage that these two variables are more likely to be confounded, but over a longer time period these drivers are more easily separable, allowing a distribution shift to be related to climate change or fishing pressure (Engelhard et al., 2011a).

This study aims to extend the knowledge regarding North Sea whiting, by analysing long-term data of international and British (England & Wales, Scotland) commercial fisheries. We present over 100 years' catch data of European countries and recent quota uptake rates, describing the trends of international whiting fisheries in the North Sea. Data from British otter trawlers on the spatial scale per ICES rectangle and covering nine decades were used to analyse the spatial distribution of British whiting landings in the North Sea. Further, based on the trawlers' landings-per-unit-effort (lpue), we analysed the long-term changes in

[1] Number of citations in http://apps.webofknowledge.com for Atlantic cod + *Gadus morhua* 7484, haddock + *Melanogrammus aeglefinus* 927, and whiting + *Merlangius merlangus* 403, as of 16.04.2012.

whiting distribution. As the study's time span covers periods of warming and cooling in the North Sea, as well as different levels of fishing pressure, we attempted to disentangle relative influences of climate and/or fishing pressure on distribution shifts. Finally, the challenges in interpreting commercial fisheries data are highlighted.

3.3 Material and Methods

3.3.1 Fisheries data

Long-term data of international and British North Sea whiting catches as well as British lpue data were collated. To outline the development in whiting fisheries, over 100 years (1903–2010) of annual whiting catch data (for human consumption) of European countries were obtained from ICES statistics (ICES, 2010a, ICES, 2011b). These were available as Excel files (1903–1949) as well as a database on catch statistics (1950–2010), being extracted with the FishStat Plus programme (FAO, 2011). These data, and whiting quotas (after exchange) from 1980 onwards (provided by the Directorate-General for Maritime Affairs and Fisheries of the European Commission), were used to calculate the quota uptake rates. For the analysis of trends in British North Sea whiting landings and whiting distribution changes, nine decades of annual effort (hours fished) and landings (kg) data of British otter trawlers landing into England, Wales and Scotland were available for each ICES rectangle (0.5° latitude by 1° longitude). Historical statistical charts[2] (catalogued in Engelhard, 2005) were digitised containing records of landings into England & Wales and Scotland (1923–1938, 1947–1966) and landings into England & Wales (1967–1980). For the years 1968–2009, an electronic database for landings into Scotland was obtained from the Fisheries Management Database of Marine Scotland. For the years 1982–2009, data for landings into England & Wales were available from the Fisheries Activity Database held at the UK Department for Environment, Food and Rural Affairs (Defra). These data include mainly medium to large whiting because small whiting were typically not landed by these otter trawl fisheries, and minimum landing size regulations have been in force since 1970 (25 cm between 1970 and 1982 (MAFF, 1968), and 27 cm from 1983 onwards (EEC, 1983)). Juvenile, small whiting are therefore not captured in this analysis.

[2] Produced by the UK Ministry of Agriculture, Fisheries and Food (MAFF; now the UK Department for Environment, Food and Rural Affairs (Defra)).

3.3.2 Distribution of British whiting landings in the North Sea

Digitised historical data and recent electronic databases were merged to create one database covering nine decades of British otter trawler landings and effort by ICES rectangle. Landings, being recorded in hundredweights (1 cwt = 50.8023 kg) until 1972, were converted into kilograms. Mean decadal landings were calculated per ICES rectangle to demonstrate the distribution of British whiting landings in the North Sea.

3.3.3 Analysis of the spatial distribution of whiting

Lpue data by rectangle were analysed to illustrate long-term trends in the spatial distribution of whiting. The British North Sea trawl fisheries shifted from using steam otter trawlers (1923–1967) to motor otter trawlers (1957–2009), going along with improvements in fishing power and technical efficiency over time (Engelhard, 2008). To account for such an increase in fishing power of trawlers, the relative annual lpue value ($lpue'_{i,y}$) for each rectangle *i* and year *y* was calculated, taking variations across years in lpue into account:

$$lpue'_{i,y} = \frac{lpue_{i,y}}{\left(\sum_{i=1}^{N} lpue_{i,y}\right) / N}$$

where $lpue_{i,y}$ represents the lpue values in rectangle *i* and year *y*, and *N* is the total number of rectangles in the defined study area. It was assumed that relative lpue values across the statistical grid indicate the spatial distribution of whiting. To assess the long-term distribution shift of North Sea whiting, the 'centres of gravity' (COG) of the longitudinal, latitudinal and depth distribution were calculated. The analysis was adopted from the methods developed and applied by Heino et al. (2003) and used in Engelhard et al. (2011a). The defined study area only included rectangles with ≥50 h of fishing effort per year and a data coverage of ≥40 years (Fig. 1).

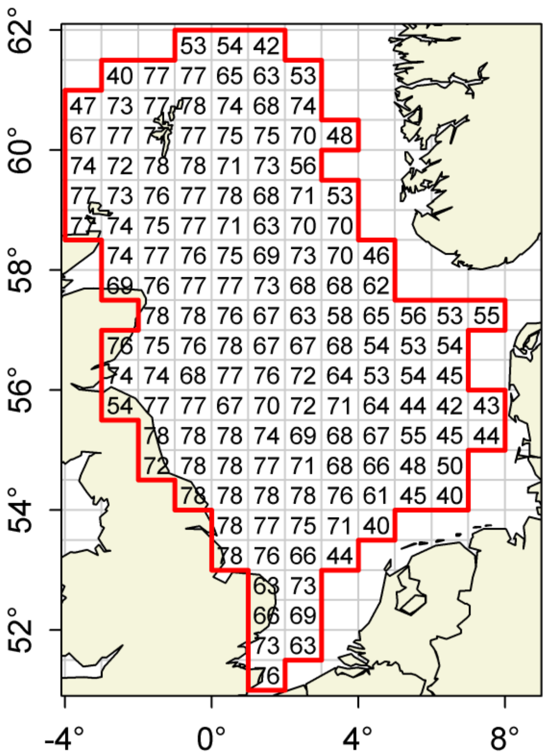

Figure 1. Map of the North Sea, showing for each ICES rectangle the number of years available for British otter trawler lpue data. The defined study area (red boundary) only included rectangles which had ≥50 h of fishing effort per year and a data coverage of at least 40 years.

To exclude data from statistical rectangles that were not adequately fished by the otter trawlers in any given year, any rectangles comprising no data or <50 h effort were removed from the analysis. This applied to 1558 out of the 11466 analysed rectangle-year combinations. Instead, the lpue in the given rectangle was assumed to be equal to the long-term mean lpue for the respective rectangle. To reveal the distribution shifts over time, the COG of the latitudinal distribution for each year was calculated:

$$COG = \frac{\sum_{i=1}^{N} lpue_i \cdot lat_i}{\sum_{i=1}^{N} lpue_i}$$

where $lpue_i$ is the lpue for each rectangle i, lat is the latitudinal centre of each rectangle i, and N is the total number of rectangles. Weighted standard deviations (sd_w) and standard errors (se_w) of the COG were calculated per year and decade:

$$sd_w = \sqrt{\frac{\sum_{i=1}^{N} lpue_i (lat_i - COG)^2}{\sum_{i=1}^{N} lpue_i}}$$

$$se_w = \frac{sd_w}{\sqrt{N}}$$

Analogously, the longitudinal and depth COGs were calculated by using the longitude of the rectangle's centre or the mean depth, respectively.

3.3.4 Whiting distribution shift in relation to climate variables and fishing pressure

To disentangle the influences of environmental and human-induced effects, climate and fishing indicators were analysed in relation to whiting distribution. For this analysis, the metrics to describe whiting distribution were the longitudinal, latitudinal and depth COG. The three climate variables were: the North Atlantic Oscillation (NAO) winter index, the Atlantic Multidecadal Oscillation (AMO), and the Hadley Centre Sea Surface Temperature data set (HadISST1.1).

The NAO is a leading pattern of weather and climate variability over the Northern Hemisphere. It is particularly dominant during the winter period, governing whether winters in north-western Europe will be wet and warm (positive NAO conditions) or cold and dry (negative NAO conditions) (Hurrell and Deser, 2009). The NAO winter index (months December to March) expresses the variability of the NAO and is based on the difference between the mean winter sea level pressure at Gibraltar and over Iceland (Jones et al., 1997; Osborn, 2000). The NAO affects a variety of marine ecological processes and, consequently, patterns of species abundance and dynamics (e.g. Alheit and Bakun, 2010; Drinkwater et al., 2003). Data from 1923 to 2007 were obtained from Jones et al. (1997) with updated values provided online by the Climatic Research Unit (CRU), University of East Anglia, UK (http://www.cru.uea.ac.uk/~timo/datapages/naoi.htm) (Fig. 2a).

The Atlantic Multidecadal Oscillation (AMO) is used as a climate index to describe sea surface temperature (SST) anomalies and is based upon the average SST anomalies in the North Atlantic. It has been identified as a coherent pattern of natural variability in the North Atlantic Ocean with oscillatory changes with a period of around 65 years (Schlesinger and Ramankutty, 1994; UCAR, 2011). The AMO index is defined as the 10-year running mean of the detrended Atlantic SST anomalies north of the equator (Enfield et al., 2001). Data were obtained from the Global Change Master Directory of the National Oceanic and Atmospheric Administration (NOAA) (http://www.esrl.noaa.gov/psd/) (Fig. 2b).

To analyse the local water temperature patterns in the North Sea, the annual mean sea surface temperature data set HadISST1.1 was used as the third climate indicator. The data is prepared and maintained by the Hadley Centre of the UK Meteorological Office (Rayner et al., 2003) and was obtained online (http://badc.nerc.ac.uk/view/badc.nerc.ac.uk ATOM dataent hadisst). The dataset is available in a 1° × 1° latitude-longitude grid size on a global scale. The analysed area was adjusted to the study's main distribution area of whiting in the North Sea (62.0°N, 4.0°W, 55.0°N, 5.0°E) (Fig. 2c).

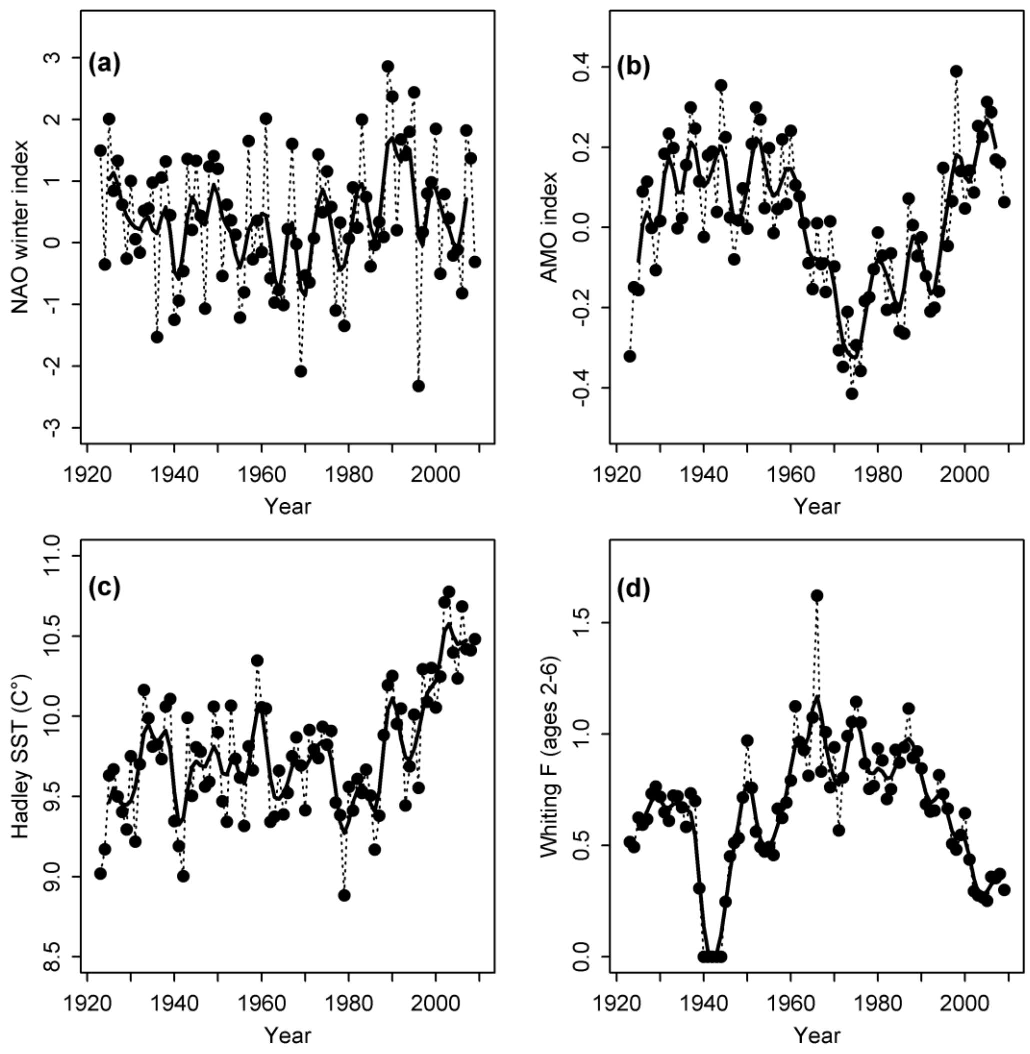

Figure 2. Time series with annual values (broken line with dots) of climate (a–c) and fisheries (d) related indicators being used to analyse possible relationships with the distribution of North Sea whiting. Solid line denotes the long-term variability of the indicators, representing values smoothed with a low-pass filter with five weights (1, 2, 3, 2, and 1) to remove fluctuations with periods <3 years (adopted from Hurrell (1995)).

For analysis of fisheries related indicators, estimates of fishing mortality (F) of 2–6 year old whiting (Fig. 2d) were used. Data were obtained from Pope and Macer (1996) for the period 1923–1979, and from the ICES Reports of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) for the periods 1980–1989 (ICES, 2008) and 1990–2009 (ICES, 2012). Correlations between the above mentioned environmental and fisheries indicators with the descriptors of whiting distribution (latitude, longitude and depth) were tested. Specifically, the Pearson's cross product moment correlation (r_p) was used as all of the variables were normally distributed (one-sample Kolmogorov- Smirnov test, $p > 0.05$). To correct for temporal autocorrelation of the variables the test procedure was adjusted following Pyper and Peterman (1998, Eq. (1)). According to the level of autocorrelation, the variables' degrees of freedom were reduced, and therefore the p-values adjusted (p_{adj}). Linear regressions were then applied to analyse the relative influence of the climate variables (Hadley SST, NAO winter index, AMO index) and whiting fishing mortality (F of 2–6 year olds) as determinants of whiting distribution (represented by the longitudinal COG, latitudinal COG, depth COG). The initial model included all predictor variables; for example:

Longitudinal COG ~ NAO winter index + AMO index + Hadley SST + F

The model was then improved by using a stepwise elimination which only retained predictors that significantly contributed to the fit ($p < 0.05$).

3.4 Results

3.4.1 Long-term landing trends of international North Sea whiting fisheries

In the first half of the 20th century, North Sea whiting landings were relatively stable at an average of around 30,000 t. Exceptions were disruptions of the fisheries due to war conflicts (1914–1918 and 1939–1945) when landings dropped (Fig. 3). After the Second World War, landings rapidly increased until the mid-1970s before declining and reaching historically low levels in the 2000s. Throughout the study period, the UK, and in particular Scotland, was taking most of North Sea whiting. Only in the years of the 'gadoid outburst' (1960s–1980s) (Cushing, 1984), Denmark dominated this fishery, recording years with exceptionally high landings (1969, 1974, and 1976 landings were between 110,000 and 142,000 t). The French fishery for whiting was minor before the Second World War, but expanded in the post-war years. However, whiting landings generally decreased since the 1980s. In the 2000s, the three main nations fishing for whiting in the North Sea were Scotland, France and England.

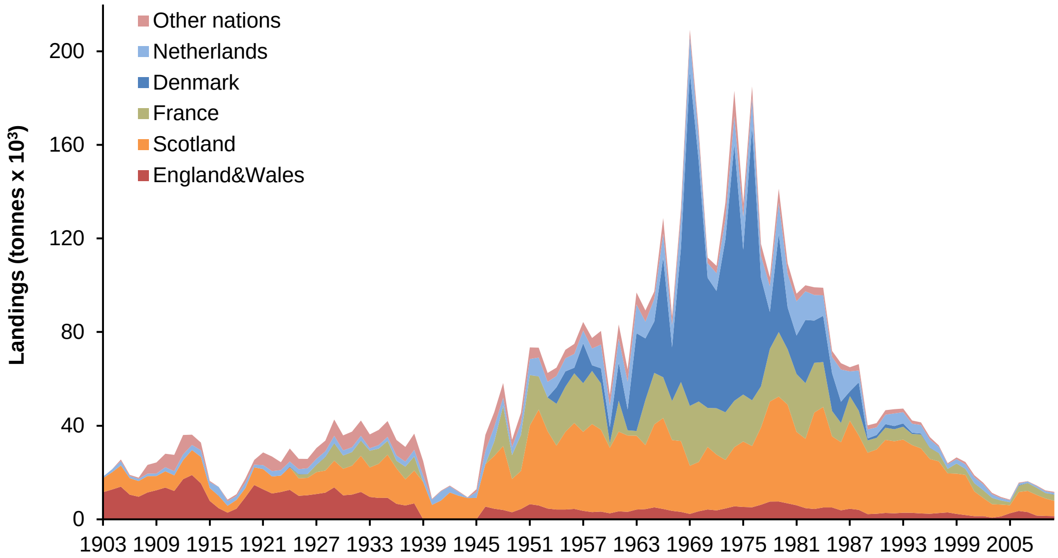

Figure 3. Long-term trend of landings of North Sea whiting, shown separately by country. "Other nations" represent the combined landings for Belgium, Germany (including former German Democratic Republic), Faroe Islands, Ireland, Norway, Poland, Spain, and Sweden.

Whiting quota uptake rates of the last three decades demonstrate the importance of whiting in UK fisheries compared to other European countries (Fig. 4). The UK uptake rates between 1980 and 2010 were fairly constant, fishing on average 83% of their quota, whereas the remaining European countries together fished on average 63% of the available quota in this time period.

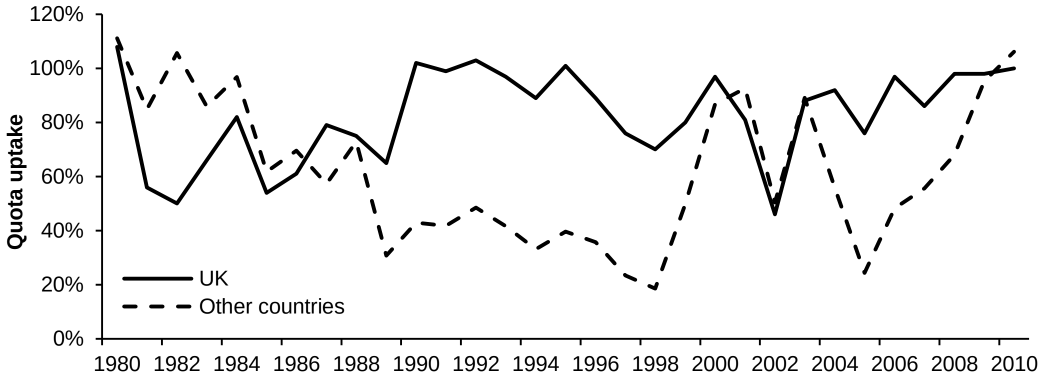

Figure 4. Whiting quota uptake rates of the UK and of other European countries including Belgium, Denmark, France, Netherlands, Germany, and Sweden.

