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22–25 November 2016

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Executive Summary

This report documents the work undertaken during the WKFISHDISH workshop which took place at ICES headquarters (Copenhagen) on November 22nd 25th 2016. The purpose of this workshop was to inform an answer to a request from the EU Commission about the distribution shifts of commercial fish stocks in relation to TAC management areas which ICES tackled in two consecutive steps: (1) data analysis carried out by the ICES secretariat (2) identify, based on both the results from the analysis and existing literature, changes in distribution and the associated drivers. This second step was done by the WKFISHDISH workshop participants. The workshop was chaired by Thomas Brunel (Netherlands), Alan Baudron (UK) and Jose Fernandes (UK).

The WKFISHDISH workshop was articulated around three terms of reference: (ToR1) consider the findings of the analyses carried out by the ICES secretariat to identify distribution changes, (ToR2) where shifts in distribution were identified, literature was used to identify likely drivers, (ToR3) implications of the distribution shifts and the likelihood of further change were discussed. 19 species were considered: anchovy, anglerfish (2 species), blue whiting, cod, common sole, Greenland halibut, haddock, hake, herring, horse mackerel, mackerel, megrim (2 species), Norway pout, plaice, Pollack, saithe, sprat, spurdog and whiting. The ICES secretariat analysed available bottom trawl surveys data for these species (bar Greenland halibut for which no data was available, only existing literature was used for this stock) and produced the following outputs for each species: (i) presence/absence maps, (ii) trends in probability of occurrence within each ICES areas, (iii) centre of gravity with associated latitude and longitude trends within each ICES areas, (iv) significant differences in relative changes in abundance between adjacent ICES areas.

These outputs were analysed by WKFISHDISH workshop participants to answer ToR1. To be consistent, during the literature review needed to address ToR2 efforts were made to assess the following potential drivers for each stock: (i) geographical attachment, (ii) environmental conditions, (iii) density-dependent habitat selection, (iv) spatial dependency, (v) demographic structure, (vi) species interaction, (vii) memory, (viii) other drivers such as fishing. 'Big movers' species (i.e. species exhibiting distribution changes likely to be problematic regarding TAC management areas) were identified as such if they conformed to at least one of the following two criteria: (1) a large, continuous and directional change in distribution was identified from the analyses and/or in the literature review, (2) a change in distribution resulting in subsequent changes in the relative distribution across TAC management areas was observed.

Based on the analyses and the literature available, all species were found to exhibit some changes in their distribution to some extent apart from Greenland halibut, Norway pout and spurdog for which no evidence was found. For these 18 'movers' species, the main drivers distribution identified were environmental conditions (mainly temperature) for all species, followed by density-dependent habitat selection (7 species), geographical attachment (6 species), species interactions (4 species), demographic structure (3 species), and spatial dependency (2 species). Other possible drivers (fishing and colonisation) were also mentioned for 4 species.

The following species were identified as 'big movers': anchovy (northward shift in the North Sea), anglerfish (regional changes in the North Sea), blue whiting (increase in the North Sea and west of Scotland), cod (northward shift), hake (expansion in the

North Sea), herring (changes across different TAC management areas), mackerel (major changes across northeast Atlantic), megrims (regional changes in the North Sea, Bay of Biscay and Celtic Sea), and plaice (increase in North Sea and Baltic Sea, changes across different TAC management areas). Despite showing clear changes in distribution, horse mackerel was not included in this list as current management measures already account for these distribution changes.

Both ecological and management implications of the changes in distribution were identified in ToR3. The main possible ecological implications include limited areas of suitable habitats (cod, sole and plaice), isolation between life stages habitats (herring), and new prey-predator interactions and subsequent competition between predators (hake and saithe). The main management implication identified is the mismatch between regional abundances and TACs allocation, with hake and mackerel being the two obvious examples. This mismatch, in combination with the landing obligation, could result in choke species issues and challenges the relative stability currently used to distribute quotas.

Regarding the likelihood of further changes in distribution, current climate scenarios project an increase in temperature and decrease on primary production and it is likely that future changes in distribution will occur. Based on the available information the following areas were identified most at risk: North Sea (warming and latitudinal shift), southern areas i.e. Celtic Sea and below (warming and lower primary production), west of Scotland (northward shift), Norwegian Sea and Skaggeak and Kattegat (increase in abundance). However, our ability to accurately predict the future distribution of fish species is hampered by both our understanding of the mechanism associated with drivers, and our ability to predict these drivers.

In conclusion, the 'big movers' species identified here (i.e. anchovy, anglerfish, blue whiting, cod, hake, herring, mackerel, megrims, plaice) are most at risk of resulting in management issues. While there is no obvious solution to address this management problem, some form of adaptive management seems the best candidate to deal with changes in fish distribution. In addition, a better monitoring of fish stocks and ecosystems is needed to improve our knowledge of the processes at play in order to increase our ability to predict future changes and foresee potential ecological and management issues.

1 Introduction

1.1 Background

Widely distributed species account for most of main stocks in the North East Atlantic (NEA) (Merino *et al.*, 2014). Four pelagic species, Atlantic mackerel (*Scomber scombrus*), sprat (*Sprattus sprattus*), Atlantic herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*), account for more than 65% of the total catches and 95% of pelagic species catches in the NEA (Merino *et al.*, 2014, Trenkel *et al.* 2014). Demersal species catches can be lower in proportion, but their price can double the pelagic species and trend to be targeted by smaller vessels with implications to coastal livelihoods and cultural value (Fernandes *et al.*, 2016). Demersal widely distributed species such as cod, haddock, saithe, plaice and hake are between the top 20 species in terms of maximum catch contribution in FAO area 27. Other widely distributed species might not be important in terms of total catches or monetary value, but have high ecological importance. For example, Norway pout is a key species in the food web preyed upon by hake and saithe as well as a forage fish fisheries for fish meal and oil. Because of their wide distribution these species have lower geographical barriers and a higher capacity to change their distribution (Cheung *et al.*, 2008; Trenkel *et al.* 2014), but are also highly vulnerable to environmental variability, including multi-decadal regime shifts (Chavez *et al.*, 2003; Alheit *et al.*, 2009; Barange *et al.*, 2009; Fernandes *et al.*, 2010). The impacts of long-term climate change on these species, both in terms of distributional shifts and mortality (Petitgas *et al.*, 2012; Shephard *et al.*, 2014), is therefore uncertain and potentially large. Historical collapses and recoveries of fish stocks have been attributed to a combination of climate and fishing effects (Planque *et al.*, 2010). In addition, populations that are heavily harvested are more likely to undergo further changes in their spatial structure in relation to environmental changes (Hsieh *et al.* 2010 in Ciannelli *et al.* 2013).

Temperature and primary production are acknowledged key drivers of species distribution and abundance that have been used for general projections of changes of potential species and catches distribution (Jennings *et al.* 2008; Cheung *et al.* 2008). Despite reproducing global and decadal trends well (Fernandes *et al.*, 2013; Jennings and Collingridge, 2016), these projections from models designed to be mechanistic are not precise and realistic enough yet for the level of details needed to inform fisheries management (Dickey-Collas *et al.*, 2014). This is partly because these models do not consider specific species or stock are often driven by additional drivers and local geographical characteristics. Moreover, those projections have to deal not only with the model and natural environment uncertainty (Payne *et al.*, 2016), but also with human decision uncertainty by using scenarios (Mullon *et al.*, 2015). Conversely stock assessment and empirical modelling work aims to be precise and realistic, but they seem to have limited forecasting or generalization power beside year by year basis (Rutterford *et al.*, 2015). Moreover, fisheries management of specific species might require early forecast when data for stock assessment is not yet available and require forecast based on satellite derived variable (Fernandes *et al.*, 2009; 2010). This highlights our limitation on predicting the future, but it also shows that there is an increasing capacity to consider long-term scenarios of change and its implications as well as short-term likely scenarios. Our capacity to secure the needed resources to provide operational tools that are regularly used for fisheries management advice is limited. However, there are increasing efforts to link scientists and policy makers work (Thorpe, *et al.*, 2016; Cartwright *et al.*, 2016).

Fish stocks in the Northeast Atlantic are managed partly through the EU Common Fishery Policy, whose objective is to maintain or rebuild fish stocks to levels that can produce their maximum sustainable yield (MSY). This policy is already yielding measurable improvements on European Atlantic fisheries (Cardinale *et al.*, 2013), particularly in relation to widely distributed pelagic species (Fernandes and Cook, 2013). For example, Atlantic herring (*Clupea harengus*) seems to have recovered from overexploitation faster than expected (Nash *et al.*, 2009), and the benefits to fisheries could compensate for the negative environmental impact on capelin in the Northeast Atlantic (Mullowney and Rose 2014). Despite these successes, there are important challenges to be addressed in terms of complexity and adaptive capacity (Boyes and Elliot, 2014). Therefore, there is high uncertainty in relation to its capacity to address new challenges in a preventive way rather than reactive. Recent examples include the Brexit uncertainty (Boyes and Elliot, 2016), choke species as result of the new landing obligation (Baudron and Fernandes, 2015) and demand for climate-ready management (Queiros *et al.* 2016). Finally, recent research highlighted the ecological and economic benefits of fishing below MSY and that there is still a fishing overcapacity (Hsieh *et al.*, 2006), Merino *et al.*, 2014; Shephard *et al.*, 2014; Da-Rocha and Mato-Amboage, 2015; Merino *et al.*, 2015; Voss *et al.*, 2015; Guillen *et al.*, 2016; Thorpe, *et al.*, 2016).

1.2 The request and the ToRs for WKFISHDISH

EU request on Distributional shifts in fish stocks (FISHDISH)

The ICES working group on **Fish Distribution Shifts (WKFISHDISH)** was convened to treat the request from DGMARE concerning distribution shift in commercial fish stocks.

The Commission wishes to be informed of distributional shifts in fish stocks that may have taken place since 1985 in relation to TAC management areas (or the earliest available reliable time series year by region).

ICES is requested to:

- 1) *Assess the proportion of each principal commercial species of fish (see list below) that is distributed within each TAC management area established for that species, from research vessel survey and additional information.*
- 2) *Identify any significant long-term trends in distributional changes between TAC management areas and between stocks of the same species.*
- 3) *Where appropriate, identify likely drivers for such changes.*
- 4) *Where appropriate, advise on likely future trends.*

List of principle commercial species with TACs, with sufficient survey information for analysis.

Common name	Latin	Number TAC management units
Anchovy	<i>Engraulis</i>	2
Anglerfish	<i>Lophius</i>	5
Blue whiting	<i>Micromesistius</i>	2
Cod	<i>Gadus morhua</i>	8
Common sole	<i>Solea solea</i>	10

Greenland Halibut	<i>Reinhardtius</i>	1
Haddock	<i>Melanogrammus</i>	6
Hake	<i>Merluccius</i>	2
Herring	<i>Clupea</i>	14
Horse Mackerel	<i>Trachurus</i>	2
Mackerel	<i>Scomber</i>	3
Megrim	<i>Lepidorhombus</i>	5
Norway pout	<i>Trisopterus</i>	1
Plaice	<i>Pleuronectes</i>	10
Pollack	<i>Pollachius pollachius</i>	5
Saithe	<i>Pollachius virens</i>	3
Sprat	<i>Sprattus</i>	4
Spurdog	<i>Squalus</i>	2
Whiting	<i>Merlangius</i>	7

Approach agreed to answer the request:

ICES decided to treat this request with a 2 phases approach:

- A. The identification of significant changes in distribution.
- B. If changes are found, the identification of drivers and implications.

The identification of significant changes in distribution.

To be carried out by the ICES secretariat. Encode the TAC management units. For the 19 species, estimate using survey and other relevant information, the time trends in abundance for each TAC unit and each stock area. This will form the basis for analysis of relative trends. Within one survey area, the trends can be directly compared, but when crossing over survey areas only the relative trends can be compared. This work will be carried out largely by the ICES data centre in the ICES the secretariat.

The method used to identify significant shifts will be determined by WGECCO in spring 2016. Method then be applied to the time series for all 17 species to identify significant shifts. This analysis will be completed by early October 2016.

If changes are found, the identification of drivers and implications.

The cases where shifts have been found will be assessed at a 4 day ICES workshop in November 2016 (WKFISHDISH- FISH Distribution Shifts). The workshop will use published studies and information to identify likely drivers for such change (new analysis will not occur). Drivers to be considered will include changes in fishing patterns, environmental variability (including climate change and ocean basin wide processes). The implications and likelihood of further change in the drivers will also be addressed.

Definitions

- TAC management unit – the area used by the EU for the local management of TAC
- Stock area – the area used by ICES to described the distribution of a stock

- Survey area – the area of a time series of surveys, i.e the area routinely surveyed with a standard gear.

WKFISHDISH resolution

WKFISHDISH met on 22–25 November 2016 at ICES HQ, Copenhagen to deal with three Terms of Reference:

ToR1: Consider the findings of the analysis of the shifts in fish distribution relative to TAC management unit for 19 stocks carried out by the ICES secretariat.

ToR2: Where shifts in distribution have been detected, published studies and information will be used to identify likely drivers for such change (new analysis will not occur). Drivers to be considered will include changes in fishing patterns, environmental variability (including climate change and ocean basin wide processes).

ToR3: Comment will also be provided on the implications of the distribution shifts and the likelihood of further change.

1.3 Populations, stocks, ICES areas, management areas

Fish species that occur in the northeast Atlantic are largely being assessed as several separate stocks which are assumed to be self-contained, interbreeding units with clear geographical boundaries. Historically, fish stocks have been defined based on biological information, fisheries characteristics and any other relevant information such as genetic studies and tag-recapture experiments. ICES areas and TAC management areas are being used to describe the expanse of stocks, the allocation of TACs of said stocks, and the applicability of management measures for certain fisheries (Figure 1.3.1).

Every year, countries with fisheries established within ICES areas carry out bottom trawl surveys in their respective waters. Information from these groundfish surveys is gathered by ICES and is readily available from the DATRAS database. The area covered by these surveys overlaid on the ICES areas is shown in Figure 1.3.2. This information, together with fisheries information and any additional observations (e.g. physical data) can be used to assess changes in the distribution of species and identify the forcing factors responsible for these changes.

Management measures for fish stocks are based on stock status (i.e. how much fish can be harvested sustainably) and area (i.e. the proportion of the stock harvested in each ICES area). For EU quota management, annual measures are agreed in the TAC regulations (e.g. Council of the European Union, 2015; Council of the European Union, 2016). While stock status is assessed for the stock area (e.g. areas 4, 6a and 3a for haddock), TACs are set for different ICES areas (e.g. haddock TACs are set for areas 2a and 4 separately than for areas 5b and 6a) assuming a constant distribution of fish throughout the stock area. An example is shown below for the EU part of the Northeast Atlantic mackerel TAC.

Species:	Mackerel <i>Scomber scombrus</i>	Zone:	VI, VII, VIIIa, VIIIb, VIIIc and VIIIe; Union and international waters of Vb; international waters of IIa, XII and XIV (MAC/2CX14-)
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While the TAC is set for stock/area combinations, specific exceptions can be made to address changes in distribution or the availability of a given stock in a certain area. These so-called 'special conditions' can be used to set specific conditions on where and how certain species may be exploited. An example of some of the special conditions for fishing NEA mackerel in 2a and 4a during part of the year is shown below. This special condition provides a temporary measure to address the changes in spatial distribution of the stock.

Special condition:

within the limits of the abovementioned quotas, no more than the quantities given below may be taken in the following zones and periods:

Union waters of IIa; Union and Norwegian waters of IVa. During the periods from 1 January to 15 February 2016 and from 1 September to 31 December 2016 (MAC/*4A-EN)	Norwegian waters of IIa (MAC/*2AN-)	Faroese waters (MAC/*FRO2)
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Where new information provides a better understanding of the stock structure that would be needed for sustainable exploitation of species, ICES recommends changes in the management areas being used to manage the species. Where the change in stock structure allows for maintenance of the TAC setting arrangements (e.g. when combining multiple areas into one stock), the management approach may be to maintain the current management areas but using the new scientific information as a way to inform the overall TAC setting.

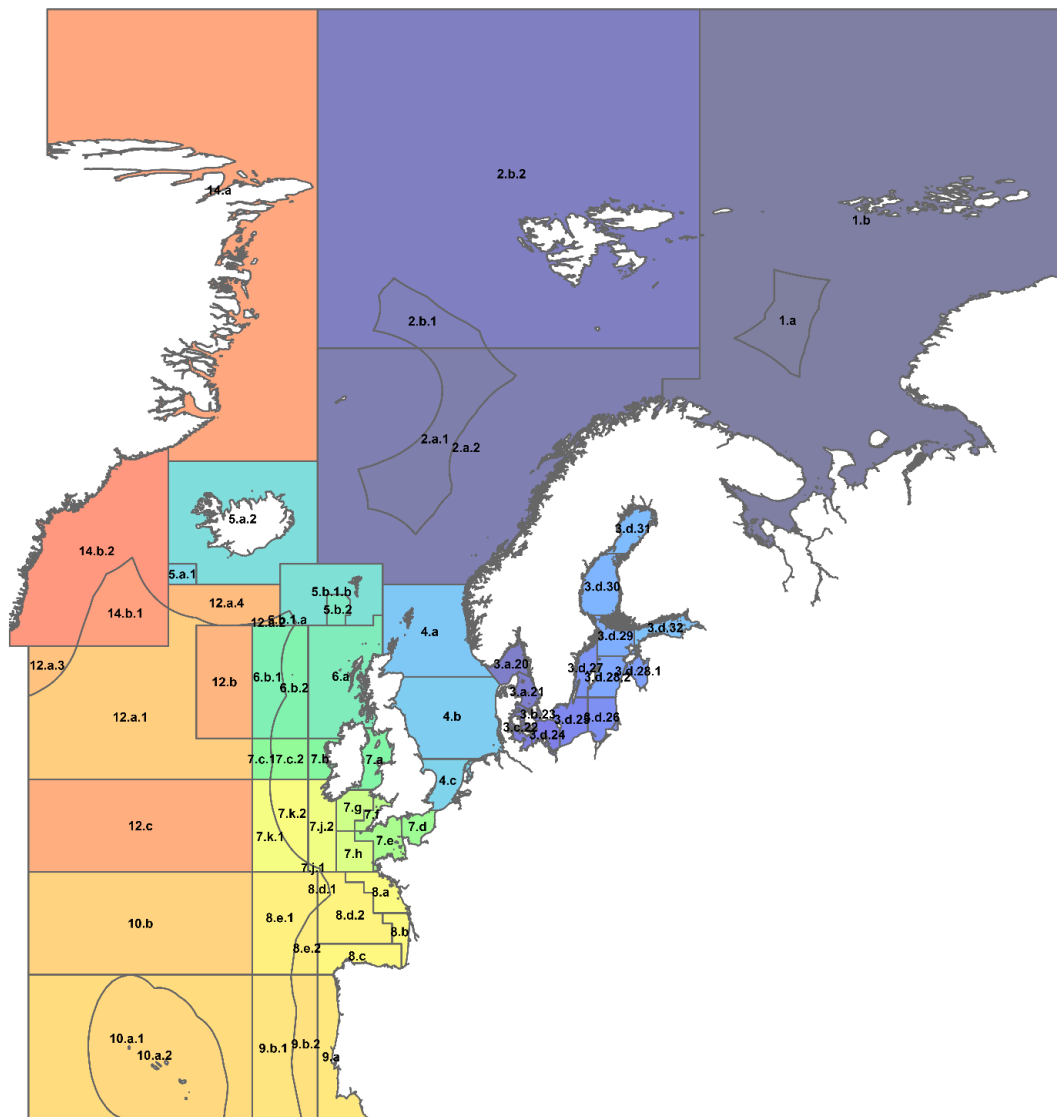


Figure 1.3.1. ICES areas (coloured blocks) with TAC management areas (numbered)

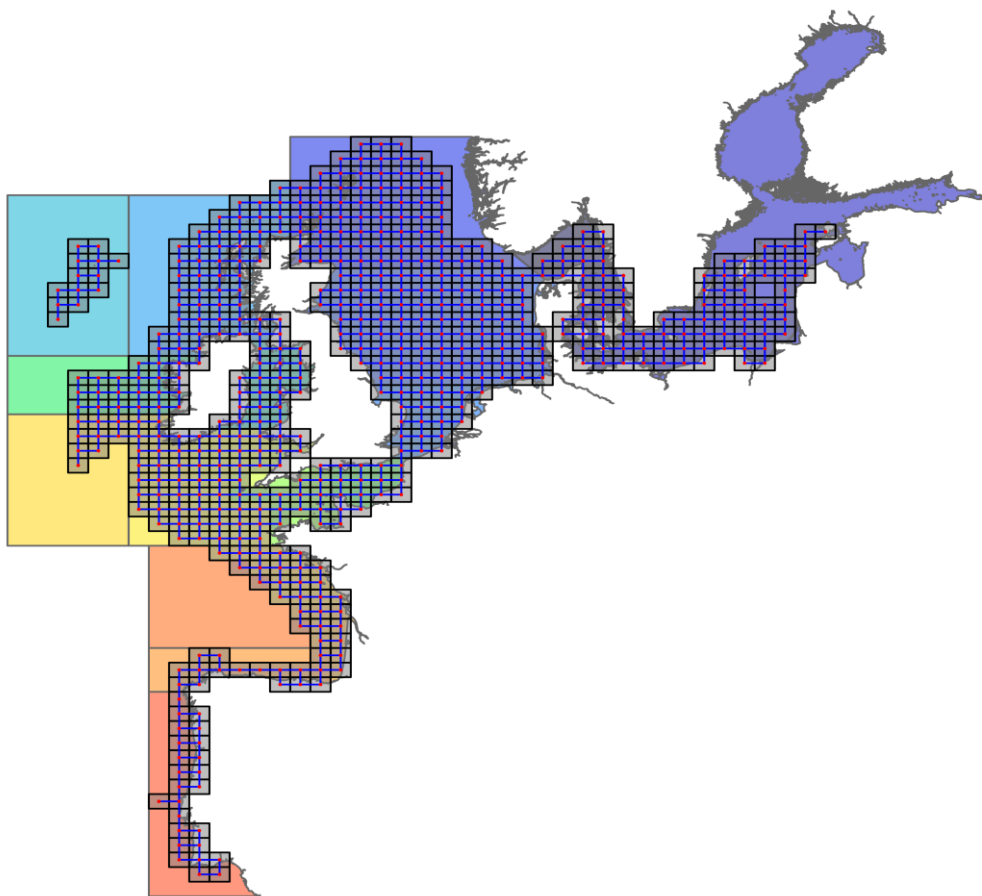


Figure 1.3.2. Survey coverage overlaid on the ICES areas to assess the spatial extent considered for the assessment of changes in distribution between stock areas. For example, Division 8.d is represented by 3 statistical rectangles traversing the shelf edge, and 7.k is represented by 9 statistical rectangles in the north eastern corner covering approximately 25% of the area defined by 7.k. Other regions are more completely covered, such as, 4.a and 4.b.

1.4 Structure of the report

The report is divided in four main sections:

- 1) This introductory section.
- 2) A section describing the approach and methods used to address each of the 3 ToRs;
- 3) A section where the 19 species are analysed one by one looking at evidences for changes in distribution, potential drivers and implications of the distribution changes.
- 4) A conclusions section summarizing the identified big movers (Tor1), the drivers of its distribution changes (Tor2) and future implications (Tor3).

2 Approach used and methods

2.1 Changes in distribution

Data

The data employed in this analysis was obtained from the ICES DATRAS database covering the various bottom and beam trawl surveys. A summary of these survey is given in Tables 2.1.1 and 2.1.2.

Species	Division	Survey	Survey name	Gear	Quarter	Start year	Notes
Anchovy, Anglerfish, Blue Whiting, Cod, Haddock, Hake, Hake, Herring, Horse Mackerel, Mackerel, Norway Pout, Pollack, Saithe, Spurdog, Sprat, Whiting	3.a	2341	NS-IBTS	GOV	1, 3	1979, 1991	
	3.b, c	2826	BITS	TVS	1, 4	1996, 1999	
	3.d	2826	BITS	TVS	1, 4	1999	
	4.a	2341	NS-IBTS	GOV	1, 3	1971, 1991	
	4.b	2341	NS-IBTS	GOV	1, 3	1967, 1991	
	4.c	2341	NS-IBTS	GOV	1, 3	1978, 1991	
	6.a	2701	SWC-IBTS	GOV	1, 4	1985, 1990	
	6.b	3473	ROCKALL	GOV	3	1999	Data from the years 2000,2004, and 2010 missing
	7.a	4784	NIGFS	ROR	4	2009	
	7.b	3520	IE-IGFS	GOV	4	2003	
	7.c	3322	SP-PORC	PORB	3	2001	
	7.d	3497	FR-CGFS	GOV	4	1988	
	7.e	3417	BTS	BT4S	3	2006	
	7.f	3488	BTS-VIIa	BT4A	3	1993	Beam trawl survey - not optimal
	7.g	3024	EVHOE	GOV	4	1997	
	7.h	3024	EVHOE	GOV	4	1997	
	7.j	3024	EVHOE	GOV	4	1997	
	7.k	3322	SP-PORC	PORB	3	2001	
	8.a	3024	EVHOE	GOV	4	1997	
	8.b	3024	EVHOE	GOV	4	1997	
	8.c	3321	SP-NORTH	BAK	4	2001	
	8.d	3024	EVHOE	GOV	4	1997	
	9.a	3320	SP-ARSA	BAK	1, 4	1996, 2003	Data from some years missing

Table 2.1.1. Summary of the bottom trawl survey data employed in the analysis

Species	Division	Survey	Survey name	Gear	Quarter	Start year	Notes
Megrim, Plaice, and Sole	3.a	2341	NS-IBTS	GOV	1, 3	1979, 1991	
	3.b, c	2826	BITS	TVS	1, 4	1996, 1999	
	3.d	2826	BITS	TVS	1, 4	1999	
	4.a	3417	BTS	BT8	3	1998	
	4.b	3417	BTS	BT8	3	1987	
	4.c	3417	BTS	BT8	3	1987	
	6.a	2701	SWC-IBTS	GOV	1, 4	1985, 1990	
	6.b	3473	ROCKALL	GOV	3	1999	Data from the years 2000,2004, and 2010 missing
	7.a	3488	BTS-VIIa	BT4A	3	1993	
	7.b	3520	IE-IGFS	GOV	4	2003	
	7.c	3322	SP-PORC	PORB	3	2001	
	7.d	3417	BTS	BT4A	3	1990	
	7.e	3417	BTS	BT4P	3	2006	
		3417	BTS	BT4S	3	2006	
	7.f	3488	BTS-VIIa	BT4A	3	1993	
	7.g	3488	BTS-VIIa	BT4A	3	1993	
	7.h	3024	EVHOE	GOV	4	1997	
	7.j	3024	EVHOE	GOV	4	1997	
	7.k	3322	SP-PORC	PORB	3	2001	
	8.a	3024	EVHOE	GOV	4	1997	
	8.b	3024	EVHOE	GOV	4	1997	
	8.c	3321	SP-NORTH	BAK	4	2001	
	8.d	3024	EVHOE	GOV	4	1997	
	9.a	3320	SP-ARSA	BAK	1, 4	1996, 2003	Data from some years missing

Table 2.1.2. Summary of the beam trawl survey data employed in the analysis

Method 1: Presence-absence

The bottom- and beam trawl surveys are based on sampling in some of the ICES Statistical Rectangles in specific quarters of the year. Each of the Statistical Rectangles are associated with the ICES area in which it resides. The fact that some rectangle's "belong" to more than one ICES area has been solved by allocating the rectangle to the division where most of the area of the rectangle lies within.

The basic data used for this method is the presence/absence of a given species with a specific rectangle in a given year. Due to the varying spatial coverage of the trawl surveys in each ICES area through time, we have chosen the measure of percent occurrence of the particular species in each ICES area (e.g. if 10 rectangles have been fished and the species have been found in all rectangles' that year, the occurrence is 100). Temporal trends in occurrence were tested by using the Mann-Kendall non-parametric test for monotonic trends. Furthermore, maps showing the occurrence by five year periods were produced.

In order to avoid any bias between different surveys only one survey per ICES area has been chosen. Surveys with the longest time series were chosen. A list of the surveys used in this analysis is given in Tables 2.1.1 and 2.1.2. Furthermore data from Quarter 2 has been excluded from this analysis since this quarter has only been sampled in the first part of the time series.

Method 2: biomass trends

Changes in biomass between two management areas over time were explored by investigating trends in survey abundance over time. Specifically, for each year, an index of abundance was estimated for each region and the ratio of these was calculated resulting in a relative measure of stock

distribution by year. For example, if survey catchability is constant across regions, then a ratio of 1 implies that each region contained the same proportion by weight. If catchability was constant within each region over time, then ratios were compared across years to assess changes in stock distribution over time.

CPUE by haul

Abundance indices were estimated by converting numbers caught at length to weight by taking all available observations of length and weight and fitting the model assuming normal errors

$$\begin{aligned} \log(\text{weight}) \sim & \log(\text{length}) + \\ & \log(\text{length}):s(\text{year}) + \\ & \log(\text{length}):re(\text{year}) + s(\text{year}) + re(\text{year}) \end{aligned} \quad (1)$$

where $re(\text{year})$ denotes a random effect for each year, and $s(\text{year})$ denotes a smooth trend modelled as a thin plate regression spline with degrees of freedom given by $0.5 * \text{the number of years in the time series}$, or 9, whichever was smaller. This model allowed for a different length-weight relationship in each year while also allowing for trends over time, while also providing a mechanism to predict a length weight relationship for unsampled years.

Equation (1) was applied to observations of length for each survey haul resulting in an estimate of total catch weight by haul. This was then divided by the haul duration to give a catch weight per unit effort of time for each haul.

Abundance index by management region and survey

Abundance indices by management region and year were calculated (for each survey) by estimating an index of abundance by ICES statistical rectangle and summing over all the statistical rectangles in each management

region. The following was used to model abundance in each statistical rectangle:

$$\log(\text{cpue}) \sim \text{gmrf}(\text{statistical rectangle})$$

(2)

where cpue is modelled using gamma errors on the log link and gmrf() denotes a spatial smoother in which neighbouring statistical rectangles are penalised to be similar to each other (specifically, this is a 1st order random walk on a lattice).

All models were fitted in R using the gam function from the mgcv package.

Hypothesis testing can be carried out by simulating from the above models. For example, to test for a change in the distribution of a stock between region A and region B, the following can be computed:

- 1) Estimate the length weight relationship (1)
- 2) Apply the length weight relationship to the survey length observations and calculate CPUE by haul for each.
- 3) To the set of estimated CPUE by haul and year fit model (2) and then simulate 1000 draws from the fitted model. This results in 1000 realisations of the distribution of abundance for each year.
- 4) Calculate the abundance index for each year for management regions A and B and take ratios. This results in 1000 realisations of the time series of abundance ratios.
- 5) Perform a Mann-Kendall test for each simulation.

The result of this procedure is a simulation of the significance of the presence of a monotonic trend in the log ratios. The trend was taken to be sig-

nificant if the median significance level was less than 0.05.

Calculating the centre of gravity of a stock within a survey region

The centre of gravity was calculated for each simulation from the spatial model fitted to each year and survey. The centre of gravity was computed by taking the coordinates of the centre of each statistical rectangle in the survey extent and calculating the weighted average of the latitude and longitude coordinates separately, where the weights were the simulated CPUE estimates from each model. This allowed for the estimation of 95% confidence intervals using the simple percentile method.

2.2 Identifying the drivers

For each species, a literature review of the published information regarding the drivers of fish distribution and of the changes thereof was carried out.

In order to facilitate the review process, a matrix approach was adopted. Each participant was asked to insert literature references as rows of the matrix, and put the relevant information in different columns related either to observed changes distribution, or drivers identified. The potential drivers proposed to the participants were taken from a review paper from Planque *et al.* (2011), and are briefly described here (see the original paper for more information and examples):

- Geographical attachment: the distribution of a species is related mainly to the geography, with areas of high abundance occurring recurrently in the same locations. This can be caused by the persistence of particular biological or physical features

the influence the distribution of a population.

- Environmental conditions: The environment is usually thought of as the major factor that controls the spatial distribution of fish populations. This constitutes an extension – in the geographical space – of the concept of ecological niche (Hutchinson, 1957).
- Density-dependent habitat selection: where the species expands its distribution to areas of less suitable habitat due to density dependent effects when the overall abundance of the population increases.
- Spatial dependency: species distribution may be affected by inter-individual interactions (e.g. either gregarious or territorial species)
- Demographic structure: distribution can be age related, therefore the demographic structure of the population may influence its overall distribution
- Species interactions: the way a species occupies its potential habitat can be modulated by resource availability (prey), competition for food or space (competitors), or mortality (predators)
- Memory: persistence of years in the distribution of a species can be due to individual memory possibility linked to natal

homing or to social interactions (young individuals learning migration routes from the older ones)

- Other: among the other potential drivers not mentioned in Planque *et al.* (2011), a particularly important one for exploited fish stocks is the intensity and distribution of fishing effort, which, by being potentially not uniformly distributed can cause changes in distribution compared to an unexploited population.

Based on the information presented on the matrix, syntheses were prepared and presented during the workshop for each species to discuss the likely drivers of the distribution and of the changes thereof. The matrix presenting the information collected during the workshop is presented as annex 1 of this report.

2.3 Implications and future changes

As one of the main tasks of this workshop was to identify the likely drivers of changes in distribution of the selected species, it is important to highlight if any of these drivers will have further implication in the future. Warming temperature is often cited as the main driver explaining spatial changes for many of the species investigated here. With further increase in temperature predicted this could affect fish distribution in the future. Several talks were delivered during the workshop to highlight general publications addressing species distribution changes in the past, future projections and implications. The aim of these talks was to boost discussion and provide additional 'hints' on how to assess the implications of future changes. Finally, from the several con-

tributions received during and after the workshop a summary conclusions section has been produced by several scientists and revised by all participants.

3 Analysis by species

3.1 Anchovy

3.1.1 Evidence for changes in distribution

3.1.1.1 Analysis of ICES trawl data

The presence/absence method shows clear increasing patterns in anchovy occurrence probability in northern Figure 3.1.2).

In southern divisions, such as these included in the Bay of Biscay, trends are non-significant, although time series are too short (

divisions (10 ICES areas are significantly increasing, none is decreasing, see Table 3.1.1) since beginning of 1990s, especially in the North Sea: northern North Sea (4a), central North Sea (4b), southern North Sea (4c), and nearby areas: Skagerrak–Kattegat (3a), Eastern Channel (7d) (Figure 3.1.1 and

Figure 3.1.2). Moreover, trawl surveys might not be the most appropriate way to obtain reliable estimates of this small pelagic fish.

3.1.1.2 Other evidence

The analysis of ICES trawl data is in agreement with previous studies indicating a higher presence of anchovy reported since the 1990s in the North Sea (Beare *et al.* 2004, Petitgas *et al.* 2012, Montero-Serra *et al.* 2015). In particular, anchovy catches in the North Sea were rare between 1925 and 1994 (with a small commercial fishery in the Wadden Sea (Boddeke and Vingerhoed 1996), compared to recent years (Beare *et al.* 2004).

In the Bay of Biscay stock, following a prolonged period of diminishing recruitment in the bay, the stock collapsed in 2005 and the fishery remained closed until 2010 (Irigoien *et al.* 2008, Petitgas *et al.* 2010), after that is now recovering.

Table 3.1.1. ICES areas with significant trends in the probability of occurrence of anchovy in survey halls. Mann-Kendall test for monotonic trends. *: $P < 0.05$; **: $P < 0.01$; *: $P < 0.001$; NO: not observed or very low occurrence. Red asterisk indicates decreasing trend whereas green indicates increasing trend.**

ICES Area	Anchovy - all years
Skagerrak-Kattegat (3a)	***
Danish Straits (3b,c)	**
Baltic Sea (3d)	**
N North Sea (4a)	***
C North Sea (4b)	***
S North Sea (4c)	***
NW of Scotland (6a)	**
Rockall (6b)	NO
Irish Sea (7a)	
W of Ireland (7b)	*
Porcupine Bank (7c)	NO
Eastern Channel (7d)	*
Western Channel (7e)	NO
Bristol Channel (7f)	NO
Celtic Sea N (7g)	
Celtic Sea S (7h)	*
SW of Ireland E (7j)	
SW of Ireland W (7k)	NO
Bay of Biscay N (8a)	
Bay of Biscay C (8b)	
Bay of Biscay S (8c)	NO
Bay of Biscay Offshore (8d)	
Portuguese Waters E (9a)	NO
Increase	10

Decrease

0

3.1.2 Review of potential drivers

Warmer temperatures is possibly the main driver explaining the North Sea expansion of anchovy population because it is associated with an expansion in its thermal habitats (Bellier *et al.* 2007, Lenoir *et al.* 2011, Petitgas *et al.* 2012, Zarraonaindia *et al.*, 2012, Raab *et al.* 2013). The hypothesis of temperature as a driver is consistent also with the subtropical distribution range of European anchovy in the eastern North and Central Atlantic and ranging from northwest Africa in the south to the North Sea and the Baltic Sea in the north (Froese and Pauly 2014), where the North Sea is within the northern range boundary of this fish. The role of other factors such as the increase of food availability might be also important in the North Sea; however, the increase in temperature along with expansions/contractions of distribution ranges appears to be the main driver (Beare *et al.* 2004, Petitgas *et al.* 2012, Raab *et al.* 2013). The increased presence of anchovy in the North Sea may come from a remnant small population rather than a northward shift from Biscay Bay populations in the south, according to the genetic analysis and circulation modelling (Petitgas *et al.* 2012). This is also supported by their apparent absence from the English Channel surveys during the period of population expansion within the North Sea (Montero-Serra *et al.* 2015).

The collapse of the Bay of Biscay anchovy population was associated to the intense exploitation by French and Spanish fleets (ICES 2013), in combination with unstable environmental conditions (Borja *et al.* 2008). Because of their short lifespan, small pelagic fish species react rapidly to environmental change, normally by expanding and contracting their stock sizes. Because warming climate is expected to increase habitat availability for spawning and juvenile stages, anchovy in the bay could cope better with environmental variability, compared to other fish species such as plaice and Atlantic herring in the North Sea, and Atlantic cod in the Barents Seas (Petitgas *et al.* 2013).

3.1.3 Implications of changes in distribution and future trends

3.1.3.1 Biological and ecological implications

The consequences of the latitudinal distribution shift in the anchovy due to thermal changing habitat might mainly occur in the North Sea, where anchovy catches were extremely rare before 1990s (Beare *et al.* 2004).

3.1.3.2 TAC management areas

The expansion of anchovy population in the North Sea would not have a direct consequence since this stock is not regulated by TACs in this area. On the other hand, if its exploitation in the future is maintained in a sustainable and profitable manner, a country might claim a quota.

3.1.3.3 Choke species?

Anchovy species is not a choke species because in general is caught without bycatch. Furthermore, since anchovy is not managed in the North Sea, this cannot act as a choke species as long as it remains non-managed.

3.1.3.4 Future expectations? Northern shifts? Northern constrains?

Habitat distribution for anchovy are expected to experience northward shift under climate change scenarios, and specially improved suitability for the North Sea (Lenoir *et al.* 2011). Concerning specifically the Bay of Biscay population, spawning depends on the season, sea temperature, prevailing winds, salinity, among others (Motos *et al.* 1996, Ibaibarriaga *et al.* 2007, Planque *et al.* 2007). Therefore, changes in abundance and phenology are expected to occur on this population under climate change scenarios that project higher temperature and lower primary production in the continental shelf (Chust *et al.* 2014).

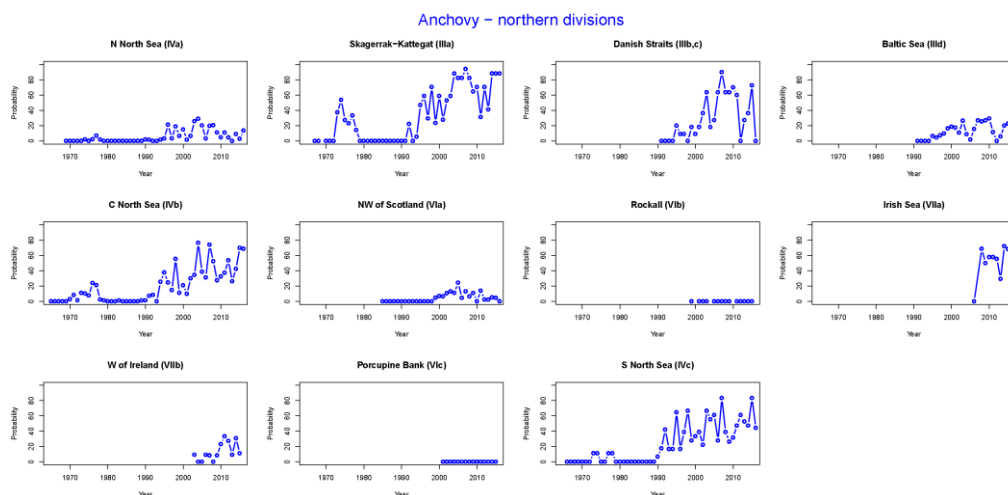


Figure 3.1.1. Trends in anchovy in northern TAC units.



Figure 3.1.2. Map of anchovy presence through time.

3.2 Anglerfish

The anglerfish encompasses two species, white anglerfish (*Lophius piscatorius*) and black-bellied anglerfish (*Lophius budegassa*), whose TAC is shared by five management units. The stock assessment developed both for west, southwest of Ireland and Bay of Biscay (divisions 7.b–k, 8.a–b, and 8.d), and for Cantabric Sea and Atlantic Iberian waters (divisions 8.c and 9.a) show, in general terms, a similar historic scenario of the fishery for the two species. This can be summarized with a good state of the stock in the early-mid 80s followed by overexploitation period in the early-mid 90s, to an increasing production of the two species in the last decade and with stock in the Cantabric Sea and Atlantic Iberian waters exploited at a rate that is consistent with producing the highest catch from in the long term (Figure 3.2.1–3.2.4, ICES 2016). In the areas North Sea, Rockall and West of Scotland, Skagerrak and Kattegat (subareas 4 and 6 and Division 3.a) the analytical assessment combines the two species. In this case, the stock status is undefined besides a recent increase in the last year.

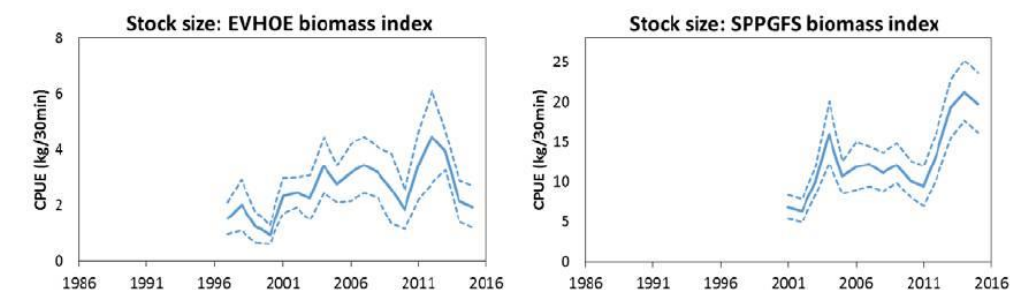


Figure 3.2.1. White anglerfish (*L. piscatorius*) in divisions 7.b–k, 8.a–b, and 8.d. Left: biomass (kg [30 min]⁻¹; dashed lines indicate ± 2 s.d.) from the EVHOE-WIBTS-Q4 survey. Right: estimated biomass index from the survey SPPGFS-WIBTS-Q4 (kg [30 min]⁻¹; dashed lines indicate 80% confidence intervals).

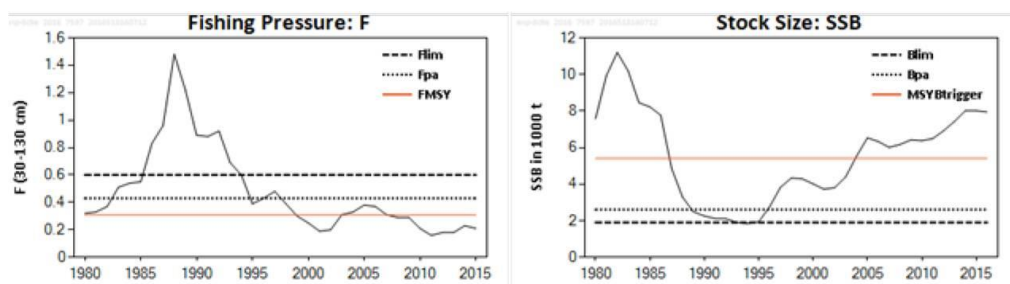


Figure 3.2.2. White anglerfish (*L. piscatorius*) in divisions 8.c and 9.a. Summary of stock assessment: F (30-130 cm) and SSB (weights in thousand tonnes).

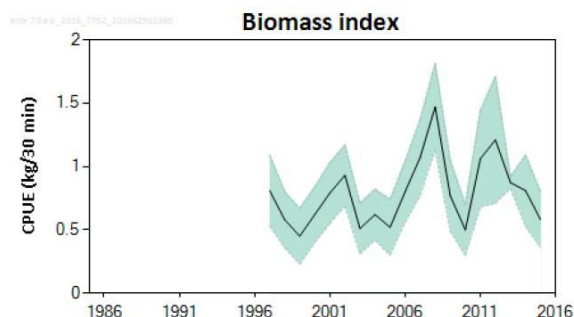


Figure 3.2.3. Black-bellied anglerfish (*L. budegassa*) in divisions 7.b–k, 8.a–b, and 8.d. Stock size (biomass, kg [30 min]⁻¹, shaded areas show ± 2 s.d.) index from the EVHOE-WIBTS-Q4 survey: biomass (kg [30 min]⁻¹, shaded areas show ± 2 s.d.).

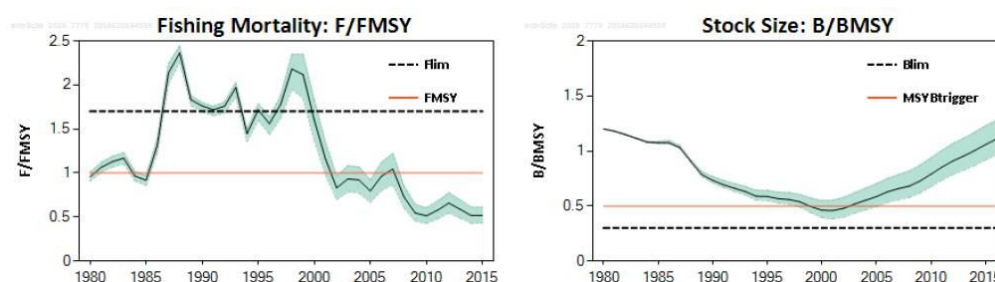


Figure 3.3.4. Black-bellied anglerfish (*L. budegassa*) in divisions 8.c and 9.a. Summary of stock assessment: F/FMSY (bottom left), and B/BMSY (bottom right) with 80% confidence intervals (shaded area).

L. piscatorius displays a larger bathymetric and geographic distribution reaching Icelandic waters and the Barents Sea, while the limit of the distribution of the *L. budegassa* is the north of British Islands. There is a geographical gradient in the contribution of the two species, with a higher contribution of *L. piscatorius* in the northern areas, through a more balanced contribution of the two species in the Bay of Biscay and Cantabric Sea, to a higher contribution of *L. budegassa* in the Portuguese coast. Finally, it is also worth noticing that the some trawl surveys such as those in the Bay of Biscay, Cantabric Sea and Portugal only capture a demographic component of the population, the juvenile component, since larger individuals are distributed deeper.

3.2.1 Evidence for changes in distribution

3.2.1.1 Analysis of ICES trawl data

Presence-absence analyses

For *L. piscatorius*, the trends in the probability of occurrence show significant increasing trends in the North Sea from the early 70s to early 90s when this increase stabilized (Figure 3.2.5). In the more recent years, a significant increase in the presence of this species was only observed in the Irish Sea (Figure 3.2.5). In the southern management units, increasing trends in occurrence were observed in the Bay of Biscay being only significant in the north (Figure 3.2.5), while a decreasing trend in the probability of presence was observed in the south Celtic Sea from early 2000s (Figure 3.2.5).

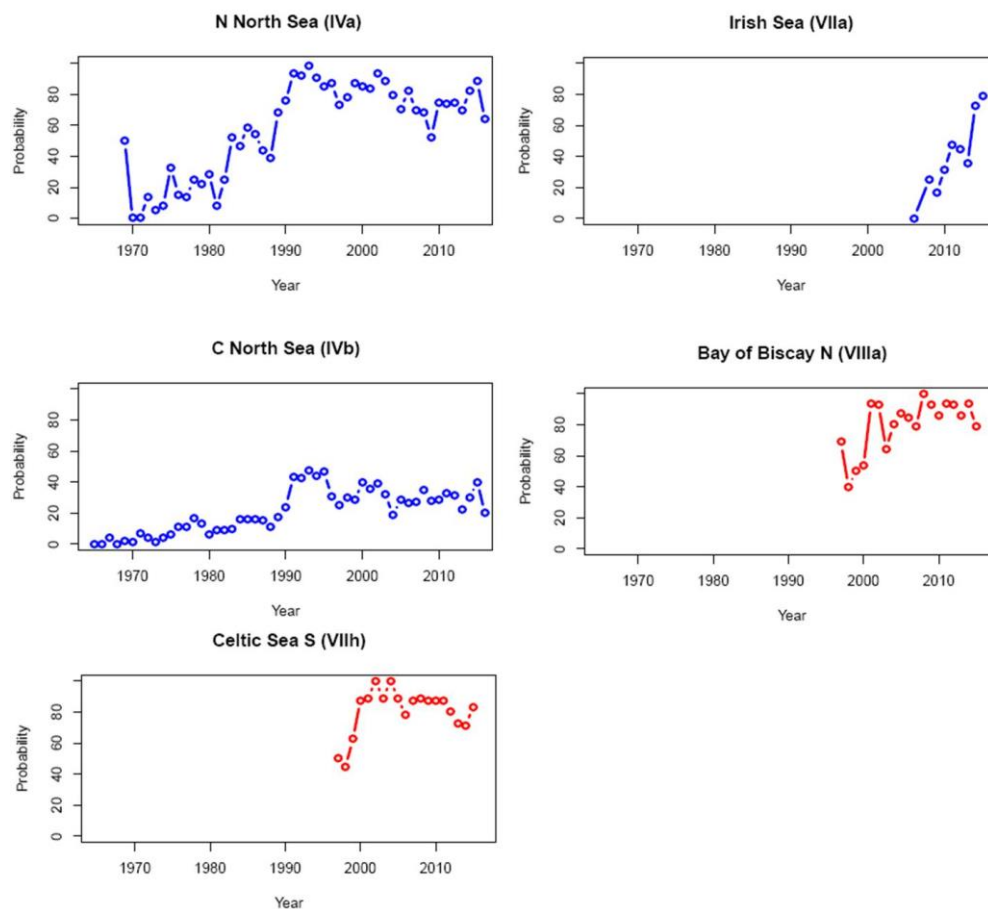


Figure 3.2.5. Trends in presence/absence (i.e. probability of occurrence) of *L. piscatorius* in the North Sea (4a and 4b), Irish Sea (7a), Bay of Biscay (7a) and the Celtic Sea (7h). Only the areas with significant trends are presented.

Regarding *L. budegassa*, only recent and light, but significant increase in the occurrence were observed in the Northern areas such as North Sea, Rockall the Porcupine. In the southern areas, the two Bay of Biscay areas show increase in the occurrence (Figure 3.2.6).

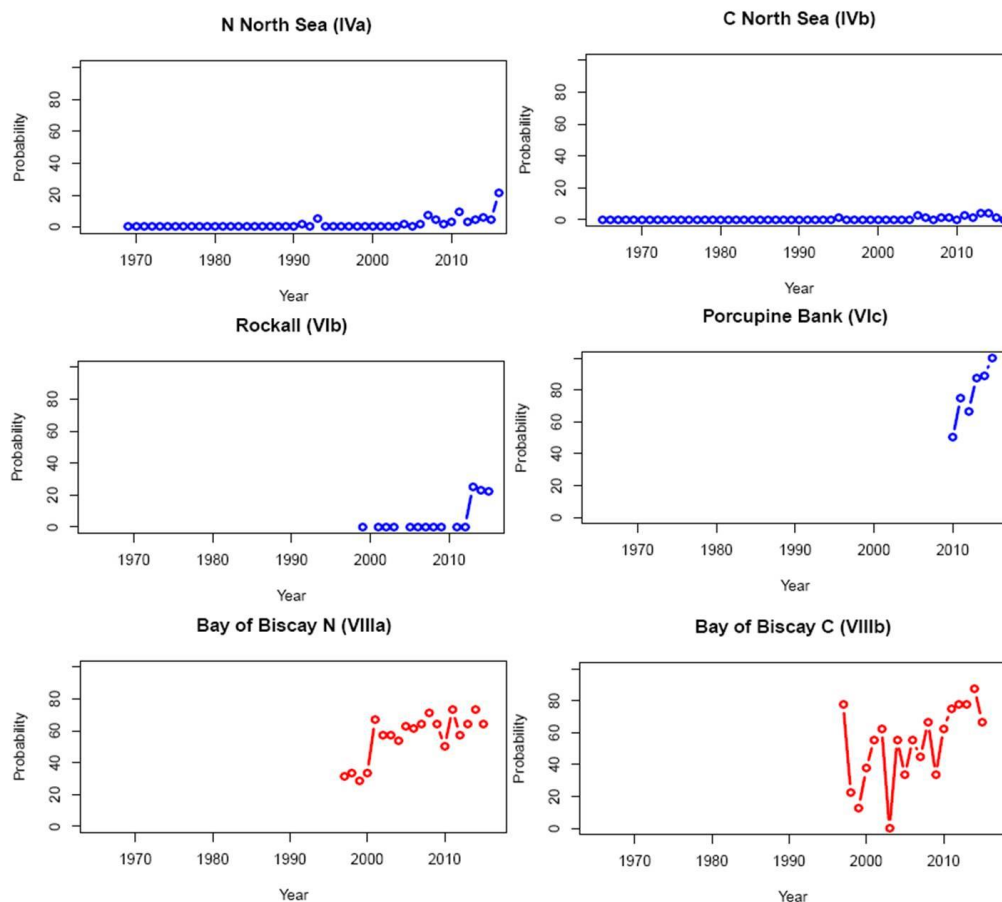


Figure 3.2.6. Trends in presence/absence (i.e. probability of occurrence) of *L. budegassa* in the North Sea (4a and 4b), Rockall (6b), Porcupine bank (6c) and Bay of Biscay (7a and 7b). Only the areas with significant trends are presented.

Centre of gravity of abundance by surveys

The centres of gravity changed for *L. piscatorius* in the recent years but, surprisingly, they showed opposed trends between seasons. In the IBTS Q1, this species showed a displacement to the southeast from late 90s to late 2000s, inverting again the tendency in the recent years (Figure 3.2.7). However, in the IBTS Q3, the tendency is the opposed with a smooth but progressive shift towards the northwest (Fig 3.2.7). This evidences seasonal migration behaviour of this species within the North Sea, but this migration pattern has changed in the last two decades. No evidence of trends were observed in the rest of surveys apart of certain inter-annual fluctuations in certain areas (see for instance the patten in the Bay of Biscay, Figure 3.2.8) that sometimes are not easy to disentangle from the lack of sufficient information in certain years.