3.4.2 Distribution of whiting landings by British fisheries

Throughout the study period, British trawlers landed whiting mainly from the northern North Sea and the western part of the central North Sea. Only at the beginning of the study period, high landings were as well recorded from the area to the south-east of the Dogger Bank (Fig. 5, grey shaded area). In the northern fishing grounds, between the 1920s and 1950s, high landings were widely spread over the northern area. In the 1960s, landings declined and came mainly from the western part of the northern North Sea. Landings rapidly increased in this area in the 1970s, coinciding with the gadoid outburst, but declined markedly in the following decades. In the 2000s, landings were mainly reported from the central-northern North Sea, and around the Shetland Islands. In the central North Sea high landings were recorded between the 1920s and 1950s, in particular to the south-east of the Dogger Bank, at the south-east coast of Scotland, and to a lesser extent at the north-east coast of England. The landings to the south-east of the Dogger Bank decreased over time, and from the 1960s onwards, high landings were reported from the fishing grounds between the western Dogger Bank and off the north-east coast of England. Landings off the south-east coast of Scotland increased in the 1970s but decreased thereafter, and remained low in this area until present. Compared to the northern and central North Sea, the southern part did not show remarkable landings throughout the nine decades, beside the 1920s and 1930s, where relatively high landings were registered off the south east coast of England.

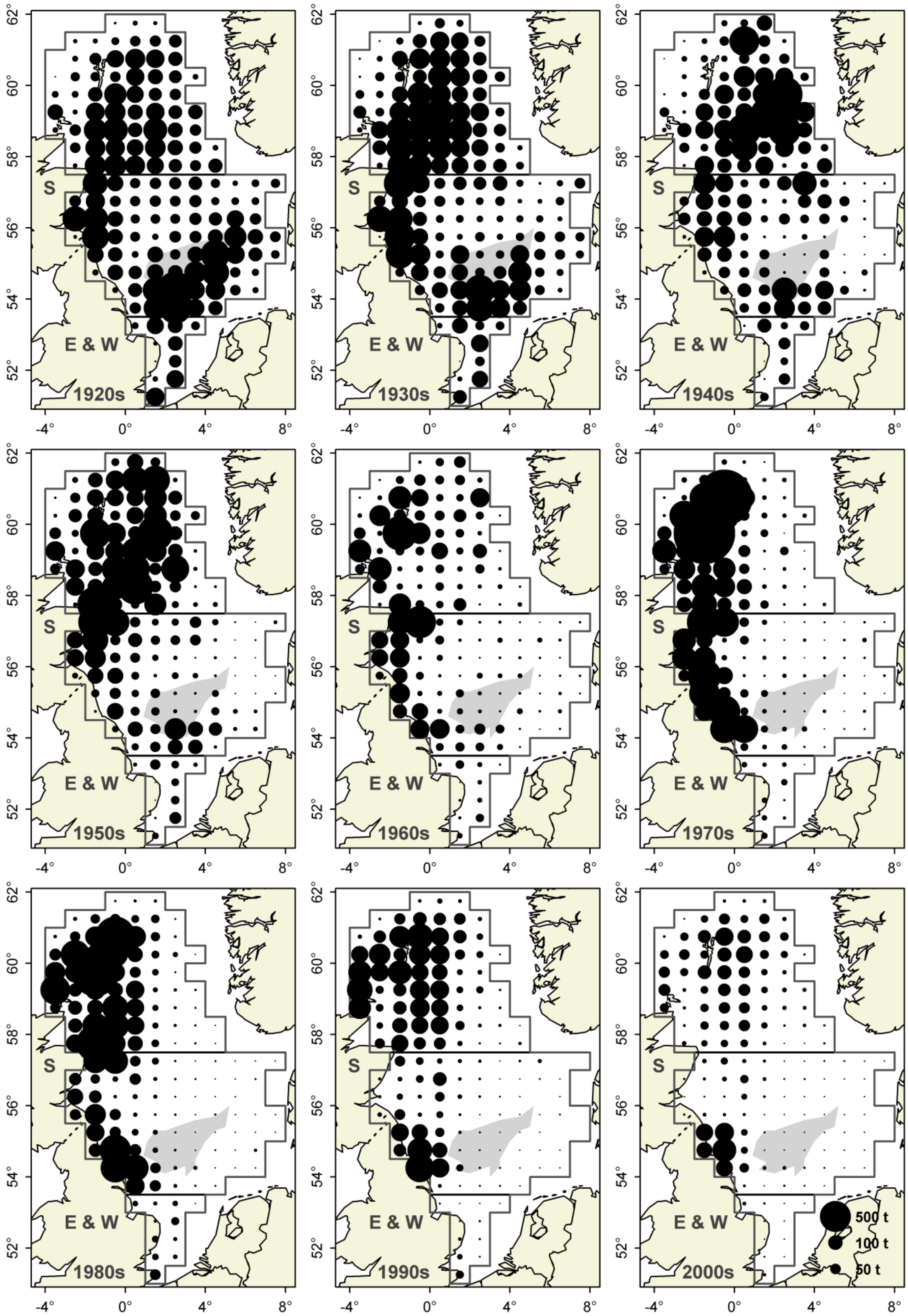

Figure 5. Decadal mean landings of whiting caught by British trawlers in the defined North Sea study area and being landed in England & Wales (E & W) and Scotland (S). The area of the black circles is proportional to the landings. The study area is divided into the northern, central and southern North Sea, according to the ICES areas IVa, b and c. Grey shaded area represents the Dogger Bank at 40 m depth.

3.4.3 Nine decades of whiting distribution

Over the last 90 years, the mean decadal COG of the long-term lpue of British trawlers indicates no major distribution shift of whiting in the North Sea (Fig. 6, red crosses). Throughout the time series, the lpue distribution reveals a distinct north–south gradient of whiting, with highest lpue in the northern North Sea, and lowest in the southern North Sea. In the northern North Sea, lpue values show a rather even distribution of whiting, however, over the course of time a slight westerly drift of the COG can be observed. In the central North Sea, whiting was more evenly distributed in the 1920s and 1930s; remarkably high lpue values were found at the Scottish and English east coast in the 1960s and 1970s, but decreasing thereafter. The southern fishing grounds did not show notable lpue values over the study period.

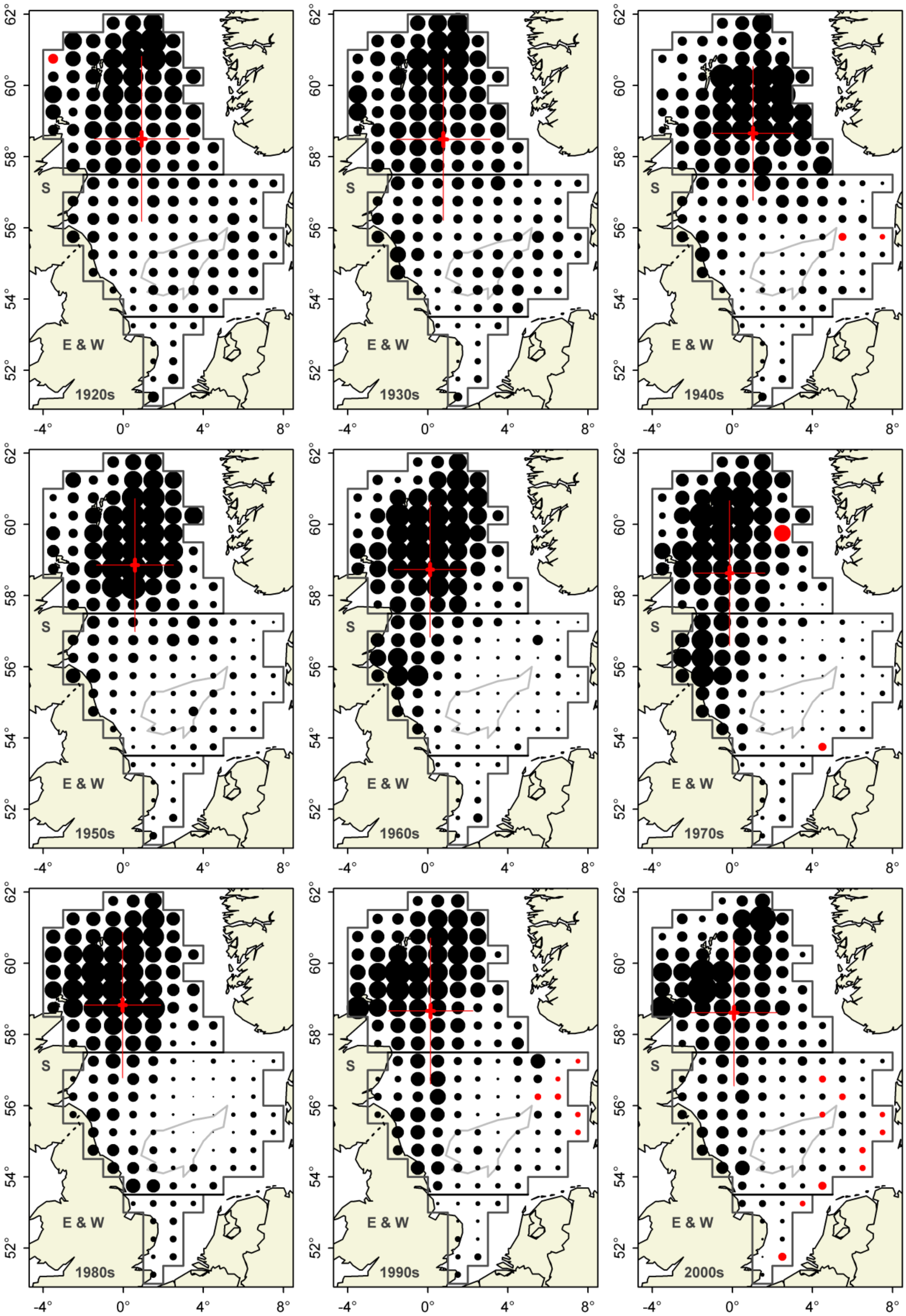

Figure 6. Long-term distribution changes of North Sea whiting represented by relative whiting lpue of British trawlers (E & W = England & Wales, S = Scotland). The red cross indicates for each decade the centre of gravity of whiting distribution. For rectangles without lpue data in a given decade (no effort), red circles represent the long-term average lpue. Standard error is shown as short, thick line; standard deviation is shown as long, thin line. For each ICES rectangle the black circles (area is proportional to lpue) represent the relative mean decadal lpue. The study area is divided into the northern, central and southern North Sea, according to the ICES areas IVa, b and c. The grey polygon delineates the Dogger Bank area at 40 m depth.

The annual COG values of the distribution indicators revealed a distinct distribution shift in longitude and no clear trend in latitude or depth (Fig. 7). Before the Second World War (1939–1945) the longitudinal COG remained constant between 0.5° and 1.0°E. Yet, after the war, within two decades, whiting showed a westward shift, from 1.4°E in 1947 to 0.4°W in 1965. From the 1970s onwards, whiting distribution was found to be more in the western part of the North Sea, at an average longitude of 0°. The latitudinal COG fluctuated mainly between 58° and 59°N over the study period. However, some events of quick southward shifts can be seen (e.g. 1950s, mid-1960s, end-1990s, and mid-2000s), which were followed by subsequent northward shifts in distribution. The average depth of whiting distribution was 115 m, and the COGs remained fairly constant around this depth. However, in some years, the depth distribution fluctuated rapidly to shallower (e.g. 1920s and 1950s) or deeper depths (e.g. 1990s). As expected from the geographical depth gradient in the North Sea, the depth COG of whiting was significantly correlated with the latitudinal COG (r_p = 0.558, $p < 0.001$).

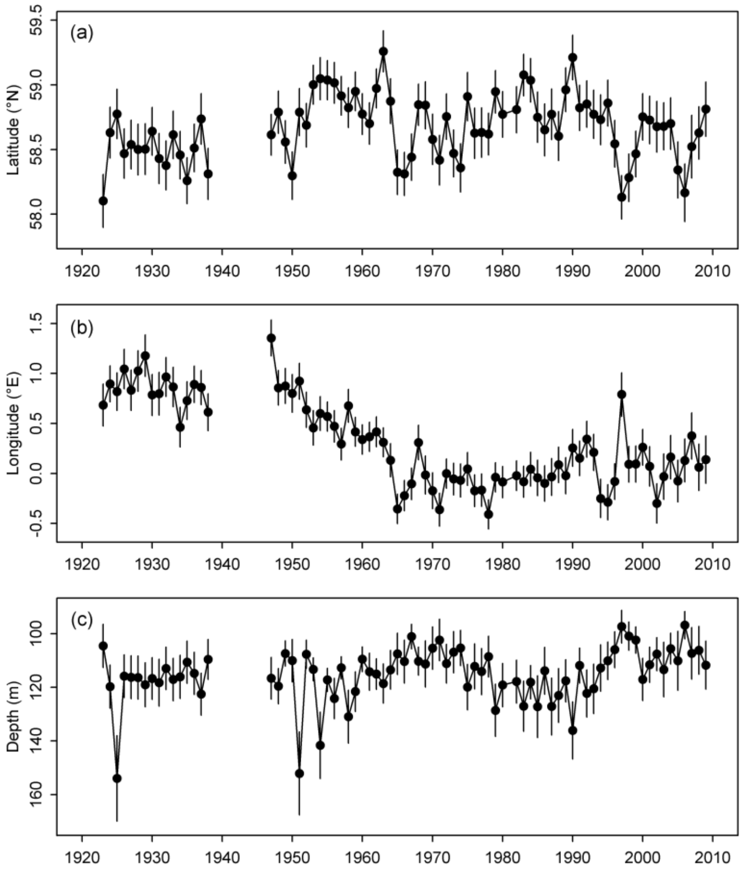

Figure 7. Annual centre of gravity (COG) changes for the (a) latitudinal, (b) longitudinal and (c) depth distribution of North Sea whiting. COG is calculated as the mean latitude, longitude and depth, weighted with whiting lpue (bars indicate s.e. of the weighted means).

3.4.4 Correlations of distribution shifts with environmental and fishing variables

Few correlations were found between the distribution indicators and environmental and/or fishing variables. The Hadley SST showed significant correlation with depth distribution, associating higher sea surface temperatures with shallower distribution patterns of whiting (Table 1 and Fig. 8a).

Table 1. Correlations (r_p) between whiting distribution variables (longitude, latitude, depth) and climate (Hadley SST, NAO winter index, AMO index) and fisheries related variables (fishing mortality (F) of whiting ages 2-6).

	Longitudinal shift		Latitudinal shift		Depth shift	
	r_p	p_{adj}	r_p	p_{adj}	r_p	p_{adj}
Climate variables						
Hadley SST	-0.156	0.188	-0.091	0.430	**-0.313**	**0.006**
NAO winter index	0.023	0.841	0.016	0.889	0.062	0.587
AMO index	**0.329**	**0.010**	-0.070	0.543	-0.056	0.627
Fisheries variable						
Whiting F (ages 2-6)	**-0.260**	**0.038**	0.076	0.514	0.104	0.370

Owing to temporal autocorrelation within the variables, the test procedure for significance of correlation was adjusted according to autocorrelation following Pyper and Peterman (1998; Equation 1). Correlations different from zero at adjusted $p < 0.05$ are shown in bold.

The longitudinal distribution was correlated such that a westerly distribution was associated with higher fishing mortality and a negative AMO index (Table 1 and Fig. 8c and d). No significant correlations were found between the NAO winter index and any distribution variables of whiting (Table 1 and Fig. 8b).

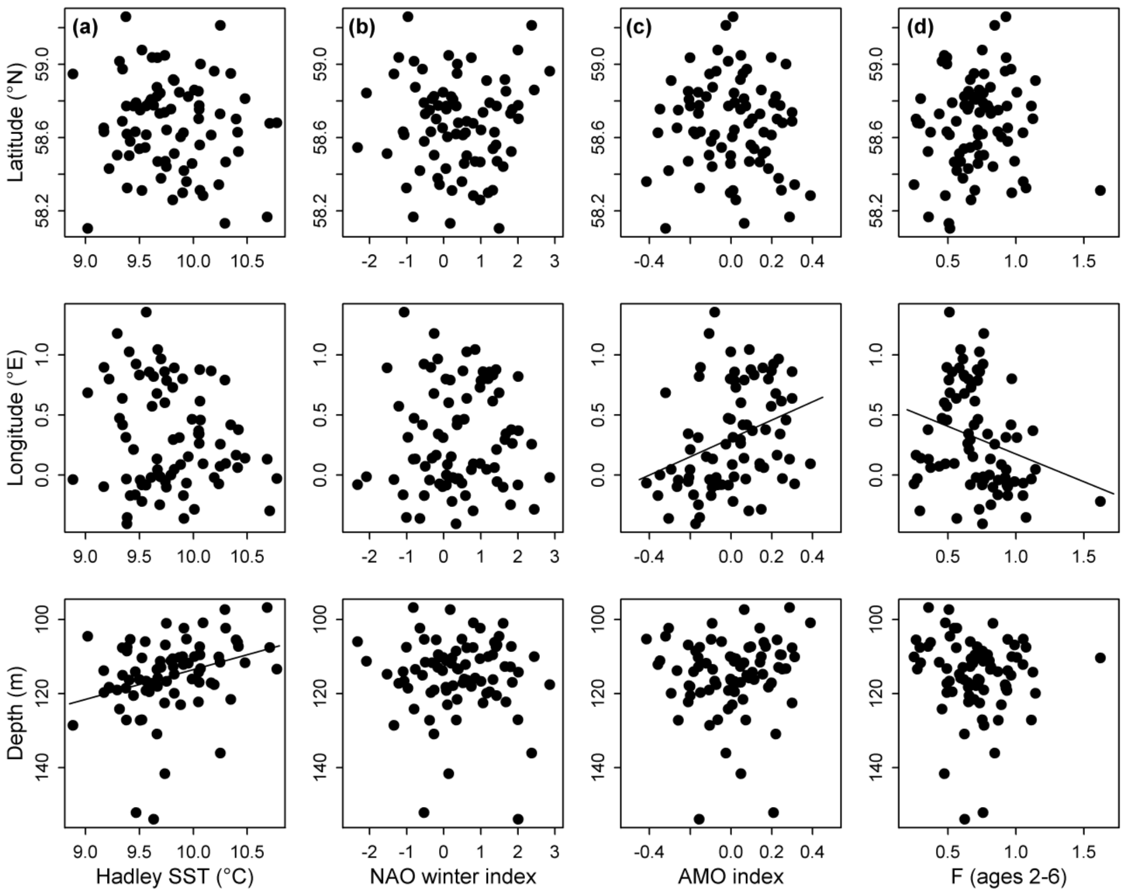

Figure 8. Relationships between whiting distribution measures (latitude, longitude, and depth) and climate (Hadley SST, NAO winter index, and AMO index) and fisheries related indicators (F 2–6 year old whiting). Regression lines indicate significant relationships.

Regression analysis demonstrated the relative strength of relationships of environmental and fishing parameters with whiting distribution responses (Table 2). The models confirmed fishing mortality, Hadley SST and the AMO index as significant predictors for the longitudinal shift of whiting. Further, only Hadley SST was retained as a significant predictor for shifts in depth. No significant relationships were found between any predictors and latitudinal response.

Table 2. Regression models testing for the relationship of distribution responses (longitudinal and depth shift) with climate variables (Hadley SST, NAO and AMO) and fishing mortality (F). Using a backward selection process, only variables were retained which significantly explained the distribution variable (*p* < 0.05). No significant effects were found between the environmental and fishing variables and the latitudinal response. The adjusted R^2 and the overall *p*-value are provided for the models predicting longitude and depth.

Response variable	Predictor	Estimate	s.e.	*t*-value	*p*-value	adjusted R^2	model *p*-value
Longitude	Hadley SST	-0.434	0.123	-3.541	**<0.001**	**0.220**	**<0.001**
	AMO index	0.864	0.273	3.167	**<0.005**		
	Whiting F (ages 2-6)	-0.445	0.209	-2.129	**0.037**		
Depth	Hadley SST	-8.025	2.798	-2.868	**0.005**	**0.086**	**0.005**

It should be noted that some of the environmental and fishing variables showed significant correlations. Therefore it cannot be fully excluded that some of the effects described above might be spurious. There were positive correlations between Hadley SST and the NAO winter index (p_{adj} = 0.004, r_p = 0.306) as well as Hadley SST and the AMO index (p_{adj} = 0.005, r_p = 0.316), but not between the AMO and NAO winter index. Whiting fishing mortality was negatively correlated with the AMO index (p_{adj} = 0.0001, r_p = −0.483), but not with Hadley SST or the NAO winter index (p_{adj} > 0.05).

3.5 Discussion

This study shows that British whiting landings came mainly from the northern and to a lesser extent from the central North Sea. Recent quota uptake rates and the international catch statistics reveal the importance of whiting for the British fisheries, and that Great Britain predominately had the biggest share of the total North Sea landings. Although Denmark had years with remarkably high landings between the 1960s and 1980s, overall we assume that the spatial distribution of British lpue is representative for the distribution of whiting in the North Sea. It is important to highlight that our analysis is based on adult whiting data. Juvenile, small whiting are not captured by our commercial data.

Our results suggest that within nine decades whiting did not undergo clear distribution shifts regarding latitudinal and depth COGs, but showed a ~1° westward shift between the late-1940s and 1960s. Although correlations were found for the longitudinal distribution of whiting and fishing pressure and the AMO index, as well as for depth distribution and Hadley SST, the relationships were not strong.

We discuss possible explanations for the distinct westward shift of whiting, but as well the lack of a clear latitudinal and depth shift. Further, we aim to explain the dominant northern distribution of whiting lpue, with only a short notable period in the 1960s and 1970s of extended distribution in the western-central North Sea, and finally highlight the challenges when analysing commercial fisheries data.

3.5.1 Lack of deepening and latitudinal shifts

Our findings do not concur with recent studies on other North Sea species, revealing distinct deepening and/or latitudinal shifts (Dulvy et al, 2008; Engelhard et al., 2011a,b; Hedger et al., 2004; Perry et al., 2005), which could be related to climate change and/or fishing pressure. In particular Engelhard et al. (2011a), using comparable data sources and analogous methods, demonstrated that plaice (*Pleuronectes platessa*) shifted its distribution mainly north-eastwards and to deeper waters, which could be attributed to climatic factors, while shifts of sole (*Solea solea*) to more south-eastern and shallower depths were attributed to the effects of both climatic factors and fishing pressure. A study on cod revealed distribution shifts, markedly in the most recent decades (1990s and 2000s), towards the deeper northern- and north-easternmost part of the North Sea. Here, longitudinal shifts could be related to fisheries indicators, but no clear relations were found for latitudinal and depth shifts and climate or fisheries variables (Engelhard et al., 2011b).

A study by Simpson et al. (2011) highlighted that North Sea whiting abundance decreased in recent three decades with warmer temperatures, however, we cannot validate or reject these findings as our study was analysing distribution changes and not abundance. Still, their study revealed that the North Sea is at the centre of latitudinal range for whiting which could explain the lack of a clear latitudinal shift in our results. This is in line with the hypothesis of Rijnsdorp et al. (2009), that populations which are at the centre of the latitudinal distribution of the species, do not exhibit strong responses to climate change compared to populations living at the limit of the species' latitudinal range (e.g. sole, plaice in Engelhard et al., 2011a). Further, the native distribution of whiting presented in AquaMaps (2010) shows that the main distribution area of whiting is found around the British Isles.

Dulvy et al (2008) classified North Sea whiting as a species with a cold thermal preference (mean autumn temperature 13.2 °C) and a narrow thermal range (3.2 °C), and responding with a shift between the 1980s and 2000s to deeper waters with warmer temperatures. Surprisingly, our study indicates for this time period a trend of whiting to shallower and not deeper depths (Fig. 7). Further, our results suggest, considering the entire study period, that a shift to shallower waters is associated with warmer Hadley SST. As at the same time no correlations were found for Hadley SST and longitude, a shift to shallower waters cannot be related with a westerly shift.

3.5.2 The longitudinal shift of whiting

The westward shift of whiting took place between the late- 1940s and 1960s, with whiting remaining westerly thereafter, in particular in the central North Sea. Our analysis suggests relationships with the Hadley SST, the AMO index and fishing mortality. The AMO index and fishing mortality might be an explanation for the westward shift in this specific period, as the AMO index went from a positive to a negative phase and F increased (Fig. 2), both being related with a westerly shift (Fig. 8). However, as in the 1980s these trends reversed, an eastward shift would have been expected. This reversed shift did not take place, questioning these two variables as potential drivers. It further has to be outlined, that the AMO index was negatively correlated with fishing mortality (p_{adj} = 0.0001, r_p = −0.483), indicating that the significant relationships between the westward shift and at least one of these variables might be spurious. Therefore the determining driver(s) remain(s) unclear, and it is difficult to relate this shift and the subsequent predominant westerly distribution of whiting to climate change and/or fishing pressure.

The longitudinal shift did coincide with a period of contraction of the British fleet after the Second World War (Kerby et al., 2012), resulting in British fishing effort being less spread out over the entire North Sea (Engelhard, 2005), and therefore reducing the total quantities of whiting taken from the easternmost parts by British fleets. However, this may explain a westward shift in landings, but seems not sufficient to explain the shift in lpue.

As no fisheries-independent survey data are available for the early decades of the 20th century at the scale of the North Sea, a direct comparison with any survey-based indices of whiting distribution is not possible. Still, for the years 1977–2005, IBTS quarter 1 average annual catch rates for adult whiting (≥20 cm) are in general agreement with our distribution patterns, showing lower catch rates mainly in the eastern-central North Sea, and higher catch rates in the northern and western parts (ICES-FishMap).

Localised depletion of whiting in the eastern-central North Sea might be a possible explanation for the westerly shift. In the 1950s, the Danish industrial fisheries commenced and developed within a short time period to a new and profitable sector in Danish fisheries. Fish which did not meet the demands for direct human consumption (juvenile or unmarketable fish) were processed to fish meal and fish oil. Mainly pelagic fish such as herring, sandeel, and later also Norway pout were caught; yet, also juvenile cod, haddock and whiting represented a substantial bycatch in this fishery (Byskov, 2009). Between 1950 and 1960, the Danish industrial landings rapidly increased from 6800 t to 244,800 t (Popp Madsen, 1978). However, the proportion of whiting in these catches is unclear. As Danish vessels were extracting large quantities of fish for reduction purposes mainly in the vicinity of Danish waters, this possible driver for a westward shift of whiting would require further investigations of Danish fisheries statistics.

Alternative causes could have led to a distribution shift of whiting. For example, herring prey on the eggs and larvae of whiting and other gadoids, and compete with juvenile whiting for zooplanktonic food resources. Changes in herring abundance over time influenced prey availability and predation pressure in the North Sea (Cushing, 1980), which might as well have affected whiting.

3.5.3 Influence on distribution patterns

Fish distribution patterns are largely influenced by abiotic and biotic factors. Of these, temperature and food availability are important criteria determining the large-scale distribution patterns of fish (Rose and Leggett, 1989; Wildhaber and Crowder, 1990). Our results illustrate that within the North Sea whiting is mainly distributed in the northern area. Zheng (2001) and Zheng et al. (2002) suggest a relationship between higher whiting abundance and favourable conditions for feeding due to the inflow of nutrient rich North Atlantic waters entering the northern North Sea. They further demonstrated that in years of relatively warm SST during winter and spring, whiting abundance is relatively high; however, these relationships do not exist in summer.

In the 1960s and 1970s, remarkable high lpue values were recorded at the north-east coast of England and east coast of Scotland. The increase of whiting in this area concurs with the onset of the gadoid outburst (Cushing, 1984), which could have led to an expansion of the northerly whiting population due to density dependent mechanisms and/or new areas were opened up due to favourable conditions (e.g. food availability). Andersen and Ursin (1977) suggested that an increase in sandeel stocks may have been associated with the decline of herring and mackerel in the late 1960s, which is as well discussed by Cushing (1980) and Hislop (1996). This change in the food web structure is corroborated by Christensen and Richardson (2008), suggesting that after the 1960s a shift towards lower trophic levels may have taken place. These results are in accordance with studies observing a shift in the diet of whiting in this time period. Stomach content analyses pointed out that whiting were eating less sandeel in the 1930s and 1940s (Jones, 1954), than in the 1980s and 1990s (Daan, 1989; Hislop, 1996) corroborating a change in diet in the intervening period. With whiting predominantly eating small fish such as sandeel, improved food availability could explain high lpue values of whiting in the 1960s and 1970s in the western-central North Sea.

3.5.4 Challenges of commercial fisheries data

Our study highlighted that commercial fisheries data represent a valuable and comprehensive source for providing information on a great temporal and spatial scale. Still, when analysing commercial fisheries data, various factors have to be taken into account potentially influencing the data. Our dataset covered around nine decades, during which a variety of technological improvements in fisheries took place (e.g. gear efficiency, engine power). As the used effort measure (hours fished) does not account for these changes, it has to be acknowledged that potential bias might arise from uneven distribution of more and less efficient fishing vessels within the North Sea during any given year (Engelhard et al., 2011a; Jennings et al., 1999). Further, drops in landings may be attributable to changes in fisheries regulations (e.g. total allowable catches) or technical measures. In recent years, for example, increased minimum mesh size (EU, 2001) and square mesh panels (SSI 227/2000, 2000) are suggested to have contributed to notable decreases in landings, in particular in the northern North Sea (ICES, 2010b).

The quality of our data might have been influenced by discarding, leading to discrepancies between catches and landings. Not only in recent years, North Sea whiting was commonly discarded (Cotter et al., 2002; Enever et al., 2009; ICES, 2012; Stratoudakis et al., 1998, 1999); this as well was practiced in the earlier decades of the 20th century (Jones and Hislop, 1978). With whiting discard rates varying both in time and space, an effect on our resulting distribution maps cannot be ruled out. As no fisheries-independent data are available before the 1980s, the effect of discarding on commercial data cannot be verified. However, despite this potential influence, confirmation for our results is found for recent decades in the broad agreement in distribution of adult whiting in the IBTS surveys, corresponding in low catch rates in the eastern-central, and higher catch rates in the western-central and northern North Sea (ICES-FishMap).

3.6 Conclusions

By compiling and analysing long-term data of North Sea whiting, we aimed to give an extensive overview over whiting fisheries and whiting distribution over the past century. While many fish species in the North Sea have shown latitudinal and/or deepening shifts that have been related to climate change (e.g. sole, plaice), in whiting we found no clear evidence for such shifts based on commercial lpue. As the North Sea is at the centre of the species' distribution, we suggest, that the populations here do not exhibit strong responses to climate change. Still, a distinct westerly shift was found between the late-1940s and 1960s, with whiting remaining westerly distributed thereafter. This westerly shift, however, remains unclear. Possible drivers on whiting distribution that remain to be investigated are the changes in prey availability (e.g. zooplankton as prey for larvae of whiting; small fish as prey for adult whiting) and predation pressure (e.g. changes in the abundance of herring as predator on whiting eggs and larvae). Further, the role of the Danish industrial fisheries and its possible impact on whiting would be worth pursuing in follow up studies. Finally, when analysing commercial fisheries data, the potential influence of various factors (e.g. technical improvements, discarding) on the data has to be acknowledged.

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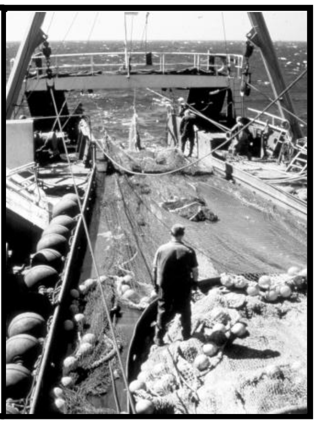
Chapter 4



The catching and landing in demersal fisheries: a comparison between commercial fisheries data and research survey data for whiting distribution in the North Sea

4.1 Abstract

We analysed North Sea whiting distribution between 1970 and 2009, comparing relative landing-per-unit-effort (lpue') data of British otter trawlers with relative catch-per-unit-effort (cpue') data of the International Bottom Trawl Survey (IBTS). Both datasets demonstrated accordance in the spatial distribution, with high occurrences of whiting in the northern North Sea and low occurrences in the eastern-central North Sea. With whiting commonly being discarded, which potentially affects lpue', we used residuals to describe discrepancies between lpue' and cpue'. Lowest discrepancies were found in the northern North Sea and at the Scottish east coast, highest in the eastern-central and southern North Sea, and fluctuations of residuals at the English east coast. As whiting is of secondary commercial importance, we further tested, if low whiting lpue' observed in some areas is correlated with a high revenue-per-unit-effort (rpue) of more valuable roundfish (cod, haddock) and very high priced flatfish (sole, plaice) species. Analysis corroborated these findings, with higher rpue of flatfish suggesting higher discarding of whiting, whereas higher roundfish rpue suggested lower discarding of whiting. Our study demonstrated the applicability of commercial data for whiting distribution analysis with strong correlations between lpue' and cpue' and highlighted the commercial interest in highly priced species. Still, it is important to be aware of the shortcomings in commercial and survey data. For whiting it is difficult to specifically assess the influence of discarding on commercial data over space and time, and IBTS data had inconsistencies in its time series, potentially influencing the reliability of the data.

4.2 Introduction

Knowledge about distributions of fish stocks is important for studying their ecology, identifying fishing grounds, evaluating fisheries management and marine conservation policies, and thus is of interest to scientists, fishing industry, governmental and advisory organisations. Particularly, distributions of a range of fish stocks are shown to have shifted in the past century (e.g. Brander et al., 2003; Dulvy et al., 2008; Engelhard et al., 2011a, b; Keeken et al., 2007; Perry et al., 2005). Such shifts in distributions can have large implications for the fisheries targeting these species and the effectiveness of fisheries management policies (Cheung et al., 2012). Therefore, the reliability and representativeness of distribution patterns of fish stocks are of importance.

Typically, two types of data sources are available for this analysis: surveys carried out onboard research vessels, and data collected from commercial fisheries. Research surveys aim to work in a standardised way, providing a balanced spatial coverage of the sampling area and using reproducible sampling protocols. They further supply information about age groups of young fish, which are either not yet recruited to commercial fisheries or discarded by these at sea as they are below the minimum landings size (Verdoit and Pelletier, 2000; Verdoit et al., 2003). With research survey catches not being influenced by e.g. market demands, quota regulations or minimum landing sizes, they are assumed to be appropriate to reflect actual fish distribution and abundance (Fox and Starr, 1996). Still, survey data only represent a 'snapshot' of the state of a fish stock with a few hours of fishing per year and per rectangle and are therefore potentially limited in providing enough data to appropriately describe population dynamics.

Commercial fisheries data benefit from providing a cost-effective and comprehensive source of information on a great temporal and spatial scale. This source has the potential to e.g. fill spatial and temporal gaps in research data or to increase sample size in specific areas (Fox and Starr, 1996). Due to the greater sampling effort, this data as well tend to be less noisy than survey data (Engelhard et al., 2011a). On the other hand, only fish above the minimum landing size occur in commercial catch statistics. Further, the data quality can be affected by factors like misreporting, underreporting, and for certain fish species also by discarding. These discrepancies between catches and landings potentially affect landings-per-unit-effort data (lpue), no longer representing the actual catch-per-unit-effort (cpue).

In a regulated fisheries, discarding is mainly driven by a combination of catches being limited through quotas, minimum landings sizes of fishes, high grading, and market conditions (Defra, 2012), influencing if and how much of a species is landed. Further, the capability for fishermen to retain their catch is not only limited by the fishing quota but as well by the vessels' storage capacity. The majority of species in ICES regions are discarded due to minimum landing size restrictions, and to a lesser extent because of lower commercial value of a certain species or smaller size groups from the same species, which still would be legal to land (European Commission, 2011). Yet, as fishermen are aiming to maximise their profit, they are trying to achieve the best revenue-per-unit-effort (rpue). Economic high grading by discarding is likely to occur if the contribution to the margin on a fishing trip could be increased. The incentive for a fisherman to discard is dependent on various factors, e.g. the relative prices between species and size groups, the relative catch rates between species and size groups, and the cost of fishing. However, discarding mainly pays off if the price differences between the species are substantial (Frost, 2003).

Whiting (*Merlangius merlangus*) is of rather secondary commercial relevance in North Sea fisheries, reaching lower prices on the market compared to higher priced species like sole (*Solea solea*), plaice (*Pleuronectes platessa*), cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (MAFF; Defra/Cefas). In the North Sea, whiting are commonly discarded, with estimated discard rates between 25% and 65% in recent decades (Cotter et al., 2002; Enever et al., 2009; ICES, 2012; Stratoudakis et al., 1999) and varying in time and space (Stratoudakis et al., 1998).

A recent study on North Sea whiting distribution (Kerby et al., 2013), based on nine decades of British otter trawlers relative lpue (lpue'), highlighted the potential influence of discarding on analysis of commercial fisheries data. Results showed that in the 1920s and 1930s lpue' of whiting was rather evenly distributed in the northern and central North Sea, with highest values in the north. Thereafter, within around two decades, a westward shift took place, in particular in the central North Sea, resulting in notable low lpue' values of whiting in the eastern-central North Sea since the mid-1960s. Analysis showed no strong relations to climate change and/or fishing pressure as possible drivers for this longitudinal shift. With whiting being subjected to different levels of discarding in commercial fisheries, it was suggested that the quality of commercial data might have affected the analysis of lpue' data and subsequent distribution patterns of whiting. To verify a possible influence of discarding on lpue', a comparison between commercial and fisheries independent data would provide useful information.