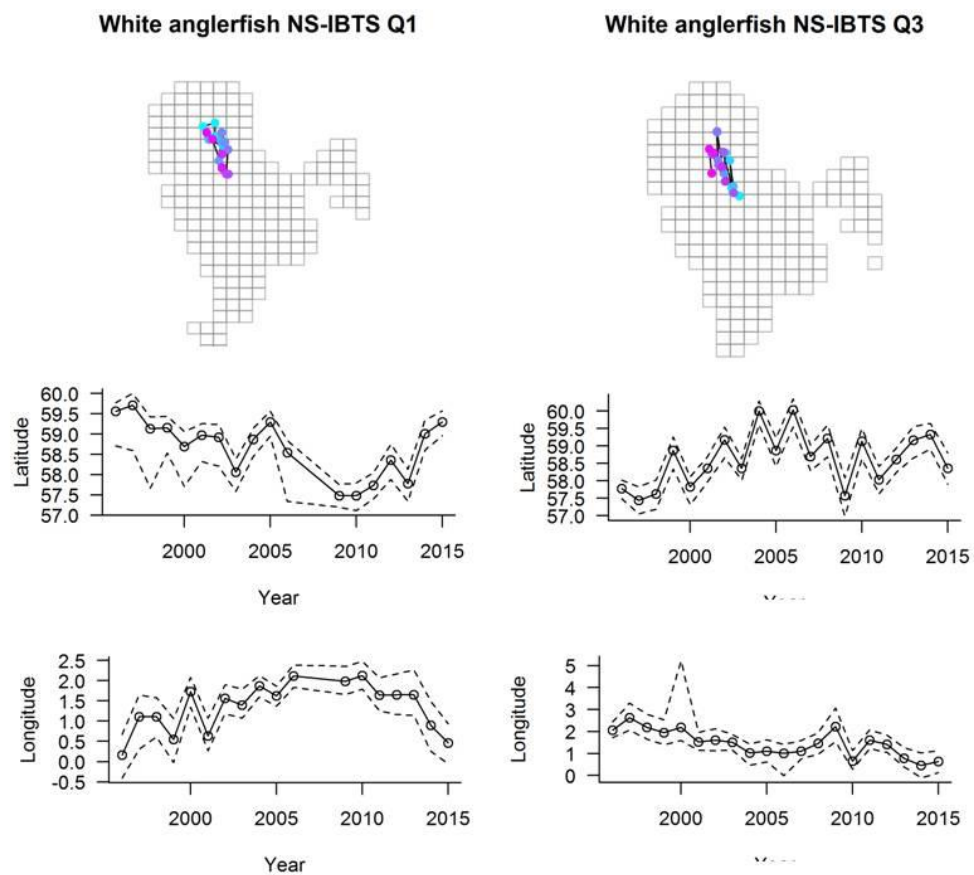


Figure 3.2.7. Shift in the centre of gravity (CG) of abundance of *L. piscatorius* observed for NS-IBTS Q1 (left) and Q3 (right). Above: geographic tracking CG. Colour codes for the inter-annual variation with blue light colours referring the early of the time series and purple de end. Middle: inter-annual variation of latitude coordinate of CG. Bottom: inter-annual variation of longitude coordinate of CG.

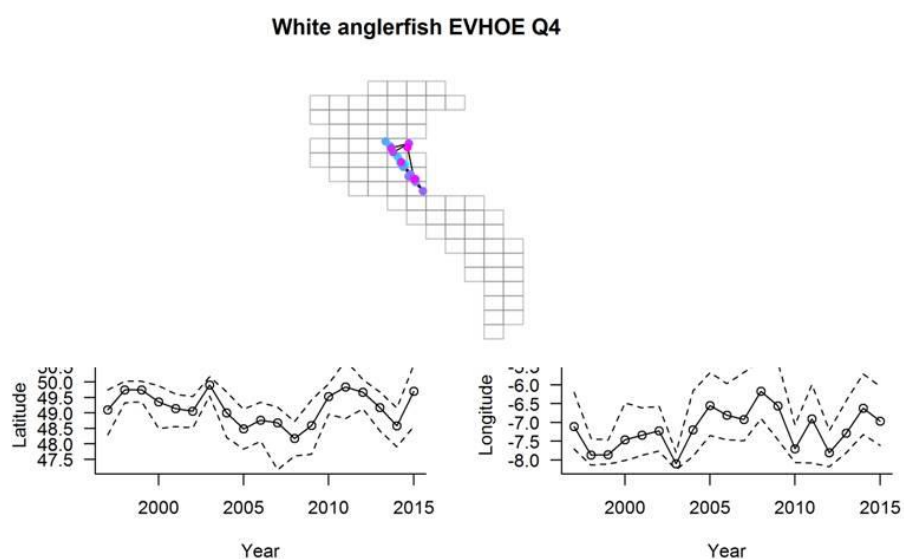


Figure 3.2.8. Inter-annual variation in the centre of gravity (CG) of abundance of *L. piscatorius* observed for EVHOE Q4. Above: geographic tracking CG. Colour codes for the inter-annual variation with blue light colours referring the early of the time series and purple de end. Bottom left: inter-annual variation of latitude coordinate of CG. Bottom right: inter-annual variation of longitude coordinate of CG.

In the case of *L. budegassa*, the only evidence of geographic displacement was observed in the north of Spain with a recent displacement towards northeast using data from 2001 (Figure 3.2.9). However, it is needed to remind that these surveys, as other IBTS, only sample the juvenile component of the populations since older and bigger individuals are distributed deeper.

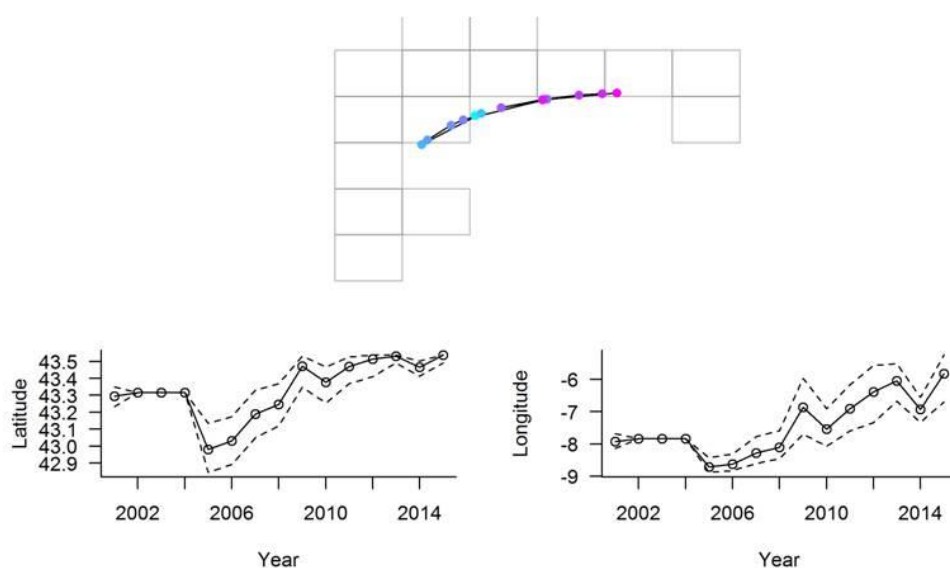


Figure 3.2.9. Shift in the centre of gravity (CG) of abundance of *L. budegassa* observed for SP-NORTH Q4 survey. Above: geographic tracking CG. Colour codes for the inter-annual variation with blue light colours referring the early of the time series and purple de end. Bottom left: inter-annual variation of latitude coordinate of CG. Bottom right: inter-annual variation of longitude coordinate of CG.

Changes in relative abundance between adjacent ICES areas

Regarding the log-ratio analysis, there was not differential contribution across management units for any of the species.

Conclusions

Large geographic shifts in the species distribution are not observed.

All the geographic changes observed occurred at regional level, with different pattern observed for each species.

An expansion of *L. piscatorius* was observed in the North Sea until early 90s when expansion stabilized. In the recent years, other areas such as Bay of Biscay or Iris Sea show increasing trends.

Centres of gravity of *L. piscatorius* in the North Sea display clear temporal patterns that surprisingly contrast between seasons, towards southeast in winter and towards northwest in autumn. Some areas display inter-annual variation with no clear trends such as the Bay of Biscay.

The unique area that shows clear distributional changes for *L. budegassa* is the north of Spain, with progressive displacement towards northeast.

No differential contribution across TAC units was observed for any of the species

Results still need to be taken with caution as some trawl surveys such as those in the Bay of Biscay, Cantabric Sea and Portugal only capture a demographic component of the population, the juvenile component, since larger individuals are distributed deeper.

3.2.1.2 Other evidence

Most of the studies currently available are those for *L. piscatorius*. Evidence of the northward biographic expansion of this species was reported by Solmundsson *et al.* (2010), who evidenced a progressive an increasing abundance on the Icelandic waters from mid 90s. In the North Sea, several studies have demonstrated the increasing and northernmost occurrence and abundance of the species in the last two decades compared with information from the 70s and 80s (Tasker 2008, Figure 3.2.10). Perry *et al.* (2005) attributed this displacement to increasing warming temperatures in the North Sea that is consistent with the deepen distribution towards northern latitudes in the same period reported by Dulvy *et al.* (2008) as temperature was increasing in whole area of distribution. In the north of Spain, recent studies show similar dependency of this species of warming temperatures, with high frequency of occurrence of *L. piscatorius* towards recent years following the increasing trend in warming in intermediate and deep water masses (Punzón *et al.* 2016).

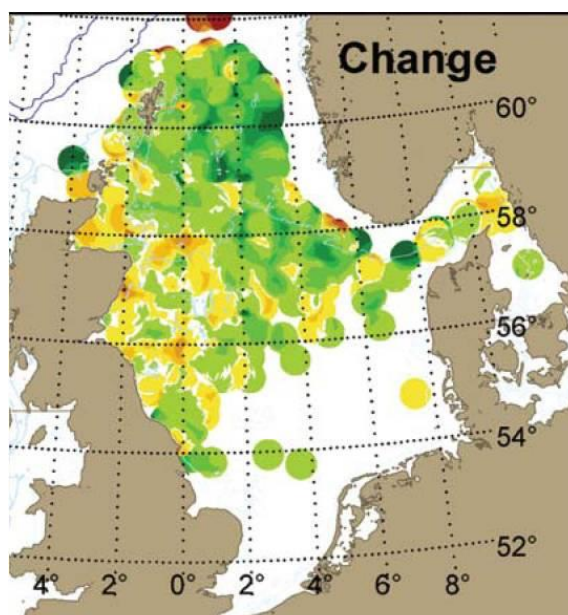


Figure 3.2.10. Relative change in the distribution of *L. piscatorius* between 1977–1989 and 2000–2005 in the North Sea, Quarter 1. Blue–green colours indicate a relative increase in density, with dark colours indicating the largest change, and yellow–red colours indicate a relative decrease in density between the two periods, with red indicating the largest changes (Figure capture from Tasker *et. al* 2008).

There are evidences from mark-recapture and surveys information that support the high capability of movement of this species (Laurenson *et al.* 2005, Velasco *et al.* 2008) that, along with genetics studies, have several times questioned the biological support of the current management boundaries (ICES 2013). By contrast, other studies also point out a high age-specific habitat selection of this species as it is observed when spatial distribution of different age classes are followed over time (Velasco *et al.* 2008).

Regarding studies with the distribution of *L. budegassa*, these are totally absent for the northern areas. However, for the southern areas, recent studies suggest an opposed response to warming temperature in the intermediate waters to that observed on *L. piscatorius*. Thus, the warming in water masses decrease the frequency of occurrence of *L. budegassa* in the north Spain towards recent years that was concomitant with a

shallower distribution of this species towards the recent years (only the juvenile component, Punzón *et al.* 2016).

3.2.2 Review of potential drivers

Although similar drivers can act on the two species there are two elements that need to be highlighted before reviewing the potential drivers. First, given that distribution of the two species geographically and bathymetrically differs and there is a geographic gradient on the contribution of each species, similar drivers in a given TAC or management unit can trigger responses of different strength of each species. And second, and more relevant, given the indications the contrasting responses to warming conditions observed for each species (Punzón *et al.* 2016) they could display opposed responses to similar ecological drivers. This contrasting pattern between species has been also observed between the two species of megrim (see below section 3.12),

Warming has been the main driver observed in the large scale changes in geographic distribution (Solmundsson *et al.*, 2010), while affecting as well the variation in the frequency of occurrence and abundance at regional scale in the North Sea for *L. piscatorius* (Perry *et al.* 2005, Tasker *et al.* 2008, Dulvy *et al.* 2008, and present analyses), and north of Spain for the two species (Punzón *et al.* 2016, and present analyses).

Density dependence habitat selection is the second important driver that, in certain circumstances, can act as a constraint. For instance, in ICES areas where geographic changes in distribution of this species are limited depth compensation mitigates local and regional increases of density, and thus anglerfish expands its habitat to deeper areas when population abundance increases. This may be the case of the progressive increasing in the frequency of occurrence and deepening of *L. piscatorius* in the North Sea during 70s and 80s that arrived to a maximum early 90s when no further change was observed thereafter. A similar pattern was observed in *L. budegassa* in the north of Spain with shallower distribution of the juveniles' distribution in the recent years concomitant with a progressive decrease in the abundance and the frequency of occurrence (Punzón *et al.* 2016). Within a regional scale, age-dependent habitat selection (**demography**) has been observed when age-based information is analysed (Velasco *et al.* 2008).

Migration is a third element to be considered. Ontogenetic (Velasco *et al.* 2008), seasonal (present results) migrations have been reported, as well as large-distance movements of some individuals (mark-recaptured information, Laurenson *et al.* 2008). However, further research is needed to assess potential inter-annual variability in the migration pattern.

3.2.3 Implications of changes in distribution and future trends

3.2.3.1 Consequences for stocks/populations

While future changes in the large-scale geographic distribution of these species are not expected, inter-annual variation of the frequency of occurrence and geographic displacement at regional scales are, with most likely contrasting responses between species. However, it is still not clear which is the relative contribution of warming, density-dependence and seasonal migration for each species and within TAC area.

A synthesis of the potential implications for each driver are shown in the Table. 3.2.3.1.1.

3.2.3.2 TAC management areas

While future regional changes expected in north Spain are not expected to affect the TAC unit (8c) beyond boundaries, changes expected in the North Sea can potentially influence TAC units in the region (4a, 4b) and the boundaries with Skagerrak region (3a). However, analyses presented in present report do not show differential trends across boundaries (i.e. log-ratio analyses).

3.2.3.3 Choke species?

This species can become a choke under the application of Landing Obligation species since it is part of mixed fishery with hake and megrim (ICES 2014). This is most likely in the case of artisanal fisheries such as those in Portugal.

3.2.3.4 Future expectations? Northern shifts? Northern constrains?

Northern large-scale shifts are not expected for any of the species. All the changes expected will occur mostly at regional scale.

Table 3.2.3.1.1. Potential influence and predictability of each the main drivers of change in species distributions.

Drivers	Influential driver	Drivers predictability (and at which time scale)	Predictability potential habitat	Predictability realised habitat
Geographical attachment	No evidence	-	-	-
Environmental conditions	Temperature	Yes (trend not inter-annual variations)	Yes	No
Density-dependent habitat selection	Yes	No	-	-
Spatial dependency	No evidence	-	-	-s
Demographic structure	Yes, age-dependent habitat selection	Yes, the most recurrent pattern. No inter-annual variation	Yes	Yes
Species interactions	No evidence	-	-	-
Memory	Recurrent migration	Yes at seasonal scale and ontogenetic level, not at inter-annual scale.	Yes	Yes
Fishing effort distribution	No evidence	-	-	-

3.3 Blue whiting

Blue whiting (*Micromesistius poutassou*) is a pelagic gadoid species with a very wide distribution in the northeast Atlantic ranging from Morocco to Iceland and the Barents Sea. The highest concentrations are found during spawning season on the west of British Isles and on the Rockall plateau (ICES, 2016). Blue whiting occur between 150 and 3000m deep, with a preference for depths between 300 and 400m. ICES considers only one stock in the Northeast Atlantic which encompasses areas 1–9, 12 and 14. TACs for blue whiting are allocated to four different TAC management areas (Figure 1.3.2): (1) areas 1–8abde, 12 and 14, (2) Norwegian waters of areas 2 and 4, (3) areas 8c, 9, 10 and CECAF 34.1.1, (4) Faroese waters.

3.3.1 Evidence for changes in distribution

3.3.1.1 Analysis of ICES trawl data

Presence-absence analyses

Blue whiting were observed throughout the entire western shelf from the south of Spain to the north of Scotland between 2001 and 2015 where survey data was available for all ICES areas considered in the analysis. In the North Sea, blue whiting were only observed in the northern part and along to Norwegian deep up to the northern tip of Denmark. However, a noticeable increase in the number of observations was observed between 1986-1990 and 1991-1995 with a clear increase in the west of Scotland and the northern North Sea. A few observations were also made in the southern North Sea and the Channel from 2001 onwards although these were scarce. This pattern has remained largely unchanged (Figure 3.3.1).

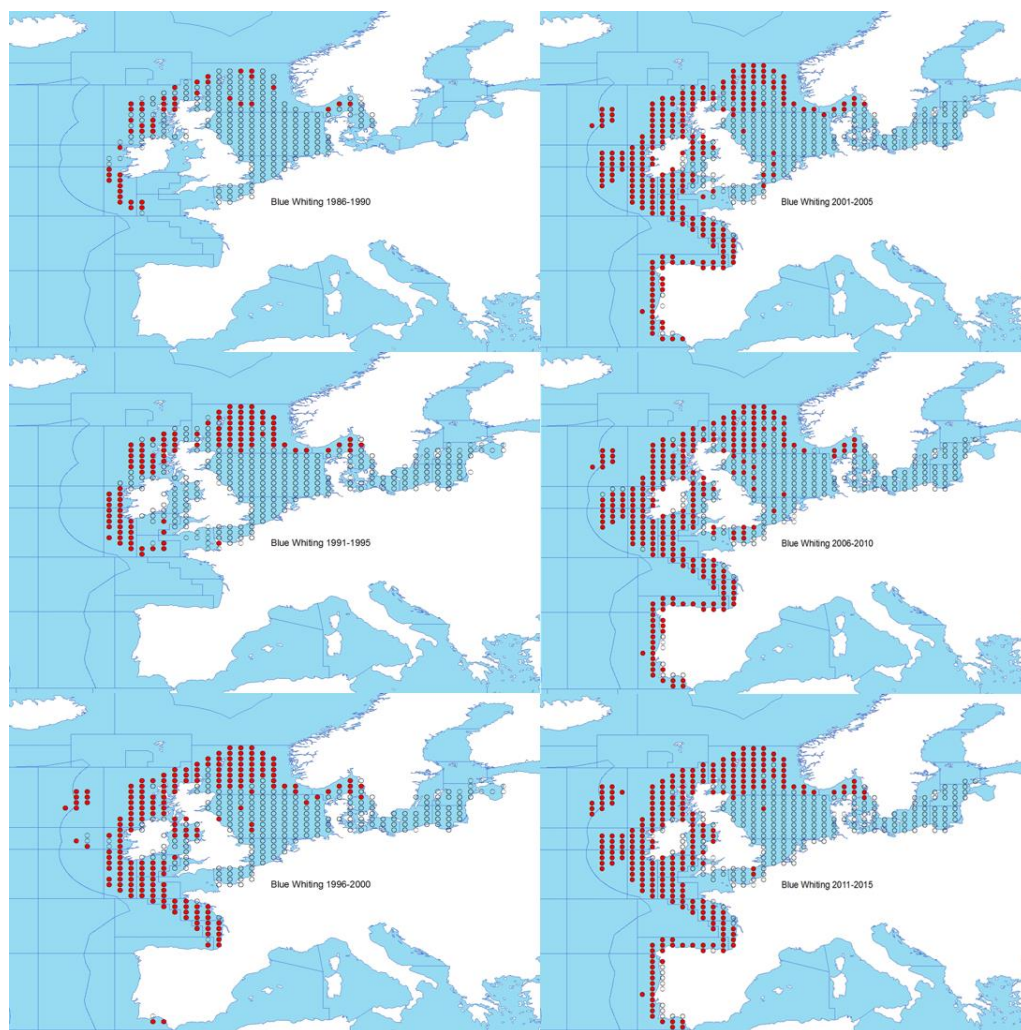


Figure 3.3.1. Presence/absence maps by ICES statistical rectangles for 1986-1990 (top left), 1991-1995 (middle left), 1996-2000 (bottom left), 2001-2005 (top right), 2006-2010 (middle right) and 2011-2015 (bottom right).

Within northern ICES areas (north of Celtic Sea), low probabilities of occurrence of blue whiting were observed in the northern North Sea (4a) throughout the 1970s and 1980s followed by a clear increase in from 1990 onwards after which values remained stable from the late 1990s onwards. This pattern was also clearly apparent in the west of Scotland (6a) with an increase in the 1990s followed by stable values, although no data was available prior the late 1980s to verify whether probabilities of occurrence were also low in the 1970s and 1980s. This pattern was also somewhat apparent in Skagerrak and Kattegat (3a) with a shift from stable and low probabilities of occurrence in the 1970s and 1980s to stable and higher values happening in the early 1990s, although this increase was much more limited (Figure 3.3.2). Within southern areas (Celtic Sea and below), only a slight increase was observed in the Celtic Sea from the late 1990s onwards albeit this trend was very noisy (Figure 3.3.3).

Blue Whiting – northern divisions

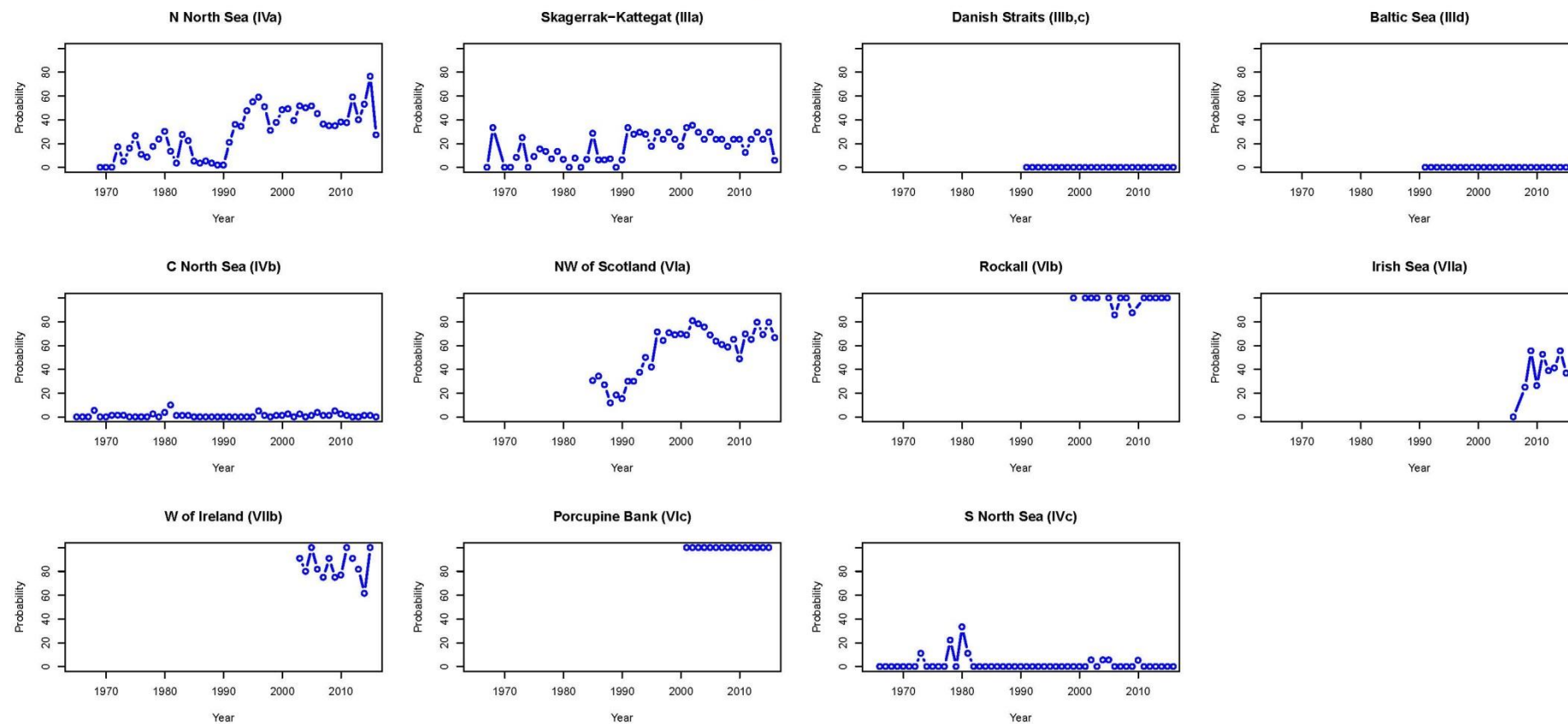


Figure 3.3.2. Blue whiting trends in presence/absence in northern ICES areas

Blue Whiting – southern divisions

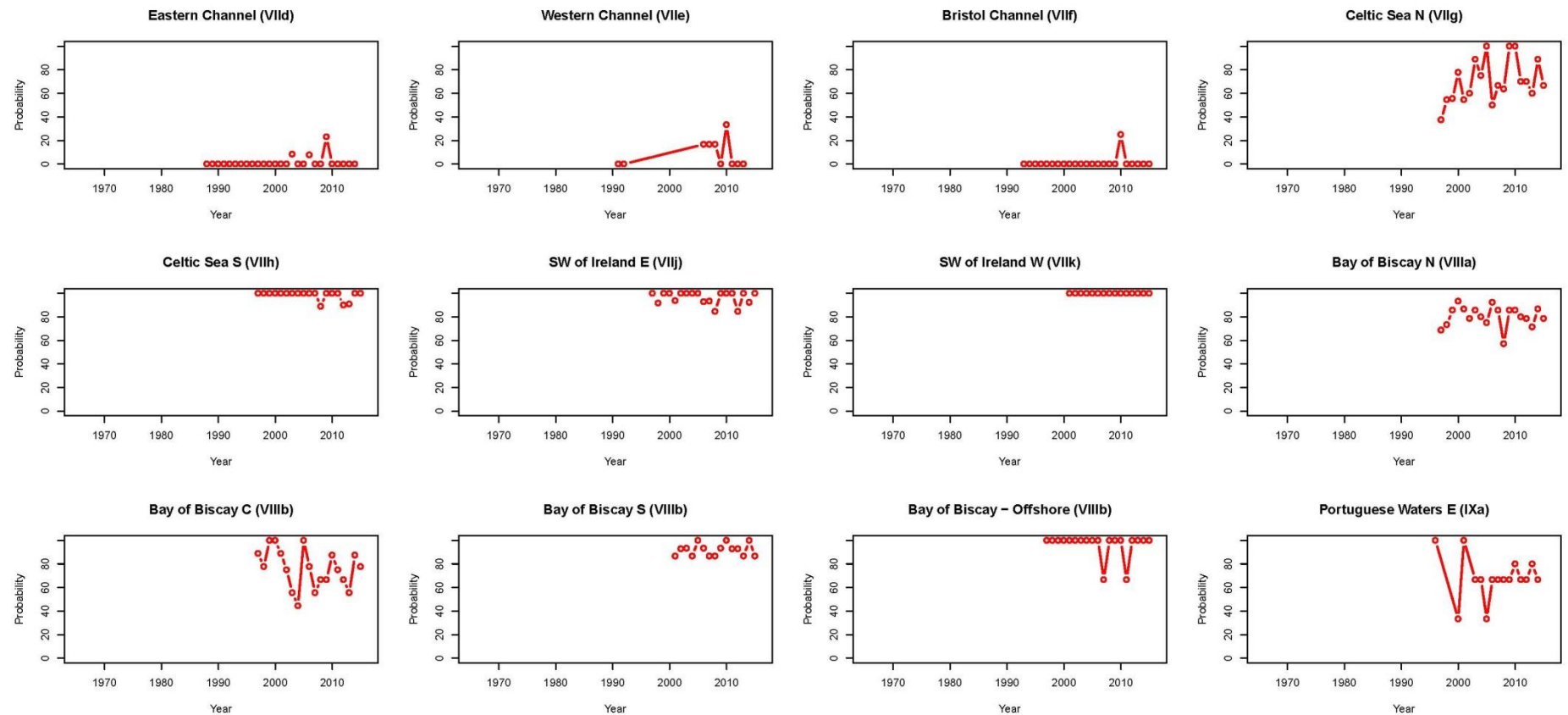


Figure 3.3.3. Blue whiting trends in presence/absence in southern ICES areas

Centre of gravity of abundance by surveys

Two surveys showed a noticeable shift in their abundance's centre of gravities over time: quarter 4 SP-NORTH covering area 8c and quarter 1 SWC-IBTS covering areas 6a and 7a-b (west of Scotland, east and west of Ireland). In quarter 4 SP-NORTH, both the latitude and longitude of the centre of gravity increased over time resulting in a north-eastward shift along the shelf (Figure 3.3.4). In contrast, in quarter 1 SWC-IBTS both the latitude and longitude of the centre of gravity decreased in the early 2000s after which they remained stable, thus resulting in a south-westward shift during this period (Figure 3.3.5).

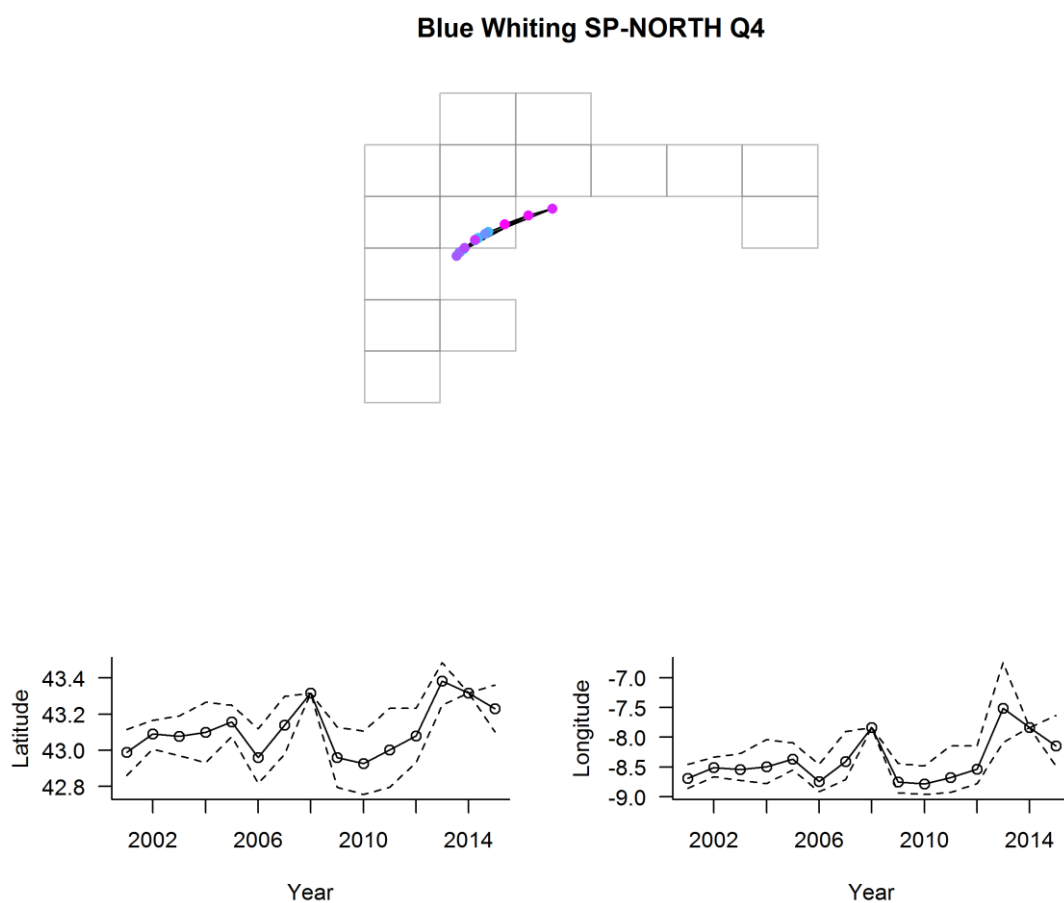


Figure 3.3.4. Shift in the centre of gravity of abundance observed for quarter 4 SP-NORTH.

Blue Whiting SWC-IBTS Q1

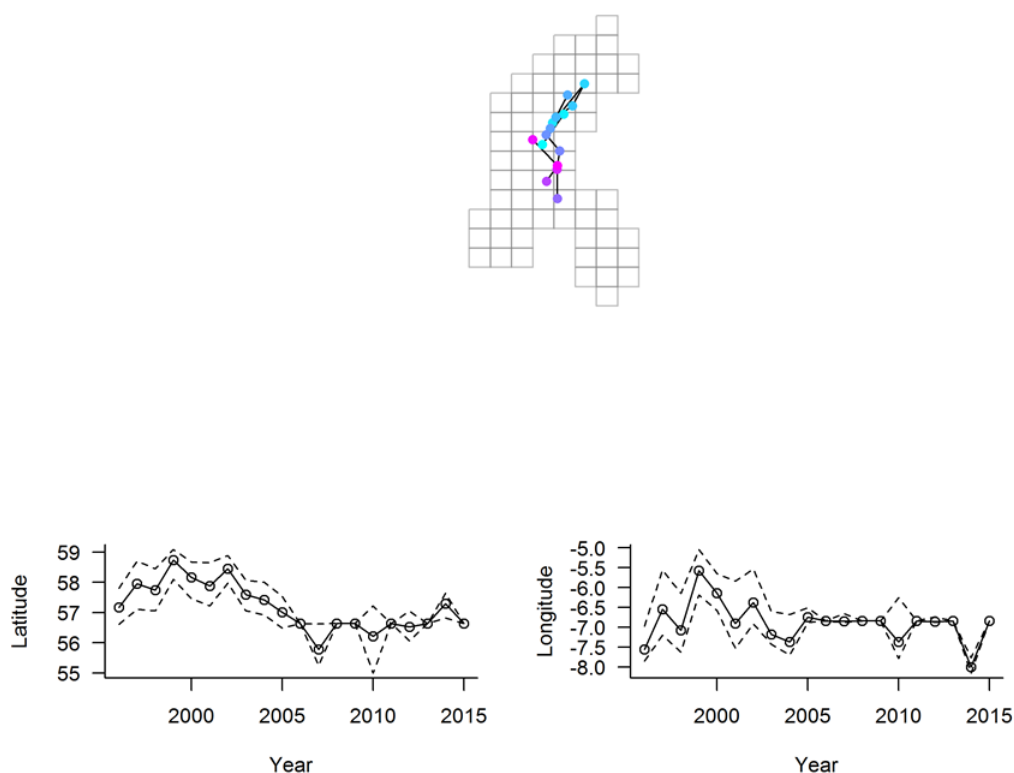


Figure 3.3.5. Shift in the centre of gravity of abundance observed for quarter 1 SWC-IBTS

Changes in relative abundance between adjacent ICES areas

No significant changes in relative whiting abundance between adjacent areas were observed.

Conclusions

Based on the analyses of trawl survey data, a clear increase in the area occupied by blue whiting occurred in the northern North Sea and west of Scotland between 1986-1990 and 1991-1995. This observation was consistent with the trends in probabilities of occurrence which show a clear increase in the 1990s in both areas 4a and 6a, and also in Skagerrak and Kattegat to some extent although this was much more limited. All trends in probabilities of occurrence have remained stable since the late 1990s and the area occupied by blue whiting has remained unchanged for the last 15 years when data was available from all surveys. A noticeable north-eastern shift in the abundance's centre of gravity from surveys was observed on the north coast of Spain while a contrasting south-western shift was observed in west Scotland. This could be explained by an increase in abundances in Biscay and the west of British Isles 'pulling' the centre of gravity, although it is not possible to confirm this with the present analyses.

3.3.1.2 Other evidence

Heino *et al.* (2008) reported a substantial increase of blue whiting in the Barents Sea in the late 1990s and early 2000s based on a combination of bottom trawl and acoustic surveys. They attributed this increase to an influx of northeast Atlantic individuals

due to high recruitment pulses driven by climate warming. Håtun *et al.* (2009) investigated the factors behind strong year classes associated with the threefold increase in the northeast Atlantic blue whiting stock which occurred in the late 1990s. Using a combination of acoustic survey, catches and CPR (i.e. plankton abundance) data they concluded that the spawning distribution of blue whiting was largely determined by the subpolar gyre and the resulting North Atlantic Current (NAC): a strong NAC is associated with low salinity and temperature resulting in spawning occurring in southwest of Scotland/northwest of Porcupine Bank while a weak NAC is associated with high salinity and temperature resulting in spawning occurring further north in northwest of Scotland/Rockall Bank. The subpolar gyre also affects blue whiting migrations routes between the spawning grounds west of the British Isles and the feeding areas in the Norwegian Sea, as shown by Håtun *et al.* (2007). A strong subpolar gyre results in colder conditions, spawning distribution confined to the European continental shelf, a migration path through the Faroe-Shetland Channel and smaller abundances. In contrast a weak gyre results in warmer conditions, spawning distribution that extends over the Rockall Plateau, a migration route west of the Faroe Islands and higher abundances.

3.3.2 Review of potential drivers

Blue whiting spawns mainly on the between porcupine Bank in the south and Hebridean shelf in the north, with intermittent spawning on the Rockall plateau (Trenkel *et al.* 2014). Blue whiting spawning occurs preferentially in water temperature comprised between 10.5 and 11.5°C (Ibaibarriaga *et al.* (2007)). The location of the main spawning grounds has been related to the intensity of the sub-polar gyre, which governs the hydrographic conditions (temperature and salinity) on the Rockall plateau (Hatun *et al.* 2009). A weak gyre is associated with warmer conditions on the Rockall plateau, due to the inflow of warmer subtropical waters. A strong gyre results in a predominance of cold subarctic water. In cold years (strong gyre) the spawning is constrained along the European continental slope and in a southerly position near Porcupine Bank. When the gyre is weak and conditions are relatively saline and warm, the spawning distribution moves northwards along the slope and especially westwards covering Rockall Plateau. The post spawning migration routes are also influenced by the intensity of the gyre.

The location of spawning determines to which areas eggs and larvae will drift, with basically drifting northwards to the main nursery ground in the Norwegian Sea when spawned north of Porcupine bank, or drifting southwards to the Bay of Biscay when spawned south of Porcupine bank (Payne *et al.* 2012).

The abundance of juvenile blue whiting in the Barents sea (nursery ground at extreme north of the distribution), has been shown to be mostly influenced by the size of recent recruitments, and the intensity of the inflow of Atlantic water to the Barents sea possibly improving the thermal habitat for blue whiting (Heino *et al.* 2008).

3.3.3 Implications of changes in distribution and future trends

3.3.3.1 Consequences for stocks/populations

Increased recruitment when the gyre is weak (Payne *et al.* 2012) : spawning then occurs more offshore and egg and larvae are less subject to predation by the mackerel, which is on the continental shelf edge at that time of the year.

3.3.3.2 TAC management areas

Observed changes in the past and current stability on the TAC areas suggest that there is no expected changes that can influence current TAC units.

3.3.3.3 Choke species?

There is some potential in relation to herring and mackerel fisheries.

3.3.3.4 Future expectations? Northern shifts? Northern constrains?

The species is already present in most of the North Atlantic except the North Sea. It seems unlikely that it will enter this area. Little is known about northern ICES areas I and II where the species could be increasing its biomass and distribution.

3.4 Cod

Seven stocks were considered for this assessment based on analysis conducted by ICES: 7a (Irish Sea); 6a W of Scotland; 7 b Rockall; Subarea 4, 7d, 3a N (North Sea English Channel and Skagerrak), IIIaS (Kattegat), subdivision 22 to 24 (W Baltic stock); 24–32 (E Baltic stock). In addition, we will mention the area within the Barents Sea (subarea 1 and 2). It has, however, to be highlighted that the log ratio plot analysis and the presence/ absence analyses did not take into account that 3a are 2 different stock and TAC areas and therefore the result cannot be used to see if there is any change in distribution between these areas.

3.4.1 Evidence for changes in distribution

There is evidence for a change in cod distribution in EU waters towards northern areas as described below.

3.4.1.1 Analysis of ICES trawl data

3.4.1.1.1 Presence/ absence analyses

None of the twelve southern areas assessed by the ICES presence/ absence analyses showed any significant change in either the long time frame or in the shorter time frame (2000 to present).

For the northern areas there were significant changes in the presence / absence analysis. For the long time period there were a significant negative trend west of Scotland (6a) however, not for the short time frame and there was significant positive trend for the area Porcupine Bank (6c), however at a very low level and this area is not included in any of the assessed cod stock regions.

In later years there is a negative trend, although not significant, in the presence/ absence analysis in the southern North Sea and in the Central North Sea.

Table 3.4.1. ICES areas with significant trends in the probability of occurrence of cod in survey hauls in recent years. Mann-Kendall test for monotonic trends. *: $P < 0.05$; **: $P < 0.01$; *: $P < 0.001$; NO: not observed or very low occurrence. Red asterisk indicates decreasing trend whereas green indicates increasing trend.**

ICES area	long time series	2000 - present
Skagerrak-Kattegat (3a)		
Danish Straits (3b,c)		
Baltic Sea (3d)		
N North Sea (4a)		
C North Sea (4b)		
S North Sea (4c)		
NW of Scotland (6a)	*	
Rockall (6b)		
Irish Sea (7a)		
W of Ireland (7b)		
Porcupine Bank (7c)	*	*
Eastern Channel (7d)		
Western Channel (7e)		

Bristol Channel (7f)		
Celtic Sea N (7g)		
Celtic Sea S (7h)		
SW of Ireland E (7j)		
SW of Ireland W (7k)	NO	
Bay of Biscay N (8a)		
Bay of Biscay C (8b)	NO	
Bay of Biscay S (8c)	NO	
Bay of Biscay Offshore (8d)		
Portuguese Waters E (9a)	NO	
Increase	1	1
Decrease	1	0

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

NO Never observed

3.4.1.1.2 Centre of Gravity analyses

North Sea cod

The centre of gravity analysis showed a significant movement towards the north in the IBTS 1st quarter survey. From 1996 to 2015 the centre of gravity for this survey is moved nearly 8 degrees towards the north. For the 3rd quarter survey the movement was not as pronounced however, there seems to be an inconsistency in the data as one of the data points occurred in the Baltic.

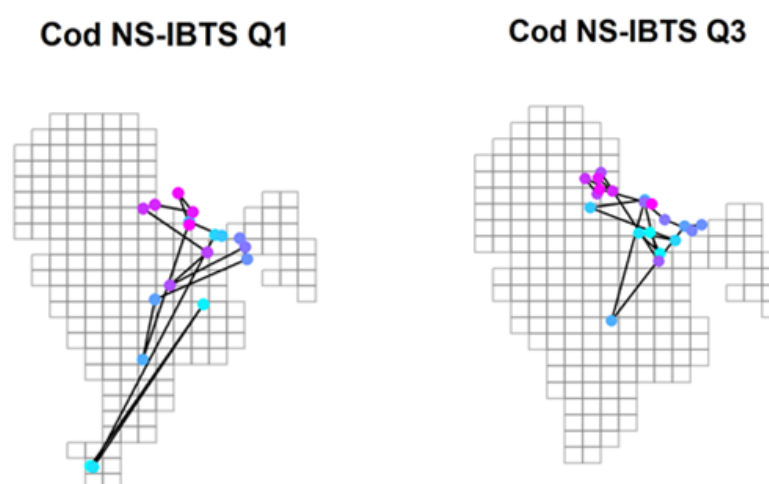


Figure 3.4.1. Annual centre of population mass based on abundance estimates in IBTS quarter 1 and 3 surveys. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

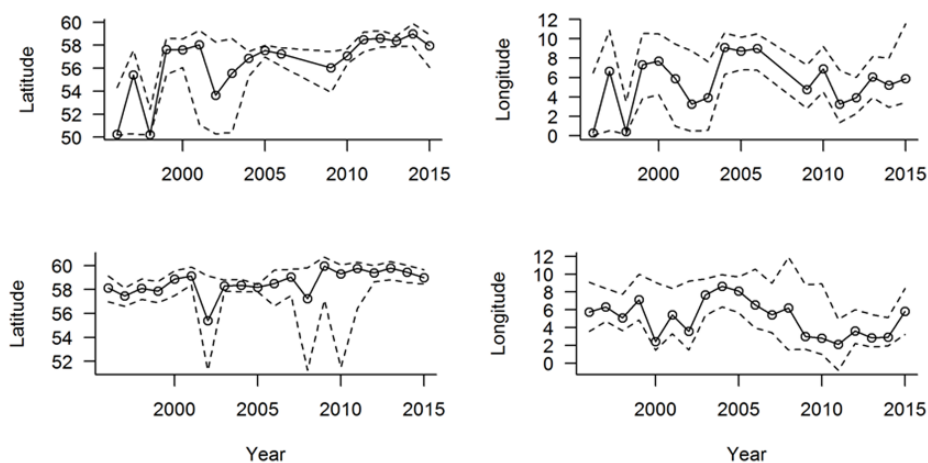
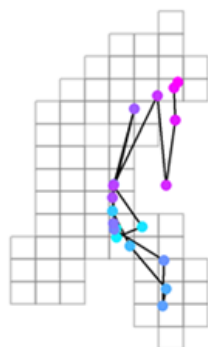


Figure 3.4.2. The corresponding latitudinal (centre panel) and longitudinal (right panel) temporal shifts to Figure 3.4.1.

West of Scotland (4a)

For the cod stock west of Scotland (4a) there was a northern shift in both the SWC-IBTS 1st quarter and 4th quarter however with a stronger trend in the 1st quarter survey (Figure 3.4.3).

Cod SWC-IBTS Q1



Cod SWC-IBTS Q4

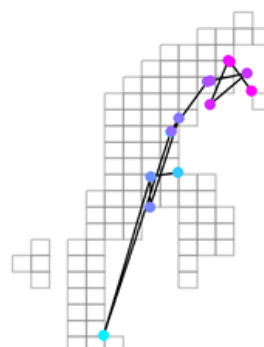


Figure 3.4.3. Annual centre of population mass based on abundance estimates in the west of Scotland survey quarter 1 and 4. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

Baltic cod

For the Baltic cod there was a small indication for a southern distribution of centre of gravity for the time frame shown. However, it was only evident for the 1st quarter survey and not for the 4th quarter survey. The reason for the Baltic shift is however more likely related to the change in stock abundance and a loss of potential spawning area in the eastern Baltic (Gdansk deep and Gotland deep) as the hydrography

changed and decreased the likelihood for cod egg survival in the areas (Eero *et al.* 2012).

3.4.1.1.3 Log Ratio plot analysis

The analyses of the relative abundances across ICES Subdivision illustrated a significant trend of relative change in abundance between two adjacent areas, in four areas; 1) a northern trend from 4b towards 4a within the North Sea management area, 2) a trend from 7d in a northern direction towards 4c, this is within the same stock area, however between two different TAC areas 3) A northern trend from 7b to 6a, that is between stock and TAC areas and 4) the only southern trend from 7b to 7j, however within the same management and TAC area.

The analysis is showing that in the 3rd quarter IBTS survey there is a highly significant movement from the central North Sea to the northern North Sea (Figure 3.4.4). The significant log ratio plot by division (Figure 3.4.5) indicate that the increase in relative abundance in the northern North Sea compared to the south is not a smooth increase over time but rather two time periods with a shift between 2004 and 2005.

All other subdivisions show no relative changes to abundance according to the relative abundance analyses. This is however not in accordance with the biomass indices by sub region produced by the WGNSSK working group and shown in Figure 3.4.6. Here there is also a strong indication of increase in area 3a compared to area 4b.

It has to be noted however, that because Skagerrak and Kattegat was not analysed separately in the log ratio analysis it is not possible to see if there was a movement towards Skagerrak, which is suggested by the analysis conducted by the WGNSSK and presented in Figure 3.4.6.

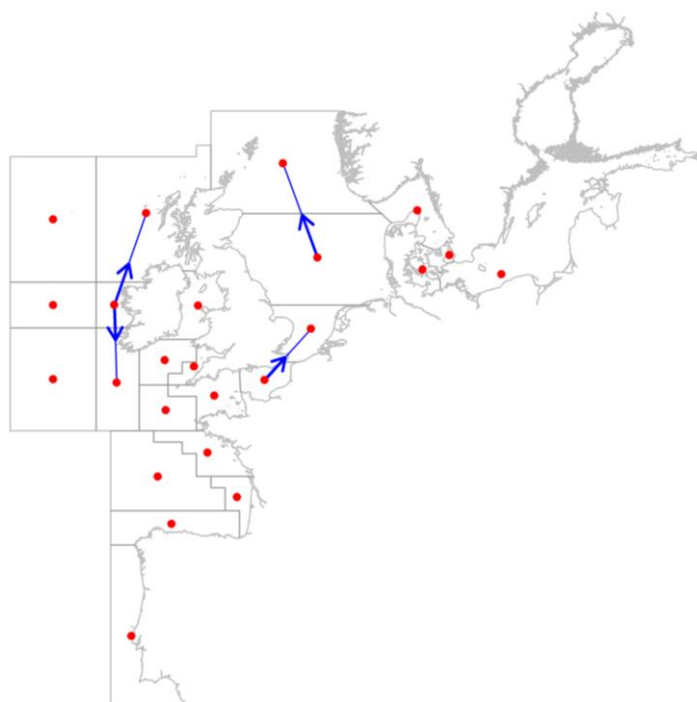


Figure 3.4.4. Significant trend maps. Centroids (red points) of ICES divisions and subdivisions (boxes) used in the analysis of relative changes in cod abundance. Arrows show significant trends where the box at the beginning of the arrow has consistently lower relative change in abundance to the neighbouring box with the terminus of the arrow.

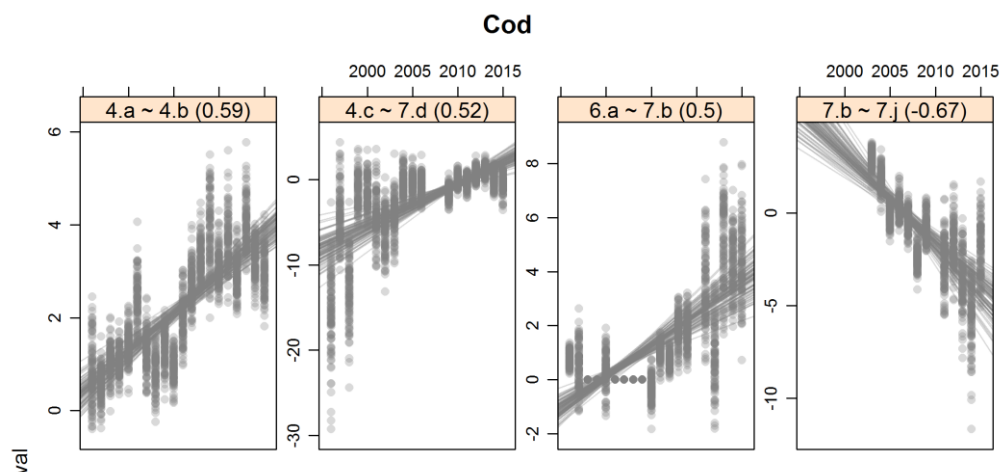


Figure 3.4.5. Significant log ratio plot by division. Indicating a shift between 2004 and 2005 in the relative abundance between area 4b and 4c

Table 3.4.2. The significant relative change used in Figure 3.4.4 and 3.4.5. with information on surveys, slope and P value.

Q	SD	SD	Survey1	Survey2	p	slope	Start year	End year	p_adj
3	4.a	4.b	NS IBTS	NS-IBTS	0.000	0.589	1996	2015	0.018
1	4.c	7.d	NS IBTS	NS-IBTS	0.003	0.516	1996	2015	0.046
4	6.a	7.b	SWC IBTS	SWC-IBTS	0.003	0.497	1996	2015	0.046
4	7.b	7.j	SWC IBTS	IE-IGFS	0.003	-0.667	2003	2015	0.046

3.4.1.2 Other evidence

Environment-driven distributional changes of Northeast Atlantic cod have been documented since the beginning of the 20th century (Engelhard *et al.* 2014). In the North Sea, cod have shown minor distribution shifts during much of the 20th century but shifts have accelerated in the most recent 3-4 decades, and cod are now distributed further north, east and deeper, than in most of the 20th century (Engelhard *et al.* 2014). Rindorf and Lewy (2006) showed that the centre of distribution of the North Sea stock has shifted north under the action of warm and windy winters. In addition the southern range of this population has also shifted north. Similarly, Perry *et al.* (2005) showed evidence of a northwards shift in the North Sea based on the shift of the centre of gravity of the cod distributional range. Statistical analyses revealed that the northward and deepening shift could be attributed to climate change; the eastward shift was most plausibly explained by fishing pressure (Engelhard *et al.* 2014). Note that otter trawl fishing effort was more concentrated in the western than eastern North Sea, at least during the 1990s (Engelhard *et al.* 2015). In recent years, there has again been a slight westward shift of mean cod distribution in the North Sea (and otter trawling effort has shifted more to the northeastern North Sea; Engelhard *et al.* 2015).

The Barents Sea stock has also shown a northwards expansion with larger quantities of cod found further north (Fossheim *et al.* 2015) supported by the highest cod abundance ever recorded (Engelhard *et al.* 2014). For cod, warm temperatures in northern colder regions increase recruitment (Planque and Fredou 1999; Drinkwater 2005) and maximum population growth rates (Mantzouni *et al.*, 2010), whereas warm tempera-

tures reduce recruitment and maximum population growth rates in stocks at the southern limits of the species range; opposite effects occur for cold temperatures. These geographically distinct effects of rising temperatures on local cod stock productivity and demographic rates are contributing to declines of some stocks in the southern part of the species range.

It is worth noting that in the Northwest Atlantic a southward shift has been observed along the Canadian shelf in the early 1990s (Rose *et al.* 1999) associated with a decline of the population. This shift was attributed at least partly to a cooling of the waters and was also observed in other species such as capelin (*Mallotus villosus*).

From the WGNSSK report 2016 analysis has been conducted on the IBTS survey by region within the North Sea and from this analysis it is very clear that cod biomass in all areas of this stock have been decreasing until 2005. Hereafter, it increased again in all areas except in the southern and central North Sea (green line in Figure 3.4.6).

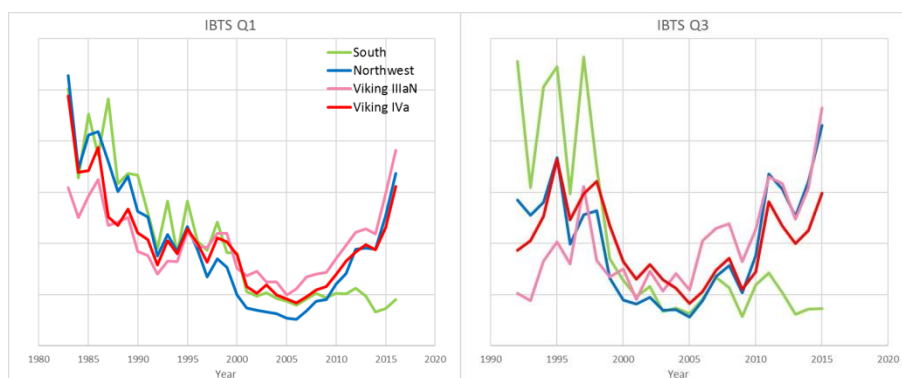


Figure 3.4.6. Cod in Subarea 4 and Divisions 3.a (Skagerrak) and 7.d. Biomass indices by subregion, based on NS-IBTS Q1 and Q3 data, colours correspond to map in Figure 3.4.7 (ICES 2016).

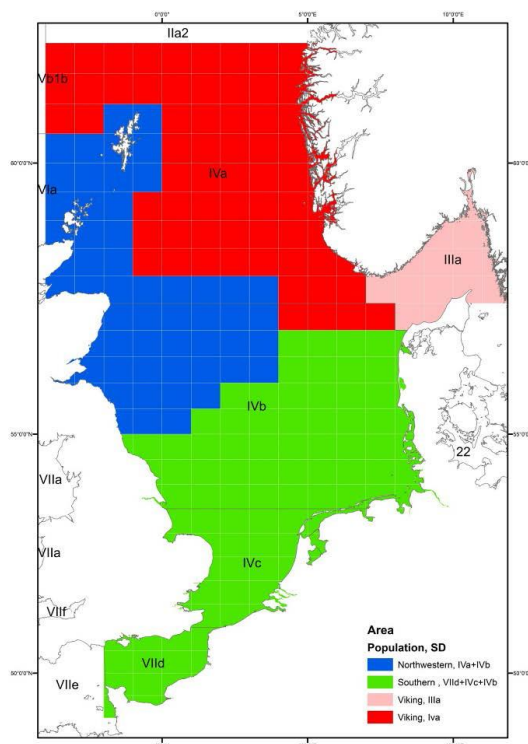


Figure 3.4.7. Cod in Subarea 4 and Divisions 3.a (Skagerrak) and 7.d. Subregions used to derive area-specific biomass indices based on NS-IBTS Q1 and Q3 data. (ICES 2016)

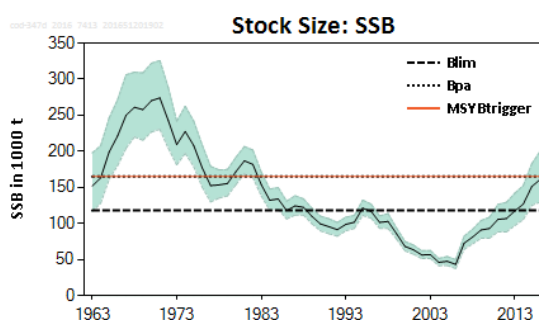


Figure 3.4.8. Spawning stock development for the North Sea, Skagerrak and 7b cod stock.

3.4.2 Review of potential drivers

The following parameters are thought to be drivers of distributional changes: bottom sea temperature, atmospheric processes such as winds, prey availability, distance to the ice edge, fisheries and management of fisheries and density-dependence mechanisms. Static environmental parameters such as depth also act as limitation to distribution.

Temperature is one of the main environmental drivers of cod distribution and recruitment (Planque and Fredou 1999) through several mechanisms ranging from effect on the fish physiology (growth rate, individual condition, age at sexual maturity, timing of spawning, recruitment) (Brander 1997) to the availability of prey for the different age classes. Atlantic cod tend to generally avoid bottom waters colder than 0°C (Gjøsæter 2009), and laboratory studies based on several cod stocks shows that eggs have highest hatch success at temperature of ca. 5-6 C (Tsoukali *et al.*, 2016). A well-documented example of the Greenland cod throughout the 20th Century shows

how rapidly a cod population can expand its range northwards under changing climatic conditions (50 km.y^{-1}) (Storr-Paulsen *et al.* 2004).

In the North Sea strong south westerly winds have been shown to be a contributing factor to the poleward movements of some groups of plankton that in turn influence the biogeography of predators under a strong ecosystem shift in this region (Beaugrand *et al.* 2008). The survival of young cod is strongly associated with the abundance and distribution of copepods in the North Sea, which in turns conditions the abundance of cod stocks (Beaugrand 2004; Brander 2010). For instance, low recruitment in the Celtic Sea is thought to be linked to the negative influence of temperature on key planktonic species for the feeding of larvae (Beaugrand and Kirby 2010).

Several of these factors can act in synergy and it is worth mentioning that as cod stocks have declined especially in the West of Ireland and the North Sea, they have become more sensitive to dynamic environmental drivers such as the NAO due to a shrinkage of the age distribution and geographical extent (Brander 2005; Planque *et al.* 2010). Engelhard *et al.* (2014) suggest that northwards shifts are mainly driven by warming while eastward shifts are mainly driven by fisheries. Cumulative effects between abiotic factors (warming), biotic (prey distribution and long-term fisheries effects have been suggested as drivers of cod distributional shifts in the Northwest Atlantic (Rose *et al.* 1999). Studies linking climatic and fisheries pressures can be found also for the Barents Sea stock although the dominant driver remains unclear (Drinkwater 2005).

Density-dependent mechanisms also influence the distribution of cod (Atkinson *et al.* 1997) with range expansion associated with an abundant stock while a range contraction is associated with a range contraction. However these effects cannot explain the northward shift seen in the North Sea because the overall spawning stock biomass of cod in the North Sea is, although increasing, not yet at the same high levels as seen in the past Figure 3.4.8.

3.4.3 Implications of changes in distribution and future trends

3.4.3.1 Consequences for stocks/populations

New evidence showing the northward spread of fish species along the European shelf appears quite frequently. The northern limits of a number of tropical and sub-tropical species have shifted northwards, particularly along the continental slope, at rates which match the shifts recorded in plankton (Quero *et al.*, 1998). This will likely influence the trophic interactions between species (e. g., between newcomers and native species in a given location) and in turn influence their geographical distribution. Contrasting information regarding species richness in the North Sea is available, however a regime shift is likely to influence trophic links between species (ICES advice book 6, 2008; Beaugrand *et al.* 2008).

3.4.3.2 TAC management areas

TAC areas for cod are in 5 cases not similar as the ICES stock units, in 4 cases there is a match (table 3.4.3.2.1).

Table 3.4.3.2.1 : correspondence between TAC management areas and ICES stock units for cod

Managment Area (TAC area)	Stock Area	Match
------------------------------	------------	-------

SD22-24	SD22-24W Western Baltic cod stock	No
SD25-32	SD24E-32 Eastern Baltic cod stock	No
Skagerrak (SD 20)	IV, SD20 + VIIId North Sea, Skagerrak and 7d stock	No
Kattegat (SD 21)	SD 21 Kattegat stock	Yes
VIIb + Vb (west of 12 degrees)	VIIb Rockall stock	(Yes)
VIa + Vb (east of 12 degrees)	VIa West of Scotland	(Yes)
VIIa	VIIa Irish Sea stock	Yes
VIIbc, VIIe-k, VIII, IX, X	VIIe-k Eastern English Channel and southern Celtic Seas	No
VIIId	Considered part of the North Sea stock	No

In the log Ratio plot analysis conducted by ICES there is evidence for a change in cod distribution in EU waters towards northern areas. Some of the changes are within the same management and TAC area, however for two areas 1) From 7b towards 4c and 2) A northern trend from 7b to 6a the shift is between TAC area.

3.4.3.3 Choke species?

If a stock is having more than one management area and these areas have a fixed proportion of the TAC and the stock is changing the distribution within the management area this could lead to increased issues with choke species. For the cod stocks analysed in this study, the only case where a shift in distribution occurred within a stock and between areas was between TAC areas are from 7b towards 4c.

From the WGNSSK working group report there is however also evidence of an increased cod abundance in Skagerrak compared to 4c and 4b, however as Skagerrak and Kattegat was not analysed separately in the ICES analysis this could not be confirmed.

3.4.3.4 Future expectations? Northern shifts? Northern constraints?

Cod is a demersal species through most of its life cycle and is constrained by the shelf break especially through spawning. In some areas (e. g., North Sea), frontal zones have important impacts on larval and 0-group stages and potentially on recruitment (Munk *et al.* 1995). Therefore temperature is not the only factor that influences the distributional range of this species and an ensemble of factors needs to be considered when looking at projections based on climate forcing scenarios. For example, although temperature range, ice-cover and prey availability might be favourable in a specific regions, cod is unlikely to occur over deep ocean basins such as the Arctic Ocean (Wisiz *et al.* 2015; Ingvaldsen *et al.* 2015).

It is likely that climate change in the coming decades will lead to a northward shift in the geographic range of the species and a shift in the geographic centre of mass of the species' biomass. Most biomass will remain on continental shelves and the productiv-

ity of southern stocks will decline. These changes will affect fishery yields and management decisions.

3.5 Common sole

3.5.1 Evidence for changes in distribution

3.5.1.1 Analysis of ICES trawl data

Presence – Absence

Temporal trends in presence/absence from select surveys over the entire time period of the individually selected surveys show significant increases in occurrence of sole in the northern areas of the Northern North Sea, Skagerrak/Kattegat, Belt/Sound and NW of Scotland (4a, 3a, 3bc, and 6a)(Table 3.5.1).

Table 3.5.1 ICES areas with significant trends in the probability of occurrence of sole in survey halls comparing all available years and only data since 2000. Mann-Kendall test for monotonic trends. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$; NO: not observed or very low occurrence. Red asterisk indicates decreasing trend whereas green indicates increasing trend.

ICES Area	Sole - all years	Sole - From 2000
Skagerrak-Kattegat (3a)	***	
Danish Straits (3b,c)	**	
Baltic Sea (3d)		
N North Sea (4a)	**	*
C North Sea (4b)		*
S North Sea (4c)		
NW of Scotland (6a)	**	
Rockall (6b)	NO	
Irish Sea (7a)	**	
W of Ireland (7b)		
Porcupine Bank (7c)	NO	
Eastern Channel (7d)		
Western Channel (7e)		
Bristol Channel (7f)		
Celtic Sea N (7g)		
Celtic Sea S (7h)		
SW of Ireland E (7j)		
SW of Ireland W (7k)	NO	
Bay of Biscay N (8a)	*	*
Bay of Biscay C (8b)		
Bay of Biscay S (8c)	NO	
Bay of Biscay Offshore (8d)		
Portuguese Waters E (9a)	NO	
Increase	5	3
Decrease	1	0

Whilst the influence of changes in survey design and execution over the longer time-scales cannot be ruled out, the latter half of the steep increase in occurrence reported in the Skagerrak/Kattegat (Figure 3.5.1) is matched by an increase in landings and abundance estimates from 1984. The significant increases detected in the deeper, more northern areas of the Northern North Sea and NW Scotland (4a and 6a) are represented by only a mild increase in their probability of occurrence but have risen from no presence to some presence. In the Northern Bay of Biscay (8a) there is a slow but increasing trend of occurrence (Figure 3.5.2) which isn't matched in the stock biomass or landings reported in the ICES advice discussed later.

The probability of occurrence in the Irish Sea was significant and decreased from 100% of hauls to ~80–90% of hauls. This drop in occurrence corroborates the large decline in stock size and catches observed in ICES advice described below.

When considering only the survey data since the year 2000 (Table 3.5.1), most of the observed long term trends are no longer significant, however the small increases in the Northern North Sea (6a) and Bay of Biscay (8a) remain significant as they were only considered as far back as 1998 to begin with. After an unexplained massive decrease in occurrence from 1996, sole in the Central North Sea has been slowly but steadily and significantly increasing in abundance here, near the northern limits of its range.

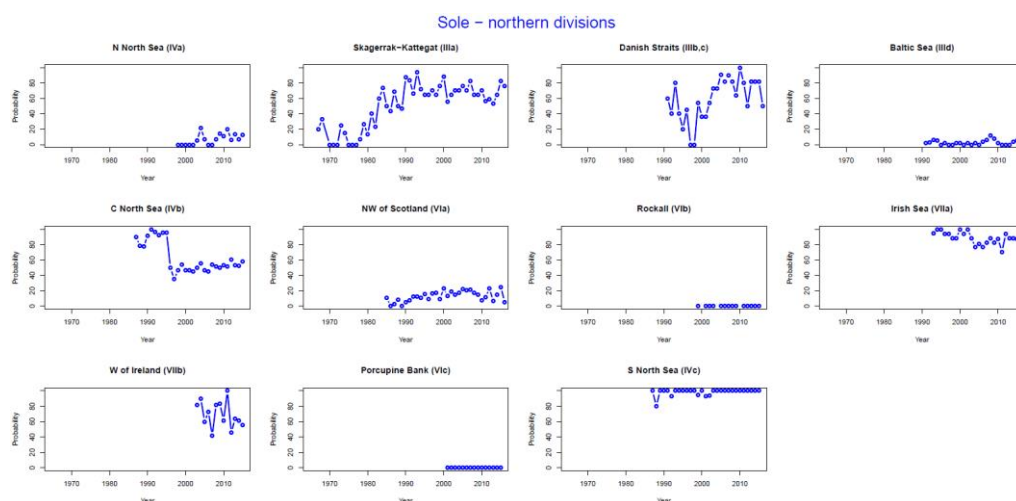


Figure 3.5.1 Probability of occurrence of sole in survey hauls within northern ICES divisions and subdivisions.

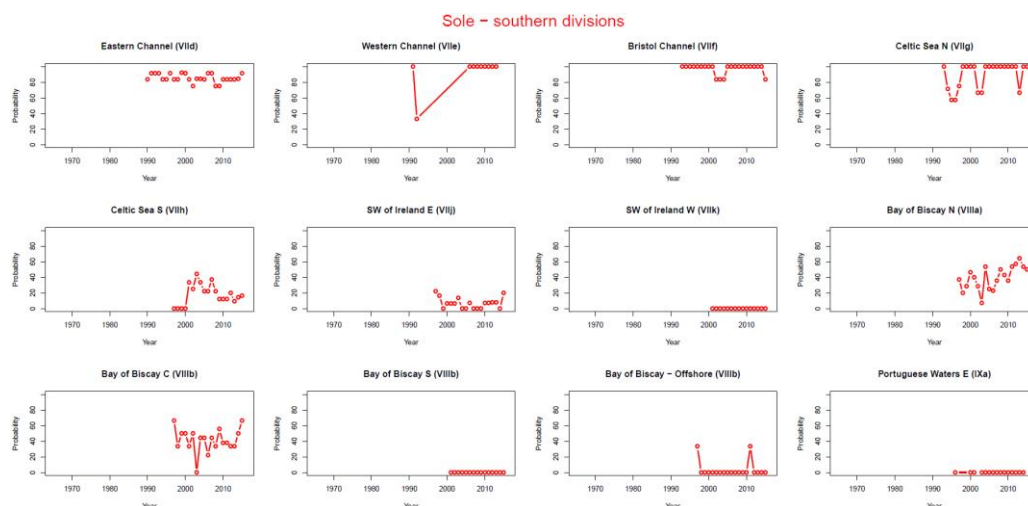


Figure 3.5.2 Probability of occurrence of sole in survey halls within southern ICES divisions and subdivisions.

Abundance Trends

Abundance index by management region and survey

The centre of population mass calculated from the first quarter, North Sea International Bottom Trawl Survey (NS-IBTS Q1) (Figure 3.5.3) shows a more consistently northern position in the latter years of the survey, however, these points remain within the historical range of the survey and their positions are confounded by the low specificity of the survey methods for sole and the inclusion of trawls into the Skagerrak/Kattegat across the Jutland Peninsula. It is therefore recommended that where possible the beam trawl surveys are used for the analysis of sole.

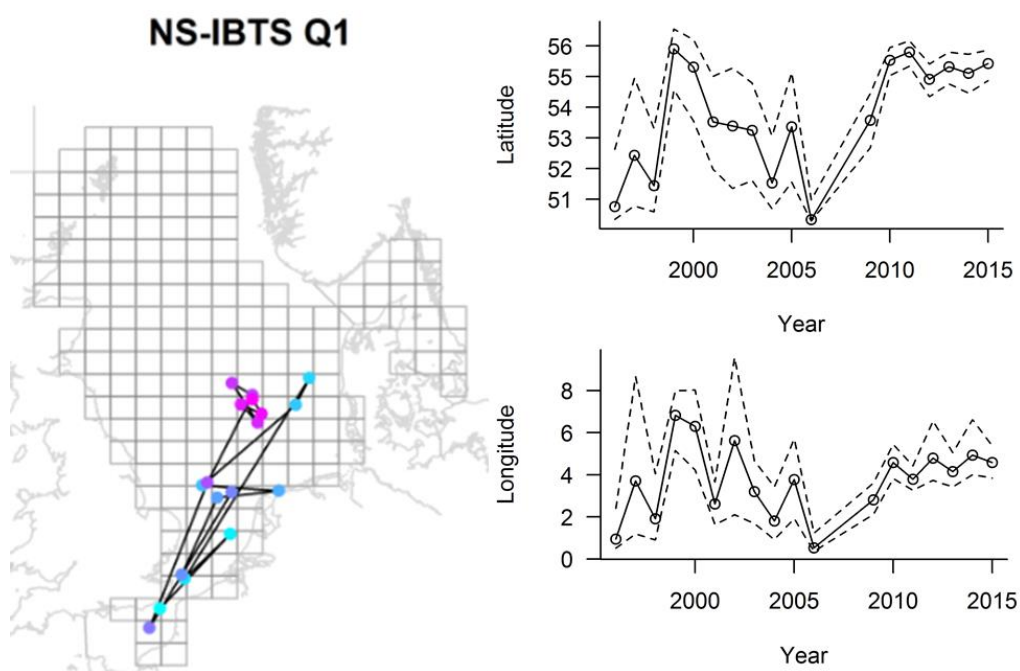


Figure 3.5.3 Annual centre of population mass (left panel) based on abundance estimates in NS-IBTS quarter 1 surveys and the corresponding latitudinal (right-top panel) and longitudinal (right-bottom panel) temporal shifts. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

In the North Sea the Beam Trawl Surveys from quarter three (Fig 3.5.4) show a much more tightly clustered centre of population mass than the NS-IBTS, with no indication of population shift. This trawl series employs a gear type which is more targeted at flatfish, and in particular, the nocturnal sole. Furthermore the analysis of this trawl series is not confounded by sampling across the Jutland Peninsula.

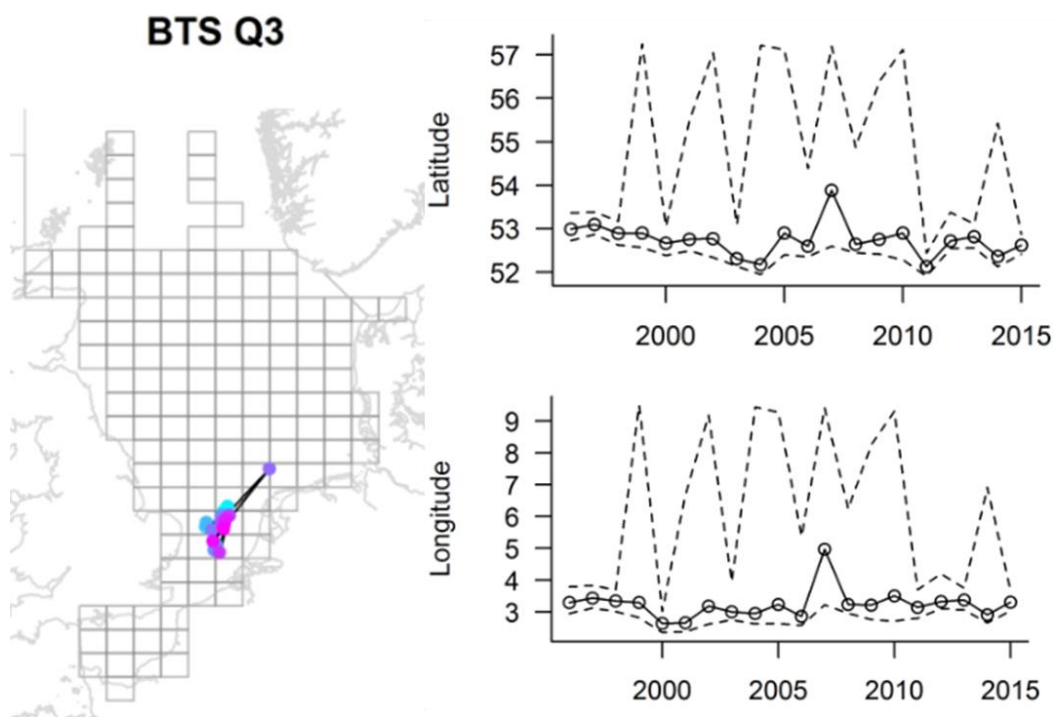


Figure 3.5.4 Annual centre of population mass (left panel) based on abundance estimates from BTS quarter 3 surveys and the corresponding latitudinal (right-top panel) and longitudinal (right-bottom panel) temporal shifts. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

Other analyses using different trawl surveys in different areas show little to no major changes. The Scottish West Coast International Bottom Trawl Survey illustrates a small northward shift off the north coast of Ireland in quarter one, whilst in the fourth quarter it shows no such directional shift. Similarly the French EVHOE surveys in quarter 4 show no consistent temporal trend between the Bay of Biscay and Bristol channel/Celtic North stocks (8ab, and 7fg).

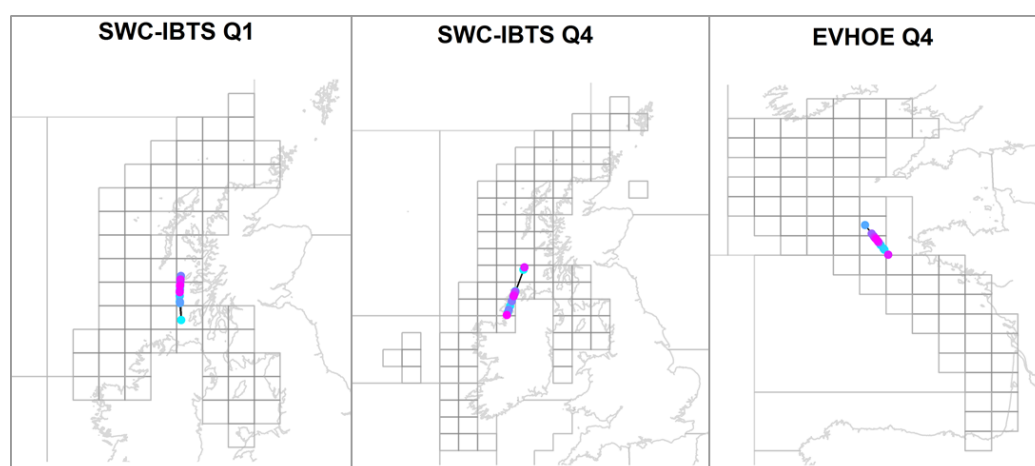


Figure 3.5.5 Annual centre of population mass based on abundance estimates from SWC-IBTS quarter one (left panel), quarter four (centre panel) and EVHOE quarter 4 (right panel). Light blue points correspond to the beginning of the time series while the light pink points represent the end.

log ratio plot analysis

The analyses of the relative changes in abundances across ICES Subdivisions (Fig 3.14.7) illustrate only one significant trend between the Eastern English Channel (7d) and the Southern North Sea (4c). Here we see that the population in the Southern North Sea area (4c) has been increasing in abundance relative to the Eastern English Channel.

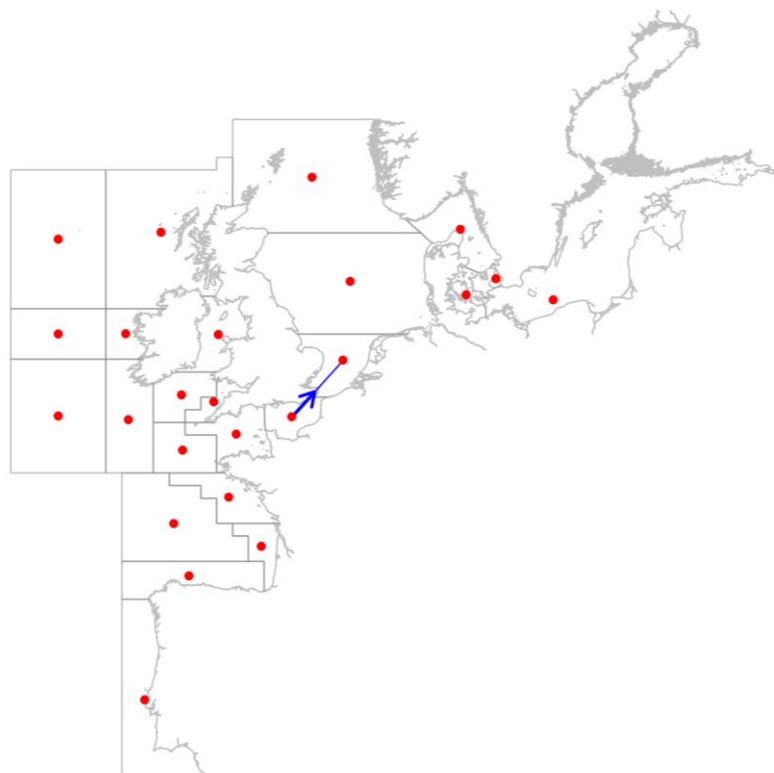


Figure 3.5.6 Centroids (red points) of ICES divisions and subdivisions (boxes) used in the analysis of relative changes in abundance sole abundance. The blue arrow shows a significant trend where the box at the beginning of the arrow has consistently lower relative abundance to the neighbouring box with the terminus of the arrow.

3.5.1.2 Other evidence

ICES stock advice for sole were considered for temporal indications of stock size change and ad-hoc comparisons of neighbouring stocks (Figure 3.5.7)

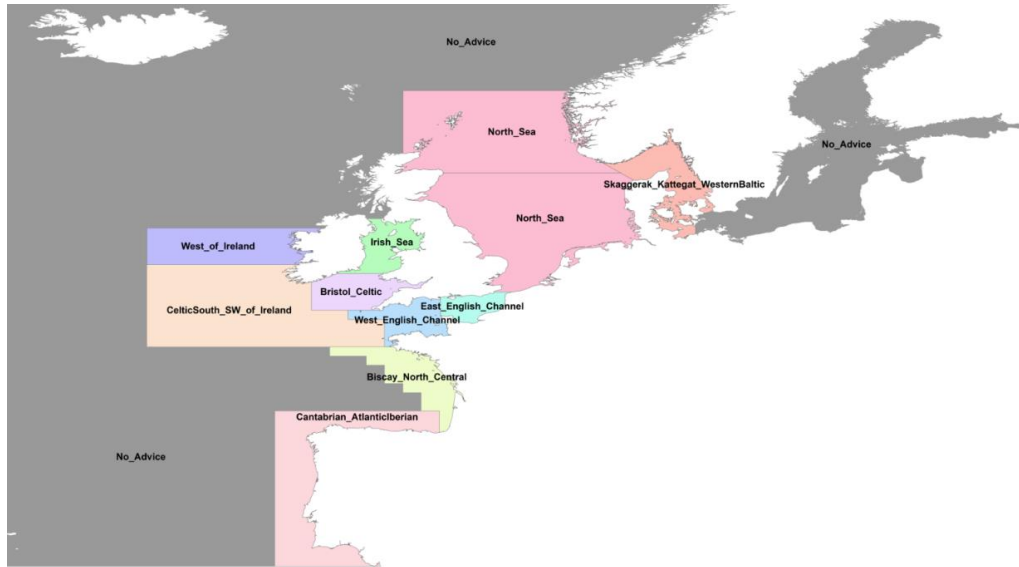


Figure 3.5.7 ICES advice areas for sole.

Comparisons of trends in SSB across the East English Channel and the North Sea (Figure 3.5.8) show no apparent explanation for the significant trend seen in the relative abundance comparisons (Figure 3.5.6). This is likely due to the advice being presented on a stock level for the whole of the North Sea (4a, 4b and 4c) whereas the above relative analysis compared only the sub-division of the Southern North Sea (4c) with the East English Channel (7d).

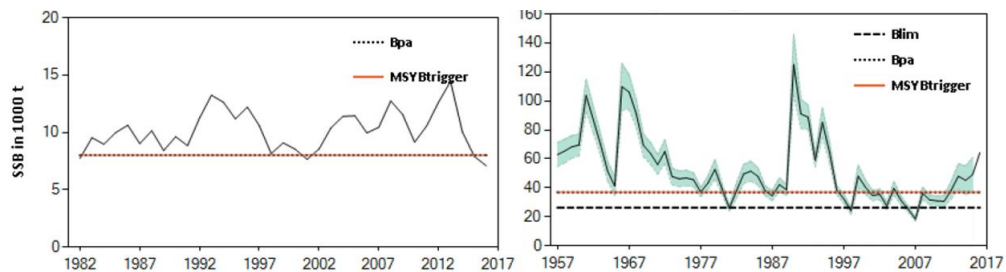


Figure 3.5.8 ICES advice SSB for the East English Channel (VII7d) and the North Sea (4abc), left and right panels respectively. Note the different scales on both x and y axes.

Besides a small period of population growth for the Irish Sea in the mid-1980s, both the Irish Sea (7a) and the Bristol Channel/Celtic Sea North (7fg) have exhibited declining stock size (Figure 3.5.9) under high fishing mortality. This shared trajectory explains why the decline in the Irish Sea (7a) was not identified in the relative trend analysis between neighbours. However, whilst the English Channel West stock (7d) has a more stable SSB, there was no difference detected between it and the declining Bristol Channel/Celtic Sea North (7fg) stock.

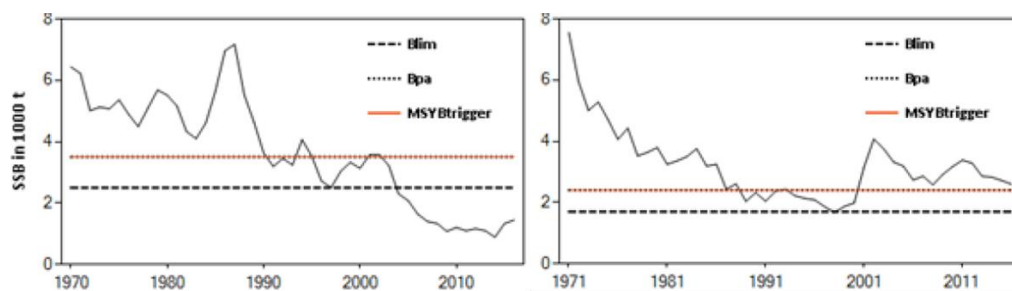


Figure 3.5.9 ICES advice SSB for the Irish Sea (7a) and the Bristol Channel/Celtic Sea North (7fg), left and right panels respectively. Note the different start dates on the x axes.

3.5.2 Review of potential drivers

In the northern areas of the species range population size seems to be tightly coupled to highly variable annual levels of recruitment. In the North Sea (4) this is illustrated by extraordinarily high recruitment of year 1 individuals in 1988 and 1992 followed by peaks in SSB two years later in 1990 and 1994, respectively (Figure. 3.5.10). Whilst in the Irish Sea (7a) peaks in abundance in 1984, 1985 and 1986 as well as a relative peak in 1991 and good recruitment from 1997 through 2000, managed to increase the spawning stock during a period of population decline under high (but decreasing) fishing mortality.

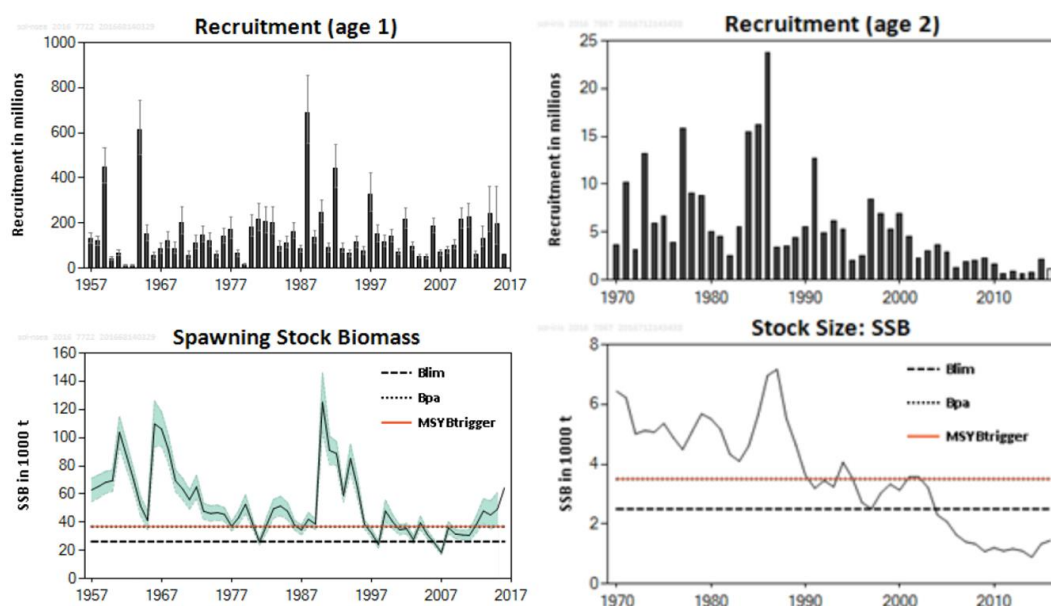


Figure 3.5.10 Time series of stock specific recruitment (top two panels) and SSB (bottom two panels) for sole in the North Sea (4) and Irish Sea (7a), left and right columns respectively.

In the northern part of its range sole recruitment is highly variable, even when disregarding cold anomaly years. This was exemplified by Rijnsdorp *et al.* (1992) where the inter-annual variation in recruitment was reported as 77% in the northern stocks and 55% in the southern stocks and was further corroborated by Le Pape, Chauvet, Désaunay & Guérault (2003). Following spawning of vast numbers of individuals, recruitment is regulated during both the pelagic pre-larval stage (J. Horwood, Cushing, & Wyatt, 2000) and the benthic post-larval stage (Le Pape & Bonhommeau, 2015). In the pre-larval stage a major bottleneck of for the cohort is the probability of settling in an appropriate juvenile habitat, which is both spatially (bathymetry and

hydrodynamics) and temporally (development and hydrodynamics) dependent. In the Vilaine estuary delta, an important nursery for sole in the Bay of Biscay, larval supply and settlement is heavily dependent on terrestrial freshwater input during settlement (Figure. 3.5.11) which is in turn dependent on changing seasonal patterns of precipitation (Bates, Kundzewicz, Wu, & Palutikof, 2008).

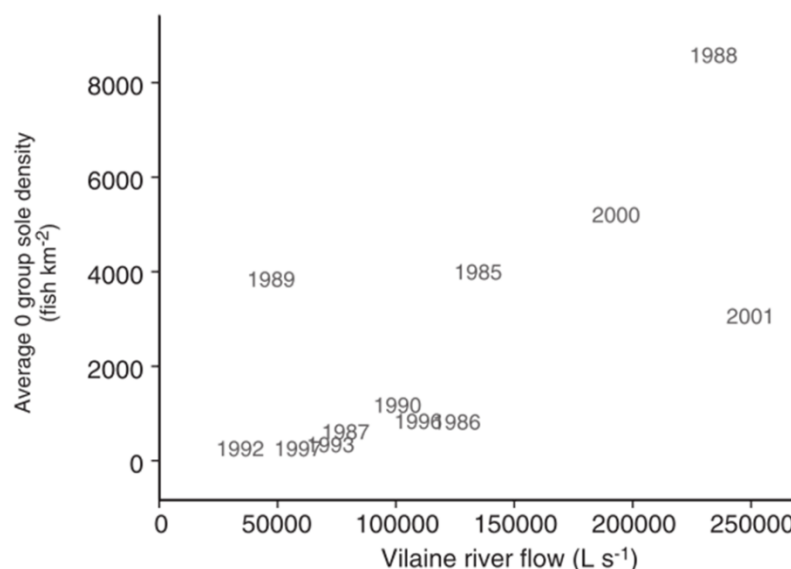


Figure 3.5.11 Young of the year settling sole density in the Bay of Vilaine, a major nursery for the Bay of Biscay sole stock, in relation to terrestrial freshwater outflow from the Vilaine River. Linear regression: $R = 0.7$, $p < 0.1$ After Le Pape, Chauvet, Désaunay, & Guérault (2003).

Furthermore, Le Pape *et al.* (2003) suggest that once settled, increased riverine run-off creates not only a larger area of juvenile growth habitat but also a more productive one for sole leading to increased growth and survival to recruitment.

In the Eastern English Channel, through the North Sea to the Skagerrak/Kattegat fluctuating coastal temperatures and benthic productivity have been shown to influence the productivity of sole (Teal, van Hal, van Kooten, Ruardij, & Rijnsdorp, 2012). Under warmer and concurrently more eutrophied coastal regimes, which are to be expected with climate change and changing land-use practices, the potential growth rates of different age-group sole increase across the studied northern and north-central parts of its range (Figure. 3.5.12), indicating a likely increase in productivity of the species here.

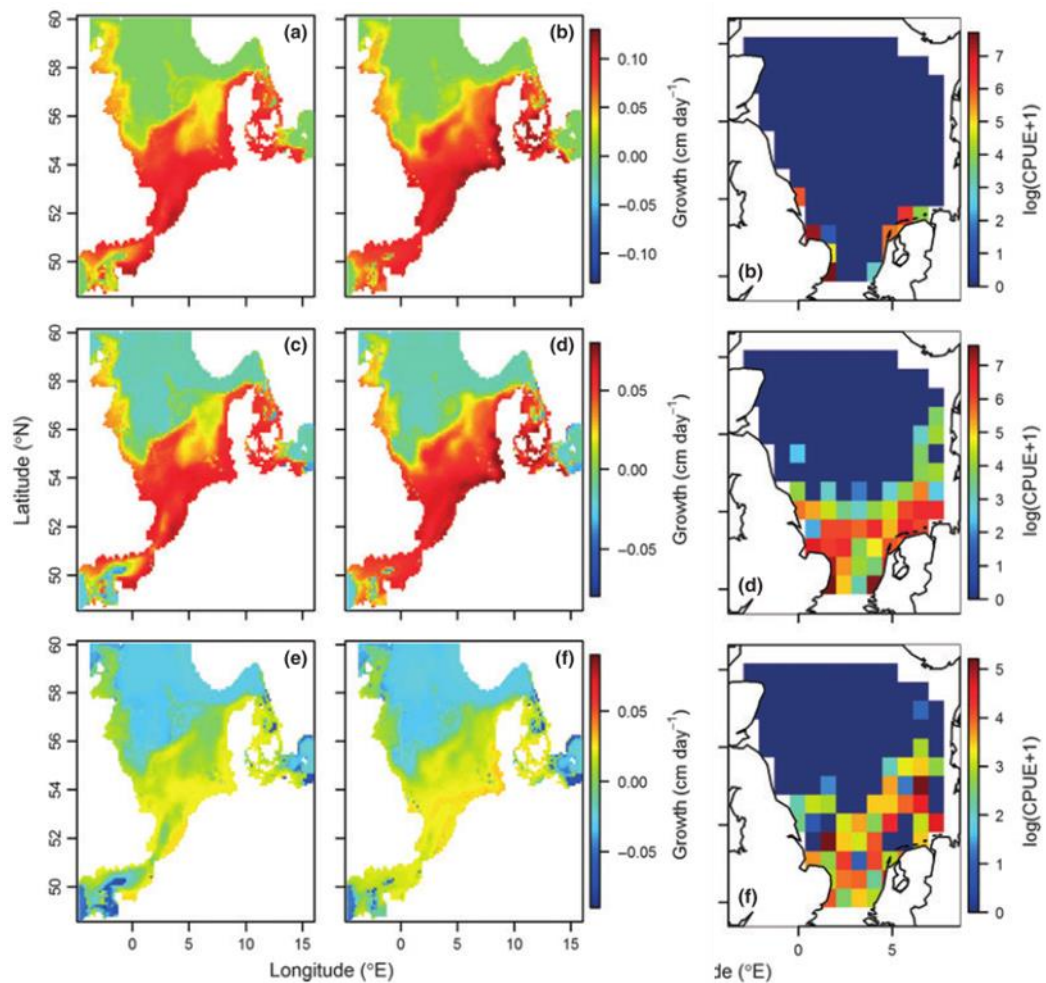


Figure 3.5.12 Maps of the North Sea including the English Channel to the Western Baltic showing maximum expected growth rate (Left two columns) from combined DEB and benthic productivity models for sole with starting lengths of 1.5cm (a, b), 20cm (c, d) and 40cm (e, f) in two different years: High nutrient, low temperature (a, c, e) and lower nutrient, higher temperature (b, d, f). The right panel shows average abundance of sole across the North Sea from 1990 – 2010 for size classes 9-15cm (top), 19-25cm (middle), >35cm (bottom). Figures taken from Teal *et al.* (2012).

The common sole has been shown to exhibit highly structured sub-population dynamics, whereby local stocks are isolated at smaller scales than currently managed (Archambault *et al.*, 2016; Guinand, Rolland, & Bonhomme, 2008; J. W. Horwood, 2001). Therefore short to medium term deviations outside of the tolerance ranges for any one life-history stage could risk local stock collapse. For North Sea sole, Engelhard *et al.* (2011) documented a southwestward, shallowing distribution shift – which is somewhat opposite to the expected with climate change. They attributed this to a lack of severe winters and therefore better survival of sole in shallow waters in recent, milder winters. There was also a significant link between the distribution shift of sole and fishing pressure, and this may relate to targeted fishing for this high-value species (Engelhard *et al.* 2011). Note that sole have not only shown a distribution shift in response to climate change, but also phenological shift – in various western European sole stocks, sole now spawn earlier in the year than they did some decades ago (Fincham *et al.* 2013).

3.5.3 Implications of changes in distribution and future trends

Increases in the northern extent of sole's range have occurred in the past and there is evidence that increasing temperatures are likely to continue this trend into the future. Whilst there was a significant trend detected comparing abundance in the North Sea and Eastern English Channel, this is unlikely to have immediate implications for management in the channel, as this detected relative change in abundance is driven by the increase in the north.

In the middle of its range, sole's juvenile habitat appears to regulate population size and so increases in population size are dependent on the availability and productivity of juvenile habitat. The former of which is at least partially mediated by changing precipitation patterns, whilst the latter may be impacted by increasing temperature and terrestrial nutrient conditions.

Sole stocks in the North Sea are highly productive although sole are reaching their northern limit. This productivity at the current edge of the species extent is likely to continue under proposed climate change scenarios; however caution must be taken to consider cold years with adult mortality and extremely variable recruitment success.

Furthermore, whilst increased growth of sole can be expected in northern areas of its extent, productivity of shallow, coastal juvenile areas may become limiting depending on the extent of benthic productivity loss expected to be incurred via the reduction in terrestrial nutrient sources.

3.6 Greenland Halibut

Greenland halibut in the North Atlantic is assessed as three separate stocks: 1) Greenland Halibut in Subareas I and II (Northeast Arctic), 2) Greenland Halibut in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland) and 3) Greenland Halibut in NAFO subarea 0. This review only deals with the two stocks in the ICES area.

The overall TACs for Greenland Halibut in the ICES area, were 19 000 tonnes (North-east Arctic stock) and 21 900 tonnes (Greenland and Iceland stock).

3.6.1 Evidence for changes in distribution

3.6.1.1 Analysis of ICES trawl data

No analysis was available of ICES trawl survey data for Greenland Halibut.

3.6.1.2 Other evidence

Limited information is available on the changes in spatial distribution of Greenland Halibut in the Northeast Arctic.

There are no strong indications of change in the distribution of Greenland Halibut in the east of Greenland, around Iceland and Faroes (ICES, 2016). Fishery in the entire area did in the past occur in a more or less continuous belt on the continental slope from the slope of the Faroe plateau to southeast of Iceland extending north and west of Iceland and further south to southeast Greenland (figures 3.6.1.2.1-2). Fishing depth ranges from 350–500 m south-east, east and north of Iceland to about 1500 m at East Greenland (ICES, 2016).

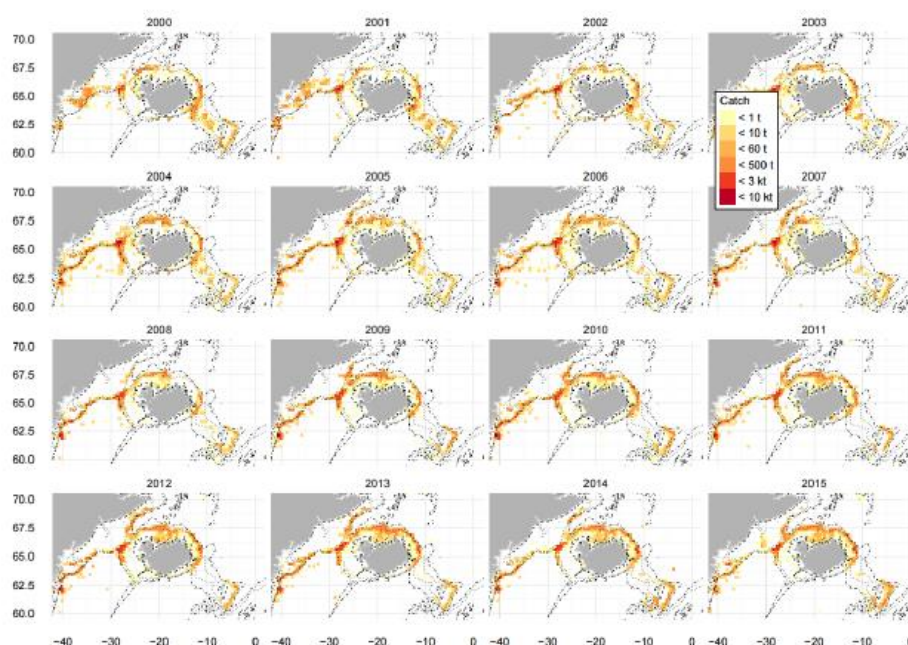


Figure 3.6.1.2.1 Greenland Halibut in subareas 5 and 14. Distribution of total catches in the fishery 2000-2015. Depth contours for 500 and 1000m shown. Source: NWWG 2016.

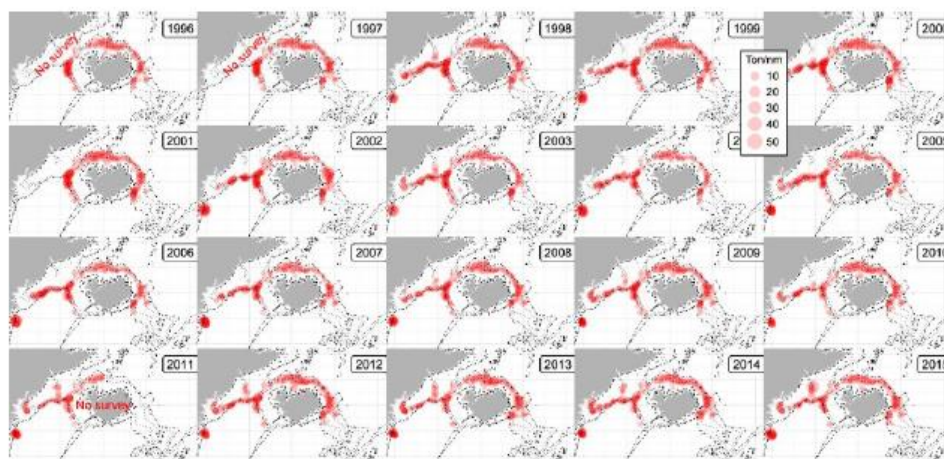


Figure 3.6.1.2.2 Greenland Halibut in subareas 5 and 14. Distribution of catch rates from the combined Greenland-Iceland autumn survey since 1996. Source: NWWG 2016.

3.6.2 Review of potential drivers

Greenland halibut are widely distributed over extensive geographic areas of both the Northwest and Northeast Atlantic Ocean with no break in the continuity of the respective distributions (Bowering and Nedreaas, 2000). Although the entire Greenland halibut resource in the North Atlantic is genetically homogeneous, they mainly comprise separate interbreeding stocks in each of the two regional areas investigated. Generally, larger fish become more abundant and smaller fish less abundant in progressively deeper water with peak abundance occurring over a depth range of 400–1000 m. Greenland halibut in the Northwest Atlantic were observed to be most abundant in bottom temperatures mainly between 2 °C and 6 °C compared to 0 °C to 4 °C in the Northeast Atlantic (Bowering and Nedreaas, 2000).

Distribution and abundance of juvenile Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*) was investigated based on annual bottom-trawl surveys in the Barents Sea and Svalbard area in 1983–2000 (Albert *et al.*, 2001). The period with extremely low abundance of Greenland Halibut (1990–1995) was associated with a northerly displacement of the distribution within the survey area. Survey abundance, the range of distribution within the survey area and the proportion covered by the surveys were all negatively correlated with temperature in the Atlantic Water of the Spitsbergen Current.

Movement, depth and temperature preferences of Greenland halibut, west of Greenland was investigated by tagging large individuals with pop-off archival transmitting tags in Cumberland Sound, Baffin Island, Canada in August 2010 (Peklova *et al.*, 2012). Greenland halibut exhibited strong site fidelity to localised deep areas (900 to 1400 m). All tags were popping off within 27 km of the tagging location. Mean depth was 1048 m during the ice-free season and 823 m during the ice-covered season. Temperature occupied by Greenland halibut from August until June ranged from 1.3 to 2.7°C.

3.6.3 Implications of changes in distribution and future trends

In the absence of clear changes in distribution of Greenland Halibut, no information is available on the implications of change in distribution. Possibly, a change in water temperature is not directly affecting stocks that are resident in deeper waters, like Greenland Halibut.

3.6.3.1 Consequences for stocks/populations

No information

3.6.3.2 TAC management areas

No information

3.6.3.3 Choke species?

No information

3.6.3.4 Future expectations? Northern shifts? Northern constrains?

No information

3.7 Haddock

Haddock (*Melanogrammus aeglefinus*) is a boreal species distributed in the demersal habitat of the Northeast Atlantic from the Celtic Sea to the Barents Sea and around Iceland (Svetovidov, 1986). Since 2014, ICES considers seven stocks in the Northeast Atlantic: (1) southern Celtic Seas and English Channel stock in areas 7b-k, (2) Irish Sea stock in area 7a, (3) Rockall stock in 6b, (4) North Sea, West of Scotland and Skagerrak stock covering areas 4, 6a and 3a20, (5) Northeast Arctic stock in areas 1 and 2, (6) Icelandic stock in 5a and (7) Faroese stock in area 5b. TACs for haddock stocks are allocated to eight different TAC management area (Figure 1.3.2): (1) areas 1 and 2, (2) areas 2a and 4, (3) areas 3a22-32, (4) Norwegian waters south of 62° N, (5) areas 5b and 6a, (6) areas 6b, 12 and 14, (7) area 7a and (8) areas 7b-k, 8, 9, 10 and CECAF 34.1.1. Survey data were only available for the area spanning stocks 1 to 4 listed above and consequently only these stocks are considered hereafter.

3.7.1 Evidence for changes in distribution

3.7.1.1 Analysis of ICES trawl data

Presence-absence analyses

Haddock were observed throughout the whole area sampled by surveys with the exception of the Spanish coastline, the southern North Sea and the Baltic Sea. This pattern has remained unchanged between 2001 and 2015 where survey data was available for all ICES areas considered in the analysis (Figure. 3.7.1).



Figure 3.7.1. Presence/absence maps by ICES statistical rectangles for 2001-2005 (top panel), 2006-2010 (middle panel) and 2011-2015 (bottom panel) when data was available for all surveys.

Within northern ICES areas (north of Celtic Sea) a clear decline was observed in areas 4c and 4b, with the former showing a drop in occurrence to near absence since the mid-1980s while the latter showed a continuous decline since 2000. In contrast area 6a showed an increase in occurrence between mid-1980s and mid-1990s, while areas 7a and 7c showed an increase in recent years albeit on a much shorter time series (Figure 3.7.2). Within southern areas (Celtic Sea and below) significant increases were observed in areas 7f-h, 8a and 8d, the latter two rising from near absence to circa 80% of probability of occurrence (Figure 3.7.3). Time series in southern ICES areas were on average much shorter than in northern ones.

Haddock – northern divisions

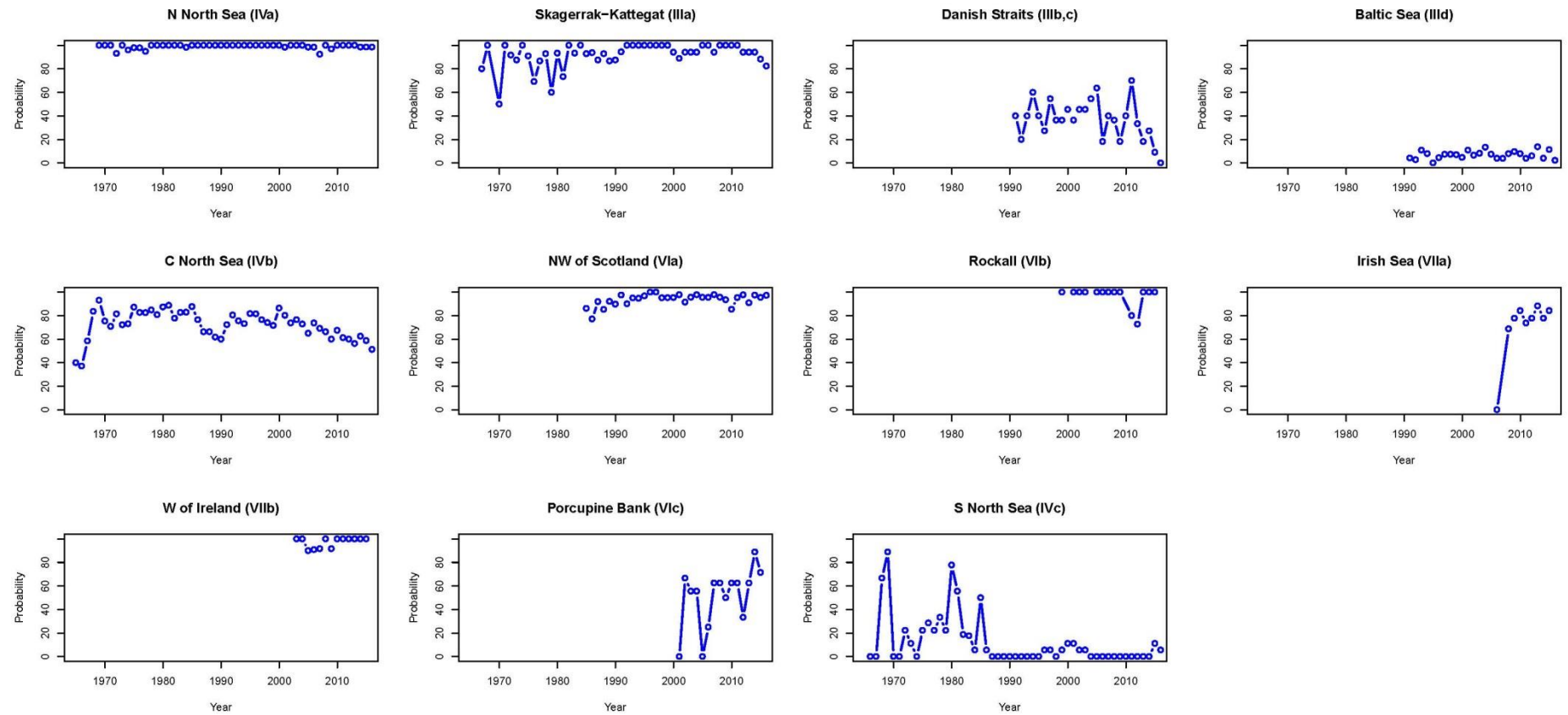


Figure 3.7.2. Haddock trends in presence/absence in northern ICES areas

Haddock – southern divisions

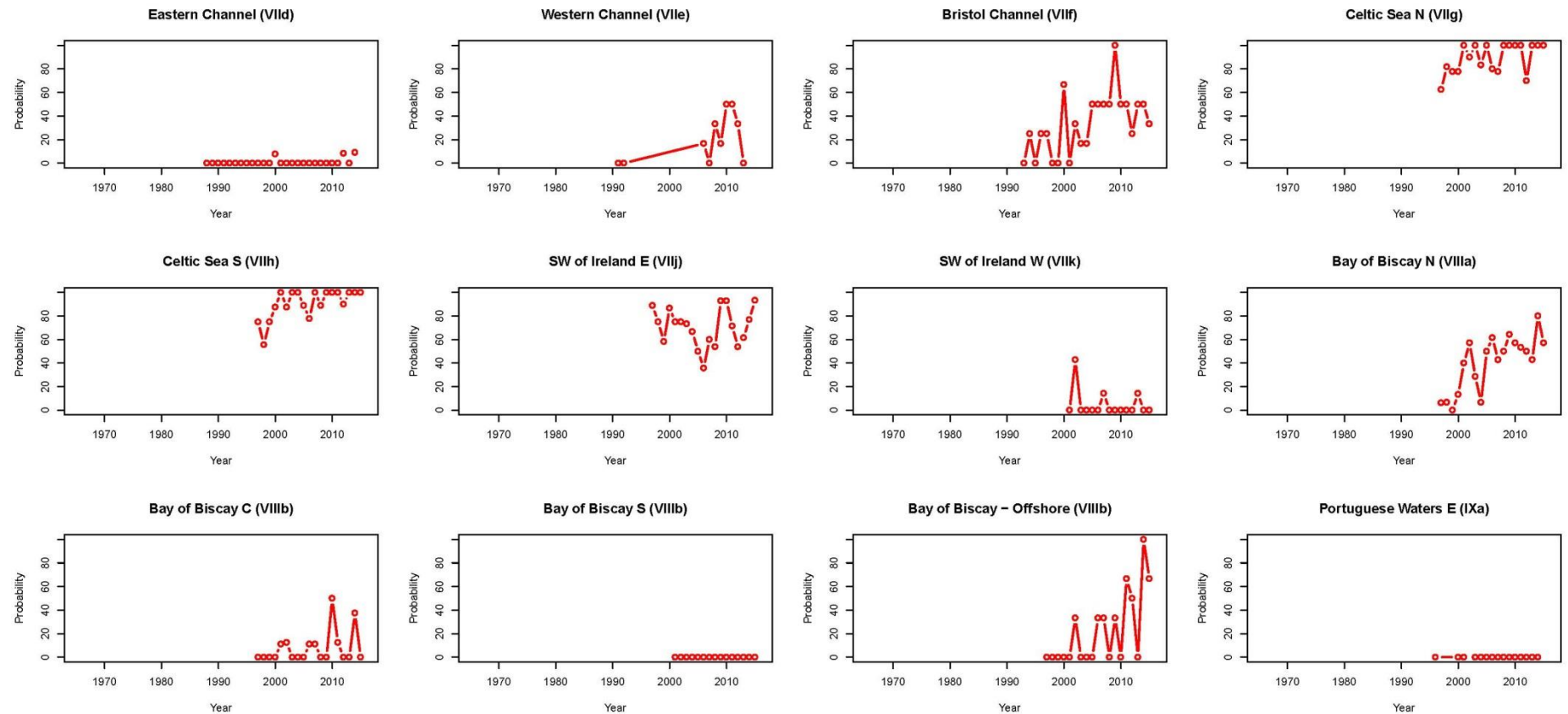


Figure 3.7.3. Haddock trends in presence/absence in southern ICES areas

Centre of gravity of abundance by surveys

Only two surveys showed a noticeable shift in their abundance's centre of gravities over time: quarter 3 SP-PORC in area 7b and quarter 4 EVHOE in Biscay. In 7b the centre of gravity showed similar trends in latitude and longitude: a decrease from 2002 to 2006 followed by a constant increase back to original values resulting in a back-and-forth linear displacement of the centre of gravity on a southwest/northeast axis (Figure 3.7.4). In Biscay the centre of gravity showed an overall decrease in latitude and increase in longitude, albeit with strong variability, resulting in a south-eastward shift (Figure 3.7.5).