In this paper we used North Sea whiting as a case study to assess the reliability of commercial fisheries data for distribution analysis of a species that is commonly discarded. Our aim was to compare the distribution patterns of whiting based on commercial lpue' with those based on research survey cpue'. We further evaluated the discrepancies between both datasets by identifying regions showing higher or lower lpue' than expected compared to cpue'. As the market prize of a fish as well influences discarding behaviour, we analysed the revenue-per-unit-effort (rpue) of higher valued roundfish (cod, haddock) and flatfish (plaice, sole) species. We examined if discarding might explain the discrepancies between lpue' and cpue', by analysing the distribution of roundfish and flatfish under the assumption that where these species are commonly caught, whiting are more often discarded.

4.3 Material and Methods

4.3.1 Sources of commercial fisheries and research survey data

For the study period 1970-2009, research data for quarter 1 (January to March) of the North Sea International Bottom Trawl Surveys (IBTS) were available from the ICES DATRAS webpage (http://datras.ices.dk/Home/default.aspx) with whiting-specific cpue (numbers h^{-1}) per total fish length (in cm) and per ICES rectangle (0.5° latitude by 1° longitude) (NS-IBTS, 2012). For the same time period, commercial British fisheries lpue data (kg h^{-1} per ICES rectangle) for North Sea whiting, cod, haddock, plaice and sole, were compiled from the following sources: (a) for the years 1970-1980, English and Welsh otter trawler landings and effort data per ICES rectangle were obtained from historical statistical charts produced by the UK Ministry of Agriculture, Fisheries and Food (MAFF, now the UK Department for Environment, Food and Rural Affairs (Defra)); (b) for the years 1982-2009 landings and effort data were available from the Fisheries Activity Database of Defra/Cefas; and (c) for the years 1970-2009, Scottish landings and effort data were available from the Fisheries Management Database of Marine Scotland.

4.3.2 Distribution analysis for commercial and survey data

For the years 1970-2009, IBTS data and commercial fisheries data were analysed for the distribution of North Sea whiting in five-year time periods. In commercial fisheries, minimal landing sizes are determined for various fish species, defining the minimum size of a fish at which it is legal to be retained, landed and offered for sale. As surveys sample all size classes, the IBTS data were filtered by the minimum landing sizes in force during the study period, to correspond with the commercial landings: 25 cm between 1970 and 1982 (MAFF, 1968), and 27 cm from 1983 onwards (EEC, 1983). To standardise the units of catch to weight, a length-weight relationship was applied to convert length of whiting reported from the survey data to weight: $W= 0.0093 \cdot L^{2.9456} \cdot 1.13$ (Coull et al., 1989), where W is the total weight (kg), and L the length (cm). The weights of all fish in the various length classes caught per year and rectangle were then calculated to estimate the total cpue (kg h^{-1}) per rectangle and year.

To allow more accurate inferences of time-series data, the analysis only included statistical rectangles where ≥15 years of both commercial and survey data were available. As survey data are sampled in a standardised way and record all caught fish, it was assumed that the spatial patterns in survey data represent the true distribution of whiting. Therefore, statistical rectangles where the number of whiting caught per hour was ≥0 were included in the analysis. To exclude commercial fisheries data from statistical rectangles that were not adequately fished by otter trawlers in any given year, any rectangles comprising no data or <50 h effort were removed. As we analysed the mean lpue and cpue per five-year period, in rectangles where no data were available within this time period, instead the rectangle specific long-term average lpue or cpue was used.

Our aim was to study trends in distribution of whiting over time, analysing relative lpue and cpue, and not using absolute lpue and cpue values to analyse whiting abundance. Therefore, relative lpue (lpue') and cpue (cpue') was calculated (see methods in Kerby et al., 2013) to make them methodologically comparable and to overcome e.g. the effects of increasing fishing power (in particular with commercial data) and sampling in specific time periods (survey data).

For statistical analysis, the variables did not show normal distribution after log-transformation (one-sample Kolmogorov-Smirnov test, $p > 0.05$). Correlations between lpue' and cpue' were tested with Pearson's cross product moment correlation (r_p), as by visual inspection the samples were approaching normality.

4.3.3 Examining discrepancies in whiting distribution between commercial and survey data

To examine the reliability of commercial fisheries data for whiting, we compared it with survey data, and assumed that survey-based cpue' were more reliable. We calculated for each 5-year period the residuals of a regression model of lpue' as a function of cpue':

$$log\ lpue' = a + b\ log\ cpue' + \varepsilon \qquad [1]$$

where a is the intercept and b is the slope. Residuals (ε) represent the difference between each lpue' observation and the value of lpue' predicted from cpue'. These residual values were used in this study to identify areas in the North Sea where lpue' was higher than expected (positive residuals) or lower than expected (negative residuals) from cpue'. Negative residuals were assumed to deliver a possible explanation for discarding of whiting in commercial fisheries.

4.3.4 Revenue-per-unit-effort of more valuable fish species

For the years 1970-1980, the average annual values (£ kg^{-1}) of cod, haddock, plaice and sole were obtained from the Sea Fisheries Statistical Tables (MAFF). For the years 1981- 2009, respective data were available from the Fisheries Activity Database held at the UK Department for Environment, Food and Rural Affairs (Defra). The average values of the fish species were corrected with the price index accounting for the changing purchasing power of the British pound over time (Office for National Statistics, 2010) and multiplied with lpue (kg h^{-1}) to obtain the average annual revenue-per-unit-effort (rpue) for each species. For each five-year period, the mean rpue was calculated for roundfish (cod, haddock) and flatfish (sole, plaice). Not all five-year periods of flatfish and roundfish rpue showed normal distribution after log-transformation (one-sample Kolmogorov-Smirnov test, $p > 0.05$). We used a multiple regression model to test for each five-year period the relationship of lpue' with cpue' and the rpue of flatfish and roundfish:

$$log\ lpue' \sim log\ cpue' + flatfish\ rpue + roundfish\ rpue \quad [2].$$

4.4 Results

4.4.1 Whiting distribution based on lpue' and cpue'

Commercial fisheries and research survey data revealed general agreement in the distribution maps of whiting lpue' and cpue' in the North Sea (Figure 1, four of the eight five-year time periods are presented). Both datasets corresponded, that the northern North Sea, in particular around the Shetland and Orkney Islands, was the main distribution area of whiting. Further agreement was found in the central North Sea, as this region could be divided into the western area, with high lpue' and cpue', and the eastern area, showing generally low lpue' and cpue' values (only few rectangles had higher values). Still, mainly in the western-central North Sea, local discrepancies were found. According to almost consistently high lpue' in this area, whiting were commonly distributed off the Scottish east coast (~56° - ~58°N). By contrast, very low cpue' were found in this part. At the east coast of England (~54° - ~56°N), cpue' decreased between the 1970s and 1980s. Since the 1990s, cpue' then consistently increased, indicating greater concentrations of whiting in this area. Lpue' as well had periods with relatively higher or lower lpue' in this area, however, in particular the steady increase in lpue' was not found for recent years. In the southern North Sea, cpue' showed generally higher values than lpue'.

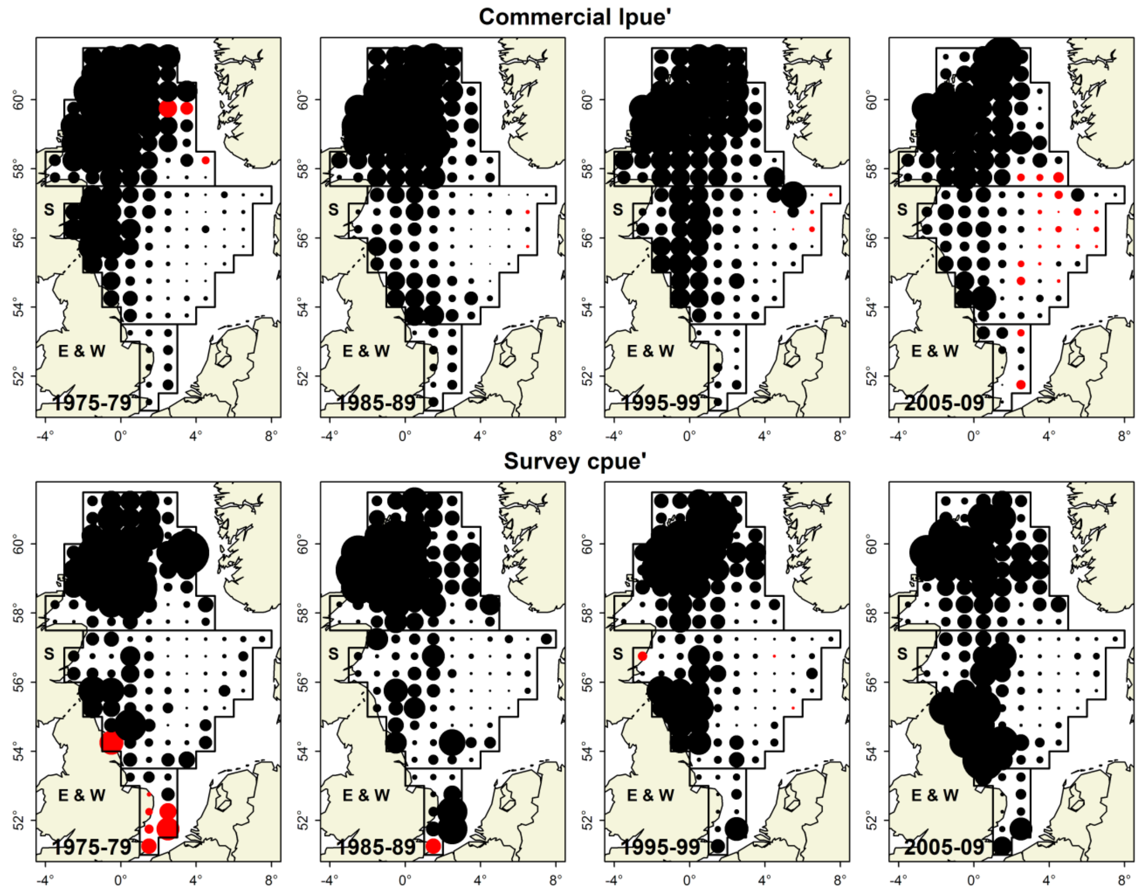


Figure 1. North Sea whiting distribution based on relative commercial landings-per-unit-effort (lpue') of British otter trawlers (top row) and relative IBTS quarter 1 catch-per-unit-effort (cpue') (bottom row). Exemplarily four of the eight analysed 5-year periods between the 1970s and 2000s are shown. For each ICES rectangle the black circles (area is proportional to lpue' and cpue') represent the relative mean 5-year lpue' and cpue'. For rectangles without lpue' or cpue' data in a given 5-year period (no effort), red circles represent the long-term average lpue' or cpue' of the respective rectangle. The study area is divided into the northern, central and southern North Sea, according to the ICES areas IVa, b and c, and showing the countries England & Wales (E & W) and Scotland (S).

Statistical analysis for correlations between commercial and survey data, confirmed for all 5-year periods the agreement of lpue' and cpue', being highly significant and positively correlated (Table 1).

Table 1. Pearson's cross moment correlations of lpue' and cpue' for the 5-year time periods between 1970 and 2009 (all variables log-transformed).

year	r_p	p
1970-74	0.598	<0.0001
1975-79	0.700	<0.0001
1980-84	0.752	<0.0001
1985-89	0.744	<0.0001
1990-94	0.790	<0.0001
1995-99	0.703	<0.0001
2000-04	0.689	<0.0001
2005-09	0.625	<0.0001

4.4.2 Discrepancies between lpue' and cpue'

With discarding potentially affecting commercial whiting data, we used residuals to describe and visualise distribution discrepancies between lpue' and cpue' (Figure 2). Lowest discrepancies between the data were found in the northern North Sea and at the Scottish east coast. In these areas, lpue' was predominantly higher than expected from cpue' (positive residuals= black circles). In contrast, discrepancies were found in the eastern-central and southern North Sea, as well as along the Norwegian Trench, with lpue' being mainly lower than expected (negative residuals= red circles). Along the English east coast (~54°N), an inhomogeneous picture was found, as over time residuals changed from negative to positive and again to negative values.

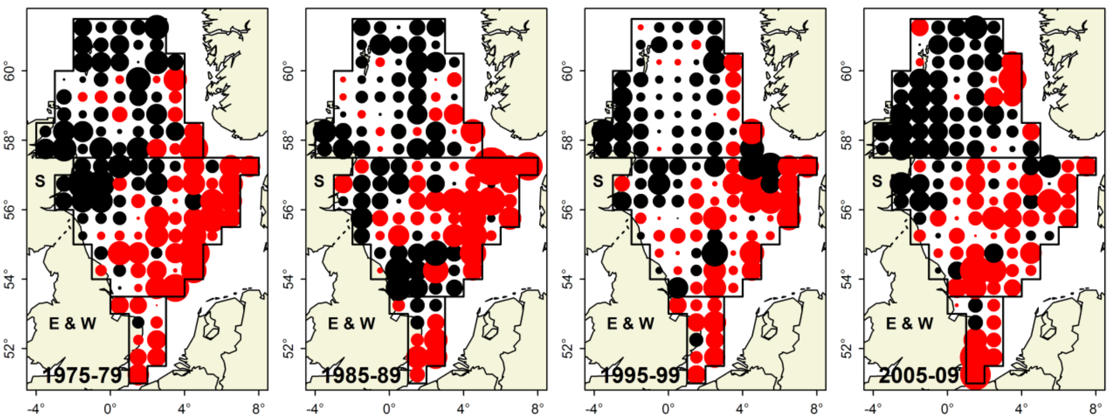


Figure 2. Distribution of locations where residual whiting lpue' were higher than expected from cpue' (black) or lower than expected from cpue' (red), based on a regression model of lpue' with cpue' (equation 1). The study area is divided into the northern, central and southern North Sea, according to the ICES areas IVa, b and c, and showing the countries England & Wales (E & W) and Scotland (S).

4.4.3 Revenue-per-unit-effort of alternative fish species

We analysed whether the revenue in commercial fisheries made by catching lucrative fish species might be related to discarding of whiting. Our results showed evidence that lpue' was associated with the revenue-per-unit-effort (rpue) of more valuable fish species.

The spatial distribution of mean rpue for flatfish (sole, plaice) and roundfish (cod, haddock) (Fig 3), revealed different distribution patterns for these groups. For flatfish, in the mid-1970s and 1980s, mainly the highest rpue was obtained in the eastern-central North Sea, but dropping thereafter. In the mid-1990s, generally low rpue was achieved for flatfish throughout the North Sea. In recent years high rpue was again recorded in the eastern-central North Sea and localised between the Orkney and Shetland Islands.

For roundfish, mean rpue distribution was very different to flatfish, revealing a consistent widespread distribution in the northern North Sea, with highest values found in the period 2005-09 along the Norwegian Trench and around the Orkney and Shetland Islands. In the central North Sea, mean rpue shifted between the mid-1970s and mid-1990s from the eastern to the western part of the North Sea, and declined thereafter. In recent years, in the central North Sea only a few locations are found with relatively high roundfish rpue. In the southern part of the North Sea, the rpue declined over time.

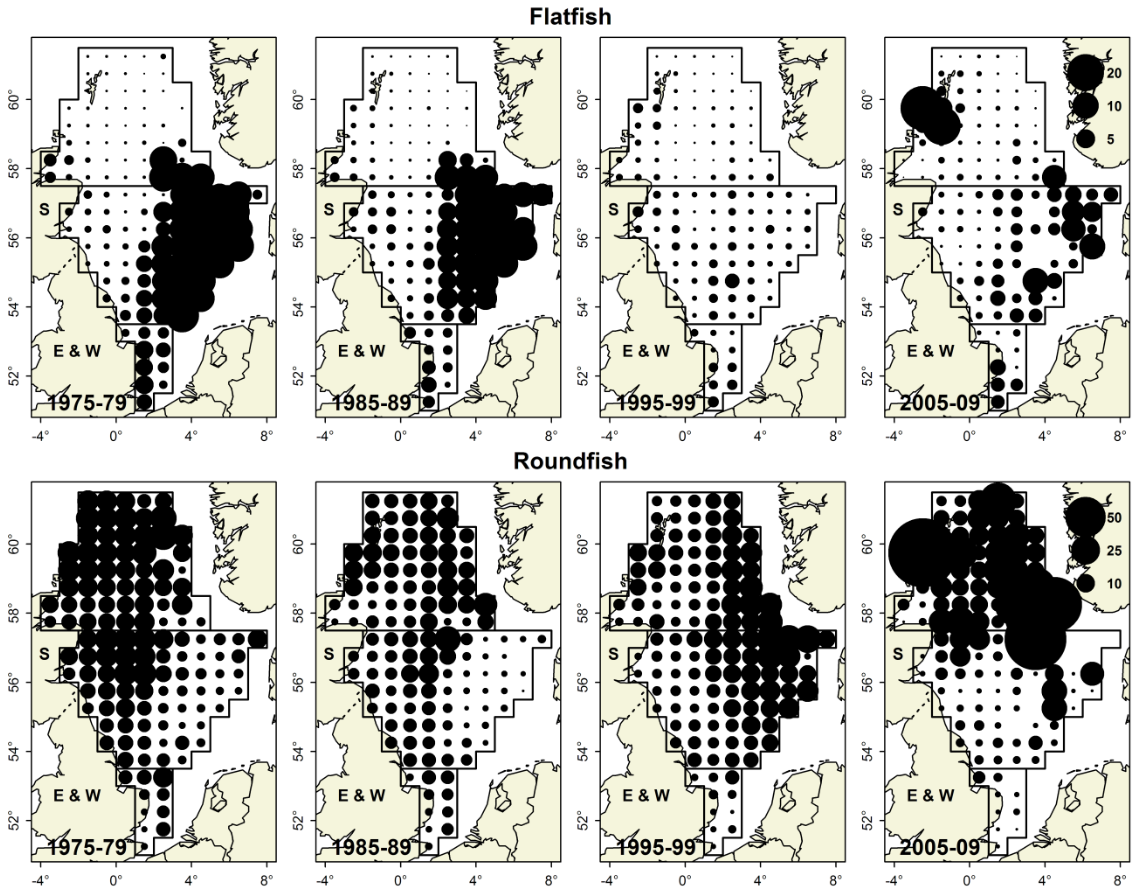


Figure 3. Distribution of mean revenue-per-unit-effort (rpue, £ h^{-1}) for flatfish (sole, plaice, top row) and roundfish (cod, haddock, bottom row) in the North Sea showing exemplarily four of the eight analysed 5-year periods in the 1970s, 1980s, 1990s and 2000s. Area of the black circles is proportional to rpue. The study area is divided into the northern, central and southern North Sea, according to the ICES areas IVa, b and c, and showing the countries E & W= England & Wales, S= Scotland.

Multiple linear regression analysis showed for almost all five-year periods that the explanatory variables cpue', rpue flatfish, and rpue roundfish were significantly related with lpue' (Table 2). No significances were found for flatfish and roundfish rpue for the time period 1995-99, and in 1990-94 for roundfish.