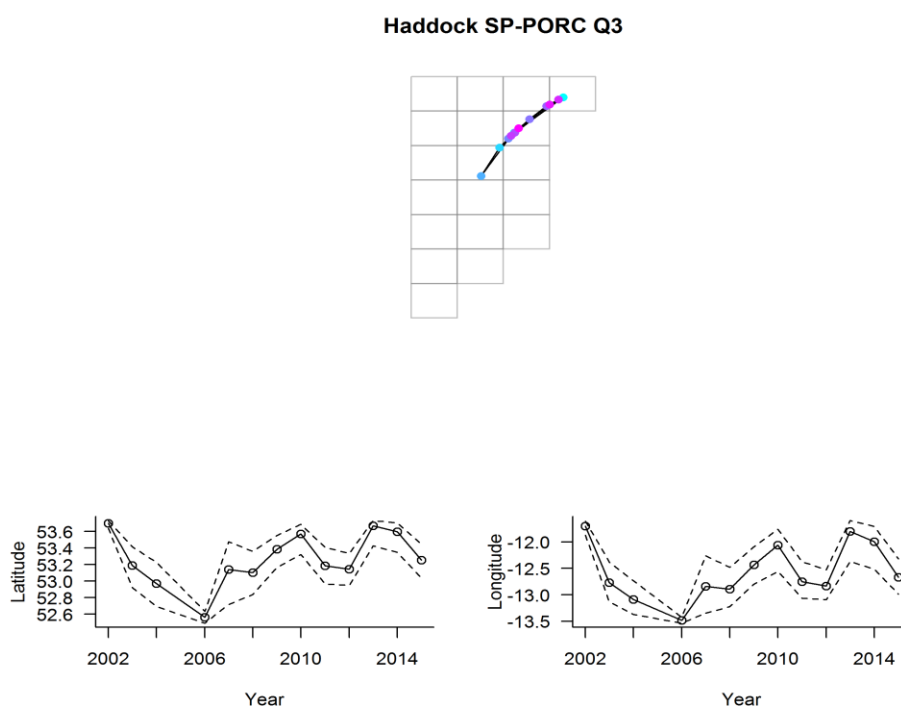


Figure 3.7.4. Shift in the centre of gravity of abundance observed for SP-PORC Q3

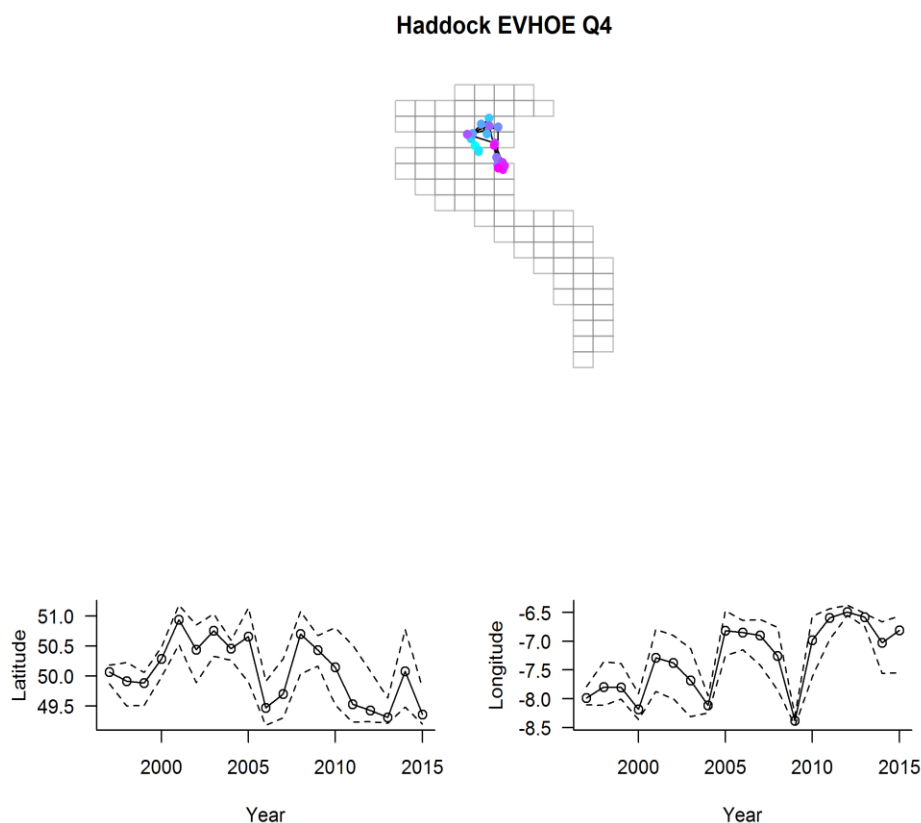


Figure 3.7.5. Shift in the centre of gravity of abundance observed for EVHOE Q4

Changes in relative abundance between adjacent ICES areas

Significant changes in relative haddock abundance between adjacent areas were only significant in southern areas, with abundances in areas 7h and 8a increasing compared to neighbouring areas (Figure 3.7.6).

Haddock

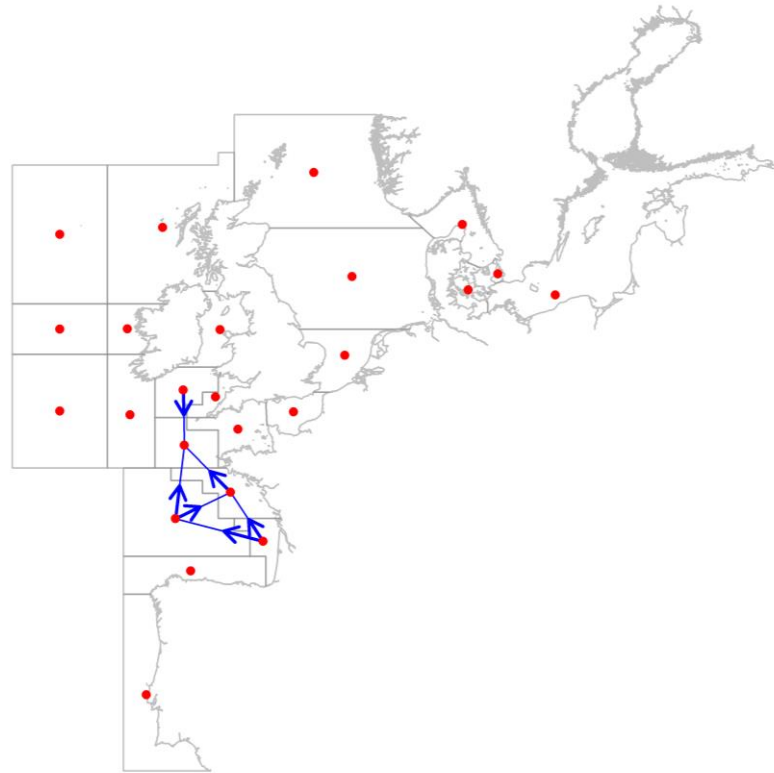


Figure 3.7.6. Relative changes in abundance between adjacent ICES areas. Red dots alone indicate no significant changes relative to adjacent areas. Blue arrows indicate significant changes pointing towards the highest increase in abundance.

Conclusions

Based on the analyses of trawl survey data, the area occupied by haddock has remained unchanged for the last 15 years. However, occurrence has decreased in the southern and middle North Sea whilst remaining unchanged in the northern North Sea. In contrast, occurrence has increased on the western shelf in both northern (west Scotland) and southern (Celtic Sea and Biscay) areas. This latter observation should however be considered with caution as data was available only for recent years and a long term trends may well show different patterns. Only two of the areas surveyed showed a clear change in their centre of gravity over time, with said changes being limited in space and either back-and-forth or with high variability, which indicates a lack of overall shift in distribution. Changes in abundance between adjacent areas were only observed in the Celtic Sea and Biscay area and are confined within a single TAC management unit encompassing areas 7b–k, 8, 9, 10 and CECAF 34.1.1.

3.7.1.2 Other evidence

Dickey-Collas *et al.* (2003) reported an expansion of haddock around the southern range of their distribution on the west of the British Isles (Irish Sea and Celtic Sea) in the 1990s. This somehow tallies with the increased occurrence in the Celtic Sea and Biscay observed here, although the two time frames do not coincide. Hedger *et al.* (2004) found no shift in the haddock distribution in the North Sea between 1980 and

1999 based on trawl survey data. Likewise, two meta-analyses using survey data reported no significant northward shift (Perry *et al.*, 2005) or deepening (Dulvy *et al.*, 2008) for haddock in the North Sea. Skinner (2009) analysed historical catch information and found no shift in the overall haddock distribution in the North Sea between 1920s and 2000s but did observe a northward shift of the southern boundary of the stock. These observations for the North Sea concur with an ecological niche modelling study for the whole North Atlantic which reported no northward movement of haddock but a decrease in the probability of occurrence at the southern edge of this species' distribution (Lenoir *et al.*, 2011). This modelling study, however, contrasts with empirical observations from Dickey-Collas *et al.* (2003) in the Celtic Sea in particular. More recently Gonzalez-Irusta and Wright (2016) reported a southward shift of haddock spawning distribution from the northern North Sea between Orkney and Shetland to the east coast of Scotland, although this shift remained confined within a single TAC management unit (area 4). Overall, the findings reported here are, for the North Sea at least, largely in agreement results from the analyses described above.

3.7.2 Review of potential drivers

Physical conditions

Haddock occur in depths less than 300 m (Knijn *et al.*, 1993) and its distribution is predominantly controlled by temperature and salinity (O'Brien *et al.*, 2000). Haddock tend to avoid mud-rich sediment for spawning (Gonzalez-Irusta and Wright, 2016). Hedger *et al.* (2004) found haddock to be occurring mainly within a particular set of environmental characteristics: depth between 75 and 125 m, sea bottom temperature above 6°C and salinity above 34.5 ppt. However Asjes *et al.* (2016) recently reported that these habitat preferences vary with age.

Density dependence

Asjes *et al.* (2016) also found the physical habitat preference for haddock to be independent from abundance, thus suggesting a lack of density dependence distribution at least in the North Sea.

Temperature

Hedger *et al.* (2004), Perry *et al.* (2005) and Dulvy *et al.* (2008) all observed a lack of distribution shift for North Sea haddock despite a concurrent increase in sea temperature, but Skinner (2009) did attribute the northward shift of the southern boundary observed for North Sea haddock to climate change. Likewise, Gonzalez-Irusta and Wright (2016) attributed the southward shift in haddock spawning distribution to changes in temperature, the cooler east coast of Scotland being closer to the optimal spawning temperature of 7°C than the northern North Sea where warm Atlantic inflow occurs.

Fishing-induced density dependence

In the Irish Sea the increase in haddock occurrence was best explained by a reduction in fishing pressure (Brander, 2010) and the subsequent increase in stock biomass in recent years (ICES, 2016a) which in turn is likely to have resulted in a density-dependent expansion.

Recruitment

Haddock is characterised by sporadically high recruitment leading to very large year classes (ICES, 2016a). While an increase in high recruitment events could explain an increase in occurrence, none of the stocks considered here show an increasing trend

in recruitment, Irish Sea stock excepted, or an increase in the frequency of high recruitments.

Other

In southern areas, Dickey-Collas *et al.* (2003) noted that the southward expansion of haddock on the west of the British Isles in the 1990s strangely coincided with an increase in temperature. This unexpected increase in biomass was attributed to a change in conditions resulting in a favourable environment allowing eggs and larvae drifting to these southern areas to survive and become self-sustaining populations. What these conditions are exactly is unknown.

3.7.3 Implications of changes in distribution and future trends

3.7.3.1 Consequences for stocks/populations

While the analyses presented here show no changes in the overall distribution area in recent years, there seem to be a dichotomy between the North Sea where haddock occurrence has either remained stable (northern North Sea) or decreased (middle and southern North Sea), and the western shelf where occurrence has mainly increased both in northern (west of Scotland, Irish Sea, Porcupine Bank) and southern (Celtic Sea) areas. However, available data spanned over 40 years in the North Sea while time series for western and southern areas were much shorter and did not allow investigating long term trends. With similar decreasing trends in fishing pressure observed across all stocks (ICES, 2016abc) it is tempting to link this dichotomy to different oceanographic processes occurring in the Atlantic in the North Sea, but differences in data availability cannot be excluded as the cause of this observation.

In the North Sea, the lack of overall distribution shift combined with the strict habitat preferences and the northward shift of the southern boundary concomitant with increasing temperature all point towards a temperature-driven reduction of the distribution area: haddock have gradually retreated from the warming southern and middle North Sea into the northern North where they have always been more abundant, but are unable to expand beyond the northern shelf edge and the Norwegian deep. This is consistent with both the analyses and the literature reviewed, however a possible absence of northward migrations beyond the shelf edge or the Norwegian deep has yet to be shown *per se*.

In northern areas of the western shelf, the north-eastward shift of the centre of gravity in Porcupine observed in recent years is consistent with a temperature-driven northward shift. However, no such change was observed in either west of Scotland, Irish Sea and Rockall. The lack of literature in these areas compared to the North Sea prevents any firm conclusion as to why haddock occurrence increased. However it can be assumed that the reduction in fishing pressure in these areas (ICES, 2016a) could be at least partially responsible, as suggested in the Irish Sea (Brander, 2010).

In southern areas of the western shelf, the cause behind the increase in occurrence observed here and by Dickey-Collas *et al.* (2003) remains unclear. Both the coincidence with increasing temperature (Dickey-Collas *et al.*, 2003) and the south-eastward shift in the centre of gravity observed in Biscay clash with the conclusions made in the North Sea about the temperature-driven northward shift of the southern boundary. A change in environmental condition (Dickey-Collas *et al.*, 2003), or the reduction in fishing pressure (ICES, 2016c), or perhaps even a combination of both could be at play here. However it should be noted that the biomass in these areas only represent a fraction (~10% or less) of the overall haddock biomass.

3.7.3.2 TAC management areas

Neither a change in the area occupied nor an overall directional shift in distribution was identified for haddock over the last 15 years. The only significant relative changes in abundance between adjacent ICES areas were found in the Celtic Sea and Biscay which fall within the same TAC management area. Based on this a mismatch between haddock regional abundances and TAC allocation seems unlikely in the near future.

3.7.3.3 Choke species?

Haddock is caught in mixed demersal fisheries and therefore could potentially become a choke species. However none of the stocks considered here are depleted (i.e. meaning low or no quota) although the stock in area 3, 4, and 6a is currently below Bpa, and no extreme increase in occurrence was observed in any of the areas considered (i.e. meaning hard to avoid once the quota is reached). Based on this haddock is unlikely to become a choke species in the near future.

3.7.3.4 Future expectations? Northern shifts? Northern constrains?

In the likely event of a continued increase in temperature, haddock abundance is expected to decrease (Simpson *et al.*, 2011; Heath *et al.*, 2012). In the North Sea, no distribution shift has been found amid warming while a northward shift of the southern boundary has been observed (Skinner, 2009) which suggests that haddock may be unable to expand northward beyond the northern shelf and Norwegian deep due to strict depth habitat requirements as identified by Hedger *et al.* (2004). In addition, two recent studies raise concerns about consequences of warming for haddock in the North Sea. Gonzalez-Irusta and Wright (2016) attributed a shift in spawning distribution to haddock avoiding temperature above the 7°C optimum which may become more difficult in warming seas, thus possibly impacting spawning success and recruitment. Asjes *et al.* (2016) identified temperature as an important constraint for age zero individuals with a thermal preference below 11°C, which in summer corresponds to a narrow region of the northern North Sea and is expected to decrease further in the future. It is more difficult to identify future expectations in western areas which show different trends in occurrence and where literature is scarcer and mechanisms poorly understood (Dickey-Collas *et al.*, 2003).

Table 3.7.1. Potential influence and predictability of each the main drivers of change in haddock distribution

Drivers	Influential driver	Drivers predictability	Predictability potential habitat	Predictability realised habitat	Reference
		(and time scale)			
Geographical attachment	No evidence				
Environmental conditions	Temperature, depth and salinity	Yes, lon term and seasonal	Yes	No	Hedger <i>et al.</i> (2004)
Density-dependent habitat selection	No evidence				Asjes <i>et al.</i> (2016)

Spatial dependency	No evidence				
Demographic structure	Yes, age-dependent habitat selection	Yes, seasonal	Yes	No	Asjes <i>et al.</i> (2016)
Species interactions	No evidence				
Memory	No evidence				
Fishing effort distribution	Yes	No	No	No	Brander (2010)

3.8 Hake

European hake (*Merluccius merluccius*) is widely distributed over the North-east Atlantic shelf, from Norway to Mauritania, with a larger density from the British Islands to the south of Spain. Since the end of the 1970s, the International Council for the Exploration of the Sea (ICES) considers two stocks units for assessment: the so-called northern stock, in ICES Division 3a, Subareas 4, 6 and 7 and Divisions 8a,b,d, and the southern stock, in Divisions 8c and 9a, along the Spanish and Portuguese coasts.

The stock dynamics of both hake stocks as assessed by ICES (ICES 2016) are presented in Figures 3.8.1 and 3.8.2. In both cases, after a period of low values, the spawning-stock biomass (SSB) has increased in recent years (since the end of the eighties). In the case of northern hake, the increase in SSB has been very significant since 2006. Over the same period, both fishing mortalities have decreased. Both recruitment series show no particular trends. Two large recruitment have however been estimated for northern hake in recent years (2008 and 2012) and one in 2007 for southern hake.

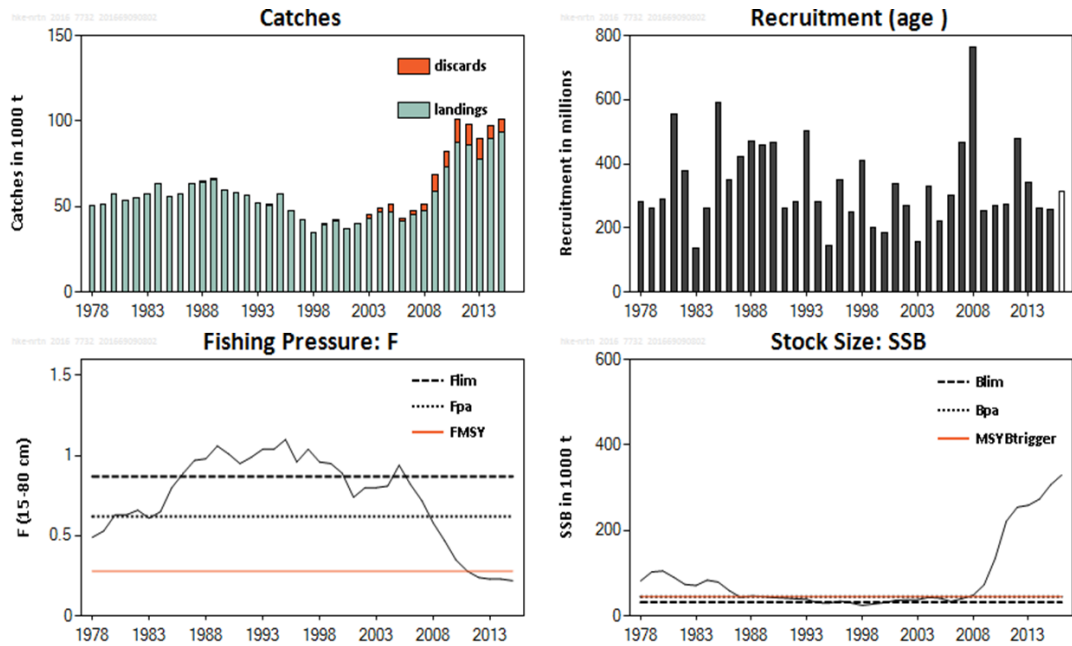


Figure 3.8.1 Hake in Subareas 4, 6, and 7 and Divisions 3.a, 8.a, 8.b, and 8.d (Northern stock). ICES estimated landings and discards (for the years with available discard data); R, F, and SSB from the summary of stock assessment (weights in thousand tonnes). Estimated R values are unshaded.

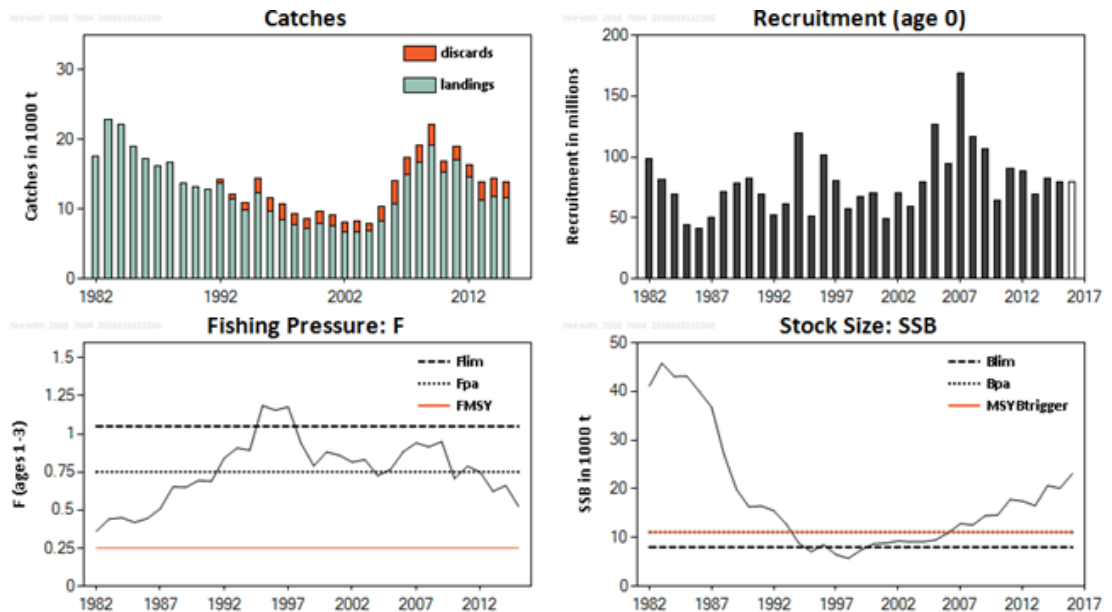


Figure 3.8.2 Hake in divisions 8.c and 9.a (Southern stock). Summary of stock assessment (weights in thousand tonnes). Assumed recruitment values are not shaded.

3.8.1 Evidence for changes in distribution

3.8.1.1 Analysis of ICES trawl data

Presence-absence analyses

The data coverage in space varies through time is better in the northern part of hake distribution. The analysis of presence-absence is thus limited to the west of Scotland and North Sea for which a longer series is available. It shows that, in recent year,

there were more statistical rectangles where hake were caught in the survey (Figure 3.8.3). This is consistent with the increase in landings over the last ten years (2005-2015) in this area.

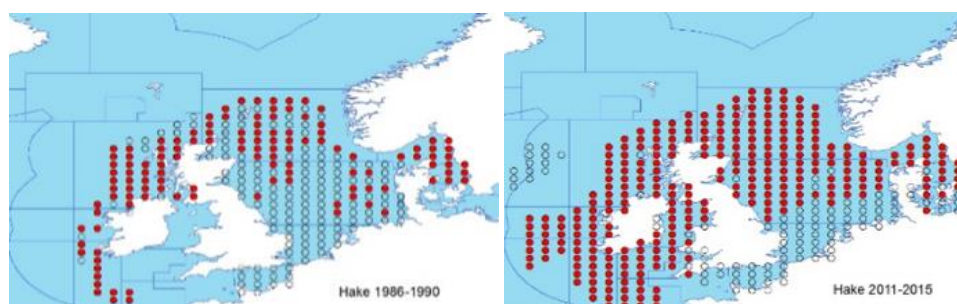


Figure 3.8.3. Presence/absence maps by ICES statistical rectangles in two periods: (left panel) early period (1986-1990) and (right panel) recent period (2011-2015). In the early period, surveys were only available for the northern part of the distribution of the stocks

Looking at ICES areas, significant positive trends in presence/absence are observed for 4 ICES areas all located in the northern part of the hake distribution (Table 3.8.1 and Figure 3.8.4): Skagerrak-Kattegat (3a), northern North Sea (4a), central North Sea (4b) and NW of Scotland (6a). A significant negative trend was also detected in the Bristol Channel (7f) but this area has very little importance in terms of hake catches and abundance.

Table 3.8.1 ICES areas with significant trends in the probability of occurrence of hake in survey halls (all available years) Mann-Kendall test for monotonic trends. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$; NO: not observed or very low occurrence. Red asterisk indicates decreasing trend whereas green indicates increasing trend.

Area	level of significance
Skagerrak-Kattegat (3a)	***
Danish Straits (3b,c)	
Baltic Sea (3d)	
N North Sea (4a)	***
C North Sea (4b)	***
S North Sea (4c)	
NW of Scotland (6a)	***
Rockall (6b)	
Irish Sea (7a)	
W of Ireland (7b)	
Porcupine Bank (7c)	*
Eastern Channel (7d)	NO
Western Channel (7e)	
Bristol Channel (7f)	***
Celtic Sea N (7g)	
Celtic Sea S (7h)	
SW of Ireland E (7j)	
SW of Ireland W (7k)	

Bay of Biscay N (8a)	
Bay of Biscay C (8b)	
Bay of Biscay S (8c)	
Bay of Biscay Offshore (8d)	
Portuguese Waters E (9a)	
Increase	5
Decrease	1

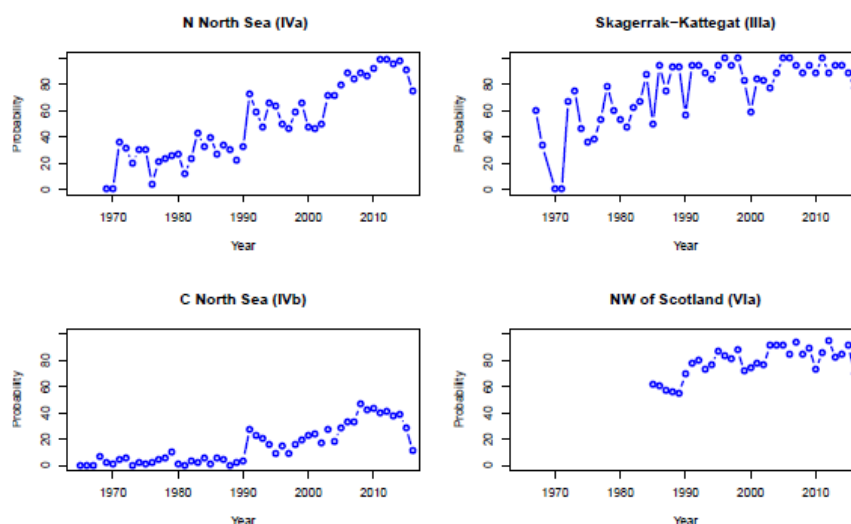


Figure 3.8.4. Trends in presence/absence by ICES areas (only the areas with significant trends are presented)

Centre of gravity of abundance by surveys

Only two surveys, both from the North Sea (NS-IBTS Q1 and NS-IBTS Q3), show significant shift in their abundance's centre of gravities over years (Figure 3.8.5). In both cases, the shift is roughly unidirectional towards higher latitudes, from Skagerrak to the northern part of the North Sea, near the shelf edge. This pattern is also clearly seen in the maps of abundance by statistical square for 1998 (when the northern stock spawning stock biomass and landings were at low level) and 2015 (Figure 3.8.6).

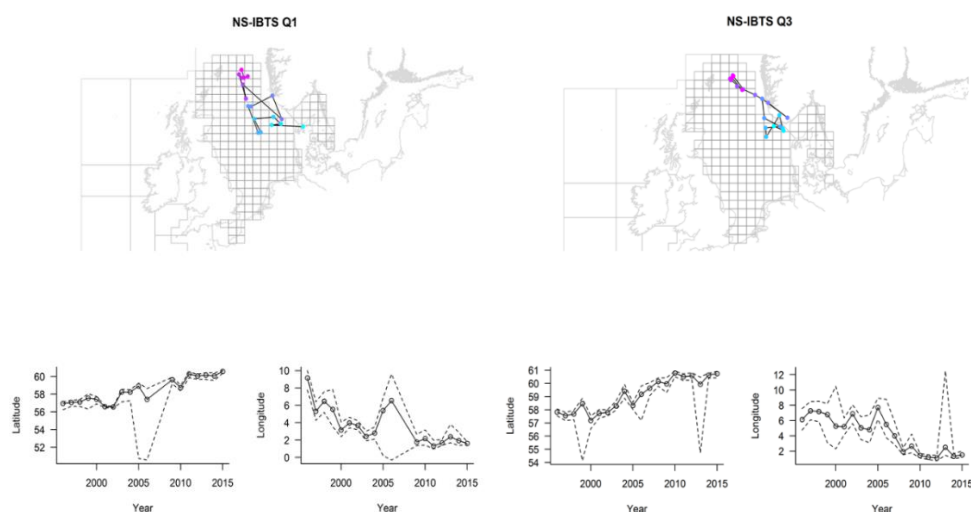


Figure 3.8.5. Shift in the centre of gravity of abundance observed for NS-IBTS Q1 and NS-IBTS Q3

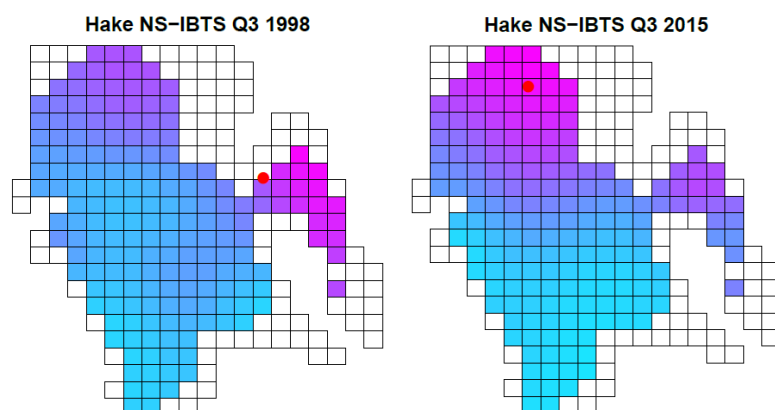


Figure 3.8.6. Changes in the hake distribution in the North Sea observed from NS-IBTS Q3 between 1998 and 2015

Changes in relative abundance between adjacent ICES areas

Figure 3.8.7 presents the relative change in abundance between adjacent areas over the periods covered by the available surveys. Here again, it is only in the northern part of the stock distribution that significant changes have occurred with an increase in the abundance of hake in ICES area 4a compared to its neighbour areas. Some changes have also occurred between Skagerrak and the western part of the Baltic Sea with a relative increase observed in ICES area 3a.

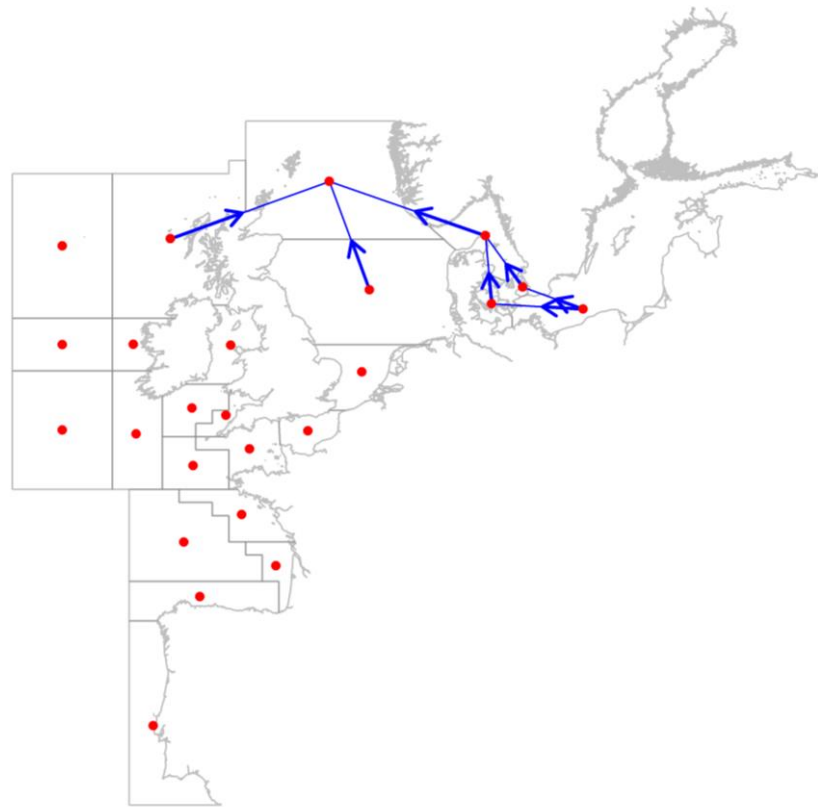


Figure 3.8.7 Relative change in abundance between adjacent ICES areas. Red dots indicate no significant change over the period analysed with adjacent areas, blue arrows indicate significant changes. The arrows point towards the areas where the increase in abundance has been higher.

Conclusions

- In recent years, changes in the distribution of hake occurred at the northern limits of its distribution: west and north of Scotland, northern North Sea and Skagerrak.
- As no shift in the centre of gravity of the population has been observed in other areas, the changes in distributions is related to an expansion of the population towards the north and not to a shift in the overall distribution of the two stocks considered.
- Results still need to be taken with caution as:
 - The trawl surveys mainly sample small hakes, as the adults are mainly distributed along the slopes.
 - Not all areas were surveyed over the whole period investigated.

3.8.1.2 Other evidence: landings

Just after the 2nd World War, hake landings in Subareas 4, 6, 7 and 8 increased to more than 150 000t (Pereiro *et al.*, 1984). This was followed by a rapid decline of the landings which stabilised around 80–90,000t per year over the period 1950–1965. During the mid-sixties a new decrease was observed and the landings fluctuated around 70 000t until the end of the eighties. From 1990 to 2000, landings decreased further reaching their lower value at 35,000 in 1998 for the northern stock and 6 700t in 2002 for the southern stock (ICES, 2016). Since then, landings have been increasing and

current landings for both stocks are about 110 000t, close to values observed in early 50s.

Recent increase in landings has been observed in all ICES areas (Figure 3.9.8) but it is more important in the northern part of the stocks distribution: the proportion of the total landings (northern and southern stock together) coming from the west of Scotland and the North Sea has increased from around 10% (1970–2002) to more than 20% in 2015.

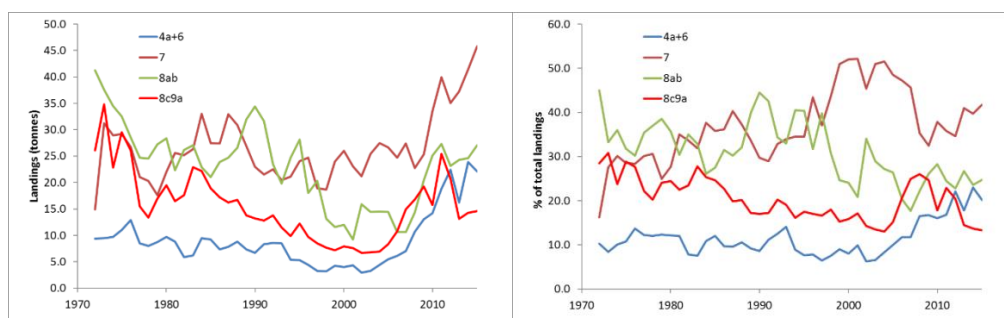


Figure 3.9.8. (left panel) Landings from ICES area (1972–2015) (right panel) Proportion of total landings by ICES area (1972–2015)

According to Pereiro *et al.* (1984), in ICES areas 6ab, total landings declined from 15000t in 1950 to 4000–5000t in early 80s. In 4a, UK and French landings decreased from 5000t (from 1950 to 1965) to around 2000t from 1965 to early eighties. They highlighted the fact that an important part of the decline in the total landings of the northern stock observed during that period could be attributed to the decline of landings coming from areas 6ab and 4a. It was not clear, however, if that decline in landings was associated to a reduction of abundance linked to an increase in fishing mortality. The authors also noted that the hake landings decrease was associated with the increase in saithe landings from French and UK fleets.

Since the mid-90s, landings have increased in 3a, 4 and 6ab from 4 000t to more than 20 000t (close to the post war levels). The larger increase has been observed in sub-area 4 (ICES 2016).

3.8.2 Review of potential drivers

Population distribution

Baudron and Fernandes (2014) use fishery independent data to investigate changes in hake distribution in the northern part of its distribution (west of Scotland and North Sea). They note that the observed increased biomass of the stock may partly be due to the decline in fishing mortality that started in the mid-2000. They show that high densities of hake in the North Sea occur mainly from April to September and may result from a density-dependant seasonal habitat expansion to suitable temperature and depth conditions rather than a climate-induced shift in distribution.

Cormon *et al.* (2014) and Cormon (2015) analyse the changes in distribution and the spatial overlap of hake and saithe in the North Sea over two periods (1991–1996 and 2007–2012) and investigate the biotic and abiotic factors which may influence this distribution. They show that hake-suitable habitat in the North Sea may be linked to temperature (ranging from 7 to 15°C), to depth and to the presence of potential preys such as blue whiting and norway pout. They consider that the recent increase in temperature in the North Sea could make the North Sea a more suitable habitat for this

species. As a consequence, there is increased potential for trophic competition between hake (increasing abundance) and saithe (declining abundance), which both prey on Norway pout and to a less extent Blue whiting. They conclude that on overall, greater spatial presence of hake may negatively impact saithe (Cormon *et al.*, 2014; Cormon *et al.*, 2016).

Recruitment

Goikoetxea and Irigoien (2013) suggest a potential link between higher recruitment estimated from 1990 onwards and regime shift in environmental conditions on the North East Atlantic. Similarly, Hidalgo *et al.* (2012) reported higher sensitivity of hake populations to environmental variability during periods of an eroded (or truncated) spawning stock composed comparatively by reproductive individuals of smaller size and age. However, their analysis was based on an assessment which has since been revised (ICES, 2010) and now, no clear trends (or shift) in recruitment levels are observed from the stock assessment. However, several good recruitments (2008 and 2012) estimated in recent stock assessment can explain the large increase in spawning stock biomass and could potentially be linked to favourable environmental conditions.

Spawning in the North Sea.

Werner *et al.* (2016) provide information on spawning in the North Sea which seems to occur over an important area, mainly in summer, along the shelf edge (100m depth and at sea surface temperature ranging from 12 to 15 °C). However, the study is limited to the most recent years and it is thus not possible to determine if spawning in the North Sea has been developing in recent years in relation with the stock expansion. The data analysed during this study suggest that hake could inhabit the deep Norwegian trench during winter and spring and move to shallower coastal and North Sea waters to spawn in summer and autumn. It is however yet unknown to what extent hake populations in different geographical areas interact with each other.

Metapopulation studies

Several studies were carried out to investigate the population structure of northern and southern Atlantic hake using microsatellites (Pita *et al.*, 2010, 2011, 2014) and otolith geochemistry (Tanner *et al.*, 2012, 2014). They show no significant spatial or temporal stable genetic substructures over the whole Atlantic metapopulation (Lundy *et al.*, 2000). Using genetic information, Pita *et al.* (2016) show that there may be movements between the southern and northern stock and estimate migration rates between the two stocks and their yearly variations over the more recent years.

Demographic spatial sub-structure within management areas may be also an important element on this species. Hidalgo *et al.* (2014) show that, for hake which exhibits strong ontogenetic pattern of distribution, the population size may influence the distribution of the different age groups: a large population leading to more spatial overlapping between age classes.

Conclusion

- The main reasons for the improvement of the stock status and increase in spawning stock biomass of the northern hake stock since 2000 may be related to decrease in fishing mortality associated with several good recruitments. It is not clear however if this improvement is linked with more favourable environmental conditions over recent years.

- The available studies suggest a density-dependent stock expansion rather than a shift.
- This expansion occurred in suitable habitat of the North Sea in terms of depth and temperature. It is not clear if recruitment has recently increased.
- Significant summer spawning occurred in recent years in the North Sea but it is not clear if spawning has recently increased. The existence of a North-Sea resident stock has been suggested but no information is available on how this hypothesized local population interact with the rest of the northern stock.

3.8.3 Implications of changes in distribution and future trends

3.8.3.1 Consequences for stocks/populations

- There is a potential competition between hake and saithe for common preys in the North Sea (Norway pout).
- It is not clear if there is a local sub-population in the North-Sea and deep Norwegian trench and how this component may interact with the rest of the northern hake stock.

3.8.3.2 TAC management areas

The agreed TAC for the northern hake stock is allocated between four TAC areas (Table 3.8.2) using a fixed proportion. As in recent years, the hake population has been increasing at a faster rate in the North Sea than in other areas, there is a potential mismatch between the TAC allocated by area and the regional stock abundance. This mismatch already led to increase in hake discards in recent years in the North Sea linked to a limited quota allocation. In the context of the landing obligation, this could potentially lead to premature closure of the North Sea mixed demersal fishery.

Table 3.9.2. TAC allocation by management areas for northern hake in 2015 and 2016

TAC (t)	2015	2016
IIIa, IIIb,c,d (EC Zone)	2738	2997
IIa (EC Zone), IV	3190	3492
Vb (EC Zone), VI, VII, XII, XIV	50944	61902
VIIIa,b,d,e	33977	40393

3.8.3.3 Future expectations

It is not possible, with the available information to predict what would potentially happen in the near future in terms of relative distribution of hake in different TAC areas. On the one hand, as we have seen, similar levels of catches have been reported in the past in the North Sea. If the major factor of expansion is related to stock-density, it would thus be possible that, if the stock abundance decreases in the future, the distribution of the population retreat in its northern limit to what was observed over the 70s and the 80s. On the other hand, it has also been suggested that the expansion might be related to improvement in habitat suitability linked to increase in temperature in the North-Sea associated with global warming. Furthermore, there are indications that a resident stock may exist in the North Sea (but no information is available on how this hypothesized local population may interact with the rest of the hake population). In that case, a decrease in total stock abundance would not neces-

sarily lead to a situation similar to that observed over the recent decades when the stock abundance was at low level.

Table 3.8.3. Potential influence and predictability of each the main drivers of change in species distributions

Drivers	Influential driver	Drivers predictability (and at which time scale)	Predictability potential habitat	Predictability realised habitat
Geographical attachment	No evidence	-	-	-
Environmental conditions	Temperature - depth	Yes	Yes	No
Density-dependent habitat selection	Yes	No	-	-
Spatial dependency	No evidence	-	-	-
Demographic structure	Yes, age-dependent habitat selection (adults at the shelf edge/juveniles at shallower depth)	Yes	Yes	Yes
Species interactions	Yes, potential with saithe in the northern north sea	-	-	-
Memory	No evidence	-	-	-
Fishing effort distribution	No evidence	-	-	-

3.9 Herring

Atlantic herring (*Clupea harengus* L.) is an abundant and widely distributed marine pelagic fish (Figure 3.9.1). Most herring populations are migratory and often congregate on common feeding and wintering grounds where aggregations may consist of mixtures of individuals from several populations. Herring are renowned for their plasticity challenging population definitions (Geffen 2009) and population delimitation and spatial distribution of these has been intensively studied.

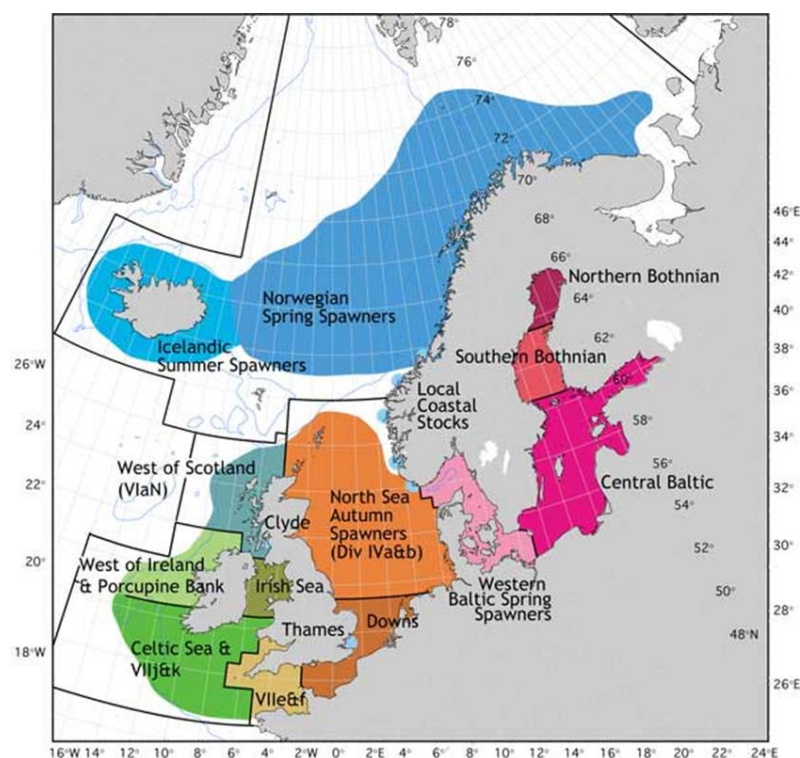


Figure 3.9.1. Schematic distribution of herring stocks in the North Atlantic (www.clupea.de)

Given that the distribution area of herring is related also to density of the species (Corten 2000, 2001; Dickey-Collas *et al.*, 2010a, 2010b), it is relevant to evaluate the potentially identified changes in spatial distribution within and across TAC management areas with the dynamics of the relevant stock. The figures 3.9.2-10 show the temporal development of the SSB for the main herring stock from the latest assessment conducted at ICES.

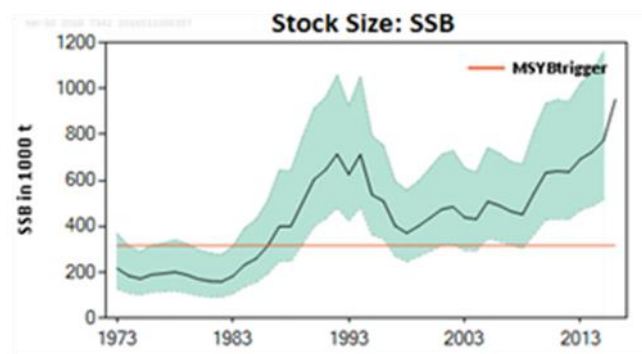


Figure 3.9.2. SSB time series for Baltic herring in the Bothnian Sea (area 30) (ICES 2016)

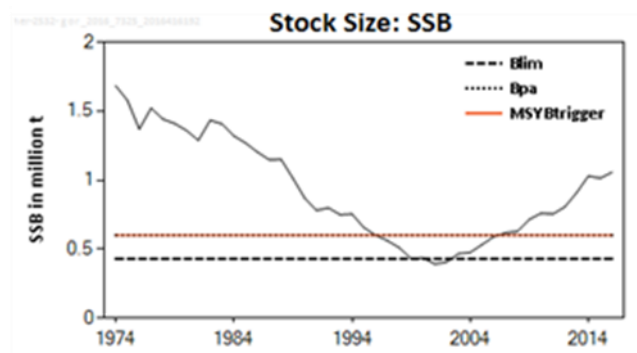


Figure 3.9.3. SSB time series for Baltic herring in the Central Baltic (areas 25-29+31) (ICES 2016)

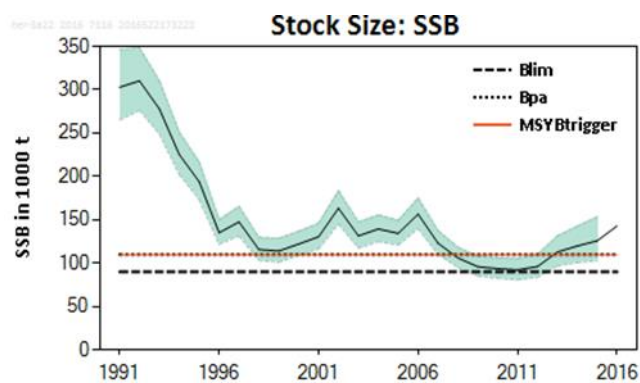


Figure 3.9.4. SSB time series for Western Baltic herring (areas 3a, 22-24) (ICES 2016)

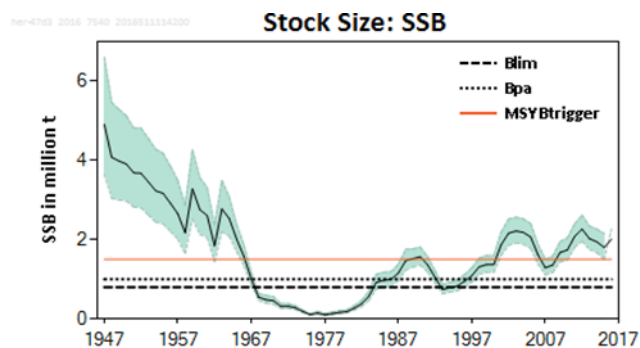


Figure 3.9.5. SSB timeseries for North Sea herring (area 4, 7d)

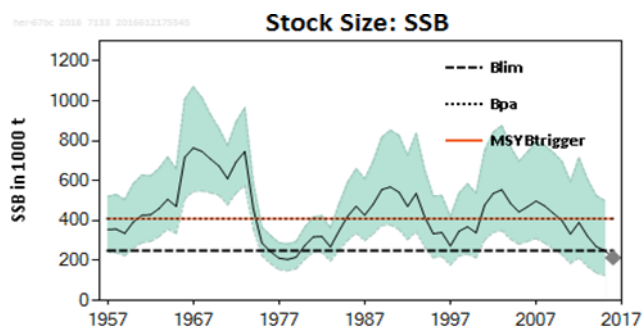


Figure 3.9.6. SSB time series for herring west of Scotland and west of Ireland (areas 6.a and 7.b-c) (ICES 2016)

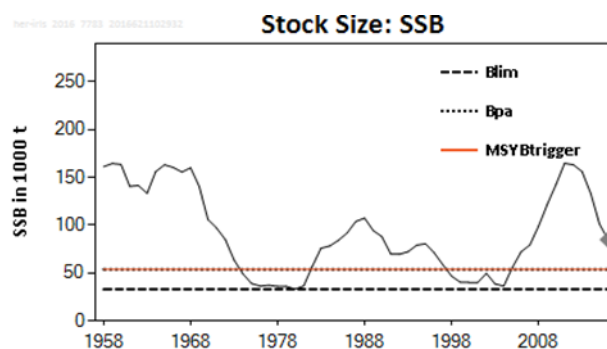


Figure 3.9.7. SSB time series for herring in the Irish Sea, Celtic Sea, and southwest of Ireland (areas 7.a South of 52°30' North, 7.g–h, and 7.j–k) (ICES 2016)

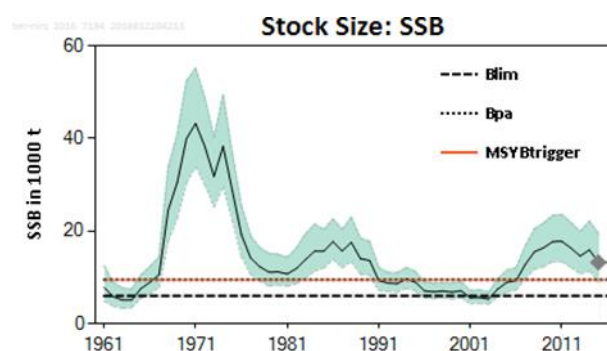


Figure 3.9.8. SSB time series for herring in the Irish Sea (area 7.a North of 52°30'N) (ICES 2016)

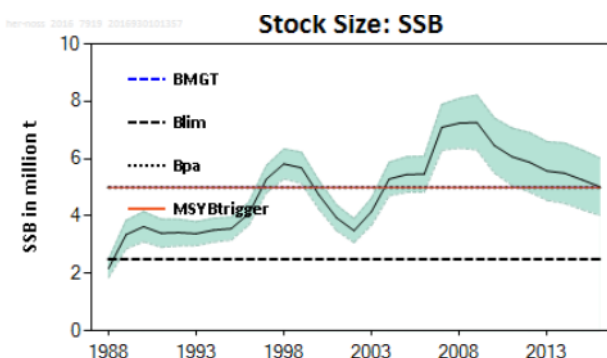


Figure 3.9.9. SSB time series for Norwegian Spring Spawning herring (areas 1, 2, 5, 4a and 14a) (ICES 2016)

3.9.1 Evidence for changes in distribution

3.9.1.1 Analysis of ICES trawl data

Presence/absence analyses

Based on the presence/absence analysis the occurrence of herring since 2000 has increased in the eastern English Channel, Celtic Sea, and Skagerrak-Kattegat, and has decreased in the northwest of Scotland. These results should be viewed in close comparison with the dynamics of the individual stocks which all have been increasing in SSB (tonnes) in this period (see section 3.9.2).

Centre of gravity of abundance by surveys

Only two surveys, both from the Baltic Sea (BITS Q1 and BITS Q3), show significant shift in their abundance's centre of gravities over years (Figure 3.9.1.1.1). In both cases, the shift is roughly unidirectional towards a more central area over the time series in the Baltic.

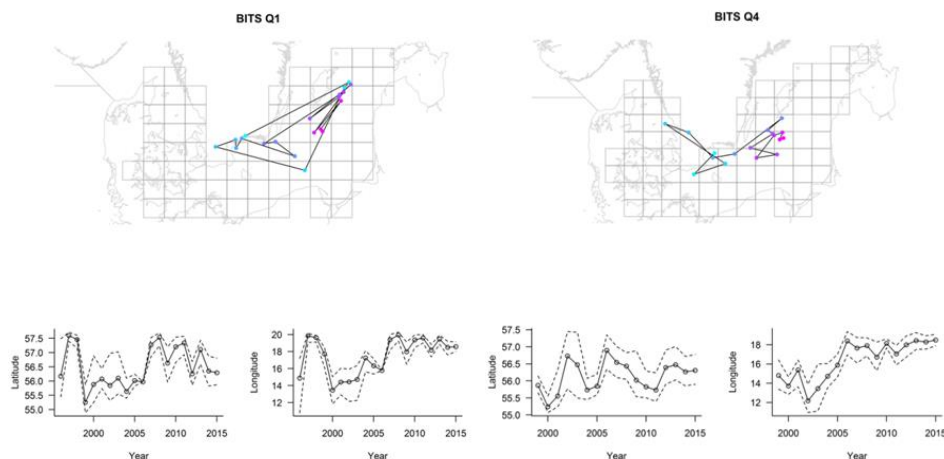


Figure 3.9.1.1.1. Shift in the centre of gravity of abundance observed for BITS Q1 and BITS Q3.

Log Ratio plot analysis

The analyses of the relative abundances across ICES Subdivision illustrated a significant trend of relative change in abundance between two adjacent areas; SD 22-24 and SD 25. However, this most likely is related to a proportional higher increase in stock biomass in the Central Baltic herring compared to the herring stock in SD 22-24 (see above). It is unlikely that the Western Baltic herring has shifted its distribution to the Central Baltic.

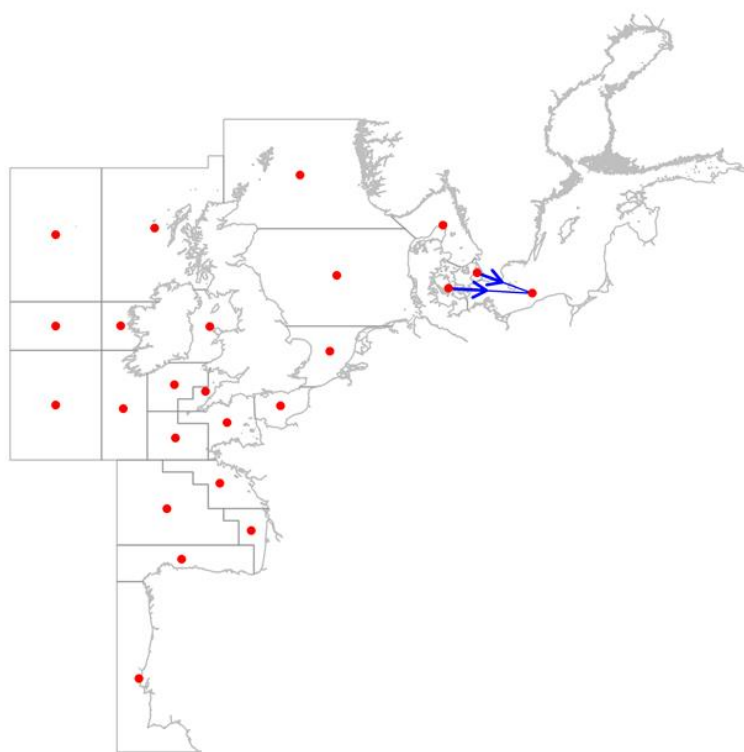


Figure 3.9.1.1.2. Significant trend maps. Centroids (red points) of ICES divisions and subdivisions (boxes) used in the analysis of relative changes in cod abundance. Arrows show significant trends where the box at the beginning of the arrow has consistently lower relative change in abundance to the neighbouring box with the terminus of the arrow.

3.9.1.2 Other evidence

The Norwegian Spring Spawning herring stock has become more concentrated in the Eastern-central part of the Norwegian Sea during the summer feeding migration the past 5 years, decreasing the summer-feeding area. A larger part of the stock now feeds in the Faroese and Icelandic waters in the early spring, followed by a North-East migration during autumn (ICES 2016a).

3.9.2 Review of potential drivers

In principle all life stages of herring and sprat may be affected by environmental drivers. The drivers may be of biotic (predators, inter and intra specific competitors, prey, human exploitation) or abiotic nature (natural or human-induced environmental effects such as hydrographical, climatic, chemical influences, etc.).

Interactions among population characteristics and environment may complicate efforts to assign distribution changes to temperature or environmental effects alone. For example, small pelagic species are known to shift their spatial distributions significantly based on the overall population size, with more habitat occupied during periods of high abundance (Checkley *et al.*, 2009). The changes observed in the analyses of abundance and presence/absence of herring is most likely linked to changes in stock biomass and composition. The change in distribution of herring in the eastern English Channel is most likely related to an increase in the recruitment from the Downs component during the early 2000s until 2010 (Figure 3.9.2.1; Payne 2010).

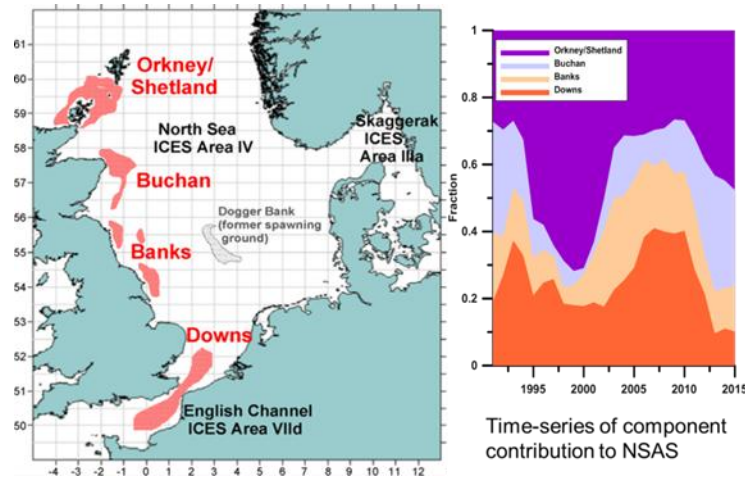


Figure 3.9.2.1. North Sea herring components and their weight in the larval index over time (re-done from Payne 2010)

The increase of herring in the Skagerrak-Kattegat is due to an overall increase in biomass of WBSS associated with sound fishery management (ICES 2016b). The decrease in herring west of Scotland is associated with declining recruitment (ICES 2016 Advice) and inappropriate harvesting of the stock components (ICES 2008).

Beside broad scale changes, North Sea herring dynamics co-vary with environmental variability (Payne *et al.*, 2009; Groeger *et al.*, 2009; Dickey-Collas *et al.*, 2010a, b). Whilst the direct mechanisms are not known (Nash and Dickey-Collas, 2005; Brunel, 2010) and the spatial and temporal scales of covariance with the environment are still unclear (Petitgas *et al.*, 2010; Fässler *et al.*, 2011) the productivity and distribution of herring have been shown to vary with the environment (large scale North Atlantic climate indices (Groeger *et al.* 2009)). Variability in advection from the spawning grounds to the nursery grounds has been thought to be a crucial factor (Corten, 2000,2001; Bartsch *et al.*, 1989) but unequivocal support for this hypothesis has not been forthcoming (Dickey-Collas *et al.*, 2010c). Physiological modelling of temperature-specific food requirements suggests that the spawning periods utilized are the most favourable ones for larval growth and survival (Hufnagl *et al.*, 2009). Indeed, changes in the planktonic system have been suggested as critical for recruitment (Cushing, 1992; Payne *et al.*, 2009), with Payne *et al.* (2013) showing that a reduction in growth rate in larvae accompanied the reduction in recruitment (early stage survival) in North Sea herring. Variations in bottom temperature near the spawning grounds (Nash and Dickey-Collas, 2005; Payne *et al.*, 2009), predation by jellyfish (Lynam *et al.*, 2005), bottom-up processes (Hufnagl *et al.*, 2009) have been proposed as mechanisms that also affect recruitment.

Climate-driven changes in temperature have potential to modify phenology of annual migrations to feeding and spawning grounds for Norwegian spring spawning herring (Huse & Ellingsen, 2008). It is not clear what environmental drivers which are linked to the changes in the migration for this herring stock, but the biomass and production of zooplankton is a likely factor, as well as feeding competition with other pelagic fish species (e.g. mackerel) and oceanographic features (e.g. limitations due to cold areas). The distribution of Norwegian Spring Spawners is clearly linked to stock biomass (Huse *et al.*, 2012) and it should be noted that beside the environmental forces the age distribution in the stock is also likely to influence the centre of gravity of the stock during summer. At present the stock consists of old individuals due to poor

recruitment in a number of years, and as the largest fish move farthest west, the stock should be in the western areas at the time being while the opposite should be expected when rich year-classes join the adult stock from the nursery areas in the Barents Sea.

3.9.3 Implications of changes in distribution and future trends

Some shifts in distribution have been recorded for herring (e.g. Brander *et al.*, 2003; Dickey-Collas *et al.*, 2010c; Trenkel *et al.*, 2014). Local population decline or extinction could theoretically occur if the rate of change in the suitable habitat exceeds the capacity of the population to change its phenology (Anderson *et al.*, 2013). The adaptive capacity of herring stocks can be difficult to determine, although those with high plasticity in spawning habitats and life history characteristics (e.g. small pelagics: MacCall *et al.*, 2009) may be more successful.

The relative contributions the environmental effect on herring stock-dynamics, however, has implications for the management of these stocks. Brunel *et al.* (2010) suggest that environmental harvest control rules (eHCRs) are beneficial when the environmental signal is strong and the environmental conditions are worsening, but under minor or gradual changes in the environment, the benefits from the implementation of eHCRs are difficult to evaluate. The current North Sea herring rule was adjusted in 2008 to account for the lower productivity of the stock: subsequent evaluations have established the robustness of this rule to the current low productivity observed in this stock (ICES 2012). Nevertheless, the development of these eHCRs (environmental Harvest Control Rules) requires an understanding of the underlying processes, which is currently lacking.

3.9.3.1 Consequences for stocks/populations

Likewise the impact of herring on the North Sea ecosystem is difficult to predict (Dickey-Collas *et al.*, 2010a). Herring population may impact on cod productivity (Speirs *et al.* 2010; Fauchald, 2010) and simulation studies suggested that the cod stock recovery may be dependent in some extent on the size of the herring population in the North Sea (Speirs *et al.*, 2010).

3.9.3.2 TAC management areas

TAC or management areas for herring are in 8 cases not similar as the ICES stock units. The management (TAC) areas for the herring are shown in Table 3.9.3.2.1.

Table 3.9.3.2.1. correspondence between the TAC management units and the stock units identified by ICES for herring

Managment Area (TAC area)	Stock Area	Match
2a, 4, 7d	2a, 4, 7d, 3a North Sea Autumn Spawners	No
3a,	3a, SD22-24, 4 Western Baltic Spring Spawners	No
SD22-24	3a, SD22-24, 4 Western Baltic Spring Spawners	No
SD 25-27, 28.2, 29, 32	SD 25-27, 28.2, 29, 32 Central Baltic herring	Yes
SD 28.1	SD 28.1	Yes

	Gulf of Riga herring	
SD 30-31	SD 30-31 Bothnian ...herring	Yes
4c, 7d	4, 4c, 7d Downs herring	No
5b, 6aN, 6b	5b, 6aN, 6aS, 6b	No
6aS, 7b,c	5b, 6aN, 6aS, 6b	No
6 Clyde	6 Clyde	Yes
7a	7a (Irish Sea)	Yes
7e,f	Included in 7a South of 52° 30' N and 7.g-h and 7.j-k (Celtic Sea and South of Ireland)	No
7 g,h,j,k	7a South of 52° 30' N and 7.g-h and 7.j-k (Celtic Sea and South of Ireland)	No

In the log Ratio plot analysis conducted by ICES there is indication for a change in herring distribution in the Baltic towards a more central Baltic distribution. Some of the changes are within the same management and TAC area, however for the shift between the 3b/3c to 3d the shift is between TAC areas.

3.9.3.3 Choke species

Herring is not considered a choke species as such; however sprat and herring could in some circumstances become choke species in each other's fisheries due to changes in spatial distributions across TAC management areas. In cases mixing of stocks within management areas occur, management rules on basis of the dynamic stock-mixture should be operational (e.g. as in the case of NSAS and WBSS in the North Sea and Skagerrak-Kattegat, ICES 2012).

3.9.3.4 Future expectations? Northern shifts? Northern constrains?

It is not possible, with the available information, to predict what would potentially happen in the near future in terms of relative distribution of herring. If the major factor of expansion is related to stock-density and opportunistic recruitment behaviour, it would thus be possible that, if the stock abundance decreases in the future, the distribution of the herring stocks will contract (Corten 2000). The environment also influences the spatial distribution of herring (Dickey-Collas *et al.* 2010b; 2010c). There are, however, currently no models to help either fully investigate how stock distribution may be impacted by environmental changes.

3.10 Horse Mackerel

Horse mackerel (*Trachurus trachurus*) is an abundant and widespread pelagic species that forms large schools and is fished mainly for human consumption. It reaches maximum length at around 40 cm and can be up to 40 years old.

In European waters Horse mackerel is divided into three separate stocks. The southern stock which is covered by TAC area division 9.a, the western, which is the largest, covers Subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a–c, and 7.e–k. The last stock is the North Sea horse mackerel which is found in divisions 3.a, 4.b–c, and 7.d. An important aspect of the division between the North Sea and Western stocks are that the horse mackerel caught in division 3.a and 4.a are included in the Western stock catches, when taken in quarters 3–4 and in the North Sea catches, when taken in quarters 1–2. This is a unique case in which management areas change during the year to take into account the migration pattern of the different populations..

3.10.1 Evidence for changes in distribution

3.10.1.1 Analysis of ICES trawl data

Based on presence-absence data, the spatial occurrence of horse mackerel has decreased in only one area since 2000 (West of Ireland, 7b). Horse mackerel distributions, as estimated by spatially-resolved survey biomass data, shows a significant trend in the log-ratio between neighbouring areas, with an increase in the North Sea division 4.b compared division 4.a, 3.a and 7.d (Figure 3.10.1).

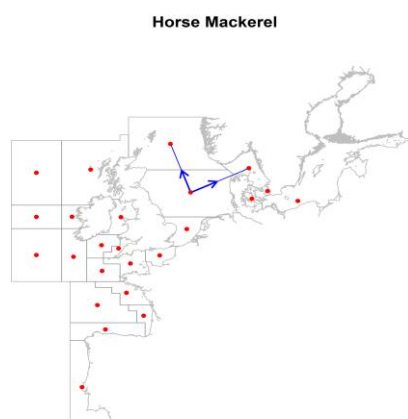


Figure. 3.10.1. Significant changes in relative abundance between neighbouring TAC area.

For the fulltime series period (varying years depending on area), number of squares with presences of horse mackerel has increased sharply in the North Sea (division 4.a, 4.b, 4.c) and 3.a around 1990. However, to what extent this increase is caused by an actual increase in distribution or a change in survey methodology is unclear.

Horse mackerel occurrence also increased, but to a lesser extent, for areas 3b–c and 3d as well as North West of Scotland (7.a) and Bay of Biscay N (8.b).

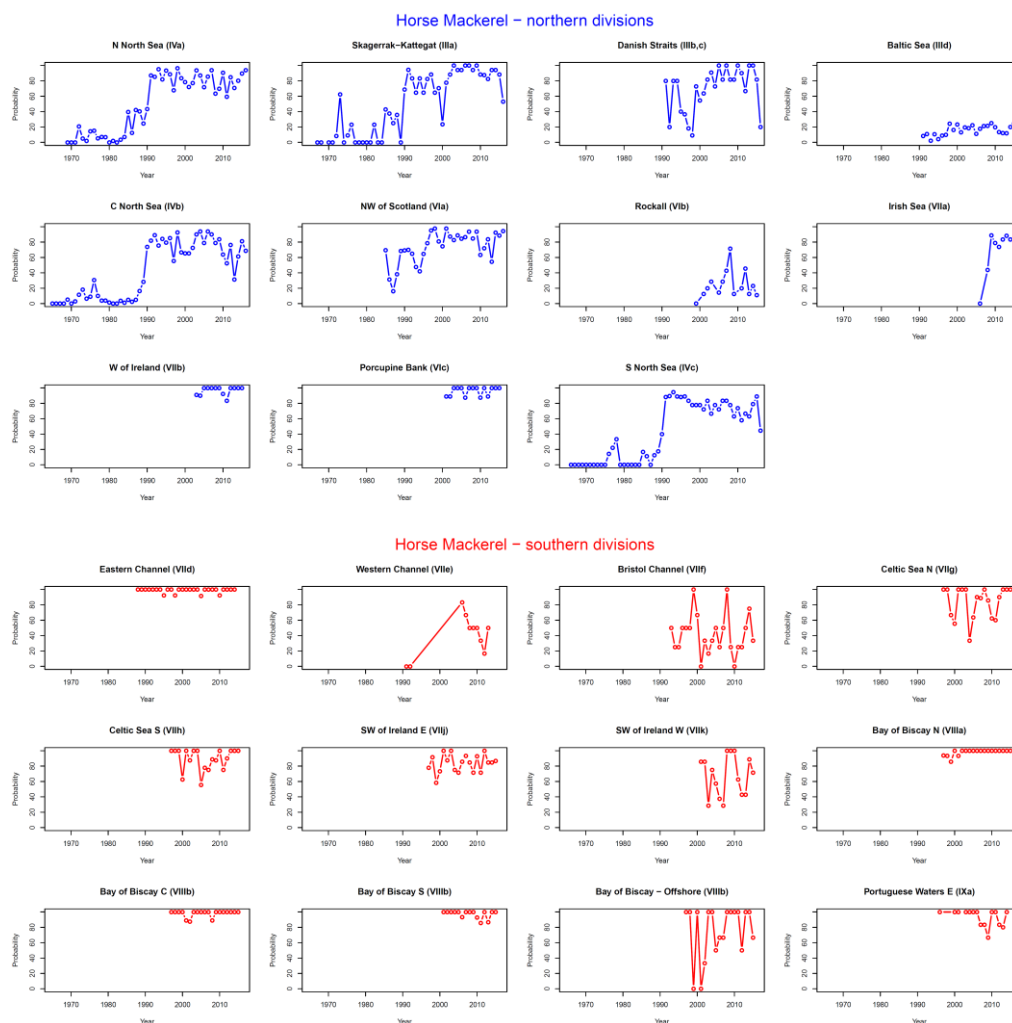


Figure 3.10.2. Presence absence plot showing the probability of catching horse mackerel in each ICES squares within the EU TAC areas.

Given the spasmodic recruitment pattern of this species, the large year classes (1982 and 2001) observed in the Western stock would be expected to result in changes in distribution, however such a pattern is difficult to detect from the analyses.

3.10.1.2 Other evidence

Distribution of catch by rectangle is available in the WGWIDE reports, but unfortunately not as data for all years. As part of the benchmark of horse mackerel taking place in 2017 (WKWIDE 2017), the historical catch data by rectangle will be made available for spatial analyses.

Historical catch data of 6 pelagic freezer-trawlers can be used as an indicator of the distribution of catches. Catches are expressed as percentage of catch of all species in a rectangle (Figure 3.10.3).

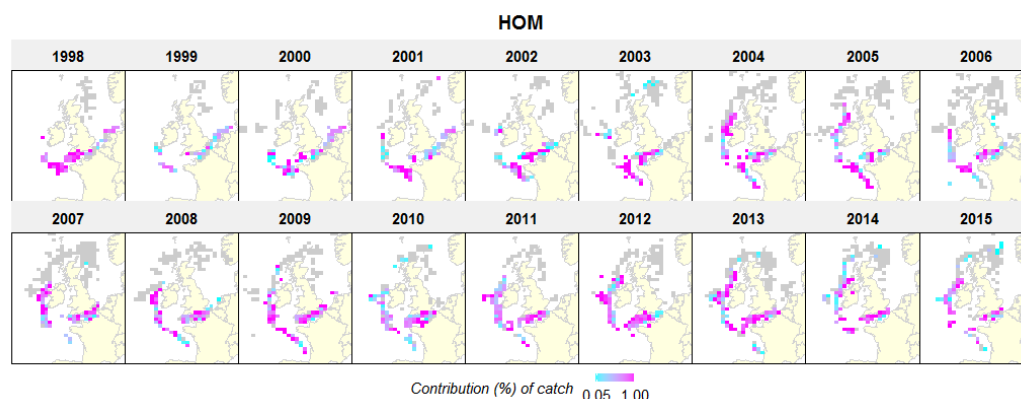


Figure 3.10.3. Historical catches of 6 pelagic freezer-trawlers. Catches from trips where horse mackerel constituted more the 5% of the total catch.

3.10.2 Review of potential drivers

Changes in the horse mackerel distribution has been found to be related to temperature, such that horse mackerel on feeding migration into the Norwegian Sea starts to migrate south at temperatures below 10 degrees and similar migration from the North Sea and into the channel area is also observed to take place at temperatures around 10 degrees (see Abaunza *et al.*, 2003 and Trenkel *et al.* 2014, for review).

Horse mackerel has a very spasmodic recruitment pattern but the drivers behind good recruitment and hence high stock size has not been identified.

Migration of horse mackerel has been linked to ontogenic changes such that smaller individuals recruits to the North of the Iberian Peninsula and then migrates south with increasing age (Murta *et al.*, 2008).

3.10.3 Implications of changes in distribution and future trends

Horse mackerel has a spasmodic recruitment and does therefore show large fluctuations in SSB. At present the western stock, which is traditionally considered the largest, is at a historic low level and therefore any changes in distribution and/or migration pattern are difficult to evaluate.

3.10.3.1 Consequences for stocks/populations

Pipe and Walker (1987), investigated the survival of eggs under temperatures ranging from 10.5–21.2°C and found optimum survival around 12–15°C. For juveniles, higher growth is connected to higher temperatures.

Horse mackerel is characterized by having a relatively long spawning period, sometimes up to 8 month, which could indicate that there are not very restrict hydrographic conditions needed for spawning to take place.

3.10.3.2 TAC management areas

In the present management of Western and North Sea horse mackerel the changing distributions is already accounts for by assigning catches in 3.a and 4.a to the western stock in quarter 3–4 and to the North Sea stock when caught in quarter 1–2.

3.10.3.3 Choke species?

Not applicable.

3.10.3.4 Future expectations? Northern shifts? Northern constraints?

It is difficult to evaluate due to the present very low size of the Western stock, however, given that the temperature limit for this species is around suggested to be around 10 degrees (see Abaunza *et al.*, 2003 and Trenkel *et al.* 2014, for review) it could be speculated that a potential rebuilding of the Western stock in combination with increasing temperatures, would result in increasing migration north into the Norwegian sea.

3.11 Mackerel

North East Atlantic mackerel (*Scomber scombrus*) is a wide-ranging pelagic species, distributed from North-west Africa to Iceland and northern Norway in the eastern North Atlantic, including the Black Sea, Mediterranean and western Baltic. ICES advice on this stock is for subareas 1–7 and 14, and in divisions 8.a–e and 9.a (Northeast Atlantic).

The stock dynamics of NEA mackerel as assessed by ICES (ICES 2016) are presented in Figure 3.11.1. After a period of low values, the spawning-stock biomass (SSB) has increased in recent years (since 2007) with fishing mortality decreasing during the same period. Recruitment series showed some strong year classes entering the stock in recent years.

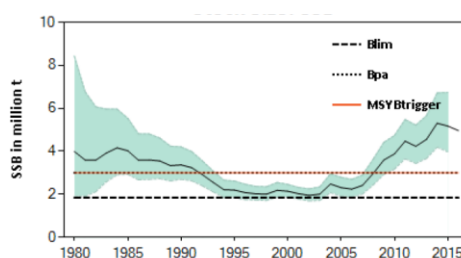


Figure 3.11.1 NEA Mackerel spawning stock biomass.

3.11.1 Evidence for changes in distribution

3.11.1.1 Analysis of ICES trawl data

Presence-absence analyses

Based on the analysis performed by the ICES secretariat on presence/absence data for the short time series and the areas considered (2000 onwards), there was little support for changes in mackerel distribution. Based on the longer time series, changes in occurrence of the species were detected, with an abrupt increase in the 3 ICES subdivisions of the North Sea and decrease in Portuguese waters.

The increase in the North Sea has been identified as an artefact of the method used : over the time period studied, an increasing number of surveys have been used to compute the occurrence of mackerel for the North Sea (first NS-IBTS Q1, then data NS-IBTS Q3 since 1991) while the geographical coverage has been relatively constant since the mid-1970's. The jump in the mackerel occurrence in 1991 is explained by the start of the NS-IBTS Q3 data, and is therefore not considered as an indication of a change in distribution.

Centre of gravity of abundance by surveys

Based on the analysis performed by ICES secretariat, no significant changes in the centre of gravity of the mackerel distribution were observed.

Changes in relative abundance between adjacent ICES areas

Based on the analysis performed by ICES secretariat on abundance ratios between adjacent areas, no significant changes in mackerel distribution were observed.

3.1.1.2 Other evidence

Mackerel is a pelagic fish, often distributed in oceanic areas, and its distribution is not likely to be well described by the demersal trawl survey data used in the analyses done by ICES. The group also reviewed published information to address changes regarding the entire extent of the stock, throughout the whole life cycle of the species.

Spawning

Changes in the spawning distribution over the period 1977-2010 were described during the Ad Hoc Group on the Distribution and Migration of NEA Mackerel (ICES 2013). The spawning distribution of mackerel has had a stable core until 2010 that covered mainly the continental shelf edge of the Bay of Biscay and west of the British Isles with a hot spot on Porcupine bank. An expansion of the spawning grounds to the north and to the northwest has been observed since 2007. In 2010, eggs were found in low densities over a large oceanic area going from north Scotland, Faroes, southern Iceland, and Rockall bank to the west. Most of the spawning however still occurred in the historical core area.

Since then (surveys in 2013 and 2016), the egg distribution has been very unusual. In 2013, most of the egg production was released in southern area (Bay of Biscay and northern coast of Spain, ICES 2014) and no high densities were observed in areas of historical high production west of the British Islands. Eggs were again found in low density over new spawning area in the north and north-west. In 2016, the egg production in the historical core spawning area was very low, and most of the spawning occurred spread over the north and north western areas where the expansion occurred since 2007 (ICES 2016).

Summer distribution

After spawning, mackerel migrates northwards to its feeding grounds. Historically the main feeding grounds were located in the northern North Sea and southern Norwegian sea (Iversen 2002). Since 2007, mackerel has been expanding its summer spatial distribution westwards, first to Iceland (2007) and then, since 2013, to south-eastern Greenland (Nøttestad *et al.* 2016). The expansion also occurred in the northwards direction, with the first catches of mackerel reported in Svalbard in 2013 (Berge *et al.* 2015). The observed summer distribution remained relatively unchanged during 2015 and 2016 (ICES 2016).

There are indications that the biomass present in the North Sea in summer remained at a rather constant level during this period (van der Kooij *et al.*, 2016) suggesting that the distribution has not contracted in south eastern limit. There are no indications on the summer distribution west of the British Islands or in the Bay of Biscay.

Overwintering areas

When NEA mackerel return from the feeding grounds in late summer, they aggregate through autumn and early winter along the continental shelf edge. The location of this so-called overwintering area have been variable over the last decades (Jansen *et al.*, 2012). Located west of Scotland in the late 1970s, the overwintering areas gradually moved along the shelf edge towards the North Sea, and into the Norwegian trench in the mid-1990s until the mid-2000s, before moving back west to the Shetland area in the recent years.

Nursery ground

The distribution of the 0 and 1 year olds has been modelled using a log-Gaussian Cox-process model (Jansen *et al.* 2015). The importance of the different nursery areas has been variable over time, but with no particular directional change.

3.1.1.2 Review of potential drivers

Spawning

Published studies suggest that there is a temperature preferendum between 10.5°C and 13.5°C in which there is increased probability of finding mackerel eggs (Ibaibarriaga *et al.* 2007). Using a GAM approach to model the distribution of mackerel eggs, Bruge *et al.* 2016 found that temperature had a significant effect both on the probability of presence and on the absolute density of eggs. Another habitat modelling study using both mixed model GAM and booster regression trees concluded that mackerel spawning habitat is primarily explained by geographical variables (geographical attachment), with a high attachment to the continental shelf edge and the Porcupine bank, possibly reflecting the dependency on some oceanographic feature characteristic of these areas (Brunel *et al.*, in prep). This study also found a dome-shaped relationship with temperature (optimum at 13°C) and an effect of the mixed layer depth. Finally, looking at growth pattern during first months of life both in juveniles on nursery areas and in spawning adults, Jansen *et al.*, (2013) found indications that females come back to spawn at a latitude similar to where they spend their first months of development.

Some studies have tried to identify the factors responsible for the changes in distribution. Hugues *et al.* (2014) have found that the latitude of the centre of gravity of the spawning distribution was correlated with the average spring temperature in the area. Brunel *et al.* (in prep) found that there was no latitudinal trend in the centre of gravity of the potential spawning habitat (i.e. area with suitable conditions, but not necessarily entirely used) reconstructed using their habitat model, while there was a northward shift of the centre of gravity of the realised habitat. They argued that the changes in distribution are therefore unlikely to be due to environmental changes, but rather in changes in habitat use, possibly linked with the increase of the spawning stock.

Summer distribution

To date there is no any published study that directly proves a relationship between the observed changes in the adult stock distribution and a specific environmental variable. Potential, not-mutually exclusive, drivers that could be explaining the observed distribution patterns of the stock during summer are a) temperature, b) prey availability, and c) stock-size [i.e. density-dependent mechanisms].

Long term catch records in Iceland show that mackerel is usually present there during warmer periods such as the 1930s or since 2000 (Asthorsson *et al.* 2012). However, higher temperature is not sufficient to explain the migration of mackerel to Iceland, as no mackerel was present during warmer periods in the 1950s.

Recent observations show that mackerel migrates northwards following the flow of the Atlantic current into the Nordic Seas, while feeding when encountering suitable prey (Nottestad *et al.*, 2014). The same author note that mackerel was never found in waters colder than 6°C. They also speculate that the rarefaction of plankton in the southern Norwegian Sea might also have played a role, forcing the mackerel to enter new and more productive regions in the northern Norwegian Sea.

Utne *et al.* (2012) found that the increase in mackerel abundance in the Norwegian Sea during the period 1995-2006 was correlated with the occurrence of 2 large year-classes (2002 and 2006) and the concomitant increase in the water temperature.

Overwintering

Jansen *et al.* (2012) have found a significant correlation between the position of the centre of gravity of overwintering mackerel and temperature.

3.11.3 Implications of changes in distribution and future trends

3.11.3.1 Biological and ecological implications

The changes in the spawning distribution do not seem to result in substantial changes in the juveniles distribution on the historic nursery grounds. Juvenile individuals (0-group) are however now found in more northern areas such as Faroes waters and Iceland (ICES, 2013). It is still unsure whether these areas are becoming suitable nursery ground for mackerel, and to which proportion they might contribute to the size of the new year-classes.

Utne *et al.* (2012) show a low spatial overlap between mackerel and herring in the Norwegian Sea, which they explained by different temperature optimum, but also possibly by a competitive advantage of mackerel on herring. In the recent years mackerel expanded over very large areas and the herring distribution was further reduced (ICES, 2016).

3.11.3.2 Management

Due to the expansion of the summer distribution of the stock, new countries have developed a targeted mackerel fishery (first Iceland, then Greenland). The new mackerel fishing countries have joined the coastal states for mackerel (formerly composed of the EU, Faroes and Norway) but did not agree with the management plan adopted in 2009. Since then, the management plan has not been followed. In addition to TAC corresponding to the management plan, Iceland and Greenland have set unilaterally their own TACs, with some of the countries involved in the agreement doing the same in some years. This resulted in a sum of agreed and unilateral TACs consistently exceeding the scientific advice since 2009. A new management strategy has been agreed between EU, Faroes and Norway in 2015 but the situation has not changed.

3.11.3.3 Fisheries

Problems of by-catch have been reported in many fisheries but this is more a consequence of the increasing biomass of the stock than a consequence of changes in its distribution.

3.11.3.4 Future changes

Despite a relatively abundant literature on mackerel compared to other species, the understanding of the drivers remains too poor to make predictions of the future distribution.

In the case of the spawning distribution, studies all agree that temperature is an important factor. Based on the models available and using IPCC temperature scenarios, the potential thermal habitat can be forecasted. Projections in Bruge *et al.* (2016) show for instance that the north-north-westward expansion observed in the recent years is likely to continue further in the Norwegian Sea during this century. However, predic-

tion based on temperature only do not consider the multi-variate nature of the habitat, and factors such as geography or bottom depth which were found to be determinant (Brunel *et al.* in prep) are not included in these projections. Therefore projection based on temperature only represent the thermal niche, but not the potential habitat.

Even in a case where reliable predictions of the potential habitat can be made, the current understanding of how mackerel effectively uses this habitat is too poor to predict the actual distribution (realised habitat). Density dependent processes, which have been suggested to be important for this population, are too poorly understood to be appropriately modelled, and their intensity depends on future stock size which is also not predictable (depends on both future recruitment and future management).

No habitat model has been developed for the summer distribution and the empirical observation that mackerel habitat is limited by the 6°C temperature line is not sufficient to make projections about future changes in the summer distribution. In addition, the factors acting in combination with the thermal habitat (prey availability, density dependence) are also not clearly identified and understood.

Table 3.11.1: principal drivers of mackerel distribution, their predictability and predictability of futur mackerel distribution

Drivers	Driver identified	predictability drivers	Predictability potential habitat	Predictability realised habitat
geographical attachment	Yes spawning attachment to shelf edge and Porcupine bank	No : no understanding of the underlying mechanisms		
environmental conditions	Temperature	Trend predictable	Spawning thermal habitat predictable (see Bruge <i>et al.</i> 2016)	No : habitat selection poorly understood
density-dependent habitat selection	Suggested, related to stock size	No : future stock size unpredictable (recruitment – fishing)		
Memory	Memory of the latitude of birth	No : underlying mechanism not identified		

3.12 Megrims

The megrims encompasses two species, four-spot megrim (*Lepidorhombus boscii*) and megrim (*Lepidorhombus whiffiagonis*), whose TAC is shared by five management units. The analytical stock assessment developed both for west, southwest of Ireland and Bay of Biscay (divisions 7.b–k, 8.a–b, and 8.d) for *L. whiffiagonis*, and for Cantabric Sea and Atlantic Iberian waters (divisions 8.c and 9.a) for the two species show, in general terms, a similar historic scenario of the fishery. For *L. boscii*, this can be summarized with a good state of the stock in the early-mid 80s followed by overexploitation period in the early-mid 90s, to an increasing production of the two species in the last decade being exploited at a rate that is consistent with producing the highest catch from the stocks in the long term (Figure 3.13.1, ICES 2016). For *L. whiffiagonis*, the good status of the stocks arrived until early 2000s and after few years of overexploitation period the stocks show increasing productive trends in the last five-seven years (Figure 3.13.2 and 3.13.3, ICES 2016). In the areas Rockall (Division 6b) and Northern North Sea, West of Scotland (Divisions 4a and 6a) a combined analytical assessment is developed for the two species showing a good status of the two stocks in the recent years.

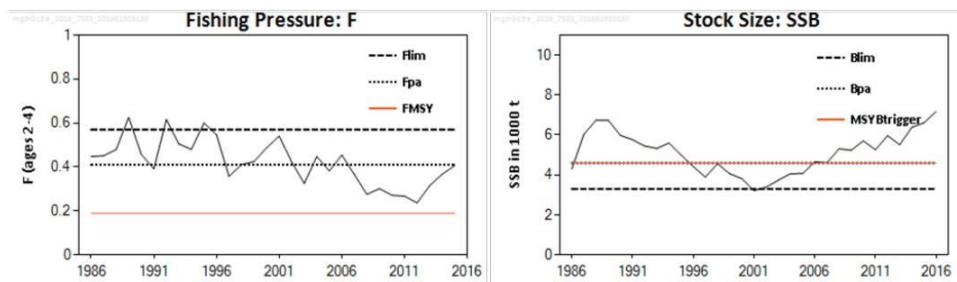


Figure 3.13.1. Four-spot megrim (*L. boscii*) in divisions 8.c and 9.a. Summary of stock assessment: F(ages 2–4) and SSB (weights in thousand tonnes).

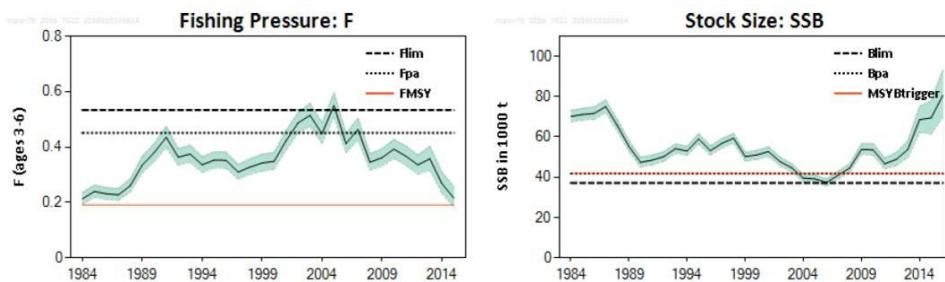


Figure 3.13.2. Megrim (*L. whiffiagonis*) in divisions 7.b–k, 8.a–b, and 8.d. Summary of the stock assessment (F –ages 3–6 and SSB) with confidence intervals of 90%.

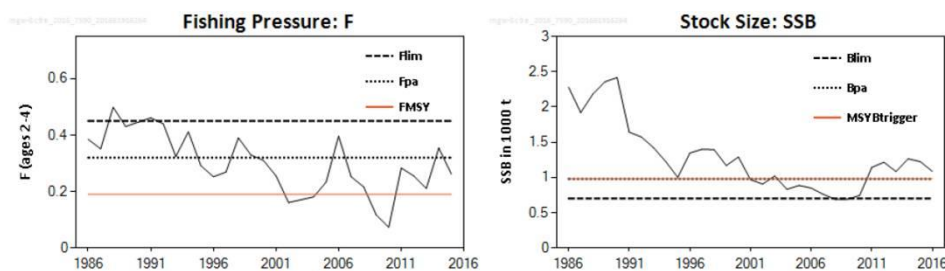


Figure 3.13.3. Megrim (*L. whiffiagonis*) in divisions 8.c and 9.a. Summary of stock assessment: F (ages 2-4) and SSB (weights in thousand tonnes).

L. whiffiagonis displays a larger bathymetric and geographic distribution reaching south Icelandic waters and middle latitudes of Norway, while the limit of the distribution of the *L. boscii* is the north of British Islands. By contrast, the bathymetric distribution of *L. boscii* is deeper compared to that of *L. whiffiagonis*.

3.13 Evidence for changes in distribution

3.13.1 Analysis of ICES trawl data

All the analyses carried out by ICES and presented in this document only includes megrim (*L. whiffiagonis*). No information for four-spot megrim (*L. boscii*) is presented. Thus, hereafter in this section we only refer to megrim.

Presence-absence analyses

No evidence of significant temporal trend of megrim occurrence was observed in the northern TAC units. However, there are several tendencies to highlight in the southern stocks. From a long term, only Bay of Biscay areas showed increasing trends in the frequency of occurrence (Figure 3.13.4). Looking at the trends from early 2000s, Bay of Biscay off-shore and Celtic Sea north (Figure 4) show also increasing trends, while SW of Ireland areas (Figure 4) show a light decreasing trend in the recent years.

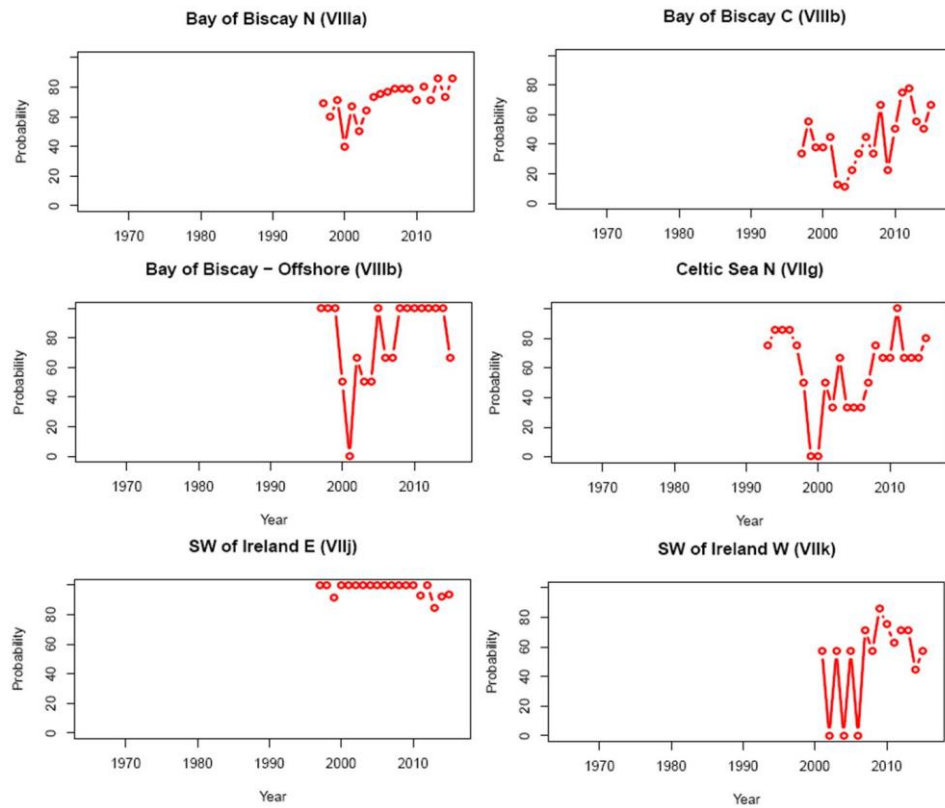


Figure 3.13.4. Trends in presence/absence (i.e. probability of occurrence) of *L. whiffiagonis* in the Bay of Biscay north (8a) and centre (7b), Bay of Biscay off-shore (8b), Celtic Sea north (7g) and, SW of Ireland east (7j) and west (7k). Only the areas with significant trends are presented.

Centre of gravity of abundance by surveys

The directional changes observed in centres of gravity of *L. whiffiagonis* are, in general, of small entity. For instance, a light south displacement was observed in the west Ireland (Figure 3.13.5) while a small trend to the east was observed in the west Scotland (Figure 3.13.5) and the Bay of Biscay (Figure 3.13.5). A shift towards northwest is observed for the in the North Sea Q3 (Figure 3.13.6), but the constant values at the early of the time series deserve further check. Other areas displayed clear inter-annual fluctuations of the mean geographic position with absence of clear trends. This is the case of the North Sea Q1 (Figure 3.13.7) or Baltic Sea international Surveys Q1 (Figure 3.13.7) and Q4 (Figure 3.13.7).

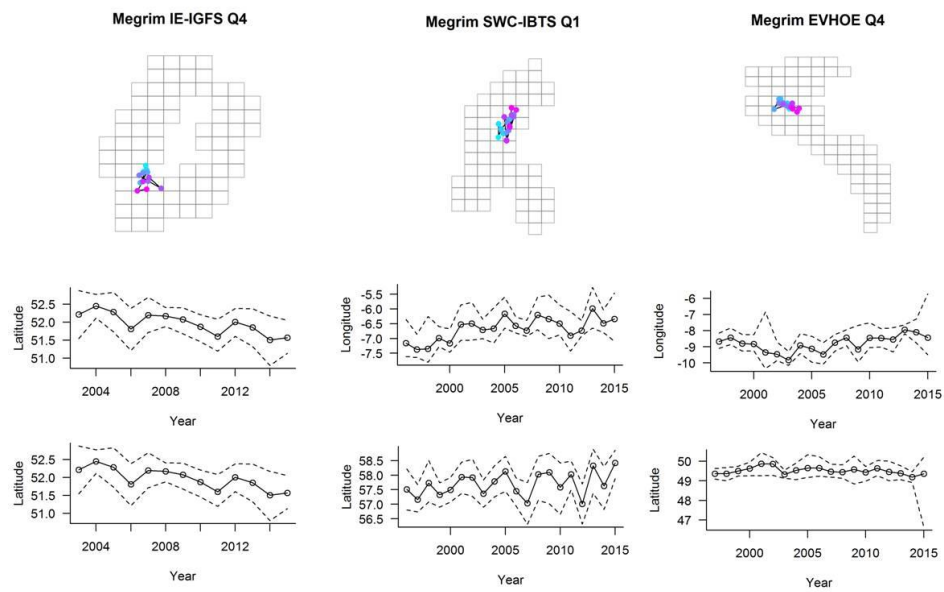


Figure 3.13.5. Shift in the centre of gravity (CG) of abundance of *L. whiffieagonis* observed for the Ireland IE-IBTS Q4, for the West Scotland (SWC-IBTS Q1) and for the Bay Biscay (EVHOE Q4). Above: geographic tracking CG. Colour codes for the inter-annual variation with blue light colours referring the early of the time series and purple de end. Middle: inter-annual variation of latitude coordinate of CG. Bottom: inter-annual variation of longitude coordinate of CG.

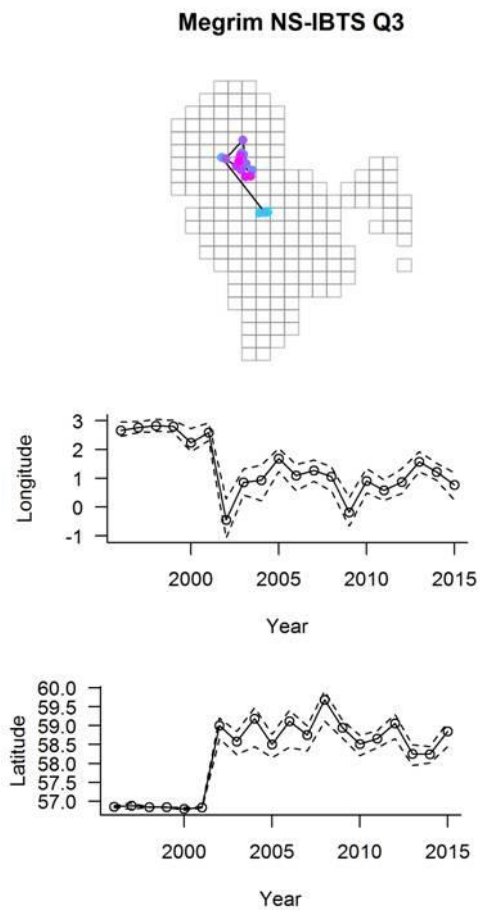


Figure 3.13.6. Shift in the centre of gravity (CG) of abundance of *L. whiffieagonis* observed for the North Sea (NS-IBTS Q3). Above: geographic tracking CG. Colour codes for the inter-annual variation with blue light colours referring the early of the time series and purple de end. Bottom left: inter-annual variation of latitude coordinate of CG. Bottom right: inter-annual variation of longitude coordinate of CG.

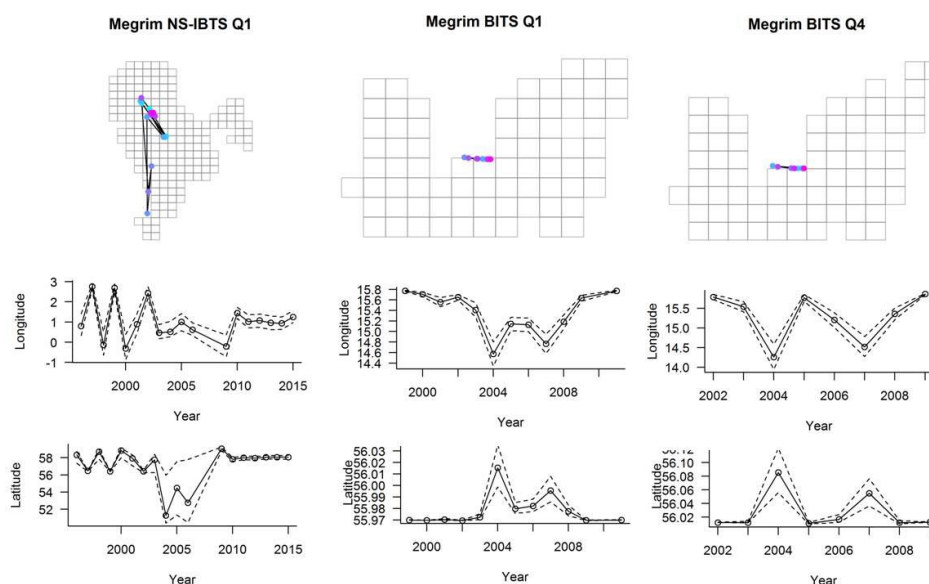


Figure 3.13.7. Shift in the centre of gravity (CG) of abundance of *L. whiffiagonis* observed for the North Sea Q1 (NS-IBTS, left), the Baltic Sea Q1 (BITS Q1, center) and Q4 (right). Above: geographic tracking CG. Colour codes for the inter-annual variation with blue light colours referring the early of the time series and purple de end. Middle: inter-annual variation of latitude coordinate of CG. Bottom: inter-annual variation of longitude coordinate of CG.

Changes in relative abundance between adjacent ICES areas

Regarding the log-ratio analysis, there were not differential contribution across TAC units for *L. whiffiagonis*. For *L. boscii*, ICES information was not analysed.

Conclusions

- Large geographic shifts in the species distribution are not observed.
- All the geographic changes observed occurred at regional level.
- Data have been only analysed for *L. whiffiagonis* and not for *L. boscii*.
- Recent expansion of *L. whiffiagonis* was only observed in the Bay of Biscay and the Celtic Sea, while a very recent decrease was only observed in the SW Ireland.
- The directional changes observed in centres of gravity of *L. whiffiagonis* are, in general, of small entity with small changes in the west of Ireland, west of Scotland and Bay of Biscay. A shift towards northwest is observed for the in the North Sea Q3, but the constant values at the early of the time series deserve further check.
- There was not differential contribution across TAC units for *L. whiffiagonis*.

3.13.1.1 Other evidence

There are several regional studies showing environmental-induced effects in the distribution of the two megrim species. In the North Sea, Perry *et al.* (2005), who assessed the influence of the warming conditions on several demersal species, did not find any effect on *L. boscii*. However, Dulvy *et al.* (2008), who analysed the other megrim species *L. whiffiagonis*, did find a strong deepening effect of this species and attributed to the warming conditions in this area. This contrasting effect of warming conditions between two congeneric species has been also observed in the north of Spain. Punzón *et al.* (2016) found a significant influence of the increasing temperature

of intermediate and deep water masses on the frequency of occurrence of *L. boscii*, while *L. whiffiagonis* showed a contrasting response with a decrease in the frequency of occurrence, along with a deeper distribution towards recent years. This deepening pattern on *L. whiffiagonis* in the north Spain is consistent with that observed by Dulvy *et al.* (2008) in the North Sea. In addition, although the two species showed correlative patterns between frequency of occurrence and abundance, the two species also displayed contrasting temporal trends in the frequency of occurrence with *L. boscii* increasing and *L. whiffiagonis* decreasing towards recent years.

3.13.2 Review of potential drivers

Although there is no evidence of large changes in the geographic distribution of these species induced by **warming**, there are clear evidences at regional scale. Indeed, the most important element for megrims is the contrasting impact of warming in the geographic and bathymetric distribution of each species (Perry *et al.* 2005, Dulvy *et al.* 2008, Punzón *et al.* 2016). Identically, the two species also contrast in the **density-dependent** responses in changes in distribution have been observed between species (Sánchez *et al.* 1998, Punzón *et al.* 2016). While changes in density of *L. whiffiagonis* mainly occur in deep with no change in local density, *L. boscii* can change both its geographic (i.e. longitudinal in the case of the Cantabric Sea) and bathymetric distribution in response to density changes (Sanchez *et al.* 1998). This results are consistent with those observed in more recent years by Punzón *et al.* (2016).

As in other flatfish, ontogenetic changes in **habitat selection** are here combined with sex-dependent habitat selection (Sánchez *et al.* 1998, Gerritsen *et al.* 2010). To date no study shows the interaction between warming conditions and demography, but one should expect that individuals of different age and sex for each species show contrasting responses to similar environmental changes as it has been observed in other flatfish species (Bartolino *et al.* 2011). Although adults *L. whiffiagonis* are more ichthyophagous and rates of crustacean in diet decrease with fish size, these two congeneric species share part of their diet associated with crustaceans (Rodriguez-Marín and Olaso 1993). However, to date, no study has demonstrated or assessed **competitive interactions**. Finally, recent reviewing work on the biological meaning of the stock boundaries have questioned the current management structure and suggested that south stocks are a tail of a larger northern population and, in consequence, north and south stock should be merged (Abad 2015). However, **complex population structures** beyond current management units need to be considered but it is still pending of conclusive multidisciplinary research (ICES SIMWG 2015).

3.13.3 Implications of changes in distribution and future trends

3.13.3.1 Consequences for stocks/populations

In these two species, the effect of temperature (warming) interacts with demography and density-dependent habitat selection. According to past research and recent results, implications of future changes in distribution will only affect at regional scale but management units should better reflect the biological boundaries on each species.

In megrims, identically to that observed in anglerfish (see Section 3.2), implications of warming and other drivers on distribution and population dynamics should be considered differently for each species due to the observed and expected contrasting ecological responses.

Finally, it is also worth considering that changes the bathymetric distribution, as those potentially expected in these species, can affect the catchability by altering the accessibility of the species to the fisheries.

A synthesis of the potential implications for each driver are shown in the Table. 3.13.3.1.1.

3.13.3.2 TAC management areas

Although regional changes potentially expected in the future do not affect the TAC units beyond boundaries, the reconsideration of stock boundaries could trigger consequences at the level of TAC unit.

3.13.3.3 Choke species?

This species has been considered to be choke species since it is part of mixed fishery with hake and anglerfish (ICES 2014). In this sense, scientists have suggested the combination of contiguous stocks in a unique stock unit will ensure that the choke effect does not occur compensating the added difficulty of the management of the two species sharing TAC in the same area.

3.13.3.4 Future expectations? Northern shifts? Northern constrains?

According to the results obtained from ICES information and the available literature, future expectations do not include northern shifts or constraints.

Table 3.13.3.1.1. Potential influence and predictability of each the main drivers of change in species distributions.

Drivers	Influential driver	Drivers predictability (and at which time scale)	Predictability potential habitat	Predictability realised habitat
Geographical attachment	No evidence	-	-	-
Environmental conditions	Temperature (Species-specific)	Yes (inter-annual variation and trend)	Yes	No
Density-dependent habitat selection	Yes (Species-specific)	Yes	Yes	No
Spatial dependency	No evidence	-	-	-s
Demographic structure	Yes, age-dependent and sex-dependent habitat selection	Yes as mean pattern. No inter-annual variation	Yes	Yes
Species interactions	Yes. Cogeneric interaction.	No	-	-
Memory	No evidence	-	-	-
Fishing effort distribution	No evidence	-	-	-

3.14 Norway pout

3.14.1 Evidence for changes in distribution

Norway Pout (*Trisopterus esmarkii*) is widely distributed over the North-east Atlantic shelf, from North of France to Iceland and Svalbard, with a larger density from west of Ireland to Kattegat, the Faroe Islands, and from the North Sea to the Barents Sea, mainly at depths between 50 and 250 m (further information in ICES WKPout; ICES, 2016d). This species is fished mainly in area 4a, although it has also been fished in area 3a. Both areas are considered to be a single stock. Recent considerations about a potential 5a stock concluded that there is no evidence for such separation given that the species spawning takes place mainly in the northern part in the area between Shetland and Norway coast (See further information and references in ICES WKPout; ICES, 2016d). There is no evidence of spawning in Skagerrak and Kattegat (ICES WKPout; ICES, 2016d).

The stock dynamics of Norway pout as assessed by ICES (ICES WKPout; ICES, 2016d) is presented in Figure 3.13.1. Fishing pressure has been kept low for the last 15-20 years. The spawning-stock biomass (SSB) has increased in recent years linked with recruitment success. Recruitment series show no particular trends, but high interannual variability with two large recruitment events in the last 10 years.

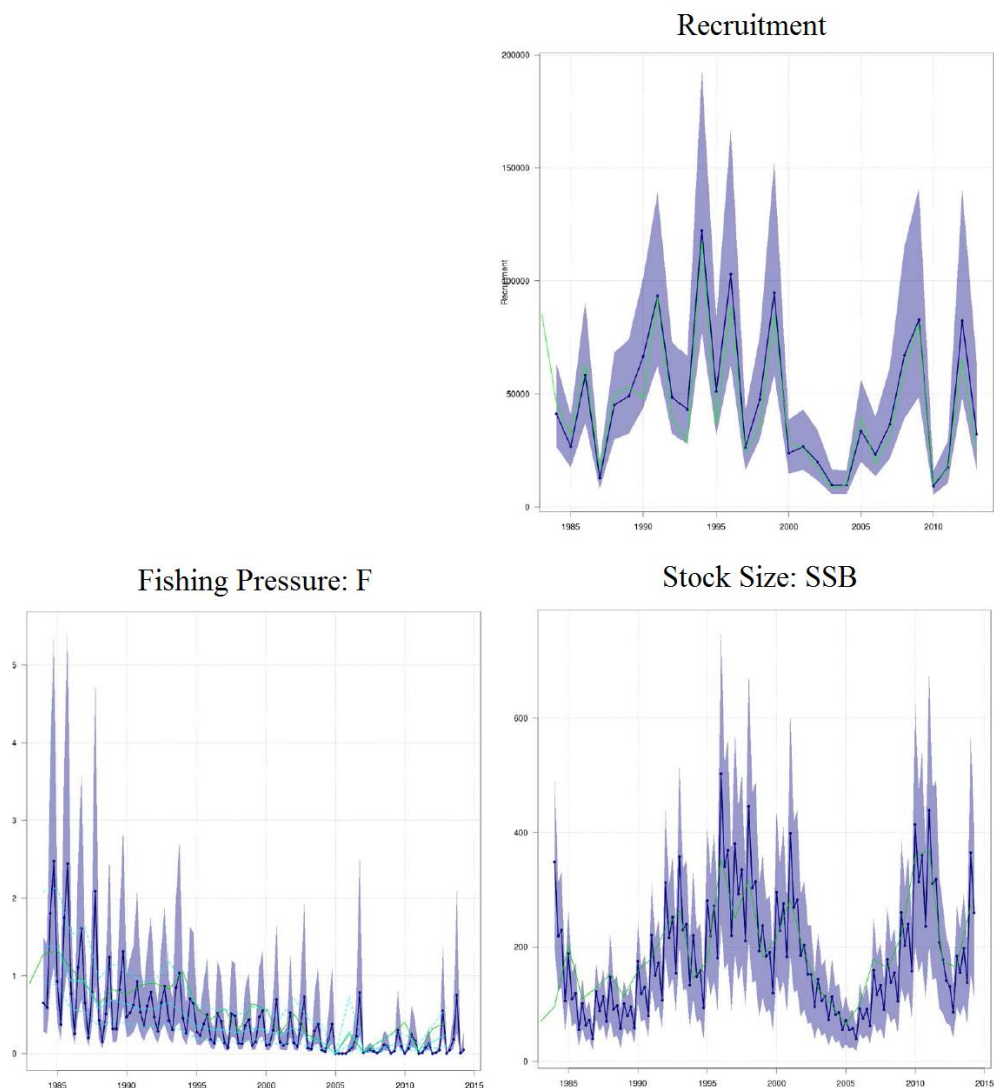


Figure 3.13.1 Norway pout assessment in Subarea 4 and Division 3a (North Sea, Skagerrak, and Kattegat) (ICES WKPout; ICES, 2016d).