Table 2. Regression models testing for the relationships of lpue' with cpue' and mean rpue of flatfish and roundfish (all variables log-transformed; significant *p*-values are shown bold). For all 5-year time periods, the models were significant (p< 0.0001); the respective adjusted R^2 values of the models are shown in the table.

	cpue'			**Flatfish rpue**			**Roundfish rpue**			
year	Est.	± s.e.	*p*-value	Est.	± s.e.	*p*-value	Est.	± s.e.	*p*-value	Model adj. R^2
1970-74	0.211	0.066	**0.0018**	-0.427	0.062	**<0.0001**	0.689	0.127	**<0.0001**	0.735
1975-79	0.297	0.061	**<0.0001**	-0.410	0.067	**<0.0001**	0.733	0.155	**<0.0001**	0.795
1980-84	0.252	0.058	**<0.0001**	-0.483	0.075	**<0.0001**	0.604	0.130	**<0.0001**	0.804
1985-89	0.441	0.075	**<0.0001**	-0.265	0.075	**0.00057**	0.679	0.151	**<0.0001**	0.703
1990-94	0.431	0.051	**<0.0001**	-0.501	0.074	**<0.0001**	0.164	0.091	0.0743	0.747
1995-99	0.661	0.066	**<0.0001**	0.068	0.101	0.50300	0.122	0.142	0.3890	0.487
2000-04	0.513	0.051	**<0.0001**	-0.306	0.079	**0.00018**	0.237	0.083	**0.0051**	0.571
2005-09	0.546	0.066	**<0.0001**	-0.178	0.063	**0.00555**	0.227	0.055	**<0.0001**	0.459

Positive coefficients of cpue' and roundfish rpue indicated that in areas with higher lpue' of whiting higher cpue' were registered in the survey as well as higher revenue-per-unit-effort of roundfish in commercial fisheries. In contrast, negative coefficients were found for flatfish, associating areas of higher revenue-per-unit-effort of flatfish with low lpue' of whiting.

4.5 Discussion

In this study we used different approaches to assess the reliability of commercial fisheries data for the distribution analysis of a commonly discarded species, North Sea whiting. Our results showed strong relations between commercial relative landings-per-unit-effort (lpue') and survey relative catch-per-unit-effort (cpue') in the distribution of whiting (with lengths above minimum landing size). Residuals were used to assess the discrepancies between both data sets. Negative residuals indicated the eastern-central and southern North Sea as areas where lpue' was lower than expected from cpue', possibly explained by discarding of whiting. These findings are corroborated by the analysis of the mean revenue-per-unit-effort (rpue) of more valuable fish species, suggesting that in areas where highly priced flatfish (sole, plaice) are caught, whiting are more likely to be discarded. In contrast, if roundfish such as cod and haddock are caught, lower discarding of whiting is suggested to take place.

4.5.1 Distribution analysis based on lpue' and cpue'

The comparison of lpue' and cpue' in this study showed general agreement in the distribution patterns of North Sea whiting over the past four decades. Our results illustrated that lpue' of whiting, despite the possible effects by discarding, was closely related with cpue'. This supports the use of lpue' to examine whiting distribution, and is in line with the close relationship between spatial commercial and survey cpue data for several species on the west coast of the USA (Fox and Starr 1996).

In the case of North Sea whiting, potential influence on the data by discarding is assumedly mitigated due to the great temporal and spatial scale commercial data are collected, resulting in a broad agreement with the survey distribution. Still, our distribution maps based on lpue' and cpue' revealed areas with discrepancies. We used residuals to describe these discrepancies and it was assumed that negative residuals are a possible explanation for discarding of whiting. Following this approach, our results suggested that in the eastern-central and southern North Sea whiting are more commonly discarded. Species such as plaice and sole (Engelhard et al., 2011; ICES-FishMap sole, plaice) or turbot and brill (AquaMaps, 2010a, 2010b) are mainly distributed in these regions. With these species being of far higher economical value for fishermen, discarding of lower valued whiting might have taken place.

On the east coast of England, residuals fluctuated over time between negative and positive values, indicating periods with and without discarding. An explanation for varying rates of discarding might be due to the highly variable recruitment of whiting while fishing effort did not vary accordingly, resulting in varying levels of discarding over time (Cappell, 2001). Another reason might be the localised distribution of whiting in combination with quota restrictions leading to over-quota discards. Especially in recent years, notably on the English east coast, localised aggregations of large whiting occurred. Due to quota restrictions, fishing vessels were not able to land whiting, resulting in locally high discarding rates (ICES, 2009; NSRAC, 2010). This is in line with a study on discarding of the English north-east coast fishing fleet during 1997 and 1998, reporting between 51-60% discarding of whiting in this region (Cotter et al., 2002).

4.5.2 Discarding for economic reasons

High grading for economic reasons may affect discarding. The higher the price differences between species the higher the incentive to discard a lower valued fish (Frost, 2003). Highly priced flatfish, such as sole and plaice, increase a fisherman's profit and are unlikely to be discarded. Our results showed that higher rpue of these flatfish were related with lower whiting lpue', suggesting potential discarding of far lower valued whiting when far higher valued fish are caught. This is in line with Stratoudakis et al. (1998), suggesting that in particular in offshore demersal fisheries economic high grading, as well as the effect of the catch composition, influences discarding behaviour. Whiting is usually a secondary target when more valuable species (e.g. cod and haddock) are abundant in the catch. In such cases, whiting are only kept at sizes comparable with those of cod and haddock, above the current whiting minimum landing size (Stratoudakis et al., 1998). Transferring these findings to even more valuable species in a catch, such as sole and plaice in our study, the incentive to discard lower valued species would even increase.

In contrast to flatfish, we found that higher rpue of cod and haddock were associated with higher whiting lpue' suggesting less discarding of whiting. When catching cod and haddock, the incentive to discard whiting seemed to be lower than in the case of flatfish. This is probably because the price differences between the roundfish species are not as substantial compared to highly valuable flatfish. The positive relationship of cod and haddock rpue and whiting lpue' might as well represent a specialisation in roundfish fisheries targeting these species. In this fishery whiting assumedly receives more economic interest. Stratoudakis et al. (1998) suggested that fishers seem to switch target species when the catch composition is dominated by whiting, and land most whiting of legal size. At least in fisheries where price differences between species are not very large, this still secures a financial benefit from a fishing trip.

4.5.3 Evaluation of lpue' and cpue' quality

The results of our study strongly support that lpue' data are a reliable source to reflect the distribution of the commonly discarded North Sea whiting. The quality of commercial whiting data might have been influenced by discarding; however, the great amount of data potentially mitigated these deficiencies, leading to general accordance with survey results. The representativeness of lpue' for distribution analysis is further corroborated by similar studies and using analogues methods (Engelhard et al., 2011a, b). Although these studies analysed lpue' of targeted species, overall the reliability of commercial data is strengthened. Survey data, not being influenced by discarding, are assumed to be appropriate to reflect actual fish distribution. Still, in particular in the case of North Sea whiting, problems with survey data should be acknowledged. The ICES Working Group for Roundfish (WKROUND) reported issues with the evaluation of the quality of the survey data for whiting (ICES, 2009). In particular during the period 1980 to 1995, mismatches between commercial catch and survey data existed. The reason is unclear, but it is suggested that various survey vessel changes might have changed catchability over time, most likely coming from changes in gear, changes in vessel, changes in spatial coverage or a combination of these.

4.6 Conclusions

It was our aim to assess the reliability of commercial fisheries data for distribution analysis of a commonly discarded species, North Sea whiting. Our study suggests that commercial data are significantly correlated with survey data, supporting its use in studying whiting distribution. However, commercial data still need to be interpreted with caution as, with whiting mainly being of secondary interest for fishermen, it is difficult to specifically assess the influence of discarding on commercial data over space and time. Further, fisheries-independent data may as well be influenced by inconsistencies in the surveys influencing the reliability of whiting data. This highlights the need for a close cooperation between scientists and the fishing industry to improve assessments.

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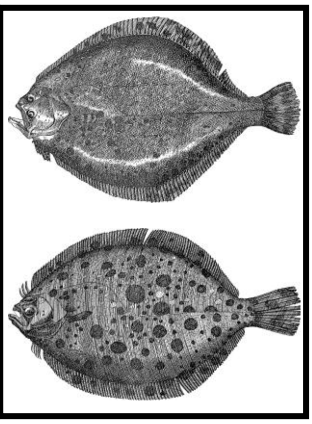
Chapter 5



Entering uncharted waters: long-term dynamics of two data limited fish species, turbot and brill, in the North Sea

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5.1 Abstract

In the North Sea, turbot (*Scophthalmus maximus*) and brill (*Scophthalmus rhombus*) represent highly valuable species in commercial fisheries. Still, available data for both species are limited, making stock assessment difficult. Long-term fisheries data have the potential to improve the understanding of stock dynamics such as long-term distribution changes or development in species' abundances. Historical British otter trawler lpue (landings-per-unit-effort) data from 1923 to 2009, and at the spatial scale of ICES rectangles, revealed that the distribution patterns of turbot and brill were different for most of the 20th century and only became similar in the recent decade. Further, between the 1920s and 1960s, turbot was commonly caught in the northern North Sea and in particular on Turbot Bank, at that time a turbot hotspot off the east coast of Scotland. Within a short time period turbot nearly disappeared from this region. Brill, in contrast, revealed a stable distribution in the southern and central North Sea with a slow expansion into the central North Sea. We used survey cpue (catch-per-unit-effort) from the International Bottom Trawl Survey (IBTS; 1970-2009) and the Beam Trawl Survey (BTS; 1985-2009), as well as British otter trawler lpue, as proxies for the abundance of adult turbot and brill. Commercial lpue suggested for brill and turbot a long-term decrease in abundance. IBTS cpue suggested an increase in abundance for turbot, but this was not confirmed by the BTS. For brill, both surveys did not show a clear trend.

5.2 Introduction

Good fisheries policy and fisheries management should be based on sound scientific information about the state of fish stocks. However, worldwide most commercially exploited fish stocks are not assessed (Costello et al., 2012). In the Atlantic, North Sea and Baltic Sea, the proportion of stocks where no scientific advice is available rose from 45% in 2003 to 52% in 2006 and then fell again to 36% for 2012 (EU, 2012). Even for fish stocks that are assessed, their assessments are based on short time-series that are generally less than three decades long (Pinnegar and Engelhard 2008). Historical data can give new opportunities to improve the knowledge and development of fish stocks in recent decades and even centuries (e.g. MacKenzie et al., 2002; Poulsen et al., 2007; Poulsen, 2010). Long time-series may allow scientists to better understand exploitation patterns of fisheries or stock dynamics and can help to disentangle environmental influences (e.g. climate change) and fishing pressure on fish stocks. Additionally, historical fisheries data also help create baselines of the state of fish stocks (Pauly, 1995; Pinnegar and Engelhard, 2008).

Historical commercial fisheries and/or survey data that are stored in archives in many fisheries departments and laboratories are useful in reconstructing long-term time-series. Only in recent years, scientists started to discover and unveil historical datasets to understand long-term changes in diversity, distribution and abundance of marine life in the world's oceans (e.g. Cardinale et al., 2009, Cheung and Sadovy, 2004; Lescrauwaet et al., 2010; Rosenberg et al., 2005). In the United Kingdom, the Centre for Environment, Fisheries and Aquaculture Science (Cefas) holds historical fisheries data in their archives of North Sea commercial fisheries, going back around 100 years. In recent years, effort was made to recover and digitise these historical paper charts, providing scientists the opportunity to analyse population dynamics of various exploited North Sea fish species.

Turbot (*Scophthalmus maximus*) and brill (*Scophthalmus rhombus*) are regarded as data limited fish species, with available information being inadequate to evaluate stock trends, making stock assessments and advice difficult (ICES, 2011a). Although both species are mainly caught as bycatch, discarding is low because of their high market prices, and therefore they are economically important for fisheries (Gillis et al., 2008). Turbot and brill grow relatively fast, in particular juvenile turbot reaches approximately 30 cm by the age three. Both are piscivorous in the adult stage and are found in similar depth ranges (brill 4-73 m, turbot 10-70 m) along the European coastline. Brill occurs mainly in areas close inshore and preferring sandy bottoms, but can sometimes be found on gravel and muddy grounds. Turbot prefers sandy, rocky or mixed bottoms (ICES, 2010a) and is a rather sedentary species. There are some indications of migratory patterns from the nursery grounds in the south-eastern North Sea to the more northern areas, as adult turbot are more tolerant of the colder conditions in the northern North Sea where temperatures are too low for juveniles to survive (Delbare and de Clerck, 2000; ICES, 2010a). Despite an intensive exploitation of turbot (F= 0.5-0.7), there is no indication that turbot recruitment is impaired at low levels of spawning stock biomass (van der Hammen et al., this volume). So far, spatial distribution maps of North Sea turbot and brill are available for recent decades and are based on survey data (see http://ecosystemdata.ices.dk).

In this paper, we aim to evaluate the changes in catches, distribution and abundance of North Sea turbot and brill in the 20th century. Specifically, we collate historical long-term data of European countries fishing in the North Sea to understand the development of international landings from the 1900s to the present. We further reveal long-term distribution changes of turbot and brill based on nine decades of British otter trawler landings-per-unit-effort (lpue) at the spatial scale of ICES rectangles. Finally, we assess the abundance dynamics of both species based on British otter trawlers' lpue and two North Sea surveys' catch-per-unit-effort (cpue).

5.3 Material and Methods

5.3.1 International landings data for brill and turbot, 1903-2010

To give an overview of the development of North Sea turbot and brill fisheries international landings data for turbot and brill in the North Sea were obtained from ICES (ICES, 2010b; ICES, 2011b). Specifically, catch statistics were available as Excel files (1903-1949) as well as an electronic database (1950-2010), the latter being extracted with the FishStat Plus programme (FAO, 2011). In the ICES database, Dutch records for turbot were missing for the years 1984-87. This also applied to brill, where as well the years 1988-89 were considered unreliable. For these years, data were obtained from the Report of the Working Group on Assessment of New MoU Species (WGNEW) (ICES, 2012).

5.3.2 British lpue data by rectangle, 1923-2009

To evaluate the spatial distribution of turbot and brill in the North Sea, we analysed British otter trawlers lpue data between 1923 and 2009. Annual effort (hours fished) and landings (kg) data of turbot and brill landed into England, Wales and Scotland were available for each ICES rectangle (0.5° latitude by 1° longitude). Historical statistical charts[1] (catalogued in Engelhard, 2005) were digitised, containing records of effort and landings into England & Wales and Scotland (1923-1965), and into England & Wales (1966-1980). For 1968-2009, data on effort and landings into Scotland were obtained from the Fisheries Management Database of Marine Scotland. For 1982-2009, data for England & Wales were available from the Fisheries Activity Database (Defra/Cefas). The combined time-series covered the years 1923-2009 (war years 1939-1946 were missing).

5.3.3 Research survey data

International Bottom Trawl Survey (IBTS) for turbot and brill were available as 'cpue per length per haul' from the ICES DATRAS webpage (http://datras.ices.dk/Home/default.aspx). The IBTS covers the entire North Sea, and data collected from all ships, gears and sampled quarters were analysed from 1970 onwards. The

[1] Produced by the UK Ministry of Agriculture, Fisheries and Food (MAFF; now the UK Department for Environment, Food and Rural Affairs (Defra))

Beam Trawl Survey (BTS) is a specialised flatfish survey operating since the mid-1980s and sampling the shallower waters of the southern and central North Sea, but not the deeper northern North Sea. Data from the RV *Isis* (source IMARES, pers. comm. J.J. Poos) were analysed, as the most consistent information regarding the BTS is provided from this research vessel (pers. comm. J.J. Poos, and see Heessen, 2010), which operates in the eastern parts of the southern and central North Sea.

5.3.4 Spatial distribution of turbot and brill based on British lpue

Analysis of spatial distribution of turbot and brill in the North Sea was conducted using commercial otter trawler lpue, following the methodology used in Kerby et al. (2013). With steam trawlers (1923-1967) gradually being replaced by motor trawlers (1957-2009), the effect of increasing fishing power over time was taken into account. Therefore, the relative annual lpue values (lpue'$_{r,y}$) were calculated for each rectangle r and year y and were assumed to be an indicator for the spatial distribution of turbot and brill:

$$lpue'_{r,y} = \frac{lpue_{r,y}}{(\sum_{r=1}^{N} lpue_{r,y})/N}$$

where $lpue_{r,y}$ represents the lpue values in rectangle r and year y, and N is the total number of rectangles in the study area. The defined study area only included rectangles with ≥50 hours of fishing effort per year and a data coverage of ≥40 years. For rectangles not meeting these thresholds, instead the relative lpue (lpue') in the given rectangle was assumed to be equal to the long-term mean lpue' for the respective rectangle.

5.3.5 Trends in abundance

Commercial mean annual lpue and survey cpue were used as proxies for abundance. Commercial mean annual lpue was calculated from statistical rectangles that met the minimum fishing effort and data coverage thresholds. For the IBTS and BTS, data within the defined study area were used to calculate the mean annual cpue of turbot and brill. IBTS data were available from ICES with standardised cpue (‘number-per-hour’), separated by length-class (cm). For the analysis of BTS data, only hauls ≥25 min were included, which were converted to ‘number-per-hour’ for each length class. Although no official minimum landings size has been set, part of the fisheries in the North Sea adopted a voluntary minimum landing size of 30 cm (ICES, 2011a). Thus, both survey data were filtered by a minimum length size of 30 cm.

The BTS and IBTS cpue data were converted from length to weight to allow comparison with the commercial data that were reported in 'kg-per-hours-fished' by applying published length-weight conversion equations: $W_{brill} = 0.0078 \cdot L^{3.1947} \cdot 1.0487$ and $W_{turbot} = 0.0039 \cdot L^{3.397} \cdot 1.0643$ (Coull et al., 1989), where W is the total weight (kg), and L the length (cm). Total catch (converted into weight from length) per haul, year and statistical rectangle was calculated, and the mean annual cpue per year was calculated for both species.

In order to test whether lpue was correlated with cpue in the overlapping time periods (IBTS 1970-2009, BTS 1985-2009), we used Spearman's rank correlation (r_s) as not all variables were normally distributed (one-sample Kolmogorov-Smirnov test, $p > 0.05$).

5.4 Results

5.4.1 International landings data for brill and turbot, 1903-2010

In the time periods 1900s-1940s and 1970s-2000s, total international landings of turbot and brill showed a similar trend (Figure 1). Turbot, however, was caught throughout in greater quantities than brill. Only between the 1950s and 1960s, the patterns of both species differed. Turbot landings had increased after the Second World War (1939-1945), whereas brill recorded very low landings.

At the beginning of the 20th century, landings for both turbot and brill decreased between 1904 and 1914 by around 50%. With low fishing pressure during the First World War (1914-1918), landings of turbot (7073 t) and brill (1672 t) peaked in the post-war year of 1920. However, in 1926, turbot landings decreased by half, and in the case of brill even decreased 2.5 times. Until 1938, landings again increased to approximately 4750 t for turbot and 1450 t for brill, but fisheries were then interrupted due to the Second World War. Whilst in the first half of the 20th century, landing trends resembled each other, the landing patterns of both species differed in the 1950s and 1960s. Landings of turbot increased rapidly after the Second World War to a higher level than in the pre-war period (8227 t in 1947), but decreased in the 1950s and 1960s. In contrast, brill catches increased only slightly after the Second World War, with registered landings (887 t in 1946) being around half of what was landed in the pre-war years. In the 1950s and 1960s, brill landings remained fairly stable at an average of around 565 t, but rapidly increased thereafter. Interestingly, between the 1970s and 2000s, the landing patterns of both species again very much resembled one another. Turbot and brill annual total landings fluctuated around an average of 4400 t and 1300 t, respectively. Further, both species had years with notably high landings in this time period. In particular turbot landings reached more than 6000 t in

1979, 1986 and 1991, whereas a peak in brill was registered in 1993 with around 2440 t. In the 2000s, both species' landings were on a lower level than in the 1990s, and showed a slight decreasing trend.