3.14.1.1 Analysis of ICES trawl data

Presence-absence analyses

The data coverage in space varies through time and, in earlier period; no surveys were available for Norway Pout in southern areas. In the early period, surveys were only available for the northern part of the distribution of the stocks. The long term analysis of presence-absence is thus limited to the west of Scotland and North Sea for which a longer series is available. In later years, the surveys show that the species rarely distributes southern of the English Channel. However in the last decade Norway Pout has been spotted in the North of Bay of Biscay in the French continental shelf.



Figure 3.13.2. Presence/absence maps by ICES statistical rectangles in decadal periods.

Looking at ICES areas, a slightly significant positive trends in presence/absence are observed for 3 ICES areas all located in the northern part of the Norway pout distribution (Figure 3.13.3): Skagerrak-Kattegat (3a), North Sea (4b, 4c) and southern North Sea (4c). A slightly significant negative trend was also detected in the Bristol Channel (7f) but this area has very little importance in terms of Norway pout catches and abundance. A similar trend for hake was identified in the Bristol Channel.

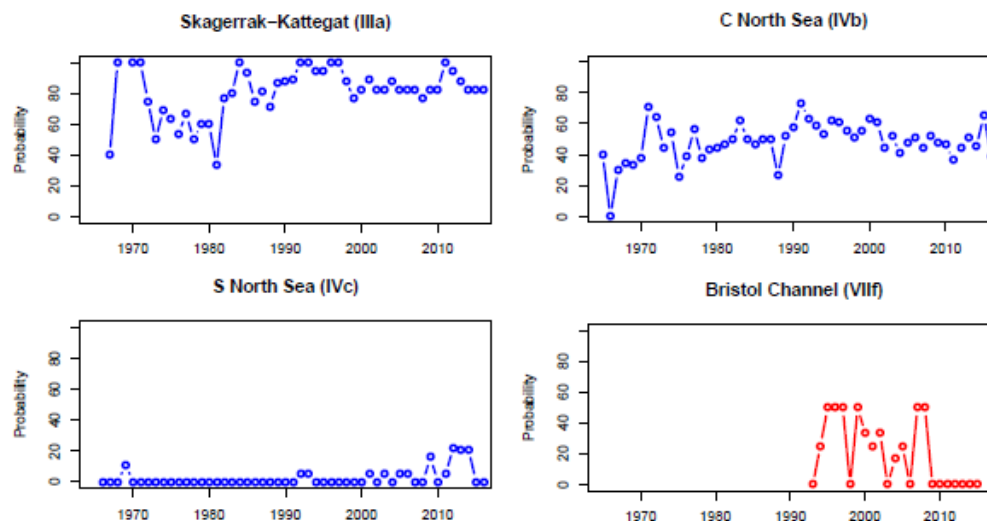


Figure 3.13.3. Trends in presence/absence by ICES areas (only the areas with significant trends are presented)

Centre of gravity of abundance by surveys

None of the surveys show significant shift in their abundance's centre of gravities over years (Figure 3.13.4). Centres of gravity seem to move forward and backward without a clear shift. This could be due to high variability of the species biomass (density driven) given that is a short living species with seem to highly depend on recruitment success (Figure 3.13.1). Still the lack of survey data northern than the North Sea does not allow to conclude that there is no northward shift.

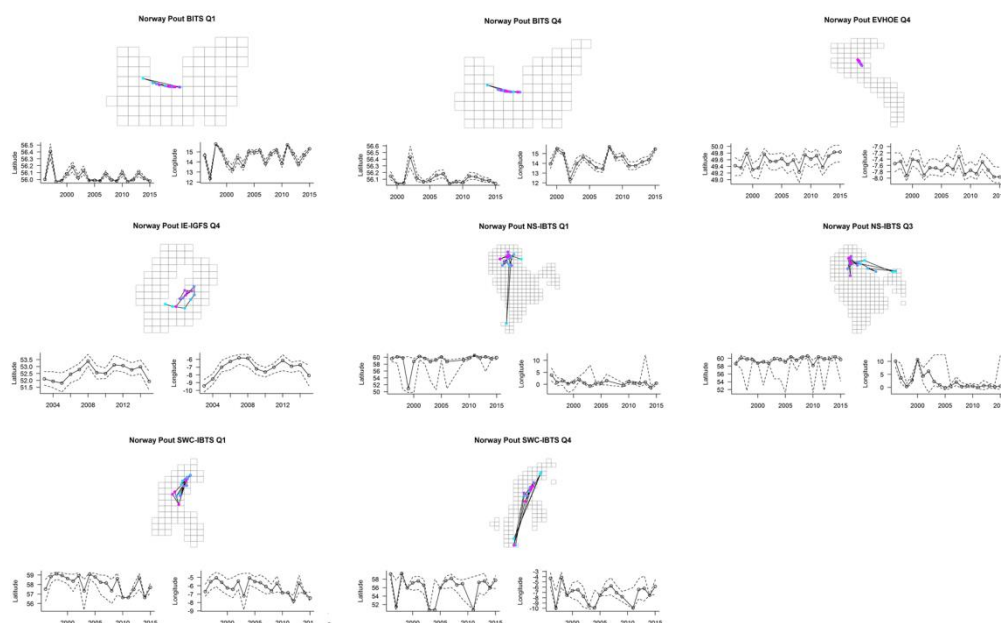


Figure 3.13.4. Shift in the centre of gravity of abundance observed in surveys.

Conclusions

- In recent year, slight changes in the distribution of Norway Pout occurred at the southern limits of its distribution in the Bristol Channel and a slight in-

creased abundance in the North Sea. However, there is no significant change in the position of the centre of gravity. There is no significant log-ratio of abundance between adjacent areas, however, the surveys does not cover the northern boundaries of the species distribution.

- Results still need to be taken with caution as:
 - The trawl surveys only have sampled the southern distribution range in the last 20 years.
 - Northern areas beyond the North Sea have not been surveyed.

3.14.2 Review of potential drivers

Literature about this species is sparse. Norway pout main prey is euphausiids and copepods (Bromley *et al.*, 1997; Pauly *et al.*, 1998; Johannessen *et al.*, 2012). In terms of distribution changes, several papers suggest that Norway pout is an opportunistic, small, fast-growing, plankton-feeding fishes that can react fast to environmental changes and replace other species such as herring and mackerel (Sherman *et al.*, 1981; Mikkelsen *et al.*, 2014). However, acoustic surveys show that Norway Pout coexists with Herring (Fässler *et al.*, 2007). Its distribution could be affected by interactions with other species. It is an important prey of Shaite and Hake for which both species compete (Cormon *et al.*, 2016a; 2016b). Marty *et al.* (2014) show that Norway pout recruitment more resilient to environment changes than other species it cohabits and therefore to fishing pressure. They also discuss a possible competition trade-off with Haddock since they have a close trophic level. Mikkelsen *et al.* (2014) also supports the opportunistic nature of Norway Pout taking over other species loses and its recruitment benefiting from changes in temperature in the Barents Sea. Perry *et al.* (2005) reported a significant southward shift of Norway pout in the North Sea. They attributed this unexpected result to the fact that Norway pout moving from central to southern North Sea actually resulted moving to colder waters. Dulvy *et al.* (2008) reported a deepening of Norway pout in the North Sea although it was found non-significant. This species suffers high mortality by spawning stress that explains the lack of spawning area in the Skagerrak, and Kattegat so far (Nielsen *et al.*, 2012).

Conclusion

- The main reasons for the improvement of the stock status and increase in spawning stock may be related to decrease in fishing mortality associated with several good recruitments. Recruitment success could be linked with more favourable environmental conditions (temperature).
- The opportunistic nature of the species stated in the literature suggests that it is a density-dependent stock with expansions and retractions. However, there is the possibility that a northern shift is starting given literature on Barents Sea and the decrease shown in the southern boundary of the species distribution from the survey data analysis. This might be constrained by the species capacity to establish a spawning area in the Skagerrak, and Kattegat. However, the evidences are weak.

3.14.3 Implications of changes in distribution and future trends

3.14.3.1 Consequences for stocks/populations

- There is a potential competition between the predators hake, saithe for Norway pout in the North Sea. There might be a competition trade-off with Haddock given they have a close trophic level.

- So far it seems there is a single population in the North East Atlantic.

3.14.3.2 TAC management areas

The species is mostly fished in 4 by Denmark and Norway, even in the past there are records of fishing in 6a and 2a area. The fishery was closed in 2008 because $SSB < B_{pa}$. Later in 2008, ICES evaluated and commented on three management strategies fixed fishing mortality (0.35), fixed TAC (50 000 t), and a variable TAC escapement strategy (ICES, 2008). However, from 2009 the F has been reduced to less than 0.35 to increase SSB . The TAC has not been taken several years because of high fishing cost (ICES, 2012). In 2014, the Norway and UE TAC were 108 and 128.3 thousand tonnes respectively while the catches were 28.4 and 18.7 thousand tonnes for Denmark and Norway respectively. Often the quota is not taken due to economic considerations (fuel, time) and other species quota (sprat for Denmark and blue whiting for Norway).

3.14.3.3 Choke species?

Norway pout species is not a choke species because in general is caught without by-catch.

3.14.3.4 Future expectations

We can conclude that Norway pout has changed its distribution based on the analyses presented here and the sparse literature available. Most trends either show no changes, or a slight fluctuation without any clear directional trend. It is not possible, with the available information, to predict what would potentially happen in the near future in terms of relative distribution of Norway pout. If the major factor of expansion is related to stock-density and opportunistic recruitment behaviour, it would thus be possible that, if the stock abundance decreases in the future, the distribution of the population retreat in its northern and southern limit to without affecting the main fishing area in the North Sea. On the other hand, it has also been suggested that the expansion might be related to improvement in habitat suitability linked to increase in temperature in Northern areas. However, it seems there are no detected spawning areas in the Skagerrak, and Kattegat.

3.15 Plaice

3.15.1 Evidence for changes in distribution

3.15.1.1 Analysis of ICES trawl data

Presence – Absence

The use of presence/absence from select survey data (Figure 3.14.1) shows a highly significant increase in the likelihood of occurrence in the Baltic Sea Proper (area 3d) (Table 3.14.1). Furthermore, the occurrence of Plaice in the northern North Sea (4a) exhibits highly significant increases from the start of the survey period, which is expected given the near ubiquitous increase in abundance across plaice's extent.

The (lower) significant increase in occurrence of plaice in the area 7j is in an area where the stock SSB is decreasing. We therefore interpret this increase in occurrence as spill over of individuals from the neighbouring area 7g where the stock SSB is increasing and plaice are generally more abundant.

Table 3.14.2 ICES areas with significant trends in the probability of occurrence of plaice in survey halls in recent years. Mann-Kendall test for monotonic trends. *: $P < 0.05$; **: $P < 0.01$; *: $P < 0.001$; NO: not observed or very low occurrence. Red asterisk indicates decreasing trend whereas green indicates increasing trend.**

ICES Area	Start Year	Plaice
Skagerrak-Kattegat (3a)	2000	
Danish Straits (3b,c)	2000	
Baltic Sea (3d)	2000	***
N North Sea (4a)	2000	***
C North Sea (4b)	2000	
S North Sea (4c)	2000	
NW of Scotland (6a)	2000	
Rockall (6b)	2000	
Irish Sea (7a)	2000	
W of Ireland (7b)	2000	
Porcupine Bank (7c)	2000	
Eastern Channel (7d)	2000	
Western Channel (7e)	2000	
Bristol Channel (7f)	2000	
Celtic Sea N (7g)	2000	
Celtic Sea S (7h)	2000	
SW of Ireland E (7j)	2000	*
SW of Ireland W (7k)	2001	
Bay of Biscay N (8a)	2000	
Bay of Biscay C (8b)	2000	
Bay of Biscay S (8c)	2000	
Bay of Biscay Offshore (8d)	2000	
Portuguese Waters E (9a)	2000	

Increase	3
Decrease	0

All other areas show little or no trends in the occurrence of plaice across the ICES areas, excluding some large short term variation most often observed in old surveys.

Critically, the ICES areas compared do not represent the stock boundaries which are more biologically relevant (at population/stock levels), exemplified by the division of plaice from 3a into 3a.20 and 3.a.21 for stock assessment.

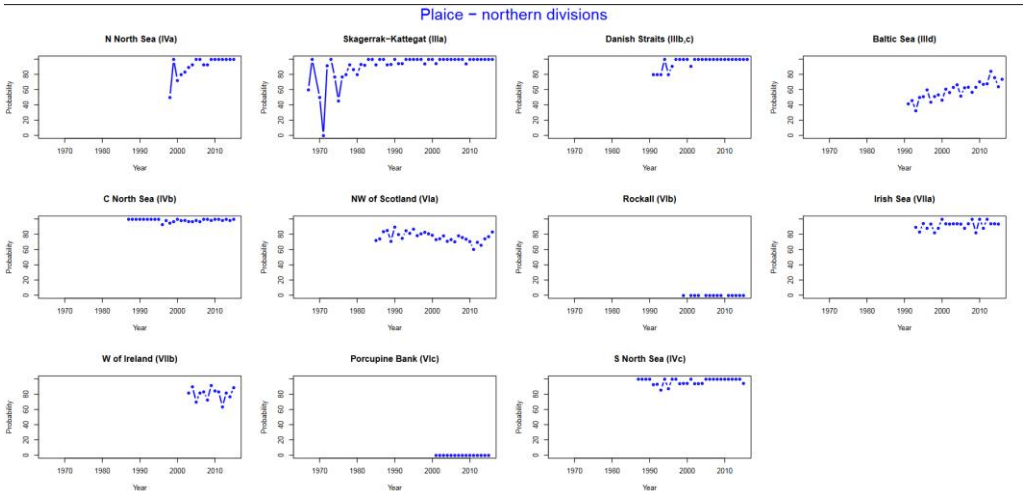


Figure 3.14.1 Probability of occurrence of plaice in survey halls within northern ICES Divisions and subdivisions

Abundance Trends

Abundance index by management region and survey

Changes in the centre of population mass in the Skagerrak – Baltic covered by the BITS exhibit a southern shift (Figure 3.14.2) in both Q1 and Q4 Surveys. This shift shows a notable change in the centre of population mass from the north of the belt seas to the south. This shift in the centre of population mass corroborates what is shown in the below test for changes in relative abundance across ICES areas.

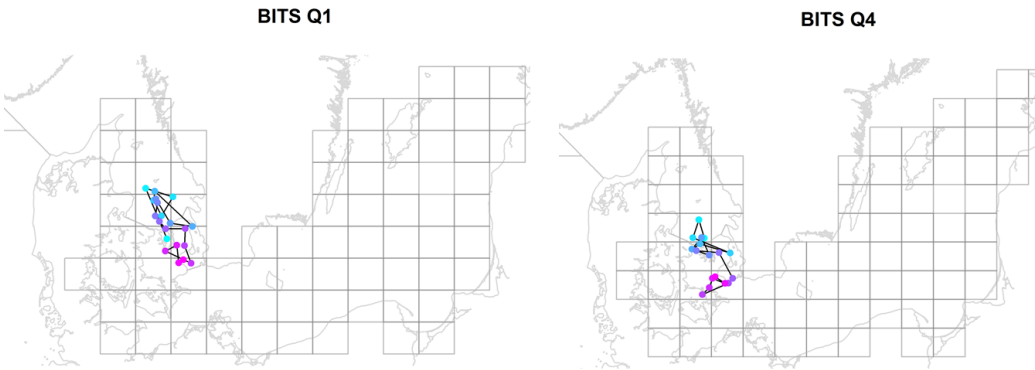


Figure 3.14.2 Annual centre of population mass based on abundance estimates in BITS quarter 1 (left panel) and quarter 3 (right panel) surveys. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

In the North Sea, the BTS Q3 survey shows a peculiar, regular shift of the centre of population mass between the central North Sea and the Skagerrak with a periodicity of about 2 years (Figure 3.14.3). This anomaly could not be explained by changes in Survey methods described in ICES (2009) but may be explained by the erroneous periodic inclusion of surveys from the Skagerrak and Kattegat in the analyses.

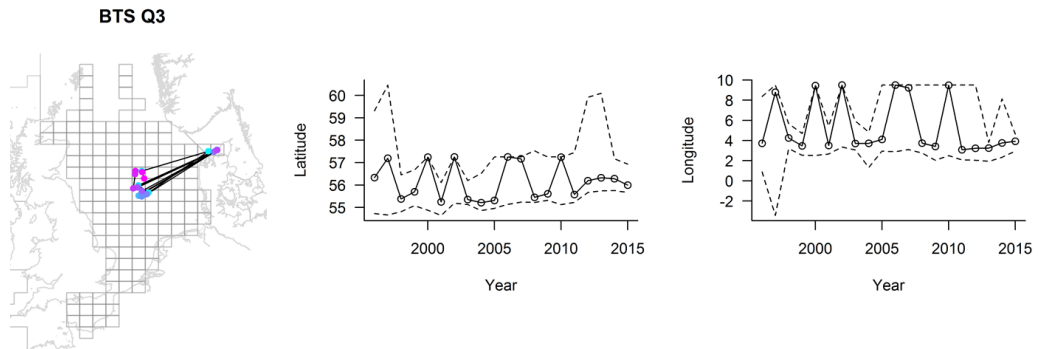


Figure 3.14.3 Annual centre of population mass (left panel) based on abundance estimates in BTS quarter 3 surveys and the corresponding latitudinal (centre panel) and longitudinal (right panel) temporal shifts. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

The NS-IBTS shows erratic movement of the centre of population mass from year to year, but centred around the middle of the North Sea (Figure 3.14.4). We propose that these erratic movements represent noise in the mean centre of mass across a range where the species is abundant everywhere (e.g. see NS-IBTS estimates of 2015 distribution in the North Sea; Figure 3.14.5). Given the nature of the survey method, we propose that the BTS survey would provide a more accurate representation of distribution. Furthermore the analysis here includes trawls into the Kattegat, across the Jutland Peninsula, and which is considered a different stock.

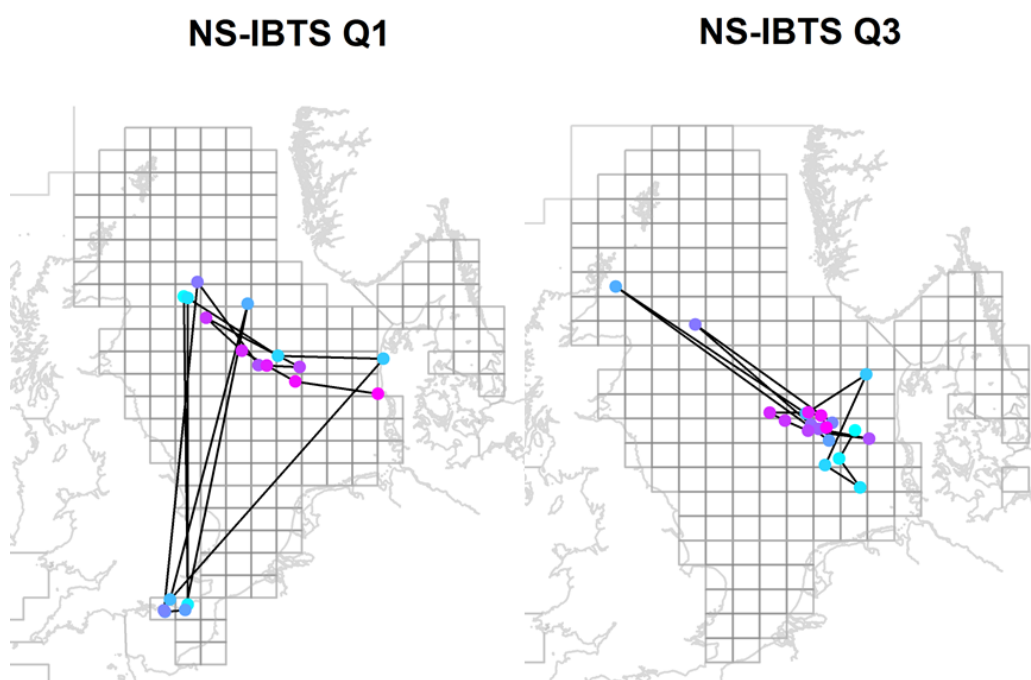


Figure 3.14.4 Annual centre of population mass based on abundance estimates from the North Sea International Bottom Trawl Survey (NS-IBTS) quarter 1 (left panel) and quarter 3 (right panel) surveys. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

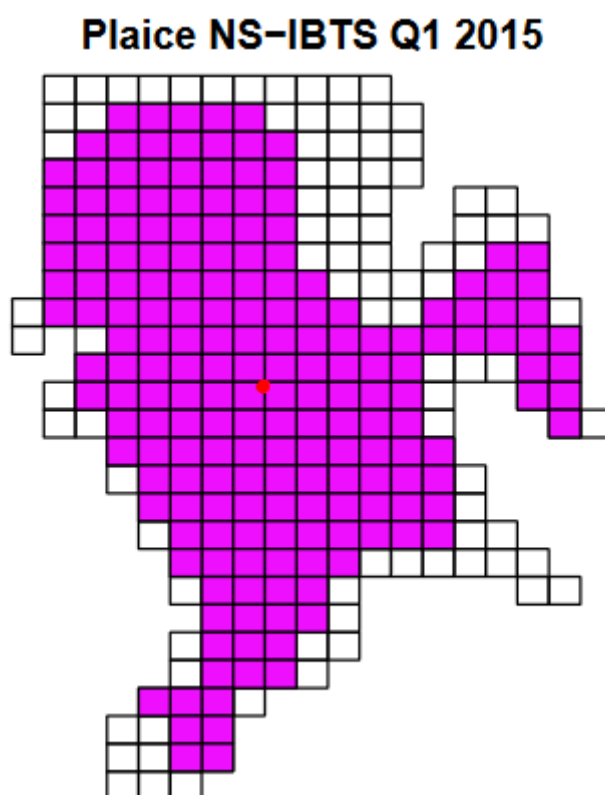


Figure 3.14.5 Ubiquitous estimated abundance of plaice in the North Sea by survey rectangle from the North Sea International Bottom Trawl Survey of 2015 and the derived centre of mass for that survey and year.

Across the other areas analysed, there are no clear trends in plaice centre of population mass shift. It should be noted that the result using the SWC-IBTS (especially Q4) are questionable given the confounding landmasses dividing the survey areas (Fig 3.14.6).

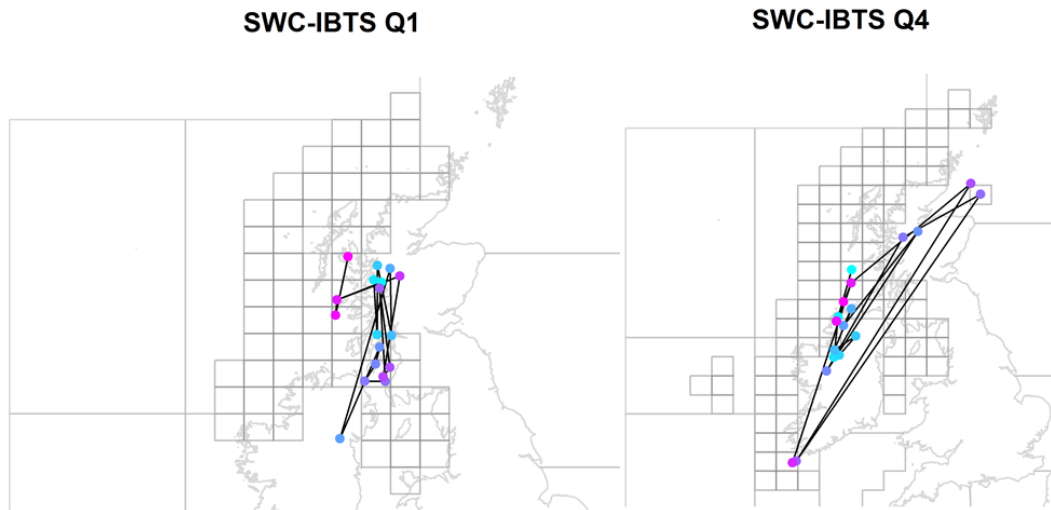


Figure 3.14.6 Annual centre of population mass based on abundance estimates from the Scottish West Coast International Bottom Trawl Survey (SWC-IBTS) quarter 1 (left panel) and quarter 3 (right panel) surveys. Light blue points correspond to the beginning of the time series while the light pink points represent the end.

Testing for changes in stock distribution

The analyses of the relative abundances across ICES Subdivisions (Figure 3.14.7) illustrate differences between the Skagerrak/Kattegat (3a) and the Belt Seas/Sound (22, 23). Similarly between the Southern North Sea and Eastern English Channel differences in relative abundance are also indicated. In both of these instances the analyses indicate an increase of abundance in the peripheral areas/subdivisions relative to the central North Sea/Skagerrak stock. It should be noted that for the purposes of the analyses, the Skagerrak/Kattegat (sub-division 3a) is considered as one population unit, whilst the ICES advice considers the Skagerrak (3a.20) part of the North Sea (4) and the Kattegat area (3a.21) is considered jointly with the Belt Seas (22) and Sound (23) (Figure 3.14.8).

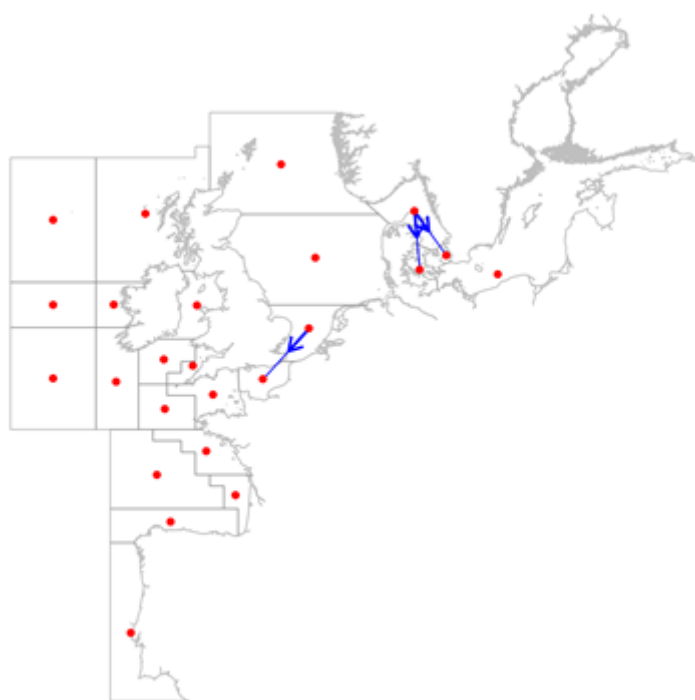


Figure 3.14.7 Centroids (red points) of ICES divisions and subdivisions (boxes) used in the analysis of relative changes in plaice abundance. Arrows show significant trends where the box at the beginning of the arrow has consistently lower relative change in abundance to the neighbouring box with the terminus of the arrow.

All other subdivisions show no relative changes to abundance according to the relative abundance analyses. Of note is the absence of a significant relative abundance change between the Bristol Channel / Celtic Sea (7fg) and the Celtic South / SW Ireland (7h-k) stocks. According to the stock assessments for these areas, there is a large increase in plaice abundance in Bristol Channel / Celtic Sea (7fg) and a decrease in abundance for Celtic South / SW Ireland (7h-k). The absence of an identified increase in the Eastern Baltic is due to the concurrent increase in the only neighbours to this stock, the Belt Seas and Sound. The absence of a significant difference in the relative abundance analyses for these areas illustrates how this method is not always suitable for identifying changes.

3.15.1.2 Other evidence

ICES stock advice for plaice were considered for temporal indications of stock size change and ad-hoc comparisons of neighbouring stocks (Figure 3.14.8).

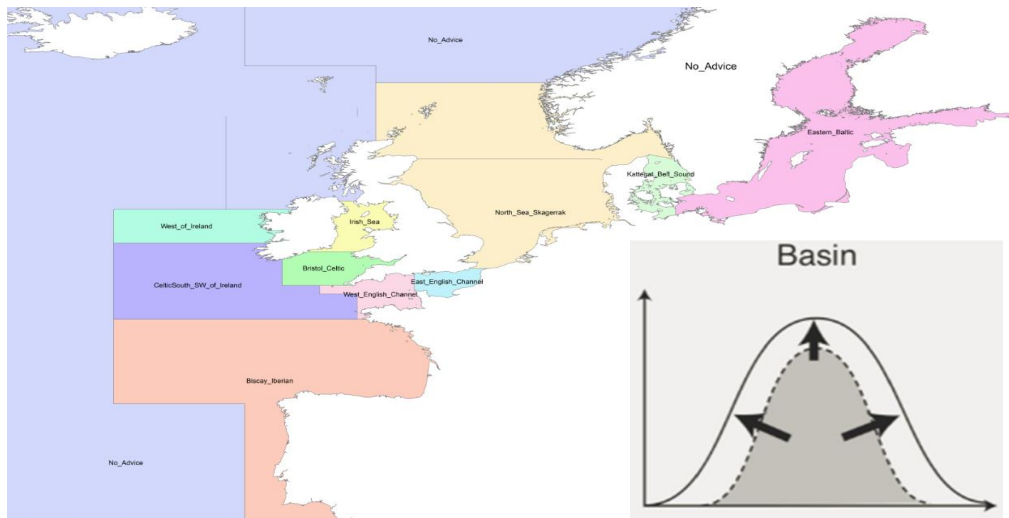


Figure 3.14.8 ICES advice areas for plaice, note the inclusion of Skagerrak (3a) in the North Sea (4a, b, c) advice. Inset (from: Unknown, simplified from Petitgas, 1998) is a hypothetical increase in population abundance where the y axis is local density and the x axis is a transect across the species' range, whereby in this example the population is expanding its range outward in multiple directions and increasing its abundance across the entire new range.

A substantial increase in SSB over the last decade (Figs. 3.14.9 – 3.14.11) was observed for the North Sea/Skagerrak, Kattegat/Belt/ Sound, and East English Channel stocks which were shown to have significant changes in relative neighbour abundance across ICES areas (4, 3a.21–23 and 7d respectively).

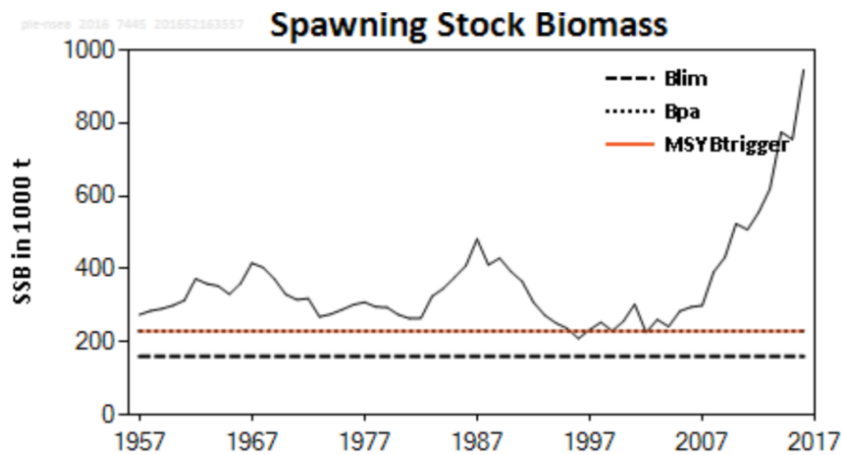


Figure 3.14.9 Temporal trends in Spawning Stock Biomass for the plaice stock in the North Sea / Skagerrak (4a, b, c, & 3.a.20).

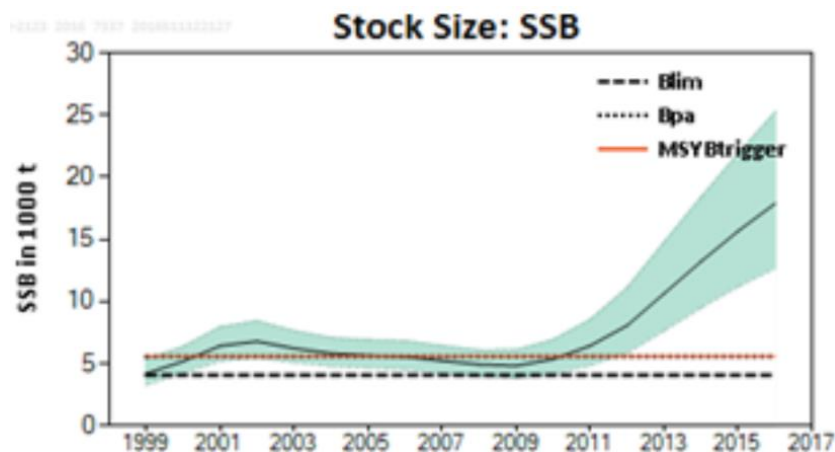


Figure 3.14.10 Temporal trends in Spawning Stock Biomass for the plaice stock in the Kattegat, Belt Seas and Sound (Subdivisions 21-23)

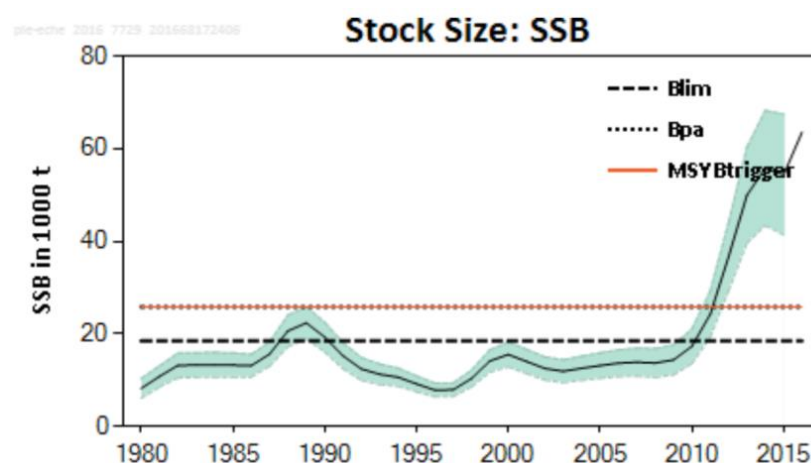


Figure 3.14.11 Temporal trends in Spawning Stock Biomass for the plaice stock in the East English Channel (7d).

Although there was no significant change in relative abundance indicated through the analyses provided by ICES we found that the Eastern Baltic Sea (3a.24,3d) has experienced a similar increase in SSB as its neighbouring stock, showing further increase in the range of the species outward toward the edge of its extent and across management boundaries. The Bristol Channel/Celtic Sea stock (3fg) showed a similar increase in SSB to those stocks mentioned above (Figure 3.14.12). Concurrently, the neighbouring stock of the Celtic Sea South/SW Ireland exhibited a stock decline (7h-k). We cannot explain why this relative difference was not identified by the analysis of relative abundances.

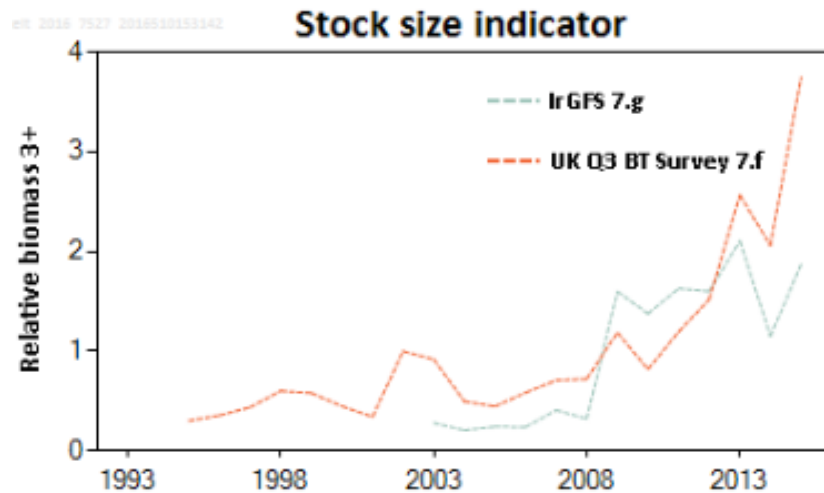


Figure 3.14.12 Temporal trends in relative stock biomass for the plaice stock in the Celtic Sea / Bristol Channel (7. f & g).

The plaice distribution shifts identified in these analyses can be summarised by an increasing abundance in their central range, with concurrent expansion and increasing abundance toward the edges of their range, illustrated by the inset of Figure 3.14.8.

3.15.2 Review of potential drivers

The review of ICES advice indicates a strong influence of fishing pressure on stock abundance. Decreases in fishing mortality allowed SSB to increase in parallel with recruitment until recruitment levels off; this formed a positive feedback loop (Figure 3.14.13) which allowed stocks to substantially increase in size with respect to both number and individual size. This trend was observed across all of the stocks considered above (North Sea / Skagerrak, Kattegat / Belt / Sound, Eastern Baltic, East English Channel and Bristol Channel / Celtic Sea).

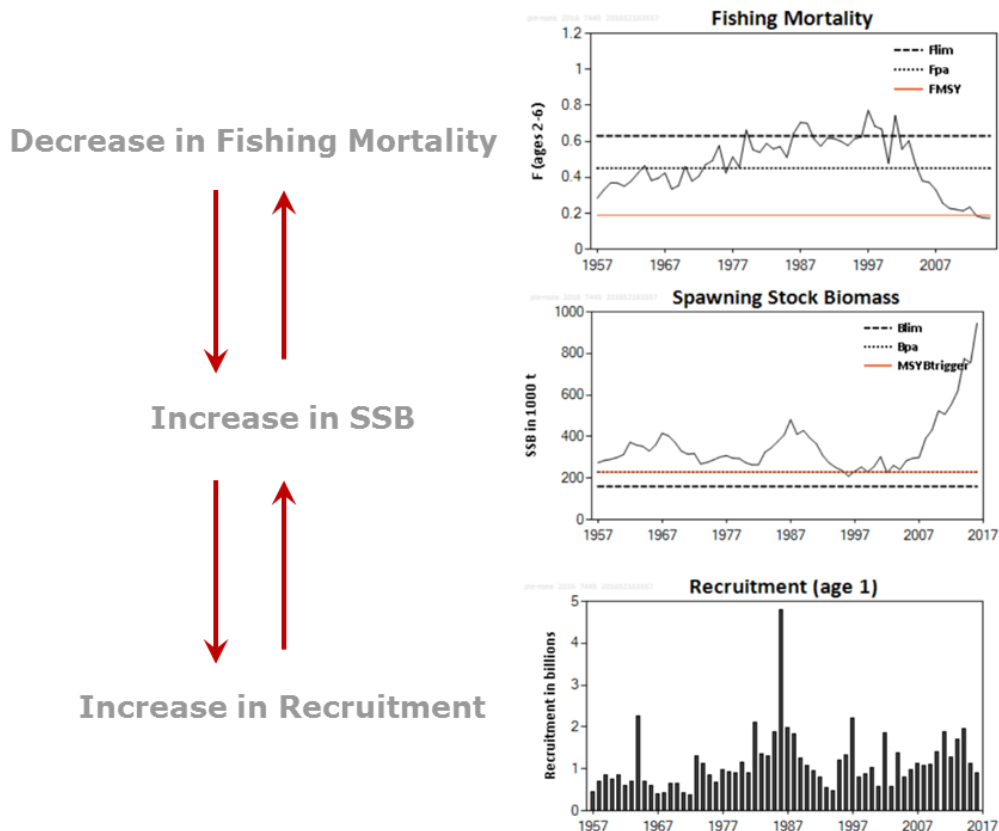


Figure 3.14.13 Typical relationship between fishing pressure, stock size and recruitment exemplified by the North Sea / Skagerrak plaice stock from ICES advice.

For different stocks the initial decrease in fishing mortality which allowed SSB to increase could be only be loosely attributed to a range of different occurrences. Whilst the change in fishing practice or environmental drivers could not be directly attributed to the drop in F , ordinarily the catches at this time were made up of fewer, larger individuals. Whilst there is a clear expansion of the stock in relation to relaxed fishing mortality, there are also more localised drivers acting within ICES advice areas but ultimately influencing the species extent.

In the south-eastern North Sea, during the 1990s–2000s, there was evidence for an offshore distribution shift (van Keeken *et al.* 2007) and this was of high relevance to management, because the shift may have made the Plaice Box (Pastoors *et al.* 2000) less effective as a means of protecting juvenile plaice. Engelhard *et al.* (2011) examined long-term distribution shifts of North Sea plaice between 1913 and 2007, and reported that plaice have, since the 1940s, shown a northward, deepening distribution shift. A recent review provides a good overview of coastal drivers to plaice distribution (Dutz, Støttrup, Stenberg, & Munk, 2016). In the north of the species' range (Skagerrak/Kattegat) the eradication of local spawning stocks occurred under high fishing pressure. However in the south of the species range, increased water temperature and continued warm coastal conditions excluded juveniles from nursery areas and caused a local collapse of the stock (Hermant, Lobry, Bonhommeau, Poulard, & Le Pape, 2010). Temperature effects in the juvenile habitat were clearly illustrated as the mechanisms for the population loss via the gradual loss of increasingly aged adults in the fishery following multiple years of unstable juvenile habitat (Désaunay, Guérault, Le Pape, & Poulard, 2006).

Furthermore, Teal *et al.* (2012), showed how shifting regimes of increased coastal temperatures and decreased coastal production (under lowered terrestrial nutrient input) led to a decrease in the growth of juveniles and a displacement of adults away from the coast in the southern North Sea. Figure 3.14.14 shows how this type of regime impacts the distribution of plaice within the ICES advice area.

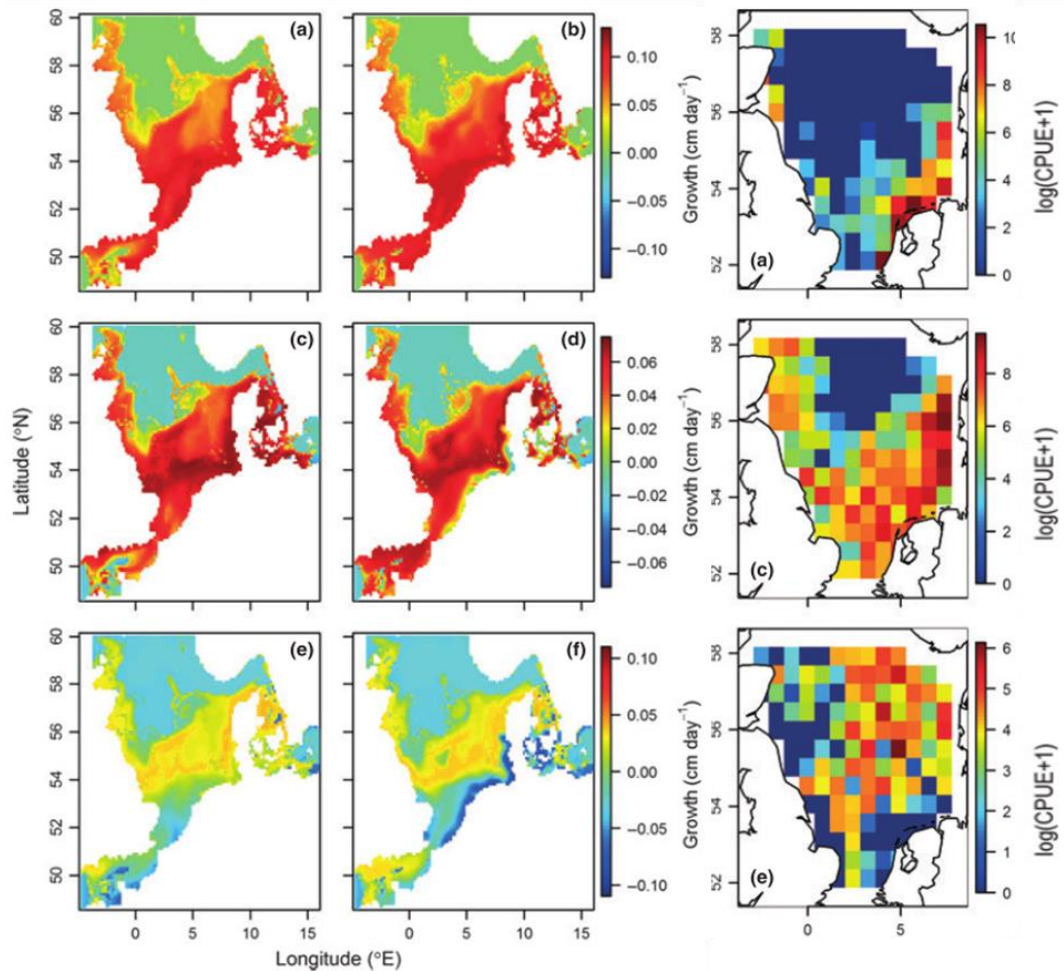


Figure 3.14.14 Maps of the North Sea including the English Channel to the Western Baltic showing maximum expected growth rate (Left two columns) from combined DEB and benthic productivity models for plaice with starting lengths of 1.5cm (a, b), 20cm (c, d) and 40cm (e, f) in two different years: High nutrient, low temperature (a, c, e) and lower nutrient, higher temperature (b, d, f). The right panel shows average abundance of plaice across the North Sea from 1990 – 2010 for size classes 9–15cm (top), 19–25cm (middle), >35cm (bottom). Figures taken from Teal *et al.* (2012).

3.15.3 Implications of changes in distribution and future trends

A large reduction in survey catches of plaice from the Bay of Biscay serves as a good example of extirpation due to warming on the species (Hermant *et al.*, 2010). Temperature as the main driver of the unsuitability and eventual loss of effective juvenile habitat is also well illustrated (Désaunay *et al.*, 2006). The retraction of this species' southern extent may continue under a scenario of continued warming.

The shallow juvenile habitats supplying the population in the centre of its range (North Sea, Skagerrak and Kattegat) are at risk from continued warming. Whilst stocks in these areas are currently increasing, the release from fishing pressure may be masking a future bottleneck to production in the juvenile areas. For plaice the ef-

fect of temperature is shown to impact adult plaice distribution independently of fishing pressure (Engelhard, Pinnegar, Kell, & Rijnsdorp, 2011) and so even under the current regime of low fishing mortality, temperature will continue to influence the distribution of plaice.

Furthermore, with reductions in nutrient input from terrestrial sources, coastal juvenile habitats and adult growth areas are likely to decrease in productivity. The combined effect of temperature and productivity was modelled by Teal *et al.* (2012) where conditions in coastal habitats caused lower growth rates of juvenile fish and even potentially detrimental physiological condition of adults (Figure 3.14.14).

3.16 Pollack

Pollack is rather coastal species, found in rocky environments and distributed from the Iberian peninsula to Norway and Iceland. ICES gives advice on this species for 3 stocks : Subareas 4 and 3a (North Sea stock), Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters) and Subareas 6-7 (Celtic Seas and the English Channel).

ICES advice is based on the precautionary approach for these stocks (Category 5 stocks) using the recent trend in the catches or landings.

3.16.1 Evidence for changes in distribution

3.16.1.1 Analysis of ICES trawl data

Presence-absence analyses

Based on the analysis performed by the ICES secretariat on presence/absence data for the short time series and the areas considered (2000 onwards), there was little support for changes in pollack distribution. Based on the longer time series, significant changes in occurrence (increase) of the species were detected only in the North Sea and the Skagerrak-Kattegat area. There is however no TAC management area defined for the pollack in the North Sea.

A significant negative trend was observed for area 7b (west of Ireland). No trend was found in the other subdivisions of division 7, which constitutes a single TAC management area for pollack.

Warning:

It should be noted that while the occurrence analyses concluded in an absence of the pollack in the southern areas (Celtic Sea and south) for the whole time series, the raw data presented for the abundance analysis showed that there were catches of pollack in the surveys (e.g. EVOHE in the Bay of Biscay) and centres of gravity were calculated. In addition most of the catches of the Celtic Sea stock (covering division 6 and 7) originate from 7e-g-h and j where the occurrence is found to be null.

Centre of gravity analysis

The centres of gravity of the abundance did not show any significant movement in any of the surveys.

Abundance log-ratios

No significant trend was found in the log-ratios of abundance between adjacent areas.

3.16.1.2 Other evidence

The group also reviewed published information to address changes regarding significant shifts in the distribution of the stock. The only available information on pollack distribution comes from Cardinale *et al.* (2012) based on a reconstruction of catches and survey data since the start of the 20th century, mainly from the Skagerrak-Kattegat area. These authors suggest that in this area pollack was present in the central part of the Skagerrak from the 1920s to the 1960s. During the 1940s, higher abundances were found also in the Kattegat, but abundances decreased in all the area in the 1970s, and since the 1990s, pollack is almost absent from the area.

The findings from this study contradict the results from the occurrence analysis, showing an occurrence of on average 50% in the Kattegat-Skagerrak area, increasing since 1970.

Information on the spatial distribution of pollack at a small spatial scale are also provided by Fromentin *et al.* (1997), where some shifts in the abundance of pollack near the Norwegian coast of Skagerrak were noted.

3.16.2 Review of potential drivers

Information on potential drivers regarding the distribution shifts of pollack can only be considered in relation to the distribution changes based on the reconstructed catches in the Skagerrak-Kattegat area, where the authors of the study suggest that the fishing pressure is probably responsible for the observed patterns (Cardinale *et al.* 2012).

At a smaller spatial scale, Fromentin *et al.* (1997) have suggested that the observed distribution patterns probably resulted from intrinsic interactions in age-structured populations, such as density-dependent competition and cannibalism, whereas the long-term trends possibly due to extrinsic forces, such as environmental changes or anthropogenic influences.

3.16.3 Implications of changes in distribution and future trends

Only minor changes have been observed in the distribution of pollack in the North East Atlantic, which should not have any major implication for the stocks, the fishery, or the management.

In the northern North Sea, pollack is mainly a by-catch species and is not managed by a TAC.

In the Celtic Sea, the area in which the occurrence has decreased (subdivision 7b), represents a negligible proportion of the catches from the Celtic Sea stock, which originate mostly from 7e-g-h and j.

No information is available on the factors controlling the distribution of pollack, and therefore nothing can be said about future changes.

3.17 Saithe

Saithe (*Pollachius virens*) is a boreal species distributed in the deep waters of the shelf edge in the Northeast Atlantic from the Bay of Biscay to the Barents Sea and around Iceland. Although a cod-like gadoid caught in trawl surveys, saithe form dense shoals and are considered semi-pelagic. Juveniles are distributed in inshore areas until age 3 after which they migrate to deeper waters (ICES, 2016a). The bathymetric distribution of saithe is very broad, and they can be found both in inshore and offshore waters, and both close to the bottom and near the surface (Bergstad, 1991). ICES considers four stocks in the Northeast Atlantic: (1) North Sea, Rockall and west of Scotland, and Skagerrak and Kattegat stock spanning areas 4, 6 and 3a, (2) Northeast Arctic stock in areas 1 and 2, (3) Faroese stock in area 5b and (4) Icelandic stock in area 5a. TACs for saithe are allocated to six different TAC management areas (Figure 1.3.2): (1) areas 1 and 2, (2) areas 2a, 3a, 3bc, 4 and subdivisions 22-32, (3) Norwegian waters south of 62° N, (4) areas 5b, 6, 12 and 14, (5) Faroese waters in area 5b and (6) areas 7, 8, 9, 10 and CECAF 34.1.1. Survey data were only available for the area covering stock 1 listed above and consequently only this stock is considered hereafter.

3.17.1 Evidence for changes in distribution

3.17.1.1 Analysis of ICES trawl data

Presence-absence analyses

Saithe were observed mainly on the west of British Isles around Ireland and along the Norwegian deep from the northern North Sea to Skagerrak and Kattegat. A few observations were also made in the southern North Sea, the English Channel and the Bay of Biscay. Saithe were absent from the Baltic Sea, Rockall, Porcupine Bank and the Spanish coast. This pattern has remained largely unchanged between 2001 and 2015 where survey data was available for all ICES areas considered in the analysis, also the number of observations on the north of Scotland has increased in later years (Figure 3.17.1).

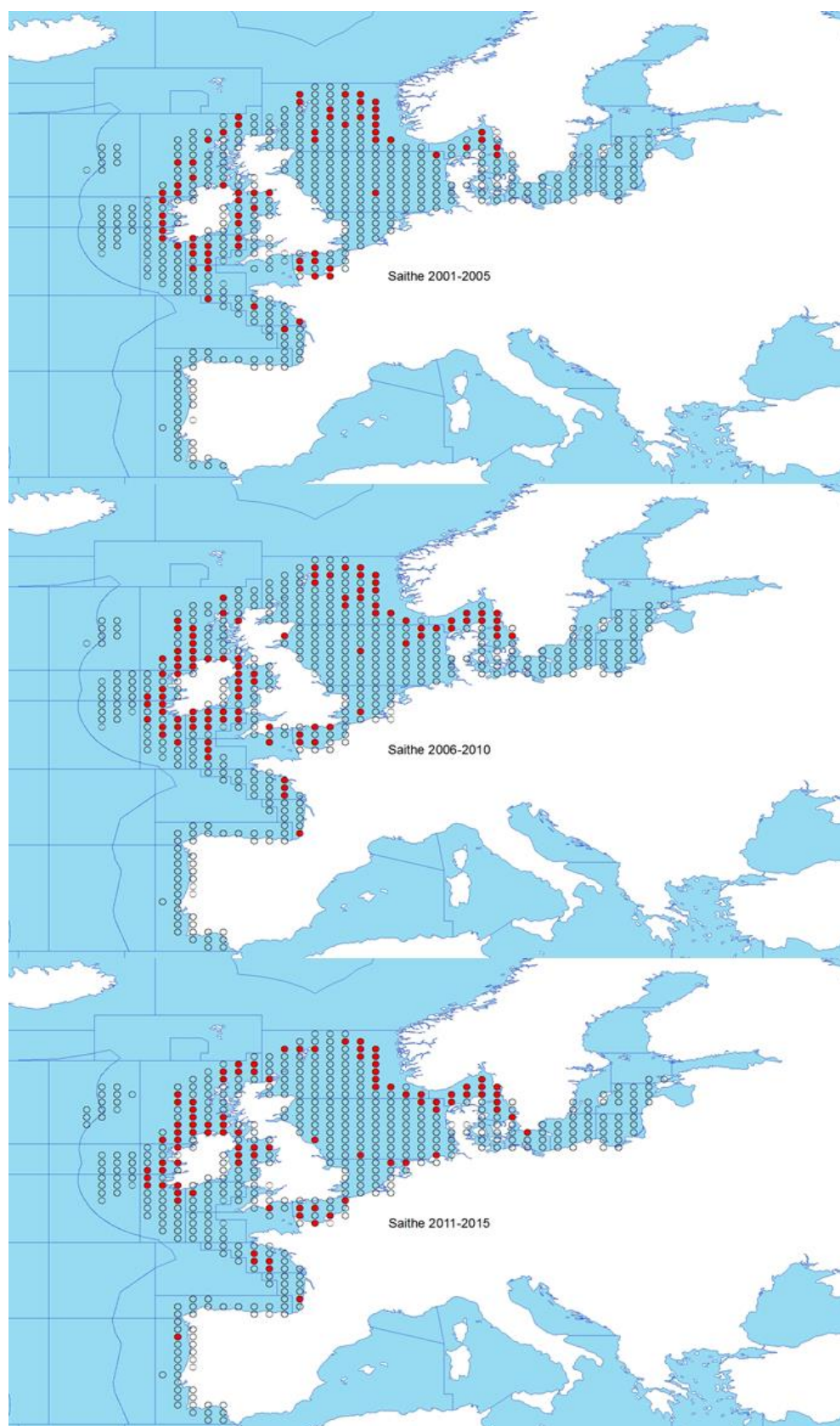


Figure 3.17.1. Presence/absence maps by ICES statistical rectangles for 2001-2005 (top panel), 2006-2010 (middle panel) and 2011-2015 (bottom panel) when data was available for all surveys.