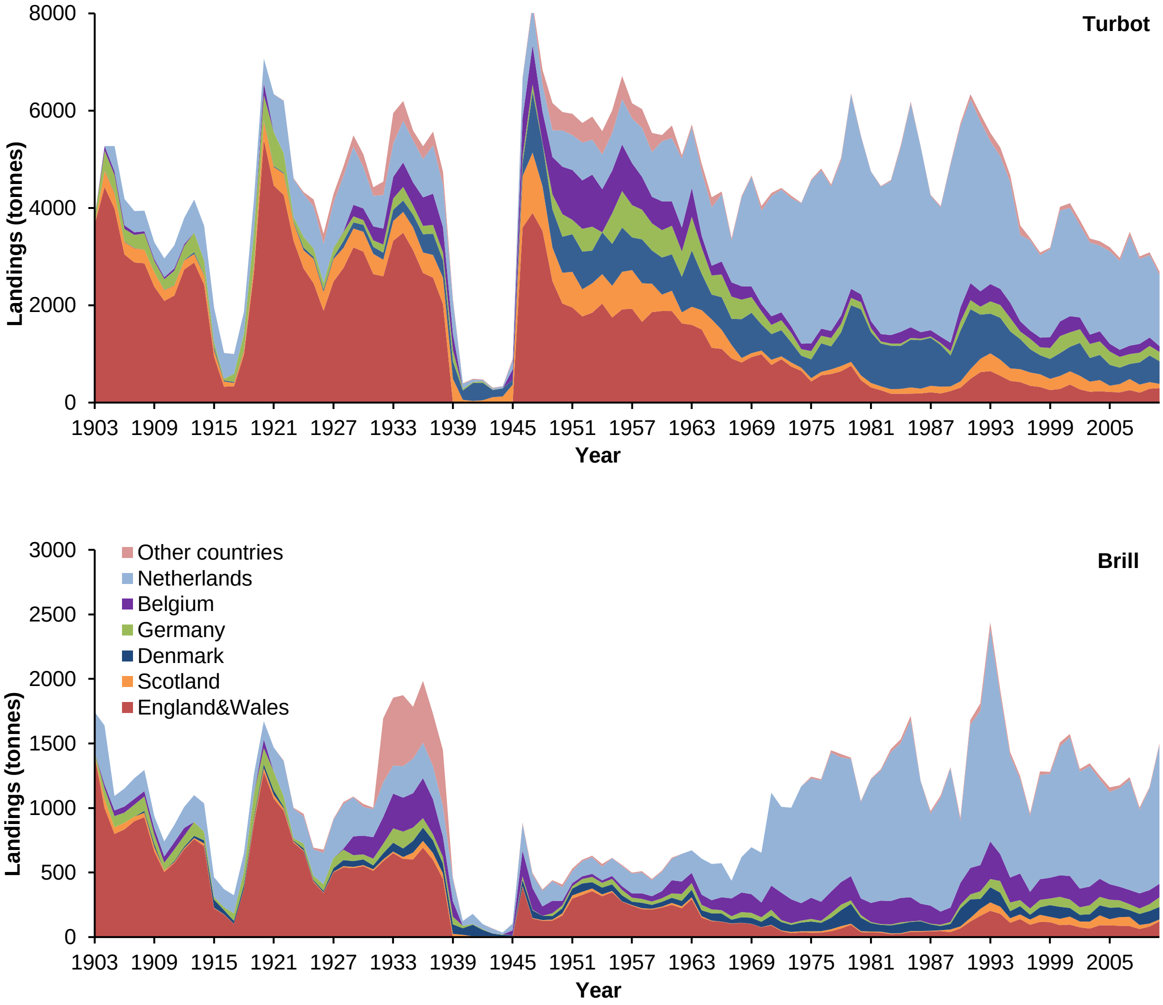

Figure 1. International landings of North Sea turbot (top) and brill (bottom) shown separately by country. "Other countries" represent the combined landings in: France, Norway, and Sweden. In the first half of the 20th century, occasionally landings by France and Norway were declared as "turbot and brill landings" and were assigned in these figures to turbot landings. Note the different y-axis scales of the panels.

In the past century, the nations with the largest turbot and brill fisheries by weight were England & Wales and the Netherlands. Between the 1900s and 1960s, British fisheries had for both species the greatest proportion of landings in the North Sea. However, British landings decreased continuously. The British as well as other countries' drop in share of landings coincided with the beginning of the sharp rise of Dutch catches in the 1960s, promoting the Netherlands to the main catching nation for turbot and brill.

5.4.2 Spatial distribution of turbot and brill based on British lpue

Between the 1920s and the 1990s, the long-term distribution patterns of turbot and brill were different. By contrast, in the 2000s, the distribution of both species was very similar. Turbot was formerly distributed widely throughout the North Sea, but since the 1960s has almost disappeared from the northern North Sea and in particular from an area off eastern Scotland where previously it had been abundant (Figure 2). Between the 1920s-1960s, high concentrations of turbot were found in this area, named Turbot Bank, however, within one decade turbot nearly disappeared. After the 1960s, turbot was mainly caught in the central and eastern-central North Sea. In the past two decades, turbot distribution expanded westwards towards the English east coast and northwards along the Norwegian trench. Its current distribution is very similar to brill.

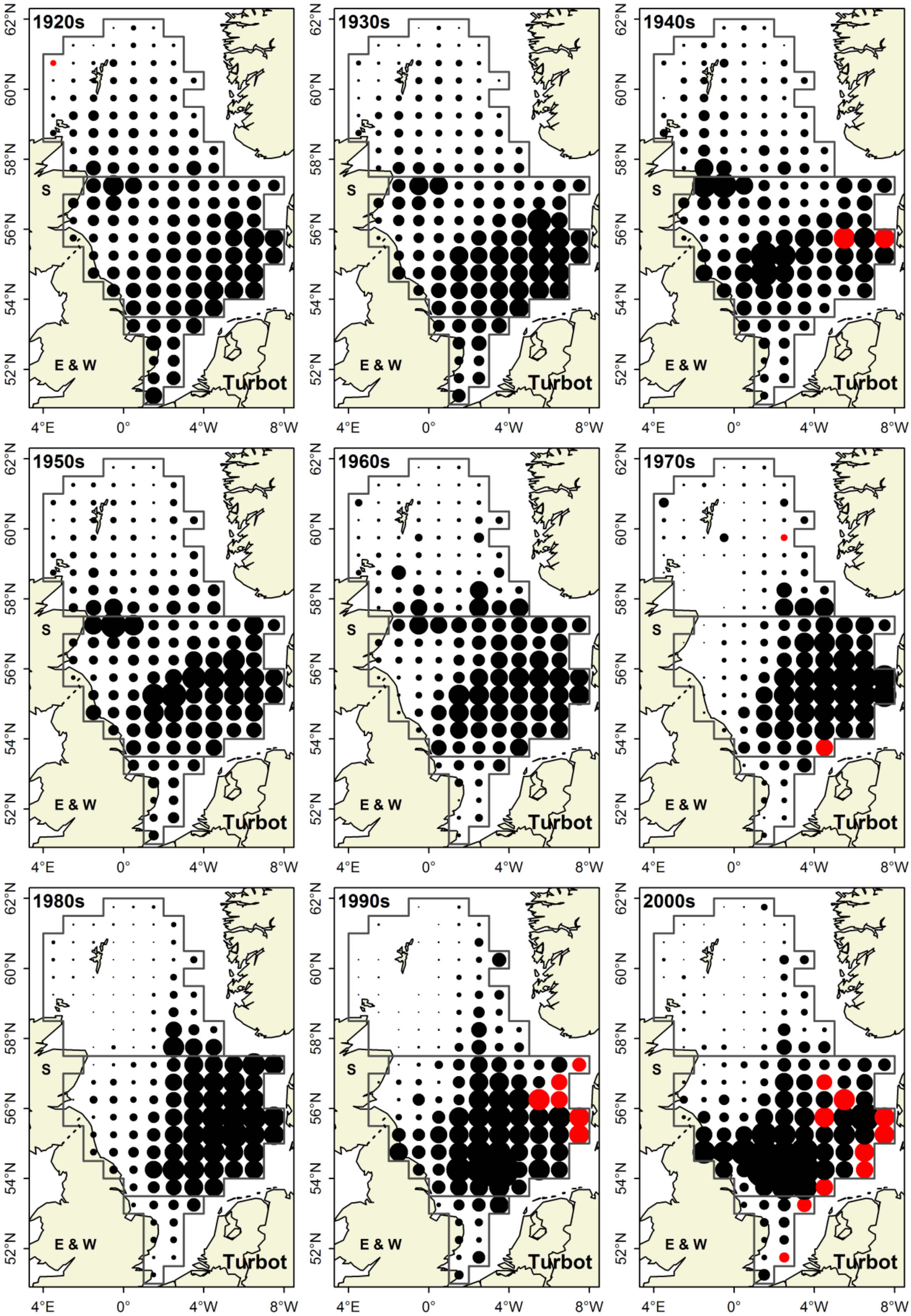

Figure 2. Long-term distribution of North Sea turbot represented by turbot lpue' of British trawlers (E & W= England & Wales, S= Scotland). For rectangles without lpue' data in a given decade (no effort), red circles represent the long-term average lpue'. For each ICES rectangle the black circles (area is proportional to lpue') represent the mean decadal lpue'. The study area is divided into the northern, central and southern North Sea, according to the ICES areas IVa, b and c.

From the 1920s to 2000s, North Sea brill was mainly distributed in the southern and central parts of the North Sea (Figure 3). Relatively small numbers of brill were caught in the northern North Sea, although higher lpue' were recorded in some rectangles off the north-eastern coast of Scotland in the first half of the 20th century. From the 1920s onwards, brill showed a general expansion of its range into the central and eastern-central North Sea with increased lpue' of brill in the German Bight and along the Danish coast. This expansion stagnated in the 1960s, but continued again in the 1970s. In the past two decades the distribution pattern of brill remained stable.

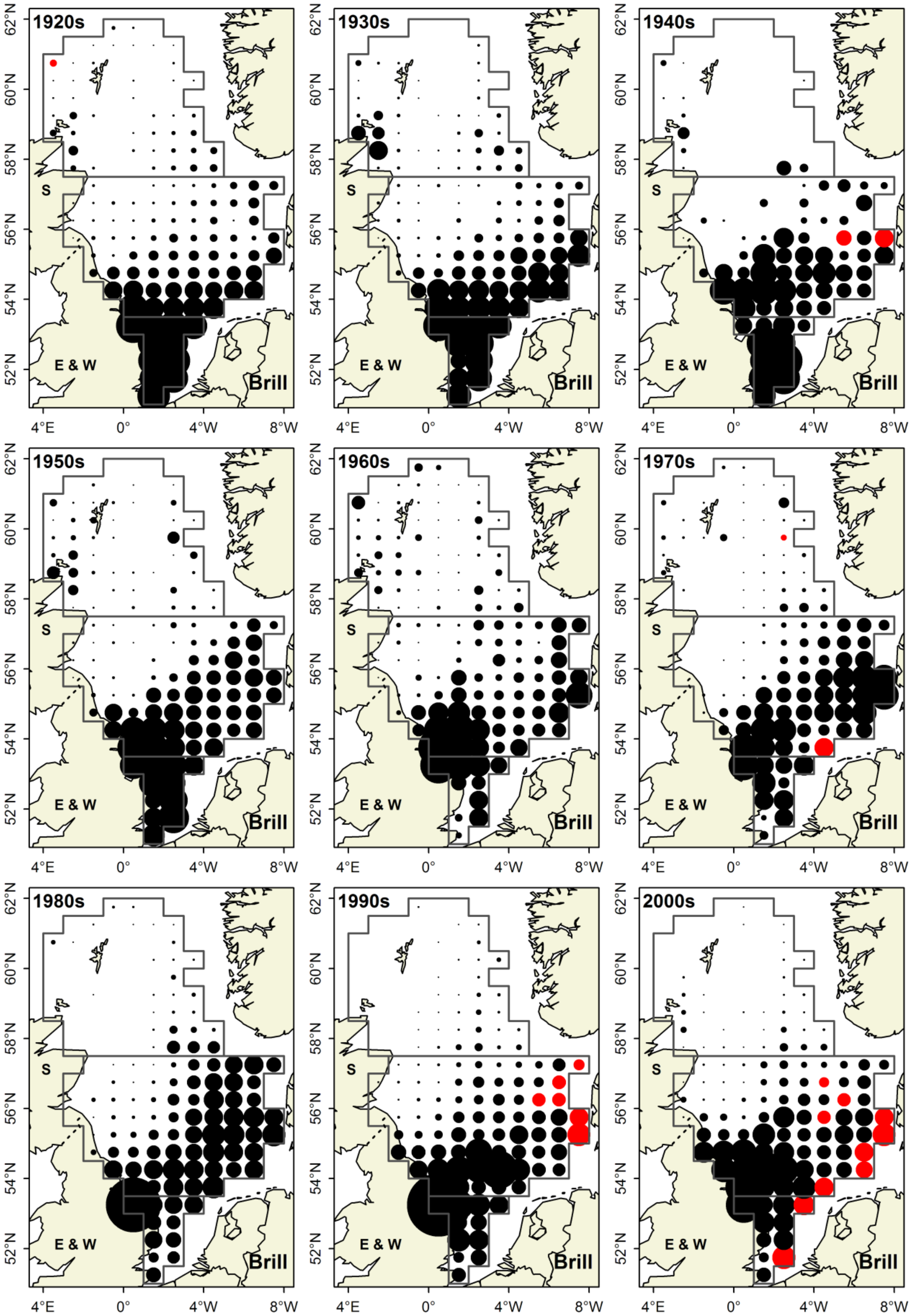

Figure 3. Long-term distribution of North Sea brill represented by brill lpue' of British trawlers (E & W= England &Wales, S= Scotland). For rectangles without lpue' data in a given decade (no effort), red circles represent the long-term average lpue'. For each ICES rectangle the black circles (area is proportional to lpue') represent the mean decadal lpue'. The study area is divided into the northern, central and southern North Sea, according to the ICES areas IVa, b and c.

5.4.3 Trends in abundance

The proxies for abundance based on mean annual commercial lpue and mean annual cpue of two surveys did not correspond in trends, neither for turbot nor for brill. There were long-term decreasing trends in commercial lpue for turbot and brill. In contrast, there was an increase in IBTS cpue for turbot, which was not corroborated by the BTS cpue. No clear trend was found for brill in BTS and IBTS cpue.

Turbot

Commercial lpue of turbot increased slowly before the Second World War (1939-1945) (Figure 4 top). A major increase in lpue took place between the pre- and post-war years, and immediately after the war lpue was more than three times higher. Within a few years, lpue decreased rapidly by nearly 60% to a level that was similar to the pre-war values. From the mid-1950s until the present, lpue showed a long-term decline, although the trend has flattened in the 1990s and 2000s.

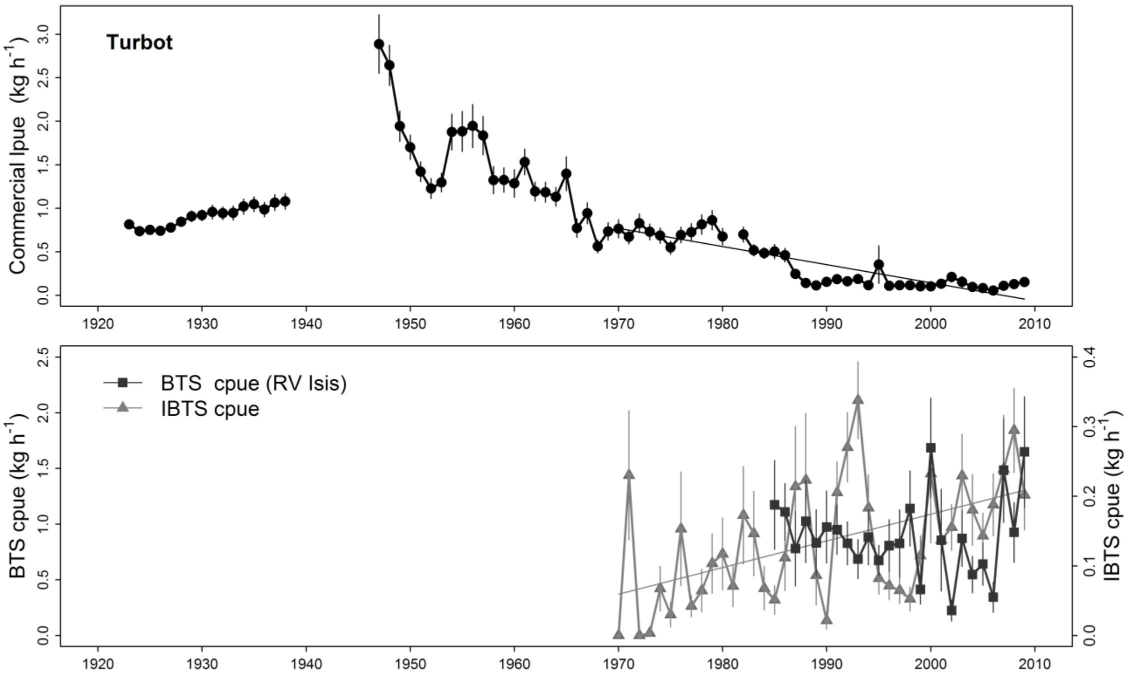

Figure 4. Proxies of abundance trends for North Sea turbot based on mean annual lpue of British otter trawlers and International Bottom Trawl Survey (IBTS) and Beam Trawl Survey (BTS, RV *Isis*) mean annual cpues. IBTS data cover the time period from 1970 onwards and BTS from 1985. To be comparable with commercial lpue, survey data only show fish with a minimum size of 30 cm. Regression lines are included only where the slope was significantly different from zero ($p< 0.05$). Error bars indicate s.e. of the mean annual lpue and cpue.

Survey data for turbot are only available for recent decades, with trends differing between the IBTS and BTS surveys (Figure 4 bottom). The IBTS indicated an increasing trend in cpue of turbot from 1970 to 2009. However, there is considerable inter-annual variability in the cpue values. For the period 1985-2009 covered by the BTS, no clear trend was discernible for turbot.

Brill

Commercial lpue of brill, similar to turbot, showed a declining trend in lpue over time (Figure 5 top). Yet, after the Second World War, and in contrast to turbot, brill lpue was around 2.5 times lower than before the war. From 1947 to 1956, lpue values increased, but showed a long-term decrease thereafter. Only in the 1960s, and 1970s, lpue rapidly increased for a few years, before declining again. Since the mid-1980s until the present, brill lpue remained stable at low levels, with a single year of high lpue in 1995.