Within northern ICES areas (north of Celtic Sea) a clear and steady declining trend in occurrence was observed in Skagerrak and Kattegat (area 3a) between 1970s and early 2000s followed by an increase in recent years, albeit not reaching historical levels. In the west of Scotland, after an increase in late 1980s and early 1990s a decline in occurrence was observed through to the late 2000s followed by an increase in recent years. Likewise, both the Irish Sea (7a) and the west of Ireland (7b) displayed an increase in occurrence in recent years although data was only available from the mid-2000s in both cases. No trend was observed in all other northern areas (Figure 3.17.2). Within southern areas (Celtic Sea and below) the only noticeable trend in occurrence was observed in the eastern Channel with a gradual decline from 1990 onwards (Figure 3.17.3).

Saithe – northern divisions

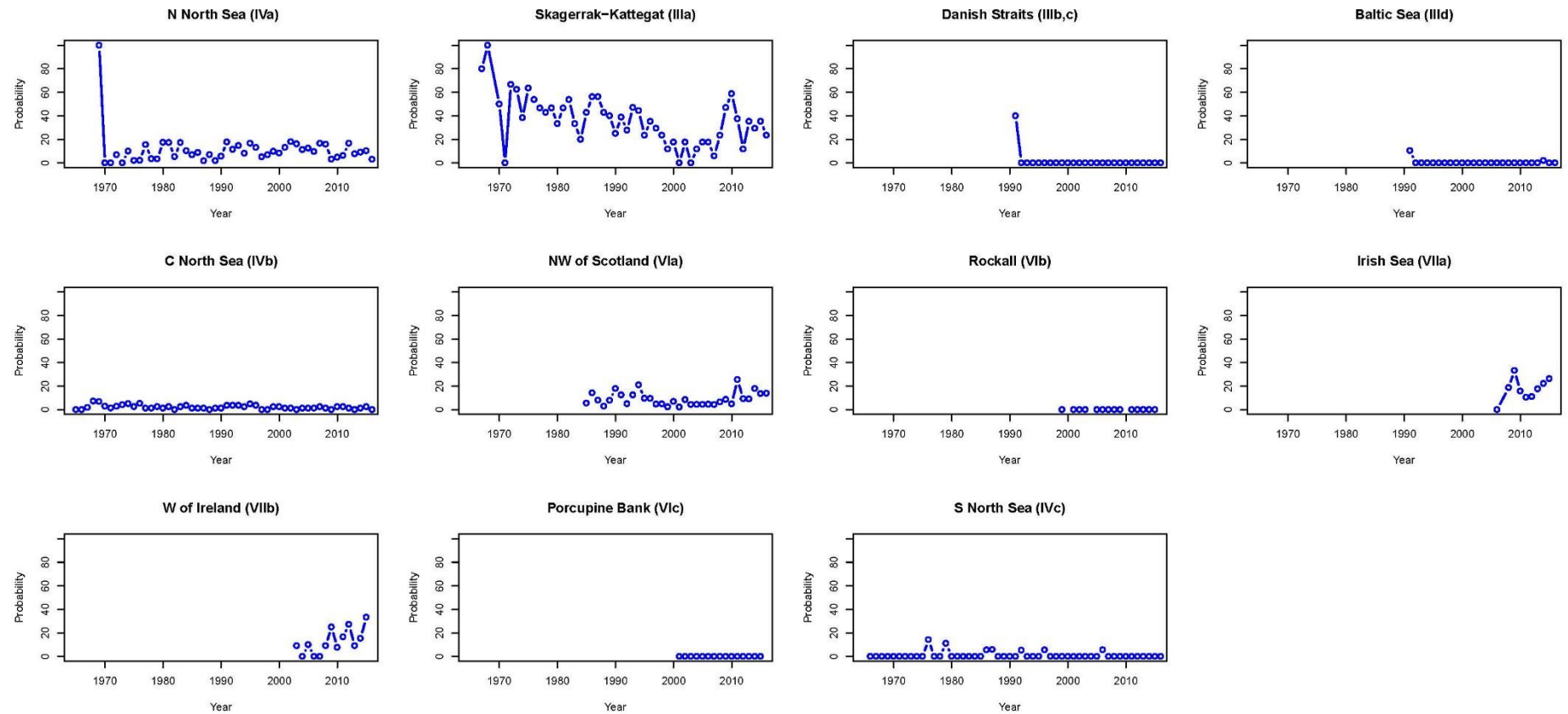


Figure 3.17.2. Saithe trends in presence/absence in northern ICES areas

Saithe – southern divisions

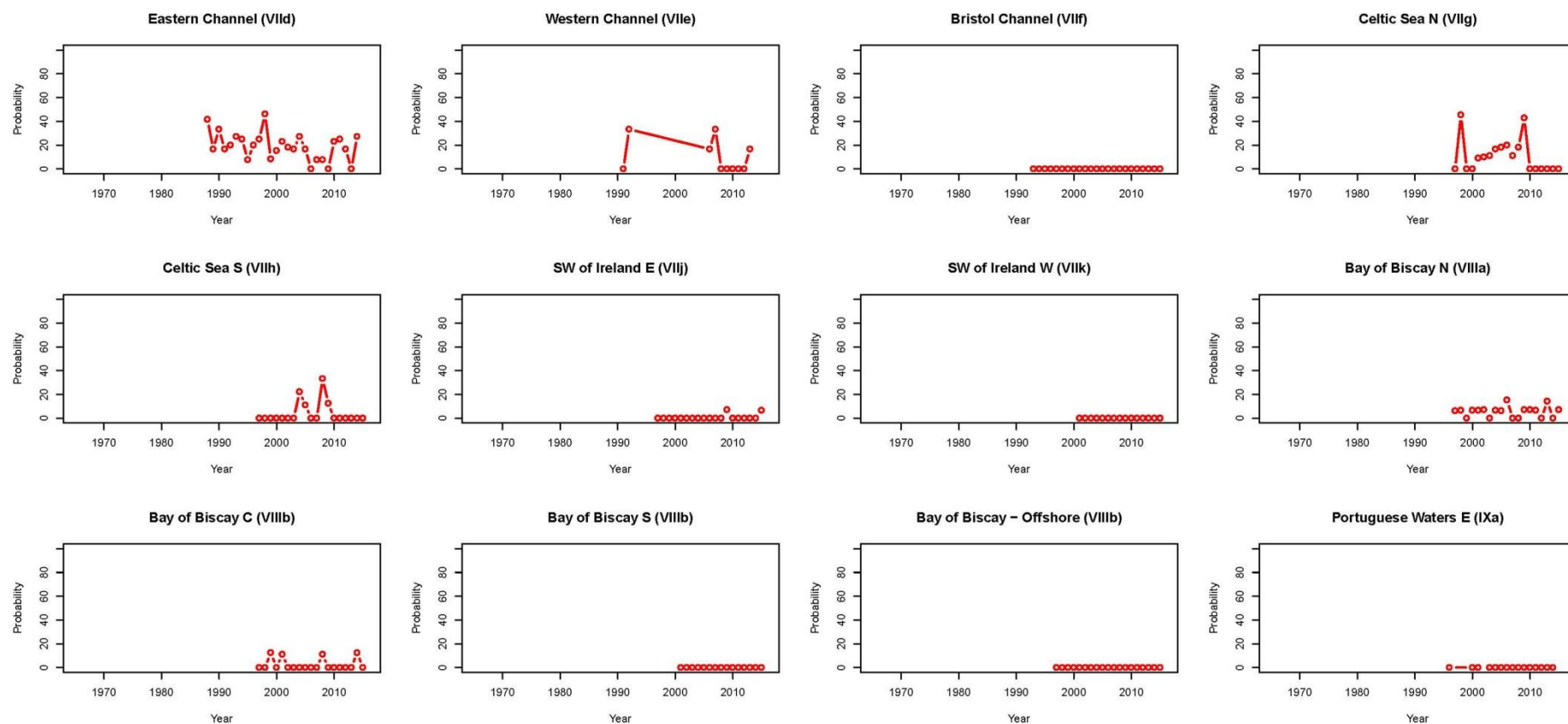


Figure 3.17.3. Saithe trends in presence/absence in southern ICES areas

Centre of gravity of abundance by surveys

Three surveys showed a noticeable shift in their abundance's centre of gravities over time, all located on the western boundary of the area surveyed: quarter 4 IGFS covering areas 7ab (east and west of Ireland), and SWC-IBTS covering areas 6a and 7a-b (west of Scotland, east and west of Ireland) in both quarter 1 and 4. All three surveys show a north-eastward displacement of the abundance's centre of gravity consistent with a distribution shift along the shelf, although with some discrepancies. In quarter 4 IGFS, both the latitude and longitude of the centre of gravity increased in the mid-2000s after which they remained stable except for the last year (Figure 3.17.4). In SWC-IBTS, the latitude and longitude of the centre of gravity remained stable until late 2000s after which they showed a clear increase in both quarter 1 (Figure 3.17.5) and 4 (Figure 3.17.6), the latter displaying the larger increase of the two with a gain of circa 3° in latitude.

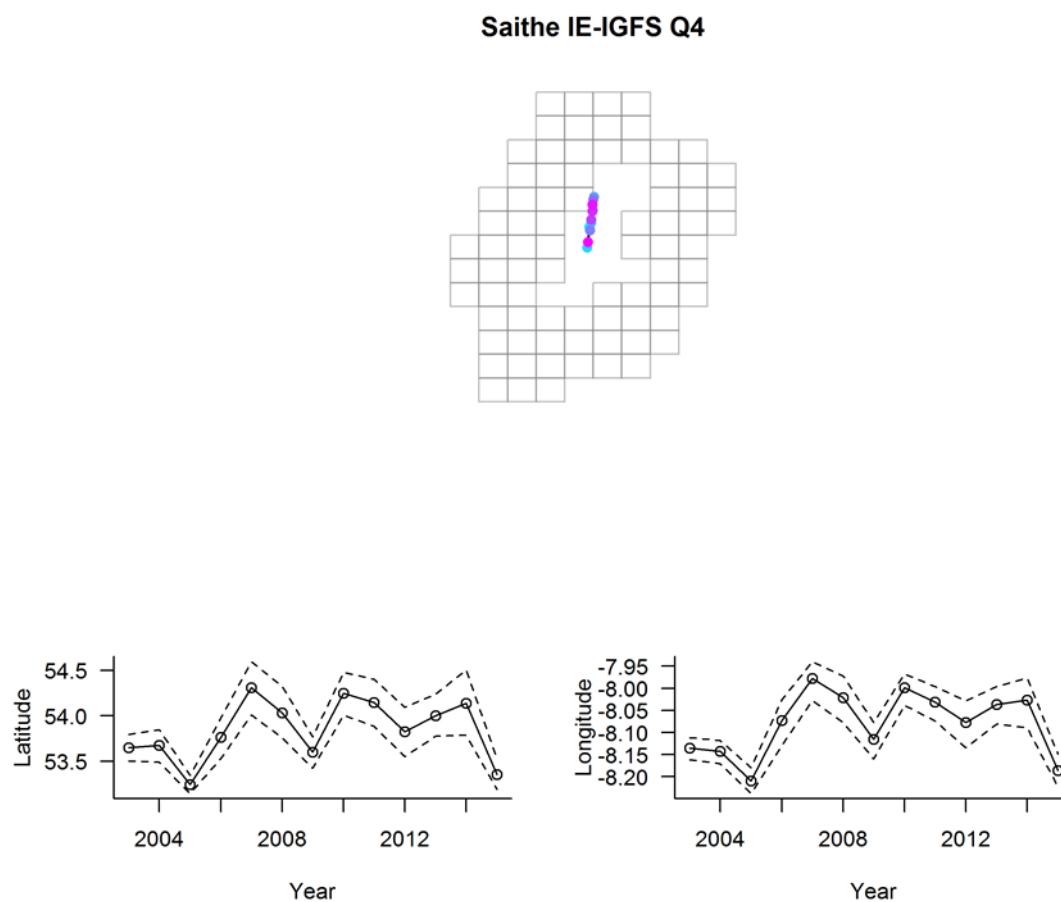


Figure 3.17.4. Shift in the centre of gravity of abundance observed for quarter 4 IGFS.

Saithe SWC-IBTS Q1

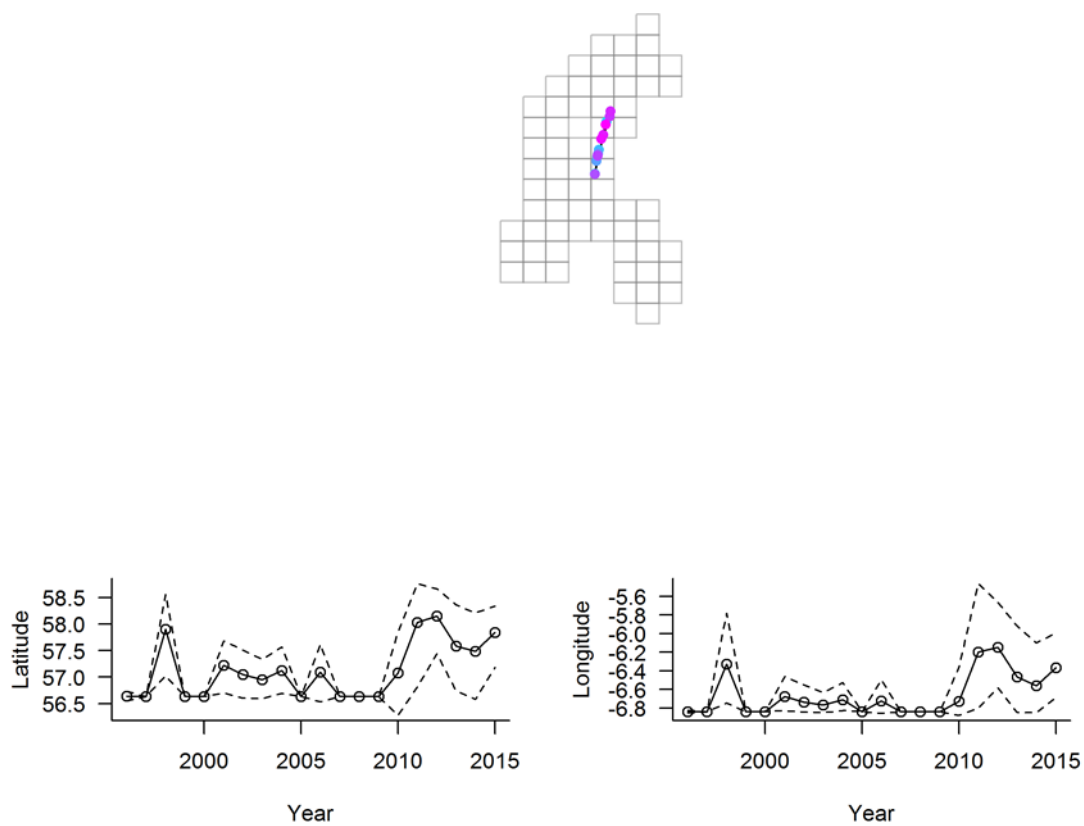


Figure 3.17.5. Shift in the centre of gravity of abundance observed for quarter 1 SWC-IBTS

Saithe SWC-IBTS Q4

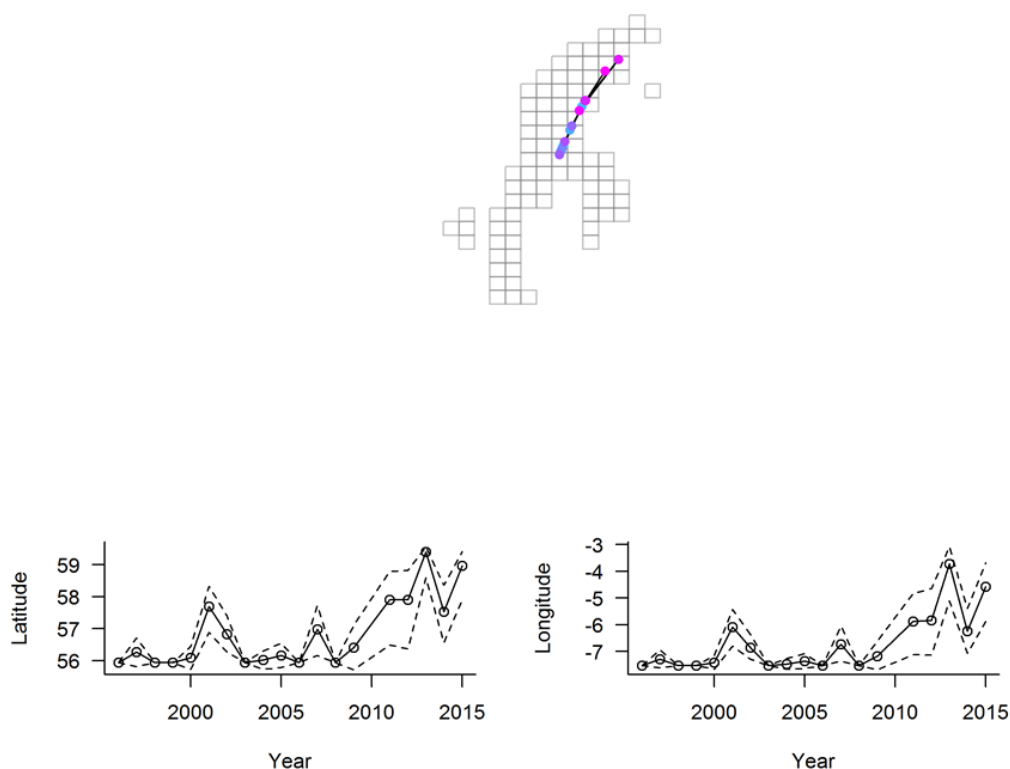


Figure 3.17.6. Shift in the centre of gravity of abundance observed for quarter 4 SWC-IBTS

Changes in relative abundance between adjacent ICES areas

No significant changes in relative whiting abundance between adjacent areas were observed.

Conclusions

Based on the analyses of trawl survey data, the area occupied by saithe has remained largely unchanged for the last 15 years, except for an increase in positive observations on the north of Scotland in the last few years. Changes in occurrence were observed in five areas: (1) in Skagerrak and Kattegat the occurrence decreased steadily from 1970s through to early 2000s after which it started increasing albeit not reaching historical levels, (2) in the west of Scotland the occurrence increased in late 1980s and early 1990s, then decreased through to the late 2000s and increase again in recent years, (3-4) this recent increase in occurrence was also observed in the neighbouring Irish Sea and west of Ireland, (5) in the eastern Channel the occurrence gradually declined from 1990 onwards. A noticeable north-eastern shift in the abundance's centre of gravity from surveys was observed for the three areas exhibiting an increase in occurrence in recent years, west of Ireland, Irish Sea and west of Scotland, consistent with a northward distribution shift along the western continental shelf.

3.17.1.2 Other evidence

While a few studies have investigated saithe migrations with tagging experiments (Homrum *et al.* 2013, Otterå and Skilbrei, 2014) and the vertical distribution in the water column (Skilbrei and Otterå, 2016), the literature is scarce regarding saithe spa-

tial distribution. In the North Sea, Bergstad (1990) identified the western and southern upper slopes of the Norwegian deep as overwintering and feeding grounds for saithe while adjacent areas at 100-150m deep showed a dominance of saithe in survey catches. In their meta-analysis on fish distribution in the North Sea, Perry *et al.* (2005) found no significant northward distribution shift for saithe. However, in another meta-analysis in the North Sea Dulvy *et al.* (2008) reported a significant deepening of saithe. This observation is relevant since saithe in the North Sea favour the deeper waters of the Norwegian deep. Homrum *et al.* (2013) conducted a tagging experiment to assess saithe migration in the northeast Atlantic. Their findings show that long distance migrations occur across the northeast Atlantic, with the distance travelled increasing with fish size, although they did not identify the mechanism behind the migrations. Likewise, exchanges between the northeast Arctic saithe stock north of 62°N and the North Sea saithe stock have been observed (ICES, 2016a).

3.17.2 Review of potential drivers

Physical conditions

Although juveniles less than 3 years old are found in inshore shallower water, saithe favour deeper waters as shown by Bergstad (1990) who identified the Norwegian deep as a preferred habitat. In their ecological niche modelling study Lenoir *et al.* (2011) found the ecological niche of saithe to be occurring around the following conditions: depth up to 400 m, sea bottom temperature circa 10°C and salinity circa 34 ppt.

Density dependence

Cormon *et al.* (2016) found the growth of saithe to be significantly impacted both by food availability and density dependence.

Temperature

Dulvy *et al.* (2008) attributed the deepening of saithe observed in the North Sea to increasing sea temperature. Cook and Heath (2005) and Ottersen *et al.* (2013) found temperature to have a positive effect on saithe recruitment. Cormon *et al.* (2016), however, found no significant effect of temperature on the growth of saithe.

Fishing-induced density dependence

Saithe in the Skagerrak and Kattegat, the North Sea and the west of Scotland are assessed as one stock and as such, no estimate of fishing mortality are available separately for these areas. Fishing pressure has been declining overall since the late 1980s and are now below F_{MSY} (ICES, 2016a). Due to the cod recovery plan, regional fishing pressure is likely to have decreased further in the west of Scotland where both the cod and whiting stocks are currently depleted (ICES, 2016b).

Other

Bergstad (1990) suggested that the saithe distribution in the Norwegian deep may be influenced by the Atlantic inflow. Cormon *et al.* (2014) showed that the distribution of saithe and hake overlap in the North Sea. A subsequent study showed that in the North Sea both saithe and hake compete for a common prey: Norway pout. An increase in hake abundances could therefore be detrimental to saithe.

3.17.3 Implications of changes in distribution and future trends

3.17.3.1 Consequences for stocks/populations

The analyses presented here show little change in the overall saithe distribution in the last 15 years, the only exception being an increase in the presence of saithe on the north of Scotland in recent years. The only trends in occurrence detected here were observed on the southern (Eastern Channel), north-western (west of Scotland and Irish waters), and eastern (Skagerrak and Kattegat) boundaries of the distribution observed here.

The southern boundary showed a slight but continuous decrease in occurrence since 1990. Such observation could indicate a temperature-driven shift of the southern distribution boundary and is consistent with the findings from Lenoir *et al.* (2011) who reported a reduction in the probability of occurrence of saithe at the southern edge of their model. However, no shift in the abundance's centre of gravity was observed in the Eastern Channel. In addition, a few observations of saithe were recorded further south in the Bay of Biscay, although this could be due to a deeper habitat favoured by saithe which is not available in the Channel. For instance, in the North Sea where deep waters are available in the Norwegian deep, no latitudinal shift was observed (Perry *et al.*, 2005) but a significant deepening was recorded and attributed to warming (Dulvy *et al.*, 2008).

In contrast the north-western boundary showed an increase in occurrence which coincided with a north-eastward shift of the abundance's centre of gravity along the continental shelf. This observation too is consistent with a temperature-driven northward shift in distribution. However, this cannot be concluded at this stage for three reasons. Firstly, the trend in occurrence in Irish waters was only observed on short term since no data was available prior to early 2000s. Secondly, in west Scotland where data was available since the mid-1980s the occurrence shows a fluctuation rather than a steady increase as described above, although the increase observed in the last few years tallies with the ones observed in Irish waters. Lastly, fishing pressure on saithe has been declining overall (ICES, 2016a) with a decline likely more pronounced on the west of Scotland due to the presence of two depleted gadoid stocks, cod and whiting (ICES, 2016b). Therefore it cannot be excluded that the increase in occurrence and north-eastward shift of the abundance's centre of gravity may be due to an increase in abundance on northern areas caused by a reduction in fishing pressure.

On the eastern boundary, the cause behind the long term decline and subsequent increase in occurrence is harder to pinpoint. The influence of the Atlantic inflow could be at play here as suggested by Bergstad (1990). However, other factors such as fishing or temperature cannot be excluded at this stage.

3.17.3.2 TAC management areas

Neither an overall directional shift in distribution nor a significant relative changes in abundance between adjacent ICES areas was observed.

3.17.3.3 Choke species?

The only increase in occurrence reported here was observed on the west of British Isles. If this increase was to persist while the abundance of the stock in areas 3, 4 and 6 remains stable or decreases, there is a slight risk of a mismatch between TAC and

regional abundance. However this seems unlikely as no extreme change in occurrence was reported here.

3.17.3.4 Future expectations? Northern shifts? Northern constraints?

In the likely event of a continued increase in temperature, saithe abundance is expected to decrease (Heath *et al.*, 2012). However, while there are some indications that a temperature-driven northward shift may be occurring as discussed above, the results reported here by no means suffice to support this suggestions and further analyses would be required to establish (i) whether a shift is, in fact, occurring and (ii) what would the cause of said shift be. Thus, no conclusions can be drawn here.

Cormon *et al.* (2016) reported that saithe and hake are competing for a common prey, Norway pout, in the North Sea. A dramatic increase of hake in the North has recently been reported by Baudron and Fernandes (2015) and is discussed in this report. If such an increase was to persist, the population of North Sea saithe may be negatively impacted.

Table 3.17.1. Potential influence and predictability of each the main drivers of change in saithe distribution

Drivers	Influential driver	Drivers predictability	Predictability potential habitat	Predictability realised habitat	Reference
		(and at which time scale)			
Geographical attachment	No evidence				
Environmental conditions	Temperature, Atlantic inflow	Yes, long term and seasonal	Yes	No	Bergstad (1990); Dulvy <i>et al.</i> (2008)
Density-dependent habitat selection	No evidence				
Spatial dependency	No evidence				
Demographic structure	Yes, age-dependent habitat selection	No	No	No	Bergstad (1990)
Species interactions	No evidence				
Memory	No evidence				
Fishing effort distribution	Yes	No	No	No	ICES (2016)

3.18 Sprat

3.18.1 Evidence for changes in distribution

Sprat is widely distributed throughout the northeast Atlantic Ocean and into the Mediterranean Sea, including Black Sea (Figure 3.18.1).

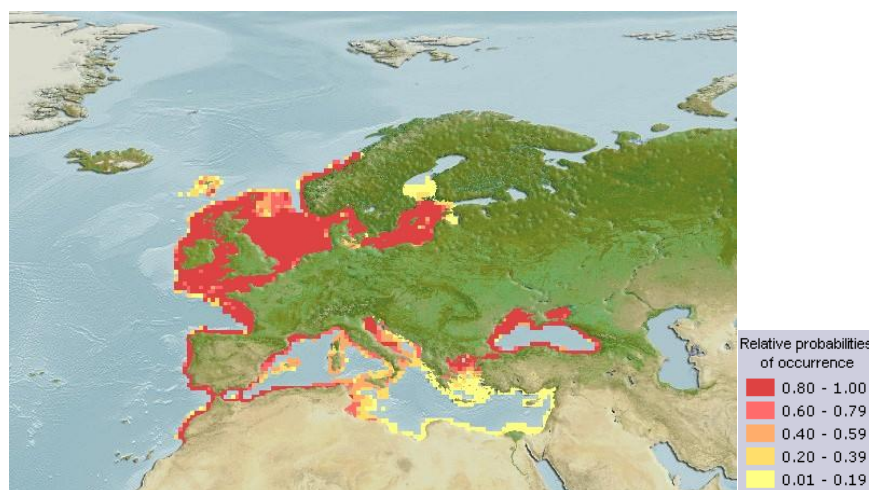


Figure 3.18.1. Range of distribution and probability of occurrence of sprat *Sprattus sprattus* (Aquamaps, 2016).

The distribution area of small pelagic fish such as sprat is partly related to abundance of the species (Checkley Jr *et al.*, 2009). It is relevant to evaluate potential changes in spatial distribution within and across TAC management areas relative to the biomass dynamics of the stock. Within the ICES area, there are only two stocks which have analytical assessments (Baltic Sea SD 22-32, and North Sea (Area 4). Both stocks are presently above B_{pa} reference points (Figure 3.18.2).

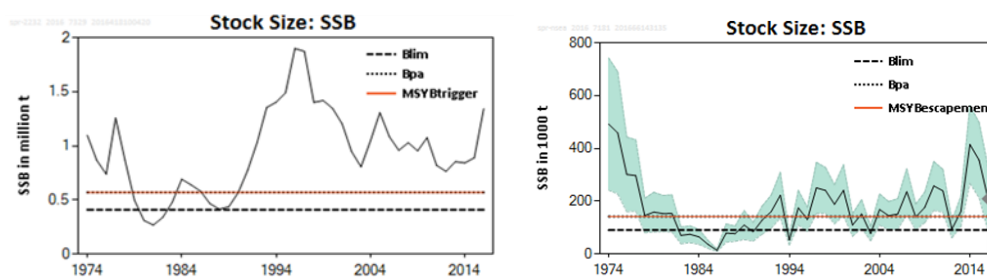


Figure 3.18.2. SSB time series for Baltic Sea (SD 22-32; left panel) and North Sea sprat (area 4; right panel) (ICES, 2016).

3.18.1.1 Analysis of ICES trawl data

Based on presence-absence data since 2000, the occurrence of sprat has increased in only one area (Baltic Sea ICES 3D).

In other areas, presence for the full time series period has increased in the southern North Sea and decreased in the northern North Sea. These changes however do not involve changes in distribution across different TAC management areas for sprat. There is also a minor decline in presence in the area SW of Ireland. These changes

may however be confounded with changes in survey sampling methods (gear types, etc.).

The ICES analysis of changes in abundance between pairs of neighbouring areas indicated that there were no significant changes anywhere in the surveyed area. However, when analysing survey-by-survey the centre of gravity of sprat changed eastward over the time series in the Baltic (Figure 3.18.3).

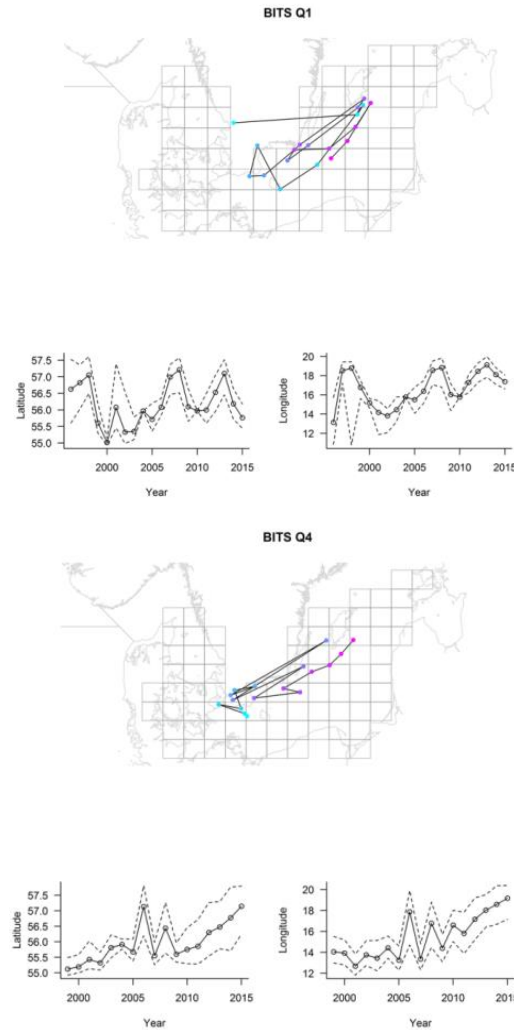


Figure 3.18.3. Top panels: Changes in centre-of-mass of distribution of sprat in the Baltic Sea, based on research vessel demersal survey data (BITS) in the first and fourth quarters. Lower panels: temporal variations in mean latitude and longitude of the centre-of-mass of sprat distributions in Q1 and Q4 IBTS surveys.

3.18.1.2 Other evidence

Sprat distributions, as estimated by spatially-resolved acoustic survey abundance data and stock assessments, have changed within the Baltic (Casini *et al.*, 2011; Eero *et al.*, 2012). According to these sources, the distribution within the Baltic has shifted eastwards and northwards (Figure 3.18.4).

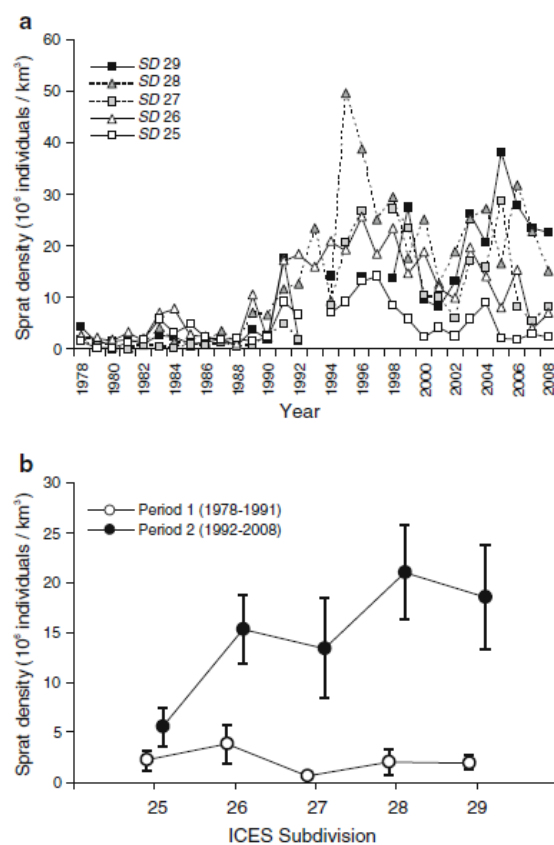


Figure 3.18.4. Temporal variability in density of sprat in different sub-divisions of the Baltic Sea 1978-2008, and by two different time periods, as estimated by acoustic surveys (Casini *et al.*, 2011).

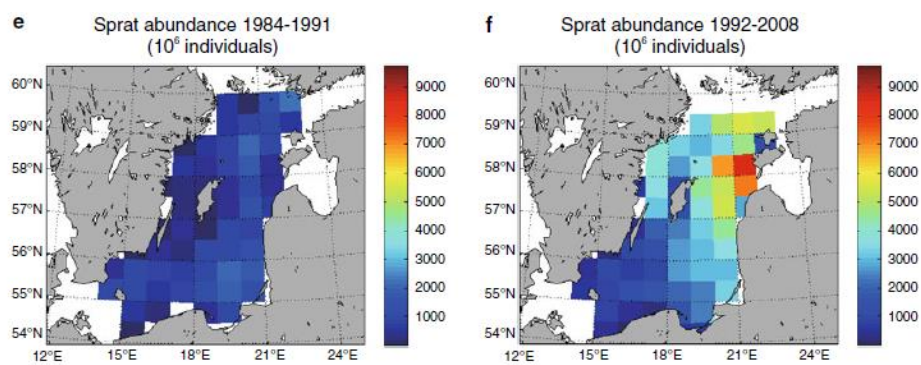


Figure 3.18.5. Sprat abundance in the Baltic Sea as estimated by international acoustic surveys for 2 different time period (Casini *et al.*, 2011).

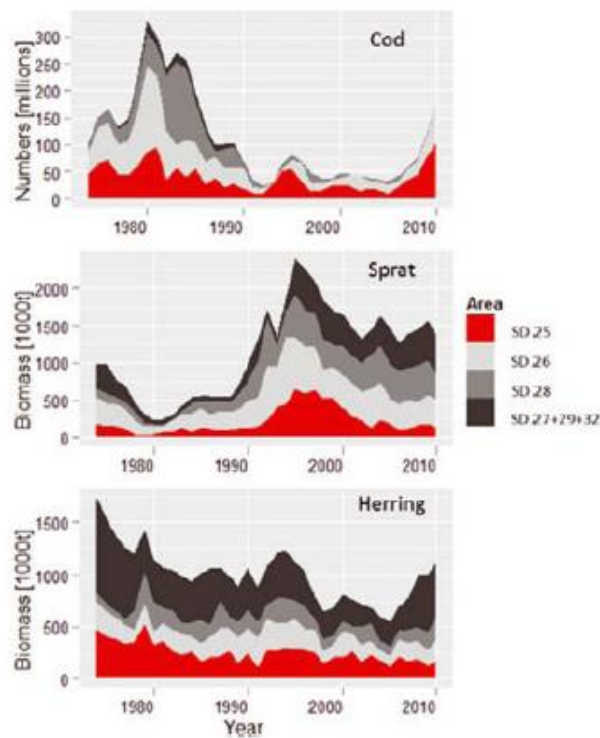


Figure 3.18.6. Time series of annual average abundance of adult cod (top panel; agegroups 4 and older), and total biomass of sprat (middle panel) and herring (lower panel), by area (Eero *et al.* 2012).

3.18.2 Review of potential drivers

Changes in the sprat distribution in the Baltic Sea are likely due to a combination of predation and climatic effects (Casini *et al.*, 2011; Eero *et al.*, 2012). Cod is a major predator of sprat (Ojaveer and Kalejs, 2010; Sparholt, 1994) and the cod distribution has been concentrated in the southern part of the Baltic Sea during most of the last 10–20 years, while its abundance in eastern and northern areas has remained low (Eero *et al.*, 2012). As a result, sprat abundances in the latter areas have increased, partly due to relatively low predation by cod.

Climate-hydrographic (temperature) conditions in the Baltic Sea during much of the last 20 years have also generally been favourable for recruitment processes including production and survival of early life history stages (MacKenzie and Köster, 2004; MacKenzie *et al.*, 2012; Margonski *et al.*, 2011; Ojaveer and Kalejs, 2010). The relatively warm temperature conditions benefit egg and larval survival by reducing temperature-related physiological stress (Nissling, 2004). Warm temperatures benefit the zooplankton species which dominate sprat diets (Dickmann *et al.*, 2007), thereby favouring increased sprat growth (Baumann *et al.*, 2006a, 2006b). Larger areas and longer periods of warm temperatures, particularly in northern and eastern parts of the Baltic Sea where cod have been relatively rare (Figs. 4–6), have likely contributed to the change in sprat spatial distributions in the Baltic Sea.

The relatively minor changes in distribution in the North Sea also are likely partly climate-driven. Some previous studies have related distributions of sprat eggs and larvae, and the dispersion of coastal sprat to central areas of the North Sea, to large – scale climate variability (Atlantic Meridional Oscillation, AMO) (Alheit *et al.*, 2014).

Water temperatures < 5 and > 17 °C cause high egg mortalities in North Sea sprat (Thompson *et al.*, 1981; Tsoukali *et al.*, 2016).

3.18.3 Implications of changes in distribution and future trends

3.18.3.1 Consequences for stocks/populations

The present statistical analyses conducted by ICES indicates relatively small changes in spatial distribution of sprat, especially across TAC management areas within the ICES area. The species is presently distributed in nearly all ICES areas considered in this workshop analysis so future climate change is unlikely to lead to occupation of new habitats within these areas.

However, given the biogeographic distribution of sprat (Figure 3.18.1), which extends farther north than the range of sprat TAC management areas considered in this analysis, it is likely that future increases in temperature will cause distributions to shift northward and reductions in abundance or productivity at the southern part of the range. As a relatively-small, short-lived, early-maturing pelagic species, changes in local temperatures will likely be followed quickly and closely by changes in distribution and abundance.

Furthermore, increases in temperature could increase the productivity of sprat populations in northern areas (Ojaveer and Kalejs, 2010): the influence of temperature on recruitment in the Baltic Sea has been positively and significantly associated with temperature during 1955-2009 (MacKenzie *et al.*, 2012). In contrast, literature information shows that recruitment in the southern end of the range (i. e., Black Sea) is negatively related to temperature (Daskalov, 1999). Future rises in temperature will therefore have spatially contrasting effects on recruitment, productivity, and potential fishery yields, with northern areas likely improving and southern areas declining. These expectations are generally supported by niche modelling studies of the impacts of future climate change on sprat distributions in the northeast Atlantic: these indicate an increase in abundance in the northern Norwegian Sea (ICES SD IIA) and Baltic Sea region and a decline in the North Sea-Bay of Biscay region (Fernandes *et al.*, 2016). A north-south spatial gradient in expected changes in productivity will likely contribute to a shift in distribution of biomass of the species throughout the ICES area towards the north.

3.18.3.2 TAC management areas

With respect to the specific case of sprat in the Baltic Sea, the ICES analysis and other analyses have documented changes in sprat spatial distribution within the Baltic (i. e., further east and north (Figure 3.18.3–3.18.6) (Casini *et al.*, 2011; Eero *et al.*, 2012). As a result, sprat have become more widespread and abundant in different herring TAC management areas (ICES SD 30-31; SD 28.1) within the Baltic. As sprat is often caught together with herring in Baltic herring fisheries (ICES 2016), these changes in sprat spatial distribution may have implications for herring and sprat management within the Baltic.

3.18.3.3 Choke species?

Sprat and herring could in some circumstances become choke species in each other's fisheries due to changes in spatial distributions across TAC management areas, which differ for sprat and herring in the Baltic Sea. See previous section for details.

3.18.3.4 Future expectations? Northern shifts? Northern constraints?

Scenarios of the possible futures of sprat biomass and distribution in the Baltic Sea have been modelled in other projects using multiple model setups that describe both the climate-hydrographic coupling at the regional scale of the Baltic Sea (Meier *et al.*, 2012) and different levels of complexity of species and foodweb interactions. These ecological interactions have been modelled using e. g. MSVPA, Ecopath and time series based methods. The scenarios have been conducted for different intensities of exploitation, climate change and eutrophication. In general, the abundance and distribution of sprat is likely to remain at modest-high levels or potentially increase, due to potentially negative effects of climate change and eutrophication on cod and positive effects of temperature on sprat recruitment processes (Gardmark *et al.*, 2013; Lindegren *et al.*, 2010; MacKenzie *et al.*, 2012; Niiranen *et al.*, 2013).

Furthermore, with continued climate change it is possible that the species will become ecologically and commercially more important in areas where there presently are few sprat and/or negligible sprat fisheries. Based on niche modelling analyses (Fernandes *et al.*, 2016), these could be in shelf waters south and southwest of Iceland (ICES Area V), in the northern Irminger Sea (east of Greenland) and northern Norwegian Sea-Barents Sea (Area 2a, b).

Table 3.18.3.4.1. Synthesis of potential drivers of changes in sprat spatial distributions and their predictability, and their potential impacts on potential and realised habitats.

drivers	Influential driver	predictability drivers (and at which time scale)	Predictability potential habitat	Predictability realised habitat
geographical attachment				
environmental conditions	Baltic Sea: Temperature North Sea: Atlantic Meridional Oscillation (AMO)	Baltic Sea: Not investigated at decadal scale. Climate change projections available from several regionally-downscaled models and for different CO2 emission scenarios. North Sea: unknown	Baltic Sea: Yes – at climate change scale (2050s-2100) North Sea: unknown	Baltic and North Sea: No
density-dependent habitat selection				
spatial dependency				
demographic structure				
species interactions	Baltic Sea: Yes – cod is important predator (cod predation used in ICES assessment of sprat mortality rates)	Baltic Sea: Yes – at climate change scale. Several scenarios available using different species interactions models (e. g., MSVPA, Ecopath, etc.) for different combinations of F, climate change and nutrient loading	Baltic Sea: Yes – at climate change scale. Several scenarios using different species interactions models (e. g., MSVPA, Ecopath, etc.) available for different combinations of	Baltic and North Sea: No

3.19 Spurdog

3.19.1 Evidence for changes in distribution

3.19.1.1 Analysis of ICES trawl data

There was an increase in the probability of presence of the spurdog in the Skagerrak-Kattegat area (3a) while there was a decrease in the areas West of Ireland (7b) and North of the Bay of Biscay (8a) based on yearly IBTS from 2000. When considering the entire time series the North of the North Sea (4a) and the Eastern Channel (7d) showed a decrease in the probability of presence. The centre of distribution of the species did not show any shift in any of the regions considered. No difference was either noted between adjacent regions.

3.19.1.2 Other evidence

In their review article, Perry *et al.* (2005) did not find any correlation between the mean latitude of the spurdog distribution and an index of warming. Due to restrictive management measures landings have drastically decreased in all ICES subareas, but are not indicative of a distributional shift.

3.19.2 Review of potential drivers

In an analysis of long-term distribution changes in North Sea elasmobranchs between 1902 and 2014, Sguotti *et al.* (2016) found that spurdog were spatio-temporally associated with colder temperatures. Within the central/southern North Sea study area, spurdog were more widely distributed in the 1980s, and much less so in the 2000s (coinciding with population decline). They noted that “Although the decline in spurdog is thought to be largely due to the overexploitation of the stock in the 1960s (de Oliveira *et al.*, 2013), there are also potential impacts of climate change as this species was revealed to have a preference for cooler water.” Spurdog undertake substantial seasonal migrations and the results of the Sguotti *et al.* (2016) study are best interpreted in conjunction with other recent studies on elasmobranch abundance and distribution changes.

3.19.3 Implications of changes in distribution and future trends

There is currently no TAC for this species; the only country reporting landings is Norway as a bycatch (215 t for 2015) (Albert, WGEF 2016). No changes are expected in the future bycatch numbers. The North East Atlantic population is currently recovering from over fishing in the 1980's that brought the population to 5%-20% of its original size (Hammond and Ellis 2004; De Oliveira *et al.* 2013). As a slow growing and maturing species this recovery process will likely be long. The observed changes in the probability presence of the species for certain areas are likely due to a combination of seasonal migration patterns and an artefact of the recovery process.

3.19.3.1 Consequences for stocks/populations

Recent studies suggest that the maximum fecundity have increased supporting the hypothesis of a density-dependence mechanism (ICES WGEF 2016; Ellis and Keable 2008). However, this is a long-lived species with a high age at sexual maturity and it is unlikely that an increase of in abundance will cause distributional shifts in a near future.

3.19.3.2 TAC management areas

The current population is managed as a single stock ranging from the Bay of Biscay to the Barents Sea (Pawson and Ellis 2005). Recent publications based on a modelling exercise suggest that a TAC corresponding to the last non 0 TAC (1422t) could be supported by the current population level while still allowing for population growth (De Oliveira *et al.* 2013).

3.19.3.3 Choke species?

Spurdog is not believed to be a choke species.

3.19.3.4 Future expectations? Northern shifts? Northern constrains?

Not applicable

3.20 Whiting

Whiting (*Merlangius merlangus*) is a Lusitanian species distributed in the Northeast Atlantic from the north of Portugal to the Barents Sea and around Iceland (Svetovidov, 1986). They occupy demersal habitats ranging from shallow waters to circa 200 m deep (ICES, 2016). ICES considers six stocks in the Northeast Atlantic: (1) southern Celtic Seas and western English Channel stock in areas 7b-c and 7e-k, (2) Irish Sea stock in area 7a, (3) Rockall stock in 6b, (4) North Sea and eastern English Channel stock in areas 4 and 7d, (5) West of Scotland stock in area 6a and (6) Bay of Biscay and Iberian waters stock in areas 8 and 9a. TACs for whiting stocks are allocated to eight different TAC management area (Figure 1.3.2): (1) areas 2a and 4, (2) area 3a, (3) Norwegian waters south of 62° N, (4) areas 5b, 6, 12 and 13, (5) area 7a, (6) area 7bcdefghjk, (7) area 8, and (8) areas 9, 10 and CECAF 34.1.1.

3.20.1 Evidence for changes in distribution

3.20.1.1 Analysis of ICES trawl data

Presence-absence analyses

Whiting were observed throughout the whole area sampled by surveys with the exception of the Spanish coastline, offshore areas of Biscay, the Porcupine Bank and the eastern Baltic Sea. This pattern has remained unchanged between 2001 and 2015 where survey data was available for all ICES areas considered in the analysis (Figure 3.20.1).

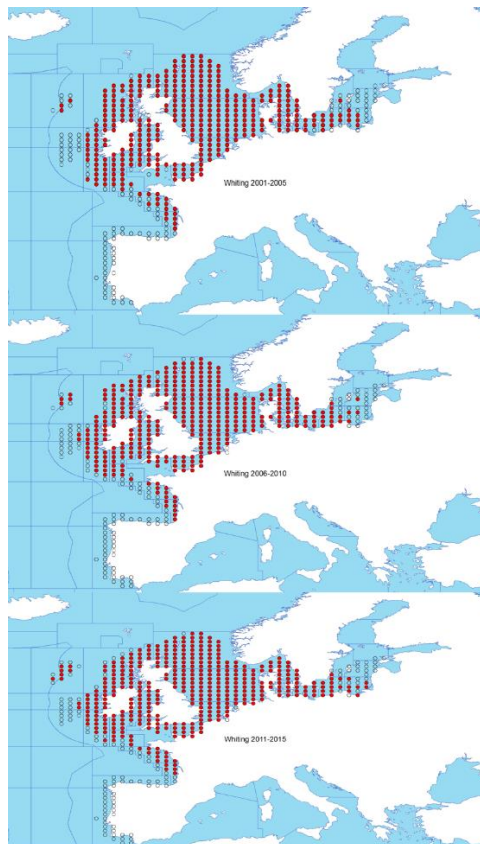


Figure 3.20.1. Presence/absence maps by ICES statistical rectangles for 2001-2005 (top panel), 2006-2010 (middle panel) and 2011-2015 (bottom panel) when data was available for all surveys.

Within northern ICES areas (north of Celtic Sea) the probability of occurrence was stable except in the eastern and western boundaries of the areas surveyed (Figure 3.20.2). On the eastern boundary, a slight gradual increase was observed in the Baltic Sea (area 3d). On the west western boundary a decline was observed on the west of Scotland (area 6a) from 2000 onwards, although it levelled off in recent years. This decline coincided with an increase observed in Rockall (area b) although no data was available prior to 2000 in this area. Within southern areas (Celtic Sea and below) no clear trend was observed in any of the areas surveyed, although time series were on average much shorter than in northern areas (Figure 3.20.3).