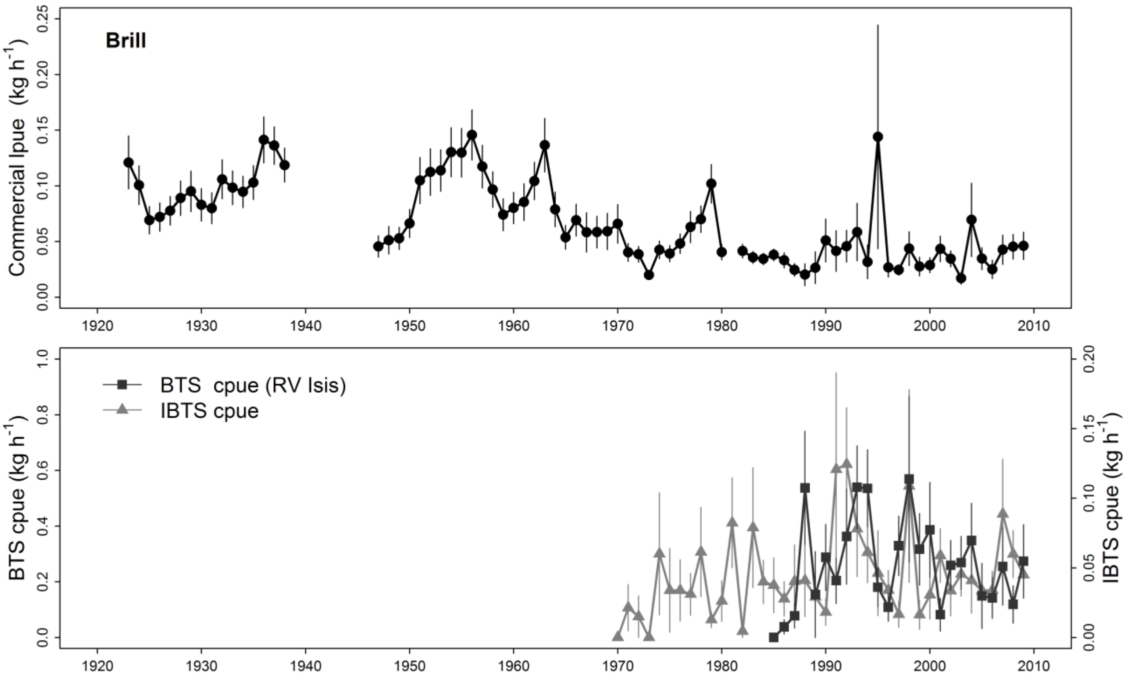

Figure 5. Proxies of abundance trends for North Sea brill based on mean annual lpue of British otter trawlers and International Bottom Trawl Survey (IBTS) and Beam Trawl Survey (BTS, RV *Isis*) mean annual cpues. IBTS data cover the time period from 1970 onwards and BTS from 1985. To be comparable with commercial lpue, survey data only show fish with a minimum size of 30 cm. Error bars indicate s.e. of the mean annual lpue and cpue.

The abundance based on IBTS and BTS cpue did not show a clear trend (Figure 5 bottom). Although on average IBTS cpue was higher in the 1990s (0.06 kg h^{-1}) and 2000s (0.05 kg h^{-}

[1]) than in the 1970s (0.03 kg h^{-1}), no significant overall increase in cpue was found (p= 0.0654). BTS cpue did not reveal an apparent trend for brill between 1985 and 2009.

For the overlapping time periods, statistical analysis tested for correlations between commercial lpue and the two survey cpues. Significant correlations were only found between commercial lpue and IBTS cpue for North Sea turbot (Table 1). Yet, the IBTS cpue and lpue were negatively correlated, associating low commercial values with high IBTS cpue. No significant correlations were found for commercial lpue and BTS cpue of turbot. For brill, none of the survey cpues and commercial lpue were significantly correlated. For the years 1985 to 2009, the comparison between the IBTS and BTS cpues for turbot and brill indicated no correlations between the two surveys (turbot: p= 0.7642; brill: p= 0.2807).

Table 1. Spearman rank correlations (r_s) between commercial lpue and survey cpues of turbot and brill for the overlapping time periods (IBTS 1970-2009; BTS 1985-2009).

	Turbot commercial lpue		Brill commercial lpue	
	r_s	p	r_s	p
IBTS cpue	-0.438	0.0052**	0.202	0.2186
BTS cpue	0.156	0.4543	0.150	0.4725

5.5 Discussion

We used international landings, commercial landings-per-unit-effort (lpue) and survey catch-per-unit-effort (cpue) data, to provide new insights into long-term dynamics of turbot and brill in the North Sea. Besides the 1950s and 1960s, international landings of both species showed a similar trend, yet, with turbot being caught in greater quantities than brill. Throughout the 20th century, the distribution of turbot and brill differed. Turbot was widely distributed in the North Sea, whereas brill was mainly found in the central and southern North Sea. Since the 1960s, turbot had almost disappeared from the northern North Sea and in particular from Turbot Bank, a former hotspot of turbot off the east coast of Scotland. Comparison of IBTS and BTS cpue with British otter trawler lpue revealed different trends in abundance for both species. Commercial lpue suggested long-term declines for both species from the 1940s/1950s to 1980s, to levels that have stayed fairly low since then, with turbot in particular currently showing historically low levels. By contrast, IBTS cpue indicated increasing abundance for turbot during 1970–2009. No clear trend was found for turbot in BTS cpue during 1985-2009, which as well applied to brill in BTS and IBTS cpue.

5.5.1 North Sea fisheries of turbot and brill

Changes in landings of turbot and brill are likely to be strongly driven by technological developments of fishing gears and fishing vessels and a change to different fishing grounds. At the beginning of the 20th century, England (including Wales) was the main catching nation for turbot and brill, however, landings decreased considerably in the years before the First World War. This is possibly a result of British trawlers abandoning local fishing areas to fish in distant but more profitable grounds in the North Sea and North Atlantic, where other species were more abundant but turbot and brill are rather scarce (Kerby et al., 2012; Rae and Devlin, 1972). The Dutch flatfish fishery developed in the 1960s and 1970s after the introduction of mechanised beam trawlers after the Second World War (Daan, 1997). Main target species were plaice and sole, with turbot and brill being valuable bycatch species. As engine power, size of the beam trawl, number of tickler chains and fishing speed rapidly increased, Dutch fishing activities expanded into previously lightly fished grounds and seasons (Rijnsdorp et al., 2008) and promoted the Netherlands to the main catching nation for brill and turbot.

Changes in abundance and/or fishing effort may also have contributed to the observed patterns of changes in landings. In particular after the Second World War (1939-1945), turbot and brill showed different trends in landings. Turbot appears to have recovered better than brill during the war-years when fisheries were limited, as turbot showed the typical patterns of stock recovery after the war with very high landings which rapidly decreased within a few years (Beare et al., 2010, Margetts and Holt, 1948). Although fishing effort in the post-war years was far less than before the war (Engelhard, 2005), recovered turbot resulted in high abundances (Figure 4) and high landings. Such distinct recovery signs did not apply to brill, as landings immediately after the war were far lower than in the pre-war years (see also van der Hammen et al., this volume). Although brill abundance was not particularly low in the 1950s compared to the pre-war years (Figure 5), landings probably remained low due to low fishing effort in that period. Between the 1960s and 1970s, international landings of brill were rapidly increasing. As from the mid-1950s to present, brill showed a continuous declining trend in lpue (Figure 5), it is unlikely that this increase in landings is due to increased brill abundance; this development is rather attributable to the uprising Dutch beam trawl fleet, fishing with very high effort in this time period.

5.5.2 Turbot- near disappearance from Turbot Bank

Up to the 1960s, there was an important fishing ground for turbot east off Scotland, which was aptly named Turbot Bank. Within a short time period, turbot almost disappeared from this area and since the 1970s have only been recorded in very low abundance levels on this ground. Scottish fishery in this area was based on a concentration of large, adult turbot (Rae, 1970). Research at that time revealed, that the stocks of young turbot around Scotland did not appear sufficient to maintain the quantity of adult fish caught on Turbot Bank as well as other Scottish fishing grounds (Rae and Devlin, 1972). Rae and Devlin (1972) suggested that the stocks of the northern North Sea were dependent on immigration of adult or near adult turbot from the southern regions. The scarcity of turbot was observed by Scottish fishermen in the early 1960s (Rae, 1963), at the time of the rise of the Dutch beam trawl fleet. The southern North Sea is the principal nursery ground for turbot, and with high fishing pressure of the beam trawlers in this area, fewer adult and adolescent turbot might have survived to migrate northwards to the central and northern North Sea (Jones, 1970; Rae and Devlin, 1972). Depletion of potential immigrants to the central and northern North Sea by fishing might be an explanation for the near disappearance of turbot from Turbot Bank and the northern areas. Research on turbot migration patterns in the North Sea and population genetic analysis would be needed to confirm this hypothesis. Through tag and recapture experiments using cultured turbot in Belgian coastal waters, Delbare and de Clerck (2000) showed that most of the recaptured fish remained in the southern North Sea, with a few turbot migrating to deeper waters in the central North Sea. It would be too simple to extrapolate from this experiment a continuous migration to the northern North Sea where Scottish fishermen once caught a great amount of turbot. Still, this endeavour would be complicated by the fact that turbot have not returned to Turbot Bank and the northern North Sea in comparable abundances for the past four decades, implying that possibly more underlying factors have contributed to this near disappearance and might aggravate the return to these fishing grounds.

Currently, turbot is rare on Turbot Bank while it is an important fishing ground for the sandeel fishery (ICES, 2011a). This area was recently assessed as a potential MPA (JNCC et al., 2012). Sandeel are not only an important prey for a range of seabirds and cetaceans (JNCC et al., 2012), but as well for turbot (Rae and Devlin, 1972; Wetsteijn, 1981). Therefore, the protection of Turbot Bank might have the potential to contribute to the recurrence of turbot in this area. Our results suggest that in the past two decades, turbot again expanded towards the English coast and northwards along the Norwegian Trench. Reasons might be improved environmental conditions (e.g. food availability), or in recent years implemented effort reductions for targeted species such as plaice and sole which might have influenced the bycatch levels for turbot and brill (ICES, 2011a). Various factors could be responsible for turbot returning to the east coast of England, and eventually again moving further north, still, further investigation would be required to identify these drivers.

5.5.3 Brill- recent distribution expansion

Over the past nine decades, brill showed a rather consistent distribution in the southern and to some extent in the central North Sea but extended its range slightly into the central North Sea and along the Danish coast. A recently discussed driver might be the response of fish species to climate change, resulting in a northward shift (e.g. Cheung et al., 2009; Dulvy et al., 2008; Engelhard et al., 2011; Perry et al., 2005). However, instead of a clear shift in distribution that has been shown for other species in the North Sea such as North Sea plaice (van Keeken et al., 2007; Engelhard, et al., 2011; Poos et al., 2013), our results suggest an expansion into the central North Sea. Brill might have benefited from increased food availability due to increased productivity on lower trophic levels such as phytoplankton or macrozoobenthos which could have led to an increase of higher trophic levels such as shrimps and fishes in the coastal waters of the North Sea (Colijn et al., 2002). These areas were subject to enhanced riverine nutrient inputs in particular during the 1950s-1980s and leading to eutrophication (Radach et al., 1990). For this time period, the influence of eutrophication and seabed disturbance by beam trawling, causing shifts in benthic communities, were analysed by Rijnsdorp and van Leeuwen (1996), suggesting that both have affected the growth rates of plaice, possibly implying improved environmental conditions as well for other species, such as brill. These and various other factors, including inter- and intra-specific competition during the different life-stages (Gibson, 1994; van Hammen et al., this volume), could have influenced the distribution of brill. Still, the analysis and evaluation of these effects and their sole or interacting impacts on the fish stock is beyond the scope of this study and might also be worth pursuing in follow-up studies.

5.5.4 Contrasting trends of different proxies for abundance

Results obtained from the different datasets (commercial lpue, IBTS cpue, BTS cpue) did not correspond in trends of abundance for turbot and brill.

Estimated cpue from the IBTS and BTS research surveys were obtained from standardised surveys and therefore similarities between them would have been expected. The discrepancies between the data might be based on various factors such as the use of different gears, the spatial extent of the data and modifications of the survey design.

A major difference between the two surveys is found in the gear, IBTS using bottom trawls and BTS using beam trawls. The beam trawl is especially designed to catch flatfish, which was well reflected in the higher BTS cpue. Therefore, BTS cpue may be considered more appropriate than IBTS cpue in representing the abundances of turbot and brill. Moreover, although these surveys aimed to operate in a standardised way, various changes took place over time in gears and the accordance amongst surveys is imperfect (ICES, 2009, 2010c; ICES-FishMap). For example, the surveys covered by the BTS have all their own origins and were not set up as one survey. Due to that, no standardisation has taken place in gears (ICES, 2009). We therefore only used data of RV *Isis*, as this survey is recommended to provide the most consistent time-series (pers. comm. J.J. Poos; Heessen, 2010). Further, in some IBTS surveys different versions of the otter trawl have been used, however, no corrections have been made to the data to compensate for the differences in catchability between these gears. The nets used by individual vessels of the IBTS are slightly different. Therefore catch rates of the different vessels are potentially influenced; yet, the effect has not been investigated systematically (ICES-FishMap).

Another important difference is found in the BTS survey being limited to the eastern parts of the southern and central North Sea, while the IBTS covers the entire North Sea. Potentially, the increase in abundance of turbot shown by the IBTS might be explained by the IBTS catching turbot in the northern North Sea which is not covered by the BTS. However, this possibility does not seem to sufficiently explain the difference in trends between BTS and IBTS.

The survey design, in particular of the IBTS, has changed over time from originally sampling juvenile pelagic herring to a bottom trawl survey mainly sampling demersal species. Also the tow duration was reduced in 1976 from originally one-hour hauls to 30-minute tows (ICES, 2010c). With turbot occurring in low densities and being scattered over a given area, the shorter trawl durations on surveys may have decreased the chance for the survey gear to encounter an individual specimen. Further, as turbot grows relatively fast, low trawling speeds on survey vessels (IBTS, BTS) compared to commercial vessels may make it easier for bigger fish to actively escape the nets, making it difficult to obtain sufficient information on the bigger length classes for turbot (ICES, 2012).

Brill and turbot are generally caught in low numbers (especially brill). Therefore, catches are rather a ‘hit and miss’, resulting in a less reliable index for abundance. This applies in particular for the IBTS using a suboptimal gear (GOV otter trawl) for catching flatfish.

Commercial data analysis as well demands caution when using lpue as an index for abundance as the catchability of species rarely remains constant over an entire exploitation history. A factor that commonly causes catchability to change over time is e.g. the change in the efficiency of the fleet (Maunder et al., 2006). Throughout the 20th century, there was a general improvement in fishing power (Engelhard, 2008). Principally, this should have led to increases in turbot and brill lpue over time which it did not, thus the indicated decrease in lpue for these species is likely to genuinely reflect a population decrease. Further, Gulland (1964) suggested for the years immediately after the Second World War, when the abundance was very high after the long period of no fishing, that fishing effort may have been concentrated at patches of high fish abundance, leading to an overestimation of the abundance by commercial lpue. Therefore, our proxy based on lpue might overestimate abundances for turbot immediately after the war. It is also possible that catchability for flatfish may have decreased in the English otter trawl fleet as a result of increased targeting of roundfish during the 1970s and 1980s (Engelhard, 2008). Although these data issues require a cautious interpretation, the lpue trend combined with the range contraction suggest that turbot are currently at low abundance levels compared to the years before the 1970s.

Although commercial fisheries data indicated a long-term decline in turbot and brill, the magnitude of decline is difficult to assess due to the problems related with commercial lpue. Still, the long-term perspective of this study gives reason to believe that the stocks of both species are currently at low levels. It appears that the decline pre-dates the initial year of the BTS time-series, 1985, after which there is no evidence for a consistent decrease or increase (based on BTS and lpue).

Our results for turbot are corroborated by Weber (1979), showing for the time period 1950-1977 a rapid decrease of turbot lpue based on international landings and effort. Further, the analysis of Dutch market sampling data from the 1980s indicated an overexploitation of North Sea brill and turbot (Boon and Delbare, 2000). The usefulness of long-term data was as well highlighted by Cardinale et al. (2009) who analysed historical research survey data of turbot in the Kattegat-Skagerrak. They estimated that between 1925 and 2007, turbot biomass in that region declined by ~86 %, maximum body size decreased by 20 cm, and the northern component of the turbot population had virtually vanished.

We do not question the usefulness and benefits of surveys, however, of the three analysed data sources we would recommend to critically consider the trend indicated by the IBTS. Principally, otter trawls are not the optimal gear to catch a rather rare flatfish. Regarding commercial data, as well being based on otter trawls, assumedly the vast amount of data commercial fisheries deliver is mitigating this shortcoming. Due to data quality considerations regarding stock assessment, the ICES Advisory Committee requested that surveys need to be developed to effectively monitor the status of brill (ICES, 2011a). This demand as well could be transferred to turbot, as the deficiencies of the current surveys are impacting both species.

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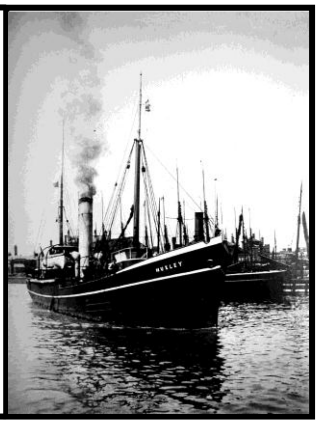
Chapter 6



Overall conclusions

Most fishery assessments are still based on time series going back around three decades, leaving scientists poorly equipped to address questions of long-term trends or impacts of e.g. climate change or fishing pressure on fish stocks (Pinnegar et al., 2006; Pinnegar and Engelhard, 2008). To understand and interpret long-term changes and dynamics of fish populations the recovery and analysis of historical fisheries data is therefore a prerequisite. The research presented in this study has shown that long-term data, giving insights into the former status of fish stocks and fisheries, can help to counteract the 'shifting baseline syndrome' (Pauly, 1995). This thesis demonstrated the usefulness and benefits of old data for fishery assessments by revealing so far unknown long-term trends of North Sea demersal fish stocks. In addition, the influence of human, human-induced, technological, economical and political drivers was assessed on North Sea fishes and fisheries. Where possible, historical data of other European countries fishing in the North Sea were implemented and compared with British data, and related to the historical context.

6.1 Key findings

Firstly, by reviewing and synthesising over 100 years of demersal landings data, this thesis demonstrated that trends in fisheries landings can be influenced by other drivers than the 'usual suspects' such as natural variations in abundance of fish stocks or overfishing (Chapter 2). The remarkable development of the British North Sea demersal fisheries in the 19^{th} and 20^{th} century illustrated that technological, economical and political drivers have greatly affected the fishing industry. The results highlight that for the accurate interpretation of fisheries data and revealing trends in fisheries, the historical context of influencing factors has to be understood and should be incorporated into the analysis of fisheries data.

Secondly, the analysis of spatially explicit landing-per-unit-effort (lpue) data showed that over the past nine decades (1920s-2000s) long-term latitudinal shifts and deepening in the distribution of North Sea whiting (*Merlangius merlangus*) cannot be detected (Chapter 3). Between the late-1940s and 1960s, this study demonstrated that whiting distribution shifted westwards for ~1°. However, no clear evidence was found to support that such changes were caused by changing climate and fishing pressure.

The third finding of this thesis was that commercial fisheries data were found to be reliable for analysis of distribution of fish stocks. In Chapter 4, lpue data of North Sea whiting were compared with fisheries-independent survey catch-per-unit-effort (cpue) data. Whiting is a commonly discarded species, thus landings data is potentially influenced and may not reflect the catch. The analysis demonstrated correspondence between both datasets in the spatial distribution of whiting and strong relations between commercial lpue and survey cpue. In areas where highly priced flatfish was caught, the discrepancies between whiting lpue and cpue were suggested to be caused by discarding of whiting.

Finally, the thesis revealed that the distribution patterns of North Sea turbot (*Scophthalmus maximus*) and brill (*Scophthalmus rhombus*) were different for most of the 20th century and only became similar in the recent decade (Chapter 5). Formerly being widely distributed in the North Sea, and found in high abundances on Turbot Bank off the east coast of Scotland, turbot nearly disappeared not only from this former hotspot but as well from the northern North Sea from the 1970s onwards. In contrast, brill demonstrated a stable distribution in the southern and central North Sea and revealed a rather slow expansion into the central North Sea. Today, the distribution of brill and turbot is very similar, with both species mainly occurring in the central North Sea. Furthermore, the long-term perspective of this study gives reason to believe that abundance levels of both species underwent a long-term decline and are currently at low levels.

6.2 Implications for the 'shifting baseline phenomenon'

6.2.1 Understanding fisheries dynamics

Knowledge on the long-term dynamics in fisheries is important to recognise drivers influencing fisheries. For this study, over 100 years of North Sea demersal fisheries data were compiled and reviewed, and findings were interpreted in the historical context (Chapter 2). As a result, individual events and developments could be placed in a systematic framework. Major drivers were identified, here technology, politics and economy, positively or negatively influencing English demersal fisheries (Figure 1). Furthermore, the long-term perspective in this study allowed to detect in which time period a driver was reversing.

This thesis highlights that by using historical data and creating such a systematic framework, any fisheries in the world could benefit as influencing drivers could be identified, improving the understanding why fisheries are progressing or declining. This study demonstrated that, when analysing commercial fisheries data, not only biological responses of fish stocks to fishing and environmental changes should be taken into account, also changing political, economical and technological drivers have to be considered. For example, the decline of England's fisheries to some extent only reflects stock declines (e.g. end of the gadoid outburst), with much of it being reflected by political developments in the

1970s and 1980s. The recovery of historical fisheries data is therefore of importance as long-term data are a prerequisite to the interpretation of long-term changes in fisheries.

Drivers positively ↑ or negatively ↓ influencing the development in English North Sea fisheries

1903-1950s Dominance		1950s-2008 Decline	
Technology		**Technology**	
- Large fleet of purpose built steam trawlers	↑	- Modern technological devices → more precise and efficient fishery	↑
- Otter trawl → 37% higher efficiency than formerly used beam trawls	↑	- Stern trawler freezers → industrial scale fisheries	↑
- Vigneron-Dahl trawl → further increased efficiency by 25-50%	↑	- Technological advances in other European countries	↓
Politics		**Politics**	
- No law restricting fisheries	↑	- Anglo-Icelandic cod wars → withdrawal of British fleet from Icelandic waters	↓
- WW I and WW II → war service and losses of fishers and fishing vessels	↓	- EEZ introduction → loss of distant water grounds; restricted fisheries	↓
		- Total allowable catches and quota regulations	↓
Economy		**Economy**	
- Railway network opened up new markets for fish	↑	- Emphasis of North Sea fleets on prolific distant waters	↓
- Population growth → increased demand → increased supply	↑	- EEZs → limited fishing grounds for overcapitalized distant water fleets	↓
- Flourishing 'fish and chip shop' trade	↑	- Decline in per capita fish consumption	↓

Figure 1. Main drivers positively or negatively influencing the development in English North Sea fisheries. Two main periods were identified (dominance and decline) for English fisheries, where the three drivers, technology, politics and economy, were mainly acting in opposite ways. Section from the poster "Great Britain's role in North Sea demersal fisheries: a long-term perspective over the past century", presented at the ICES Annual Science Conference, Gdansk, 2011.

With fisheries having impacted marine ecosystems for many decades, there is general agreement that environmental and fisheries policies must be elaborated in order to protect the environment and ensure the sustainability of the fish stocks and the associated fisheries (OSPAR 2002). Management approaches such as the ecosystem approach to fisheries management (EAF) aim to develop and improve fisheries management. To achieve these goals, the tools and techniques of EAF need to be applied in a manner that addresses the wider interactions between fisheries and the whole ecosystem (Garcia and Cochrane, 2005). One of the elements needed for successful ecosystem management is expressed by the demand that conservation and management decisions for fisheries should be based on the best scientific information available, also taking into account traditional knowledge of the resources and their habitat (Garcia and Cochrane, 2005). The research conducted for this thesis, utilised such 'traditional knowledge' by analysing historical fish (Chapter 3, 5) and fisheries data (Chapter 2). The detailed information on the development of British fisheries and the identification and the impacts of the drivers of change, as well as the extended knowledge on fish population dynamics of whiting, turbot and brill, are of great value to improve fisheries management strategies.

Important scientific organisations such as ICES have already recognised the value of analysing historical dynamics in fisheries as conducted in Chapter 2. As ICES science aims to “remain relevant and credible” and “generate innovative research”, the published paper of Chapter 2 was selected in their annual report as one of the “scientific highlights” in 2012 (ICES, 2012a).

6.2.2 Fish distribution shifts

Several studies have reported that over the past three decades, various North Sea fish species have shifted northwards in their distribution, and that the whole fish assemblage has ‘deepened’(Dulvy et al., 2008; Hiddink and ter Hofstede, 2008; Perry et al., 2005).

By analysing nine decades of fisheries data, this thesis highlights that fish distribution shifts cannot simply be described as ‘fish move further north’ and ‘into deeper’ waters. The study has shown that the different species have undergone different shifts in their distribution. North Sea whiting did not exhibit a latitudinal and deepening shift, but is now more westerly distributed than in the 1920s and 1930s (Chapter 3). Turbot was once widely distributed in the North Sea, but contracted in the 1970s from the northern North Sea and nearly disappeared from the former hotspot ‘Turbot Bank’. Brill, in contrast, did not show major distribution shifts in the past nine decades, and only slowly expanded into the central North Sea (Chapter 5).

Findings of this thesis, combined with the results described for plaice, sole and cod in Engelhard et al. (2011a,b), both using the same data sources and analogues methods, contribute to the conclusion that distribution shifts can vary between species. The studies demonstrated that some species have moved northwards (plaice, cod), some southwards (sole), and others remained relatively stable (brill). Further, in certain time periods some species shifted westwards (whiting) or contracted mainly (turbot) or declined (cod).

Distribution shifts potentially have implications for fishery population dynamics, stock assessments and management outputs as they may hamper the ability to properly assess and evaluate the population status (Link et al., 2011). The long-term perspective given in this thesis, with the new insights into former distribution ranges of whiting, turbot and brill, has the potential to newly define reference conditions of these stocks and reset current baselines.

Although this study could not identify the main driver(s) causing the shift of whiting and the contraction of turbot, various North Sea species have shown to respond to climate change and/or fishing pressure (Dulvy et al., 2008; Engelhard, 2011a,b; Perry et al., 2005). It is important to identify underlying mechanisms responsible for distributional shifts.

However, data are not always available, or do not cover such long time-periods, and therefore limit analysis. In this case, historical literature may give an indication about developments in fisheries in specific time periods. For example, long-term fishing mortality data were not available for turbot and brill, constraining the assessment and how this driver might has influenced their distribution. In the case of turbot, historical literature gave the indication that the uprising beam trawl fisheries of the Netherlands might have impacted the distribution of turbot in the northern North Sea (Rae, 1963, 1970; Rae and Devlin, 1972). Further research is as well required to explain the distinct westward shift of whiting in the late 1940s-1960s. Besides analysing biological drivers (predator-prey interactions), also the influence of the uprising Danish industrial fisheries on whiting in the eastern-central North Sea would require further investigations of Danish historical fisheries data.

Distribution shifts of fish stocks as well have economical implications for fisheries due to changes in catchability and yield (Cheung et al., 2013). Further, with stocks moving away from the operating range of fishing fleets, vessels have to travel longer distances to reach the target resources, impacting fuel costs and time at sea (Pinnegar et al., 2010). The findings in this thesis illustrated that, for example, the disappearance of turbot from the northern North Sea had an economic impact on Scottish fisheries. Although turbot landings in Scottish waters were relatively small compared to other species, high prices on the market made it economically far greater important for Scottish fishermen. The disappearance of turbot meant an economic loss for fishers which had to be compensated (Rae, 1963).

Future effort has to be invested in the different management approaches reacting to the different types of shifts (e.g. expansion, contraction, shift, splitting, merging of stocks) fish stocks reveal (Link et al., 2011). As climate change, one of the main drivers for distribution shifts, is predicted to persist, spatial distribution shifts of fishes are likely to continue (Cheung et al., 2009; 2012; IPCC, 2007). Fishing nations have to be prepared that fish stocks which are currently in their operating range may move out of reach, resulting in an economic loss for the fishing industry. Additionally, fisheries management need to be prepared to adapt to changes in existing fisheries production, and need to prepare for new opportunities associated with emerging fisheries in response to shifts in fish distribution (Link et al., 2011).

6.2.3 Changes in fish abundances

Management of exploited fish stocks depends largely on knowledge of the historical development in their status. The appropriateness of subsequent management advice depends on the accuracy of the historical and current population estimates. If historical abundance levels are unknown, population estimates are likely to be biased influencing subsequent management measures (Kraak et al., 2009).

This thesis was able to generate new knowledge on historical abundance levels of turbot and brill (Chapter 5), which, in this temporal extent, did not exist before. The findings in this thesis give the opportunity to reset current baselines of turbot and brill in fisheries assessment, as the results suggest that both species are currently at low abundance levels compared to the early 20th century. The knowledge of earlier conditions of fish stocks such as turbot and brill potentially has policy implications with respect to setting rebuilding targets and current management strategies may have to be re-assessed.

In recent years, improvements have been made in fisheries policies, and a recent new, reformed Common Fisheries Policy aims to bring fish stocks back to sustainable levels (EU, 2013). However, it is not until we have fully understood the baseline conditions of fish stocks in the past, that the success and effectiveness of policies can be evaluated.

6.3 Implications of fisheries data

The analysis of commercial fisheries data is generally accompanied by concerns about potential bias. The usefulness and reliability of commercial data for fisheries assessment is controversially debated by Daniel Pauly, Ray Hilborn and Trevor Branch (Pauly et al., 2013). Hilborn and Branch argue that commercial data are misleading because many factors determine the hauls by fishermen. The amount of fish caught does not necessarily reflect the number of fish in the sea. The authors urge researchers to use all the available scientific data in addition to commercial data, and to validate their results by consulting local experts or other data sources. Pauly pleads for the use of commercial data for fisheries assessment, as, although they should be used with care, such data is easily available from fisheries, not as costly as scientific data (important especially for developing countries), and cover long-time periods. Furthermore, for most fisheries, commercial data are the only source available and fisheries scientists can and should use these data to infer fishery status, at least tentatively. Pauly claims, that even when stock assessments or scientific surveys are conducted, such information should always be used in conjunction with any and all available commercial data.

To assess the reliability of commercial fisheries data for distribution analysis, this thesis compared commercial data with survey data. The results demonstrated that commercial fisheries data are reliable and therefore represent a valuable and cost-efficient source for fisheries assessment, agreeing with the view of Pauly (Pauly, 2013). Further, this finding is in line with various studies analysing and comparing fisheries- and fisheries-independent data (e.g. Engelhard et al., 2011; Fox and Starr, 1996; Petitgas et al., 2003; Verdoit et al., 2003).

The research in this thesis illustrates that commercial data provide a long-term perspective, a benefit not provided by survey data covering only three to four decades. By using longer timer series, long-term trends and patterns in fishes and fisheries are more likely detected and the influence of drivers such as fishing pressure and climate change on fish stocks are more easily separable. Furthermore, the long-term perspective provided by commercial data, combined with the understanding of historical developments in fisheries, help to improve the interpretation of data. The gained knowledge can be added to and combined with survey data, allowing an improved understanding in fisheries which would not have been possible without the analysis of historical fisheries data.

6.4 Outlook

This thesis has demonstrated that the recovery of historical fisheries data can help to understand the past and has the potential to improve the future in fisheries.

This should be an incentive for fisheries and marine institutes to start or continue to recover and analyse historical information about fisheries. The long-term benefits of the gained knowledge assumedly outweigh the not negligible costs for such projects, as scientist can learn from past fish stock and marine conditions and apply gained knowledge to present and future assessments.

This study was part of a research project aiming to examine how fish distributions have changed and might be related to human-induced and/or natural drivers (Defra project MF 1108). Still, only a fraction of fish species so far have been analysed. Further, this research used annual catch and effort data, covering nine decades, longer than many studies; however, these data could not evaluate e.g. seasonal patterns of fish populations. Monthly data are available in the Cefas archives, but still need to be digitised. Analysis of such data would give an in depth understanding of temporal and spatial behaviour of fish species.

Various changes took place in fishes and fisheries in the 20th century and many fishermen have experienced these changes. The great value of anecdotes, personal observations and the knowledge about the state of past stocks has been described by Pauly (1995) and Sáenz-Arroyo (2005a, b). Future research should make effort to document (via e.g. questionnaires and interviews) the knowledge of senior or retired fishermen who have long-term experience in fisheries. The detailed knowledge of such fishermen regarding the when and why they changed for example fishing grounds, target species, gears or experienced a species' decline or increase, represents a valuable source of information. Combined with available fisheries data, this information could help to close knowledge gaps. Retired fishermen are still very interested in fisheries and assumedly would be very motivated and supportive to carry out such research. This is shown, for example, by the visit of the North Shields Retired Fishermen at Cefas in May 2013, exchanging their experience with Cefas scientists and updating their knowledge on e.g. latest regulation changes or current fisheries assessments. Future research should take advantage of such interest of former fishermen. The valuable knowledge and memories of these fishermen should not be lost but should be passed on to the current generation of scientists.

"By understanding what once existed, we can plan better for what might again be possible"

A. Canright, 2006. California Coast Ocean Vol. 22, No. 3.

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Declaration

This statement certifies that the work presented in this thesis was conceptualised, conducted and written by myself, Tina Kerby. I was responsible for the review of literature, the compilation, analysis and conclusion of the data and I wrote the six chapters presented in this thesis.

My work was closely associated with Cefas (Centre for Environment, Fisheries and Aquaculture Science) as large parts of the data were stored in their archives. Georg Engelhard, fisheries scientist at Cefas and my supervisor, was involved in all aspects of this work including conceptualisation, analysis and critical reviews of earlier draft versions of the presented chapters. My supervisors at the University of East Anglia, William Cheung (now University of British Columbia) and his successor, Cock van Oosterhout, reviewed earlier drafts of the chapters in this thesis and also provided advice on statistical analysis and improved my scientific writing skills.

Tina Kerby was the lead author on the published papers of Chapter 2, 3 and 5 as well as the manuscript of Chapter 4.

Chapter 2 - Kerby, T.K., Cheung, W.W.L., Engelhard, G.H., 2012. The United Kingdom's role in North Sea demersal fisheries: a hundred year perspective. Reviews in Fish Biology and Fisheries 22: 621-634.

Tina compiled and analysed British and international demersal fisheries data. She reviewed the respective literature, interpreted the trends in the historical context and identified different drivers influencing UK demersal fisheries. Tina wrote the paper and Georg Engelhard and William Cheung reviewed drafts of the manuscript.

Chapter 3 - Tina K. Kerby, William W.L. Cheung, Cock van Oosterhout, Georg H. Engelhard, 2013. Wondering about wandering whiting: Distribution of North Sea whiting between the 1920s and 2000s. Fisheries Research 145, 54-65.

Tina collated long-term data of international and British North Sea whiting catches as well as British lpue data. She conducted the analysis of British whiting landings, the spatial distribution of whiting in the North Sea and the influence of climate change and fishing pressure on the species' distribution. Tina wrote the paper and Georg Engelhard, William Cheung and Cock van Oosterhout reviewed drafts of the manuscript.

Chapter 4 - The catching and landing in demersal fisheries: a comparison between commercial fisheries data and research survey data for whiting distribution in the North Sea.

Tina collated research survey and commercial fisheries data of North Sea whiting as well as commercial data and average annual values of cod, haddock, plaice and sole. She analysed whiting distribution based on research and commercial data and investigated the discrepancies between both data sets. She further tested whether higher priced fish species influenced discarding behaviour of whiting. Tina wrote the chapter and Georg Engelhard, William Cheung and Cock van Oosterhout reviewed drafts of the manuscript.

Chapter 5 - Tina K. Kerby, William W.L. Cheung, Cock van Oosterhout, Georg H. Engelhard, 2013. Entering uncharted waters: long-term dynamics of two data limited fish species, turbot and brill, in the North Sea. Journal of Sea Research 84, 87-95.

Tina compiled long-term data of international and British catches of North Sea brill and turbot as well as British lpue and research cpue data of these species. Phil Davison (Cefas) supported the digitisation of British lpue data of brill and turbot. Jan Jaap Poos (IMARES Wageningen UR) provided detailed BTS survey data of the RV Isis. Tina analysed the international development in brill and turbot fisheries and the spatial distribution changes of these species in the North Sea. She further investigated the trends in abundance of brill and turbot based on British data and two research surveys. Tina wrote the paper and Georg Engelhard, William Cheung and Cock van Oosterhout reviewed drafts of the manuscript.

Archival statement

For this thesis various data sources were used. The great majority of data analysed in this thesis were freely available, such as:

- Detailed British demersal fisheries data in Chapter 2 and average annual values of demersal fish species in Chapter 4 were extracted from the historical books ‘Sea Fisheries Statistical Tables’ of England and Wales and of Scotland. These books are as well freely available in a scanned version (PDF) in the ‘UK Sea Fisheries Statistics Archives’ on the website of the Marine Management Organisation (MMO), UK: http://www.marinemanagement.org.uk/fisheries/statistics/annual_archive.htm.
- Price index data used in Chapter 4 were freely available from the website of the Office for National Statistics: http://www.ons.gov.uk/ons/datasets-and-tables/data-selector.html?table-id=3.6&dataset=mm23.
- International North Sea landings data of total demersal fish (Chapter 2), whiting (Chapter 3), and turbot and brill (Chapter 5) were freely available from the ICES website: http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx.
- ICES provide research survey data freely available on their web-based data portal. Research survey data on whiting (Chapter 4), turbot and brill (Chapter 5) were extracted from the DATRAS database of trawl surveys: http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx.

For the analysis of British whiting (Chapter 3 and 4) as well as turbot and brill (Chapter 5) lpue, historical statistical paper charts, archived at Cefas (Lowestoft, UK), were digitised. The paper charts were produced by the UK Ministry of Agriculture, Fisheries and Food (MAFF; now the UK Department for Environment, Food and Rural Affairs (Defra)); for detailed information see Engelhard (2005). The analysed whiting, turbot and brill lpue data in this thesis are subjected to Crown copyright and represent therefore not freely accessible data. If you wish to access the data, please send a request to:

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