Whiting – northern divisions

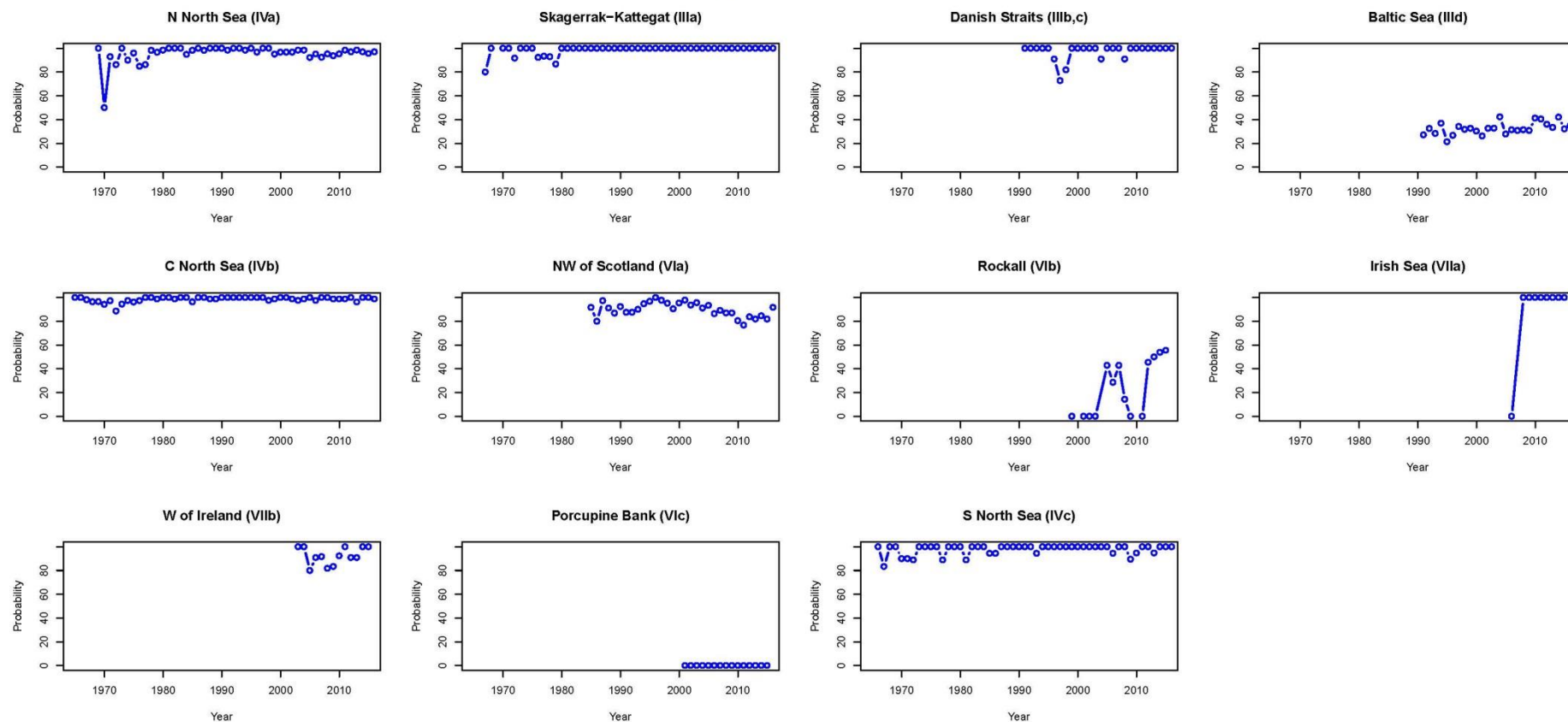


Figure 3.20.2. Whiting trends in presence/absence in northern ICES areas

Whiting – southern divisions

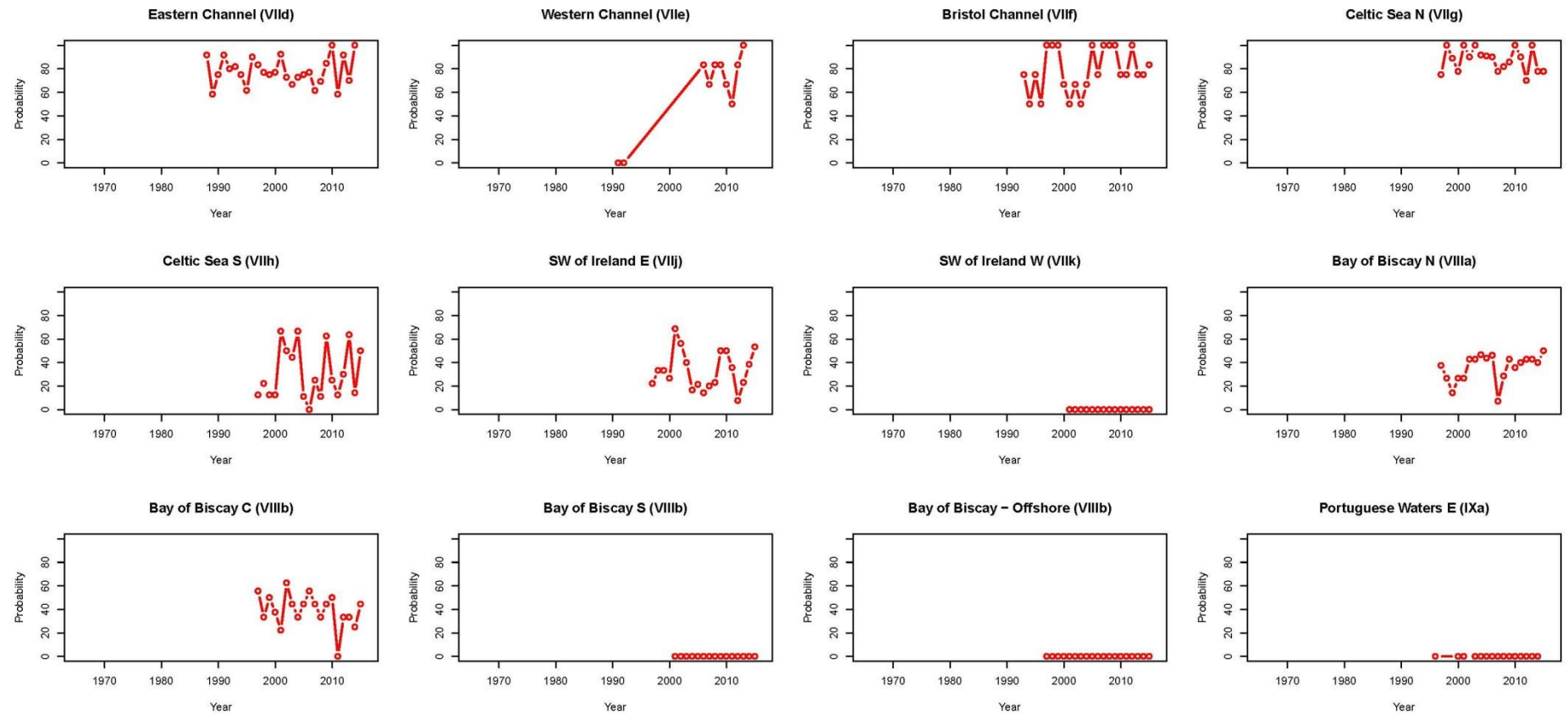


Figure 3.20.3. Whiting trends in presence/absence in southern ICES areas

Centre of gravity of abundance by surveys

Only two surveys showed a noticeable shift in their abundance's centre of gravities over time, albeit quite limited in both cases: BITS in both quarter 1 and 4 which samples areas 3a-c, and quarter 4 EVHOE in Biscay. BITS showed similar trends in both quarters: a slight decrease in latitude accompanied by a slight increase in longitude resulting in a south-eastward displacement down in Kattegat (Figure 3.20.4 and 3.20.5). In Biscay, a slight increase in latitude was accompanied by a slight decrease in longitude resulting in a north-westward displacement along the shelf, although this pattern was only discernible from 2006 onwards (Figure 3.20.6)

Whiting BITS Q1

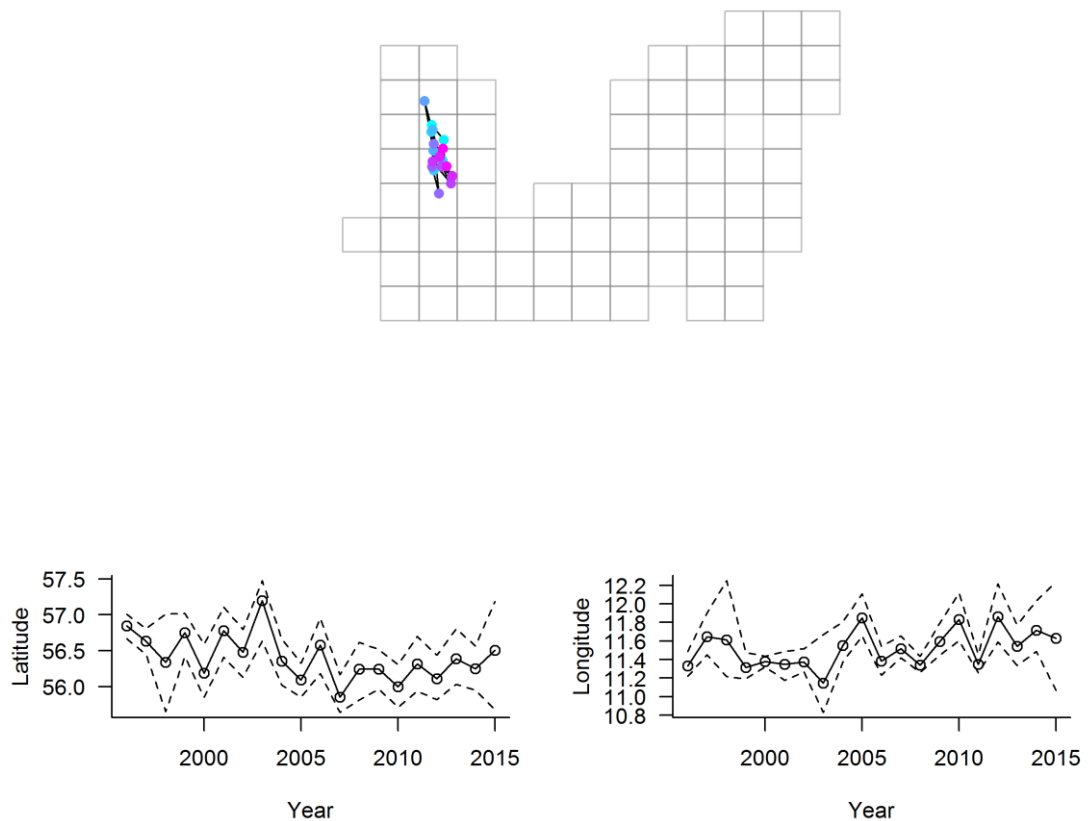


Figure 3.20.4. Shift in the centre of gravity of abundance observed for BITS Q1

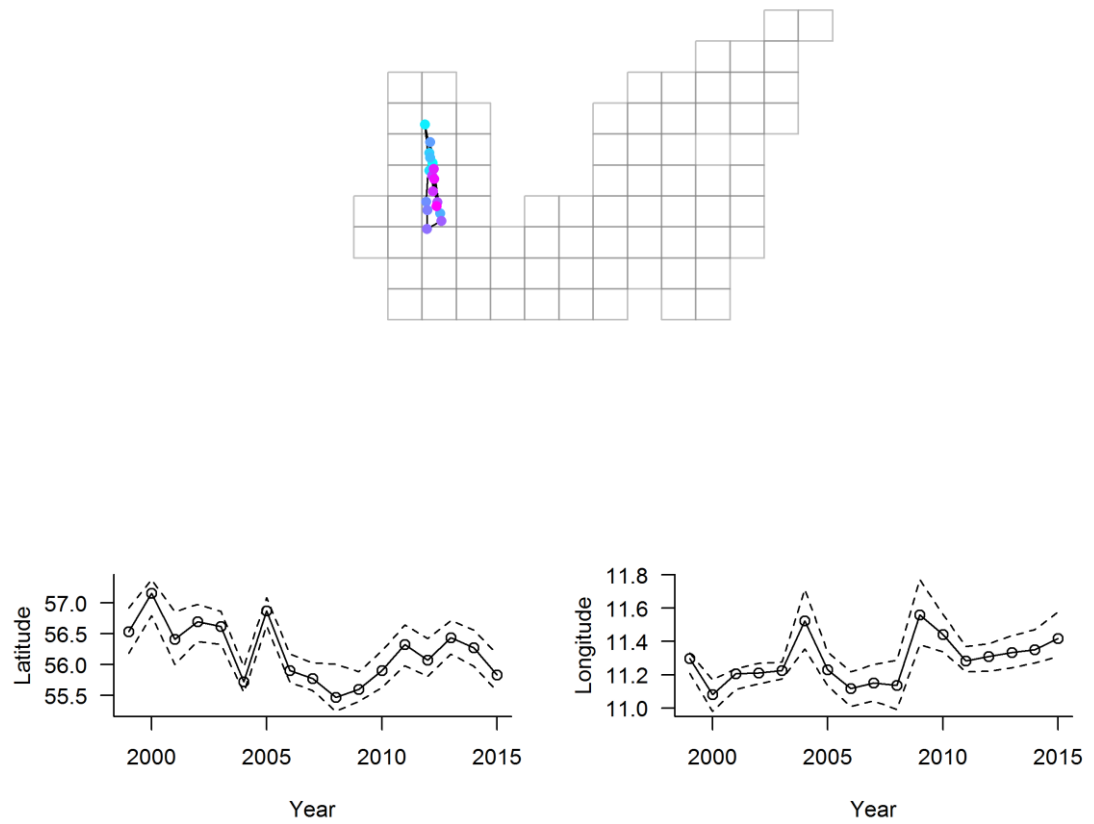
Whiting BITS Q4

Figure 3.20.5. Shift in the centre of gravity of abundance observed for BITS Q4

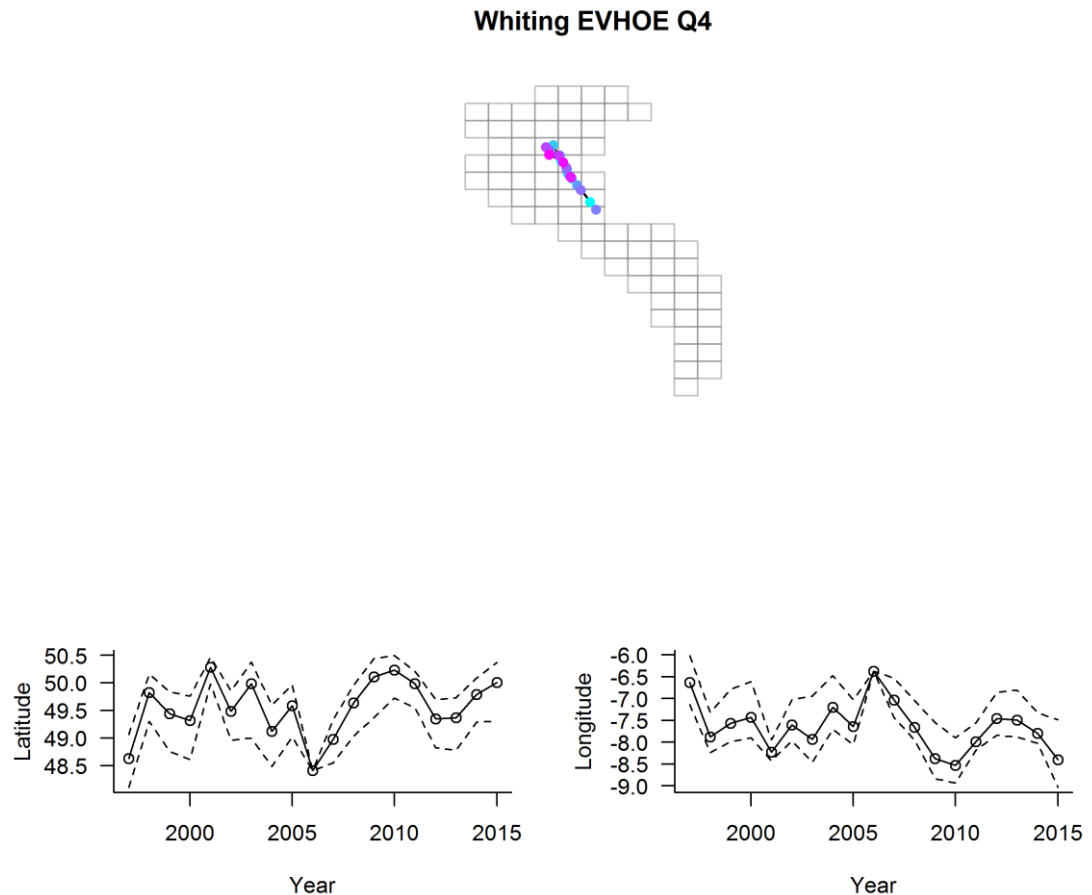


Figure 3.20.6. Shift in the centre of gravity of abundance observed for EVHOE Q4

Changes in relative abundance between adjacent ICES areas

No significant changes in relative whiting abundance between adjacent areas were observed.

Conclusions

Based on the analyses of trawl survey data, the area occupied by whiting has remained unchanged for the last 15 years. Changes in occurrence were only observed in the northern areas on the eastern and western boundaries of the area surveyed, with a slight increase in the Baltic Sea (3d) in the east while in the west a decline in west of Scotland (6a) coincided with an increase in Rockall (6b). Only two of the surveys, BITS and EVHOE, showed a noticeable change in their centre of gravity over time, with changes being only observed from 2006 onwards for the latter. No changes in abundance between adjacent areas were observed.

3.20.1.2 Other evidence

Two meta-analyses using survey data both reported a significant northward shift between 1971 and 2001 (Perry *et al.*, 2005) and a significant deepening between 1980 and 2004 (Dulvy *et al.*, 2008) for whiting in the North Sea. However both these studies contrast with the work from Kerby *et al.* (2013) who analysed nine decades of landings data covering the whole North Sea between 1920 and 2010 and, while they did observe a $\sim 1^\circ$ westward shift between the late 1940s and 1960s, reported no latitudi-

nal or deepening shifts which is consistent with the lack of trends in occurrence observed here. Similarly, Loots *et al.* (2010) investigated changes in whiting spawning distribution in the North Sea using survey data and found that spawning mainly occur north and south of the Dogger Bank, a pattern that has remained stable for the last 30 years.

In western areas, Neat and Campbell (2011) analysed survey data ranging from 1986 to 2008 from the west of Scotland and adjacent Rockall plateau. They observed that whiting first appeared on the Rockall plateau in 1993 and has been increasing ever since, which is consistent with the occurrence trend observed here. They suggested that whiting be could currently be establishing a niche on Rockall, a plateau isolated by depth, distance and ocean currents. This is consistent with the assumption that whiting in area 6b (Rockall) are likely migrants from the neighbouring area 6a (west Scotland) (ICES, 2016). Tobin *et al.* (2010) investigated the connectivity between nurseries and spawning ground using otolith microchemistry and observed that nurseries west of Scotland do contribute individuals to spawning grounds in the North Sea with no evidence of the converse, but whether this pattern is persistent or no is unknown.

In eastern areas, Fromentin *et al.* (1997) observed a very high spatial variability in the abundance of whiting in Skagerrak and Kattegat but made no mention of a directional shift or expansion in abundance.

3.20.2 Review of potential drivers

Physical conditions

Fromentin *et al.* (1997) observed that whiting tend to favour inshore sheltered habitat in Skagerrak and Kattegat. Loots *et al.* (2011) found that whiting in the North Sea has a high fidelity to spawning sites, probably due to geographical attachment, while both temperature and salinity seem to affect the extent of the spawning whiting distribution.

Temperature

In the North Sea, Zheng *et al.* (2002) found the distribution of whiting to be impacted by the spatial pattern of sea surface temperature in winter and spring as whiting were found to be more abundant in areas where warm Atlantic inflow was occurring. They did not observe the same relationship in summer. Perry *et al.* (2005) and Dulvy *et al.* (2008) both attributed their findings warming, although Perry *et al.* (2005) mention that while they did observe a significant relationship between the northward shift and a principal component representing warming, they found no significant relationship with winter temperature. Simpson *et al.* (2011) reported that North Sea whiting abundance has decreased in the last three decades amid warmer temperatures. Kerby *et al.* (2013) found no relationship between the $\sim 1^\circ$ westward shift observed for North Sea whiting and temperature.

Fishing

In area 6a the decline in occurrence observed here coincides with a history of high fishing pressure while recruitment has been low since 2002, although it is estimated to have increased in recent years (ICES, 2016). Alexander *et al.* (2016) recently investigated the cause of the decline of gadoids in area 6a using an ecosystem model and concluded that fishing pressure rather than seal predation or juvenile bycatch by the *Nephrops* fisheries was to blame. In the North Sea Kerby *et al.* (2013) found no relationship between the $\sim 1^\circ$ westward shift observed for whiting and fishing pressure.

Other

Following the observed colonisation of Rockall, Neat and Campbell (2011) suggested that whiting could still be in a dynamic equilibrium phase of extinction and colonisation and thus could be currently expanding its distribution range to new area irrespective of climate change.

3.20.3 Implications of changes in distribution and future trends

3.20.3.1 Consequences for stocks/populations

The analyses presented here show little change in the overall whiting distribution. The only noticeable changes were observed in northern areas on the eastern and western boundaries of the areas surveyed, as described above. These observations clash with two recent meta-analyses which both reported a shift in whiting distribution in the North Sea. However the findings reported here are consistent with a recent study based on long term landings data which reports no latitudinal shift for North Sea whiting (Kerby *et al.*, 2013). This latter study concludes that, the North Sea being at the centre of the distribution range for whiting, the current increase in temperature is probably within physiological tolerance limits. This assumption is consistent with the fact that distribution is affected around boundaries of distribution range, and is supported by Zheng *et al.* (2002) findings which show that whiting are in fact avoiding cooler temperatures in the northern North Sea during winter months.

In western areas, the occurrence increase in Rockall observed here is consistent with a previous study suggesting that whiting is currently expanding its distribution into area 6b and colonising the Rockall plateau (Neat and Campbell, 2011). Although no evidence backing this hypothesis was found in the literature, one could assume that the occurrence increase on the eastern boundary observed here could also be due to a colonisation of new habitats by whiting into the Baltic Sea. This hypothesis is somehow supported by the south-eastward shift of the centre of gravity observed in both quarters of the BITS survey, although no clear eastward movement into the Baltic could be identified.

The west of Scotland is the only area showing decrease in whiting occurrence which is most likely due to a combination of high fishing pressure and low recruitment. However, this trend seems to have levelled off and shows signs of increase in recent years which tally with the recent assessment of the whiting stock in 6a (ICES, 2016a).

In southern areas, the north-western shift in centre of gravity observed in Biscay is consistent with a potential climate-driven northward shift since this area is closer to the southern distribution boundary of whiting. However no change in occurrence was observed in any of the southern areas surveyed, although time series were shorter than in northern areas thus precluding the identification of long term trends.

3.20.3.2 TAC management areas

Neither a change in the area occupied nor an overall directional shift in distribution was identified for whiting over the last 15 years. In addition, no significant relative changes in abundance between adjacent ICES areas was observed. Based on this a mismatch between whiting regional abundances and TAC allocation seems unlikely.

3.20.3.3 Choke species?

Whiting is caught in mixed demersal fisheries and therefore could potentially become a choke species. While both the North Sea and eastern English Channel, and southern

Celtic seas and western English Channel stocks are currently within safe limits, the west of Scotland is currently depleted and has not been allocated a TAC since 2006 (ICES, 2016). It is therefore likely that whiting will become a choke species once the landings obligation comes into place in 2019.

3.20.3.4 Future expectations? Northern shifts? Northern constraints?

Although both Perry *et al.* (2005) and Dulvy *et al.* (2008) reported climate-induced shifts in whiting distribution, both the analyses reported here and the recent study by Kerby *et al.* (2013) indicate a lack of latitudinal shift. The shift in centre of gravity along the shelf observed in Biscay could indicate a temperature-driven northward shift of the southern distribution boundary, however the lack of directional trend in occurrence in all southern areas surveyed suggests otherwise. On the western boundary, the increase in occurrence observed in Rockall appears to be due to a niche colonisation by whiting (Neat and Campbell, 2011). The similar increase observed in the Baltic Sea coinciding with a shift in the centre of gravity suggest that a similar colonisation could be occurring on the eastern boundary, although no published evidence backs up this hypothesis at the moment. Whether such an increase will persist or equilibrium has been reached for whiting is unknown. In the west of Scotland, while the whiting stock is currently still depleted it is showing signs of increase and may recover above safe limits should the current low levels fishing pressure be maintained.

Table 3.20.3.4.1. Potential influence and predictability of each the main drivers of change in whiting distribution

Drivers	Influential driver	Drivers predictability	Predictability potential habitat	Predictability realised habitat	Reference
		(and at which time scale)			
Geographical attachment	No evidence				
Environmental conditions	Temperature	Yes, long term and seasonal	Yes	No	Zheng <i>et al.</i> (2002)
Density-dependent habitat selection	No evidence				
Spatial dependency	Yes, high fidelity to spawning sites	Yes, long term	Yes	Yes	Loots <i>et al.</i> (2011)
Demographic structure	No evidence				
Species interactions	No evidence				
Memory	No evidence				
Fishing effort distribution	Yes	No	No	No	ICES (2016)

4 Conclusion

4.1 Distribution changes

Most of the species considered in the present report had exhibited changes in their distribution to some extent throughout the examined period. These changes were not unexpected as fish populations are dynamic entities which respond to changes in environmental conditions and/or exploitation patterns. However, the purpose of this report is to assess changes in fish distribution in relation to TAC management areas. Based on this, species were classified as 'big movers' if they showed either (1) a large, continuous and directional change in distribution reported in the present analyses and/or in the literature, or (2) a change in distribution resulting in subsequent changes in the relative distribution across TAC management areas as this could have clear implications for management and TAC allocation. The big movers and the reason why they were identified as such are listed in the Table below (for details please refer to the species' specific sections):

Species	Brief description of change in distribution
Anchovy	Northward shift within the North Sea from 1990 onwards, evident from both the analyses and the literature
Anglerfish	The relative distribution has directionally changed at regional level within the North Sea affecting TAC management areas within this region (IVa - IVb).
Blue whiting	Large occurrence increase in the northern North Sea and west of Scotland, with published evidence that spawning distribution and migration routes are heavily influenced by the oceanic circulation patterns
Cod	Evidence of northward shift both from analyses and literature, with significant relative changes between adjacent TAC management areas
Hake	Expansion of the distribution from the western shelf into the North Sea TAC management areas, with published evidence of implications for management
Herring	Different trends in occurrence between areas 7b and 7g which fall within different TAC management areas and significant relative changes between adjacent TAC management areas in Skagerrak-Kattegat and the Baltic Sea. Additionally, changes in the migration and distribution of Norwegian spring spawning herring in summer, affecting the proportion in the EEZ of the different coastal states, as derived from the literature
Mackerel	Published evidence of changes in distribution with major management implications in the northeast Atlantic
Megrim	Published and observed changes in the regional distribution with changes in occurrence in the Celtic Sea (TAC areas VIIg - VIIh) and Bay Biscay (VIIIa - VIIIb).

	Similarly, the relative distribution has directionally changed at regional level in this areas and in the North Sea (IVa and IVb).
Plaice	Increase in occurrence in the North Sea and Baltic Sea, with significant relative changes between adjacent TAC management areas

It should be noted that horse mackerel was not considered as a big mover, although this species clearly showed changes in distribution (section 3.11). The reason for this is that current management measures have already accounted for these distribution changes, and as such, the latter are less likely to result in future issues.

The results presented in this report and the list of big movers identified, were obtained from analyses of bottom trawl survey data. However, it should be kept in mind that despite the standardized collection scheme, especially in the later years, the gear employed does not sample representatively species that differ in biology and lifestyles. Bottom trawl surveys are efficient in sampling benthic and demersal species, but are not designed to sample large schools of pelagic species which demonstrate changes in their vertical distribution, often resulting in a 'hit-or-miss' response. Additionally, bottom trawl surveys are also limited by sampling depth and are known to sample ineffectively large individuals of species living in deep waters such as hake and anglerfish. Therefore, the reliability of the observations on which the analyses were based upon, can be questioned for some species, not least pelagic ones. In addition, the spatial coverage of the survey data available increased over time, and a standard coverage is available only since 2000. In some areas, the number of surveys have increase over the years, which was identified for some species (e.g. mackerel and horse mackerel) as a cause for the increase in occurrence.

Nevertheless, analysing trends in data collected through a standardised and consistent protocol should allow detecting major changes in distribution, especially for non-pelagic species. In addition, for each species considered the findings from the performed analyses were compared to peer-reviewed scientific evidence before concluding on distribution changes, or lack thereof, and the drivers responsible for these changes.

In most species characterized as 'big movers', the general pattern observed was associated with an expansion to the North of the distribution range of the species with no retraction of the southern limit of distribution. Obvious cases of shifts in distribution were also found, but to a much lesser extent (e.g. cod). Unfortunately, the nature of the analyses performed cannot clearly answer whether the identified changes in distribution are due to retraction of a stock's boundaries or due to changes in the relative size of different stocks between southern and northern areas. When combined with available information from the literature, however, most species appear to be expanding their northward boundaries of distribution without disappearing from their traditional southern distribution boundaries.

4.2 Main drivers identified

4.2.1 Climate impact on distribution

A number of meta-analyses have looked at global imprint of climate change across taxon and geographic areas (Parmesan, 2006, Poloczanska *et al.* 2013) and concluded that shifts in species geographical distribution were already observed worldwide.

Marine organisms have, on average, expanded the leading edges of their distributions by 72.0 ± 13.5 km/per decade (generally poleward) (Poloczanska *et al.*, 2013). Many factors can influence responses to changes in the environment, including species' generation time, dispersal ability, somatic growth, physiological tolerances to abiotic factors, habitat and food preferences, and the composition of existing or receiving communities in the case of range shifts. For various species, the occurrence or the development of fisheries in the Northern limit of the species distribution have been correlated with cycles in temperature, driven by climate (e.g. anglerfish and mackerel in Iceland in this report). Another well-documented example of the Greenland cod throughout the 20th Century shows how rapidly a cod population can expand its range northwards under changing climatic conditions (50 km.y^{-1}) (Storr-Paulsen *et al.* 2004).

Temperature was found to be an important controlling factor of the distribution for all the species considered here, with at least one published reference for each species. However, for various species, the existence of a link with temperature varied depending on the spatial scale at which this effect was analysed, and the location of the studied areas compared to the species distribution range. The importance of changes on productivity that can be a limiting factor was discussed (Fernandes *et al.*, 2013; Jennings and Collingridge, 2016.)

The expected effect of sea warming has been well explained for cod (Drinkwater 2005). Southern cod stocks are likely suffer from a deterioration of their habitat affecting all life stages. Recruitment is expected to decrease (Planque and Fredou, 1999) due to the negative direct (physiology) and indirect (changes in plankton abundance and species composition) effects of temperature on the survival of eggs and larvae. Reduced growth rates are expected at the extreme ends of temperature range, in part due to the changes in feeding rates (Drinkwater, 2005). Due to the combined effect of the decrease in population abundance and contraction of the suitable habitat, population distribution is expected to contract, with as ultimate consequence, local extinction. Opposite changes are expected at the Northern limit of the species distribution. At the centre of the distribution, recruitment was found to be not correlated to temperature (Planque and Fredou, 1999) and little changes in abundance are expected. For some species, a dome-shaped relationship with temperature is observed (e.g. mackerel, Brunel *et al.*, in prep) which would correspond to a description of the thermal niche of the species. In other cases, the study considers only one population in a specific portion of the species distribution range and only a portion of the full thermal tolerance can be observed (e.g. anchovy in the bay of Biscay, Planque *et al.* 2007). Some studies covering area in limit of the species distribution (hake in the North Sea, Baudron & Fernandes, 2015) identified a monotonic relationship with temperature, corresponding to one end of the thermal niche of the species.

Table 4.2.1 summarises the evidence for distribution changes presented in this report, and shows to which extent they are in agreement with the expectation of a widespread temperature-driven poleward shift in distribution. The majority of the evidence is in agreement with the expectation, but a number of cases, the changes observed were not expected (see discussion below in this section).

Table 4.2.1. Synthesis of the information (published and present analyses) on distribution change and their link with temperature in relation to the position in species distribution ranges, and agreement with the expected effect of global warming on species distribution.

POSITION IN SPECIES DISTRIBUTION RANGE			
	Southern	Central	Northern
Expected Changes consistent with northwards shift driven by global warming			
	Declining occurrence or northward shift as temperature increases	No change	Increasing occurrence or northward shift
Distribution Changes consistent with northwards shift driven by global warming			
anchovy			Expansion of the North Sea population due to increase of suitable habitat
White anglerfish			Increase in Iceland related to temperature Increased abundance in the northern North Sea explaining increase in mean latitude
Cod	movement northwards in the North Sea, avoiding the south part northward movement for the west of Scotland cod		Northward expansion in the Barents Sea area concomitant to increase in abundance
sole		Distribution mainly controlled by relative contribution of different nursery areas (linked to river runoff) not by temperature	
megrim	(<i>L. whiffiagonis</i>) frequency of occurrence negatively correlated to temperature in Spain.		(<i>L. boscii</i>) increasing latitude in the North Sea with temperature reflecting an increase in abundance
haddock			Decreasing occurrence in the southern North Sea
hake			Increasing abundance in the northern North Sea (density dependent expansion combined to increase thermal habitat)
plaice	Local abundance decreasing in the bay of Biscay due to detrimental temperature effect on juvenile habitat		
Distribution Changes NOT consistent with northwards shift driven by global warming			
White		Decrease in occurrence	

anglerfish		in Spain linked to temperature
Black anglerfish		increase in occurrence in Spain linked to temperature
Cod	Increase in occurrence on Porcupine bank	
megrim		(<i>L. boscii</i>) frequency of occurrence positively linked to temperature in Spain
Haddock	Increase occurrence in the bay of Biscay, Celtic Sea and Irish Sea coinciding with increasing temperature	

4.2.2 Density-dependent habitat use when changes in abundance

Another factor frequently put forward as the likely cause of the observed distribution changes is density-dependent habitat selection, namely the expansion or contraction of the distribution of populations following the changes in their overall abundance. The basin model (MacCall, Figure 4.2.1) is one example of how density-dependent habitat use has been conceptualised. In this model, the change in abundance is the driver influencing the portion of the suitable habitat actually used by the species, with contraction to the most suitable part at low abundance and expansion to less suitable areas at higher abundance. In some instances, increase in population abundance may lead to the colonisation of new areas where the habitat is suboptimal (as illustrated on Figure 4.2.1).

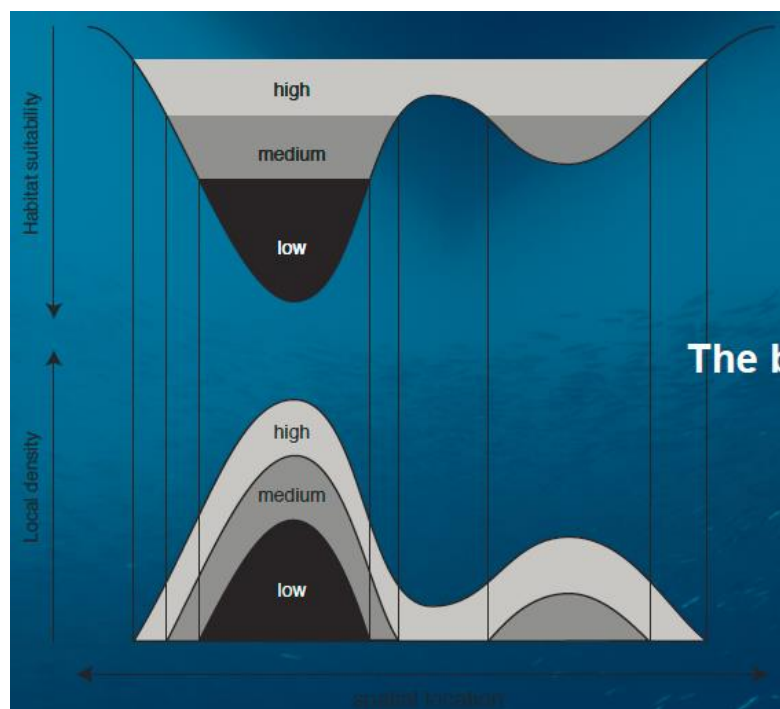


Figure 4.2.1. Representation of the Basin model (MacCall 1990), showing how habitat use corresponding to low, medium and high population abundance (upper graph) and the consequences on the spatial distribution of the species (bottom graph). Taken from a presentation from B. Planque, EuroBasin training workshop, 26-28 October 2011, with permission of the author.

In the present review, a number of populations have shown moderate to strong increases in their biomasses in the period covered by this study (anglerfish, North Sea cod, hake, different herring stocks in the Baltic, mackerel, megrims, North Sea, Kattegat, eastern Channel plaice stocks). Others have shown pronounced decrease (sole in the Irish Sea and in the Celtic Sea). The factors explaining the change in abundance itself are usually a combination of change in fishing pressure (plaice, hake) and environmentally driven change in recruitment (mackerel, hake), but these two effects are difficult to disentangle.

The evidence for density dependence related changes in distribution collected during this review are most of the time based on empirical observations rather than mechanistic approaches (e.g. correlations of mean latitude or mean depth with SSB).

Brunel *et al.* (in prep) have made use of a habitat model to describe to which proportion highly, average and low suitable areas were actually used by the mackerel, in relation to stock size which gave indication of density dependent habitat selection, but some years being clear outliers.

4.2.3 Disentangling the different effects

While temperature and stock size changes are the two main drivers put forward to explain distribution changes, these changes are more likely the result of a combination of these two (and possibly more) factors. These two effects can act in synergy: environmental changes favouring both the increase in abundance and the expansion of the habitat, most likely for stocks in the northern edge of the species distribution, and the opposite at the southern edge. The effects of habitat changes and stock size changes can also act in opposite ways, e.g. stock rebuilding (e.g. because of management measure) in areas where the habitat has deteriorated. These antagonist effects

may explain the part of the changes observed were not in agreement with the expected poleward shifts expected from ocean warming (bottom part of Table 4.2.1)

Studies focussing particularly on distribution changes most often summarise the distribution in one metric and look for empirical correlations between this metric and covariates such as temperature or total population abundance. Such metrics can be based on the weighted mean of latitude, longitude or depth position (i.e. centre of gravity, Hughes *et al.*, 2014, Perry *et al.* 2005), or its projection on a continental shelf (Jansen *et al.*, YEAR for mackerel, Hatun *et al.* 2009 for blue whiting), or the frequency of occurrence in a given area (Puzon *et al.* 2016Y). Such correlative studies might be useful to detect potential causal links or directional changes in distribution, but, by simplifying the distribution to one value, may be difficult to interpret and not useful to make projections. The study of Perry *et al.* (2005) found for instance a positive correlation between temperature increase and the increase in mean latitude between 1977 and 2001 both for cod and white anglerfish in the North Sea. However, this northward movement of the centre of mass in a period of warming corresponds to different realities for both species. In the case of anglerfish, it is due to an increasing abundance in the northern North Sea presumably due to an improvement of the thermal habitat combined with a general increase in stock size (this report). For cod on the other end, abundance has been mainly decreasing over this period and the remaining cod has moved away from the warmer part of the North Sea in summer located in the south (Engelhard *et al.* 2014).

Although northern displacements induced by changes in the sea temperature are the most common recurrent pattern observed, species can display contrasting responses to the same environmental drivers, a pattern that has been also observed between cogenetic species. This is the case of the two species of megrims or the two species anglerfish, each of them included in the same TAC. Finally, it is also worth considering that some of the geographic displacements retrieved from the trawls surveys can be only attributed to the juvenile component of the population. This is the case of hake and anglerfish from Bay of Biscay to the south Portugal.

The main type of evidence for the effect of drivers found in the literature is statistical or even “visual” correlation between concurrent trends. While this type of results can give an indication of a potential causal link, examples of spurious or circumstantial correlations are abundant in the fisheries literature (Myers, 1998). Therefore as mechanisms are not identified, there is a risk of spurious correlation, and a possibility that another covariate, not analysed, was driving both the abundance and the distribution (e.g. environment). For this reason, no definitive conclusion can be made on in this report on the drivers of the changes observed.

Clearly identifying the mechanisms involved and their interaction require considerable research effort, combining empirical habitat description (such as Brunel *et al.* in prep, Planque *et al.*, 2007, Loots *et al.* 2010 and 2011), mechanistic models (for instance DEB models as done by Teal *et al.* 2012) and field studies (looking for instance at condition, stomach content, to identifying effects of increased competition).

4.2.4 Other factors

Geographic attachment

For a number of species (mackerel, plaice, whiting), habitat modelling studies have concluded on the importance of geographical attachment, i.e. high abundance occurring recurrently in the same locations. The underlying mechanisms are not identified in these studies, but geographical attachment is usually ascribed to the persistence of

particular biological or physical features, *a priori* not identified, that influence the distribution of a population (Planque *et al.* 2011). In the case of mackerel, a link with oceanographic features occurring at the continental shelf edge (internal waves) and the Porcupine bank (Taylor column) has been proposed to explain the geographical attachment of the spawning location (Brunel *et al.*, in prep). Population memory could be to some extent also involved (Jansen *et al.* 2013). For demersal spawners as plaice, geographic attachment was ascribed to depth, sea bed stress and sediment type, combined with site fidelity of spawning plaice (Loots *et al.*, 2010).

Importance of oceanographic features

For some species the distribution is impacted by mechanisms affecting the environment at shorter time scales than long term climate change. This is the case for blue whiting for which 5-10 years cycles in oceanic circulation explain the expansion and contraction of the population. In other cases, highly dynamics oceanographic process (e.g. mesoscale structures, upwelling strength) occurring in a relevant timing within the life cycle of a species can affect the inter-annual variability of species distributions (e.g. mesoscales structures shaping spatial pattern of recruitment in the north Spain). However, these highly dynamic processes are often difficult to identify because they operate a short temporal and spatial scales.

Species interactions

Species interactions can also influence the distribution. This was reported here for sprat in the Baltic Sea, for which the presence of a predator (cod) only in the southern part of the Baltic Sea favoured the relative increase of abundance in the North and resulted in the apparent north-eastwards shift of the population. The retraction of saithe in the North Sea induced by the change in distribution of hake is also a well-documented example (Cormon *et al.* 2014, 2016).

Fishing effort distribution

Fishing mainly affects fish distribution through its effect of on stock size, through density dependent habitat use. Only in one instance (Engelhard *et al.* 2014, North Sea cod), it was reported that the distribution of the fishing effort and its changes had affected the distribution of the target species, in this case by causing a eastward movement of the centre of gravity of the stock.

4.3 Implications and future changes

4.3.1 Biological and ecological implications

Ordinarily a species' extent is regulated by a number of inter-related factors derived from interaction between their physiological tolerances/preferences and their external physical and biotic environment, as described in section 4.2. Whilst species' distributions are dynamic within the confines of these regulating factors, shifts due to gradual or punctuated environmental change can be driven by a single or minority of these factors which can, in turn, disrupt existing ecological interactions or create novel ones. Whilst this working group did not consider them directly in the literature review, we will, in this section, illustrate some of the implications of distributional change for the species of interest and the environments which they inhabit.

Many pelagic species experience simultaneous shifts in their spawning, juvenile and adult growth habitats (e.g. mackerel), however others exhibit stronger geographic attachment often at specific life history stages (e.g. herring). Those in the latter category may find that shifts in the distribution of one life history stage result in isolation from traditional habitat for other life-history stages, establishing sink-source relationships between areas, as suggested for North Sea herring (Petitgas *et al.*, 2013).

For those species pushing the northern boundary to their extent in response to temperature, they may find that the areas in the higher latitudes are more or less stable in terms of other regulating factors than their traditional latitudes. Two contrasting examples are cod and sole, and their demersal habit. Where cod in the North Sea are exhibiting a shift into the northern North Sea, they are simultaneously experiencing areas of greater depth (Dulvy *et al.*, 2008) and their expansion is likely to be limited in places by bathymetry (Ingvaldsen *et al.*, 2015; Wisz *et al.*, 2015). To the contrary, for sole in the North Sea (the northern extent of their range) they have access to large areas with suitable bathymetry. Especially in the eastern North Sea, there are large areas of shallow, coastal waters for spawning and juvenile growth, which are adjacent to productive shelf seas which support adult growth and overwintering (Rijnsdorp *et al.*, 1992). The result being that as temperatures in the north of the soles extent become more favourable the potential habitat area will be large for both juveniles and adults (Teal, van Hal, van Kooten, Ruurdij, & Rijnsdorp, 2012). Coincidentally, the available area of suitable habitat in the centre of sole's latitudinal range is one of the key limitations to production (Archambault *et al.*, 2016; Le Pape *et al.*, 2003).

Where a large portion of the literature appears focussed on the increasing northern extent of NE-Atlantic species in relation to climate change, these expansions are often accompanied by a retraction in the south of their extent. A clear example of this has been documented for plaice where summer maximum temperatures in the shallow, estuarine influenced juvenile habitats, repeatedly excluded juvenile plaice and subsequent reductions in landings tracked the last successfully recruited year class of adults to collapse (Désaunay, Guérault, Le Pape, & Poulard, 2006; Hermant, Lobry, Bonhommeau, Poulard, & Le Pape, 2010).

In addition to the ecological challenges faced by shifting fish species, they themselves impact upon the environments they move to/from. One of the most predominant mechanisms for such impacts is through direct exploitation of new prey and the resultant competition with similar trophic level organisms. This has been described on two occasions in this report via the expansion of both demersal and pelagic fishes. With increasingly favourable temperatures and winds promoting successful recruit-

ment, hake have moved into the north of the European continental shelf seas, where they are competing directly with saithe for the Norway pout (Cormon, Loots, Vaz, Vermard, & Marchal, 2014; Goikoetxea & Irigoien, 2013). Similarly in the pelagic stocks, the seasonal encroachment of mackerel into typically herring dominated areas likely leads to competition for planktonic prey (Utne *et al.*, 2012).

There remain a vast multitude of other potential ecological implications when species assemblages change in with distributional expansions and contractions. However, the complexity of ecological interactions makes these hard to predict and therefore speculation is not warranted.

4.3.2 Fisheries and management implications

The spatial distributions of fish underlie the basis for stock identification and management, and consequently any factors that affect those distributions can potentially have implications for fisheries management. In general, a distributional change of a species can occur via a relatively small number of mechanisms, which individually or collectively, can influence how its stocks should be managed. For example, a species or a stock could expand its range northwards by a *movement of some individuals*, or by systematic, geographically-explicit *changes in productivity throughout the species range*. Consequently in many cases in which climate change is driving the distributional change, productivity changes are also occurring which lead to changes in distribution of centres-of-biomass (e. g., at the species level). This situation appears to be the case for e.g., Atlantic mackerel whose distribution expanded north and westwards, while the overall biomass also increased. As a result of the change in productivity, there was an increase in overall biomass, and some of this biomass was/is distributed in jurisdictions which previously had no or negligible quota. In other situations, and as climate change progresses, one could expect or observe declines in productivity in southern regions, which would exacerbate changes in distribution due to movements of individuals to new areas and increased productivity in northern parts of the range. The impacts of changes in distributions and our capacity to forecast them have implications for fisheries management which are detailed below.

Despite this report highlighting a list of 'big movers', WKFISHDISH concluded that they were not in a position to predict which species will shift their distributions in the future, and where (see section 4.3.3). Future projections, as are current stock assessments, are also limited by the quality of data from scientific surveys and the fact that they often target certain age-classes (e.g. bottom trawl surveys from Bay of Biscay to south Portugal only sample effectively the juvenile component on hake and anglerfish populations). Changes in species' distributions may have implications for the design and implementation of scientific surveys. Many surveys sample a fixed grid of survey stations that is kept constant from year to year. It is important to regularly review whether surveys effectively cover the main distribution areas of species as this has a direct impact on the ability of surveys to provide accurate biological information needed for the stock assessment and scientific research. Adaptive survey approaches like the mackerel egg survey or the IESSNS mackerel summer feeding survey are examples of survey approaches that are intended to adapt to changes in distribution patterns. In addition, higher efforts to incorporate surveys from Northern (e.g. Norway, Iceland and Greenland) and Southern countries (e.g. Morocco) in ICES databases would be helpful for future research and will help to address some of the limitations in the analysis performed in this report. It is also important to ensure that surveys collect physical and environmental information which can later be used to identify the cause of changes in species' distribution. Furthermore, it is not species

distribution, but stocks distributions that are usually surveyed in line with management needs. This can be detrimental when a stock includes different species. For instance, both anglerfish and megrims stocks are composed of two distinct species. In both genus the two species display contrasting patterns of changes in distribution and contrasting responses to similar environmental drivers. While the two species can be investigated separately using survey data, the interpretation of the results regarding stock trends and subsequent implications regarding TAC management areas can be complicated.

The landing obligation introduced in Europe since 2015 is posing a number of challenges relative to a potential change in distribution of the main target species. The distribution of the TACs decided for each stock between TAC management areas and then into national quotas based on the principle of “relative stability” was established in the early 1980s, based on historical track records of landings until then. Before the landing obligation, any catches of species for which no quota was available for a given country had to be discarded. With the landing obligation being currently phased in this will, progressively, no longer be possible. The combination of a change in species distribution and the fixed allocation of quotas set by the relative stability framework has the potential to result in a mismatch between regional abundances and TACs allocated to member states in certain areas. With the enforcement of the landing obligation this mismatch can jeopardise fisheries if fleets cannot avoid unwanted catches of species for which they have not enough quota. Forecasting which TACs or areas will be problematic can be challenging given the possible mismatch between the wide distribution of some species, advice (stocks) and management units (TACs) coupled with difficulties to access the TAC trading data (PETRAS database).

A good example for TAC and regional abundance mismatch is the expansion of northern hake into the Northern North Sea. The bycatch of hake (and its associated choke species issue) in the mixed demersal fisheries has increased dramatically but the quota share available to the countries fishing in those waters has not changed to reflect this increasing abundance. This challenges the validity of the relative stability. With the landing obligation, all hake caught must now be landed while the available quota needed to make these landings legal is limited. This issue can be exacerbated by new challenges such as the Brexit if UK decides not to abide by the CFP and discard or even land over quota. Quota swaps between neighbouring ICES areas can provide opportunities to legally land unwanted catches. However, as shown by the North Sea hake example it is not a suitable solution to cope with large abundance increases. Such quota swapping is impaired as stakeholders and countries hold onto quota till late in the year, so as to ensure that all catches can be accounted for. Added uncertainty due to changes in regional abundance of stocks further hinders the process of trading quota for stocks in question. It has been reported within stakeholder bodies such as the advisory councils that it becomes increasingly hard or expensive to gain needed quota to cover all catches, whereby so-called choke species are created. This suggests that there is still space for improving management and stakeholder awareness given the number of recent research stating the ecological and economic benefits of fishing under MSY and that there is still a fishing overcapacity. New or different transnational quota swapping platforms as well as more adaptive quota allocation on a national basis have been proposed by stakeholders in workshops to aid this problem.

While scientists can provide early indications of changes in stock distribution with regard to management units, this issue can only be addressed through management. It can be also potentially addressed with technical measures such as gear selectivity

or further fleet decommissioning where there is still a fishing overcapacity. What this management would entail is yet to be determined, but a more holistic approach is needed to translate current stock distributions into appropriate TACs reflecting regional abundances which do not jeopardise fisheries whilst abiding to the Common Fisheries Policy i.e. the landing obligation. However, changes in distributions of widely migratory fish species such as mackerel had already implications in the past for international agreements between Coastal States. In such cases, TACs are set in annual negotiation rounds between the Coastal States. With the expansion of e.g. mackerel into the EEZ's of Iceland and Greenland, claims have been raised to change the sharing arrangement of the TAC. Such claims were probably also partly motivated by the fact that the overall biomass of the stock was increasing, presumably due to improved productivity of the stock. Consequently the change in distribution was not only associated with a spatial re-arrangement of existing fish in the water (which if so, would have *reduced* the relative amounts in all previously occupied TAC areas), but due partly to an overall increase in biomass due to changed productivity. In the absence of agreements between the Coastal States this has led to a situation of setting unilateral TACs exceeding the scientific advice by ICES. This also had repercussions on the sharing of other widely distributed stocks like blue whiting and Atlanto-scandian herring.

The hake and mackerel examples show that changes in the spatial distribution of fish species can lead to major challenges in establishing methods for sharing access to these resources. There is no obvious way of addressing that challenge from a management perspective even with an increasing forecasting capacity. Although in theory it would be possible to attempt to estimate the proportion of species in certain coastal waters, there are major challenges in delivering the scientific data and analysis that would be needed for such advice. For example in cases where a species spawns in the EEZ of one Coastal State and feeds in the EEZ of another Coastal State, it is not straightforward to assess the relative importance of the different life stages to the overall stock and their management. In addition, there may be a substantial amount of yearly variability in the spatial and seasonal distribution of species and lack of ability to effectively monitor those distributions.

Hake and mackerel are both well-known examples of the impact of changes in fish distribution on fisheries management. However other species were identified in this report as having experienced significant changes in their distribution and as such could also introduce management issues in the future, particularly those that are part of mixed fisheries. Identifying the driver(s) of these changes in distribution can be difficult, not to mention our ability to accurately predict these driver(s), and ultimately forecast future changes in distribution or near real-time monitoring and forecasting technologies (e.g. satellite or autonomous sampling devices). The 2002 CFP reform led to an overall reduction in fishing pressure through better enforcement and fleet decommissioning, which may have (led to or helped) stocks recovering (e.g. northern hake) or increase to high levels (e.g. North Sea plaice) of abundance likely to result in density-dependent stock expansions. In addition, current climate scenarios project an increase in temperature and decrease on primary production that would trigger stocks declining at their (southern) distribution boundaries or shift distribution altogether. Thus, it is likely that future changes in distribution will occur for the species identified here, although whether the extent of those changes will result in management issues remain uncertain.

The following key areas where management can be affected by species' distribution changes have been identified in this report through survey data analyses and a literature review:

- 1) The North Sea is an area where changing thermal habitat and other changes can lead to latitudinal shifts of regional populations (e.g. anchovy, cod, sole, hake, mackerel, plaice and pollack, anglerfish). Moreover, plans for wind turbine parks, protected areas and the potential of recreational fishing can further complicate the management of these fish stocks.
- 2) Southern areas are becoming less suitable for some species due to increase in temperature and lower primary production (e.g. haddock, plaice and spur-dog). However, survey data time-series are shorter in that area which questions the reliability of these trends. In contrast other species such as herring, anglerfish or megrims are increasing in southern areas.
- 3) West of Scotland and Ireland also show a northern shift of species such as cod, sole, hake and herring as well as a decrease in pollack. There is evidence in the literature that northward and deepening species shifts have accelerated in the last 3-4 decades (e.g. cod).
- 4) North Scotland, Norwegian Sea and Skagerrak-Kattegat are areas that are also likely to show changes in species distribution. Current stock assessments and literature suggest that effective shifts of species distribution can be limited by a species capacity to establish new spawning grounds. However, adult migration can show high abundance in areas without known spawning grounds due to changes in habitat suitability or species high densities. Species identified as increasing their abundance in these areas are anglerfish, cod, sole, hake, herring, plaice, pollack, saithe and spurdog.

In conclusion, adaptive measures for better science, monitoring (stocks and ecosystem) and management to deal with changes in fish distribution in EU waters is likely to be a good investment that will help us to detect and cope better with such changes in the future. Indeed, climate change literature is finding more and more evidences that these changes might be accelerating. A summary of the key findings in relation to implications for management of species distribution shifts is:

- Uncertainties in forecasts are large preventing definitive forecast; still we might not be using all the potential of current models and knowledge.
- There are some areas that are most likely going to have biggest implications for management: North Sea, southern areas, West of Scotland, North of Scotland, Norwegian Sea and Skagerrak-Kattegat.
- We have identified several species that have the potential to become choke species: anchovy, anglerfish, blue whiting, cod, hake, herring, mackerel, megrims, and plaice.
- Solutions identified are adaptive management and monitoring, improve use of our forecasting capacity and increase accessibility to survey and TAC trade data.
- The gaps in knowledge or management practice that need most operational or strategic attention are access to survey data beyond the southern and northern boundaries of current surveys, access to TAC trading data for scientific analysis and improve our use of existing forecasting capacity.

4.3.3 Predictability of future changes

A number of studies presented to WKFISHDISH produce distribution maps for various species at the horizon of the end of the 21st century (Bruge *et al.*, 2016, Fernandes *et al.*, 2013; Jennings and Collingridge, 2016). Such studies should be considered as scenario-based projections, presenting future changes conditional to 1) climatic scenarios, 2) a down scaling of the effect of climate change on the local environment and 3) a generic perception of how species distribution respond to changes in the environment. This type of “what if” approach is useful as it presents potential scenarios of future changes, that could help anticipate the potential ecological or economic consequences and develop strategies to adapt to such changes. However, these types of approach are not considered precise and realistic enough for the level of details needed to inform fisheries management at shorter time scales (Dickey-Collas *et al.*, 2014).

WKFISHDISH concluded that the predictability of future changes with a good degree of confidence was quite limited. The main reasons for this limitation are:

- The lack of strong evidence for the drivers identified.

As mentioned in section 4.2, evidence for the drivers are often pretty weak (based on temporal correlations) and without an understanding of the underlying mechanisms, they do not represent a basis solid enough for making predictions.

- The lack of predictability of the drivers.

While spatially resolved scenarios of future ocean conditions corresponding to IPCC climate scenarios are available, some other drivers cannot be predicted. The development of future stock size, for instance, depends on future management decisions and their efficiency. In addition, management strategies evaluations show that even when a management strategy is apply consistently over a long period of time, the range of possible realisations of future stock size is generally very wide, due to the various sources of uncertainty in the system and the natural variability of the population.

- The lack of understanding of the interplay between different drivers.

- Even though different conceptual models are available to represent the interaction between habitat occupation and population abundance, no concrete application of such model was available for the species studied in WKFISHDISH. Even in situations where potential habitat can be forecasted, without a formalised representation of density-dependent habitat selection in these species it is difficult to make any prediction on future distribution.
- The complexity of life cycles is another obstacle to making realistic predictions. The different steps of the life cycle each depend on the existence of particular features (retention and transport of the larvae, size and suitability of the nurseries, feeding grounds). It is essential to consider the importance these feature when trying to predict future distribution. Projecting the environmental niche of species under climate change scenarios, without considering that species depend on some specific geographic features (oceanographic, substrate...) to complete their life cycle, may lead to overestimate the rate of change in species distribution.
- Whether or not a species will change its distribution as a result of changes in its thermal habitat depends also the abundance other (prey, competing or predator) species in areas where the habitat ex-

pands, which adds a level of complexity to the prediction of future distribution changes.

Given the multi-annual nature of species distribution shifts, our capacity for early detection of these shifts was not addressed. Certainly there is space to use current existing modelling capacity to try to address this. The above model projections are available, but never tested to be used for management advice. Statistical and machine learning models have also shown their potential as early warning systems or to provide forecasts based on limited data. Finally, the models used for stock assessment can be also used as short-term forecast tools. An appropriate framework needs to be setup to make available fisheries forecasting science more operational. This report highlighting species, areas and models that can be the basis for such a framework.

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Annex 2. Advice on the request from WGECO.

<http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2015/WGECO/01%20WGECO%20-%20Report%20of%20the%20Working%20Group%20on%20the%20Ecosystem%20Effects%20of%20Fishing%20Activities.pdf>

ICES Special Request

WGECO was requested to advise on possible methods to detect distributional change for a range of species in the Northeast Atlantic (Table 6.2) and the group identified species and survey combinations where metrics of geographical extent, occupancy and aggregation could reliably be evaluated on a species and stock level. For instance in western waters it should be possible to evaluate movement in the southern limit for some northern species such as haddock or cod. Northern limits for other species e.g. sardine should also be possible to determine. However, for other species, it will be necessary to limit the analysis to sub-regional distribution due to the lack of overlap in time and space between different surveys.

For each species and, where relevant, sub-region, WGECO recommends including metrics of each of the three aspects geographical extent, occupied area and aggregation to detect large-scale distribution shifts, including parallel shifts, expansion/contraction and splitting/merging. The metrics should preferably be based on smoothed distributions assuming an appropriate error distribution (e.g. non-symmetrical such as delta or negative binomial). An appropriate selection of indicators to quickly detect geographical trends in distribution over time could be 5% and 95% tiles, and average of latitude, longitude, depth and temperature of recorded specimens (Geographical extent), surface area of realised occupied areas (Occupied area), the area containing 95% of the population and standard deviation of average latitude, longitude, depth and temperature (Aggregation). As these metrics are likely to be highly correlated, they should be combined in a multivariate analysis of the trend or in a composite indicator using e.g. principal component analyses prior to determining the trend to avoid detecting spurious correlations.

WGECO recommends that care is taken when using the survey data available in DATRAS. Combining the surveys on a regional level without accounting for the differences in each survey could lead to a misinterpretation of the information they provide. Surveys shouldn't be combined without first addressing issues of catchabilities between surveys and standardizing the survey areas both temporally and spatially. The surveys vary spatially and temporally, survey goals and objectives have changed over the years and the fishing gear has changed on many vessels. For example in the Baltic Sea although the Baltic International Trawl Survey series starts in 1991, there was a gear change in 2001. In the Celtic Seas there are a number of surveys which vary temporally, the West Coast of Scotland has data as far back as 1985, but the most recent ground gear change occurred in 2009. The current Irish Ground fish survey began in 2003, with but spatial coverage changed in 2005 (it moved out of the Irish Sea and increased its stations on the shelf). The Northern Ireland Ground fish survey is available in DATRAS from 2008 onwards, but the Northern part of the Irish Sea and St Gorges Channel are surveyed using two separate survey designs and they are not directly comparable. In the North Sea data are available in DATRAS from 1965 for the first quarter survey and 1987 for the third quarter survey. There has been several changes in survey design in the history of this survey. It is perhaps more sensible

to use first quarter data from 1983 and third quarter data from 1998, (although it is considered possible to use third quarter data from 1991, with less confidence attached). For the Bay of Biscay, the EVHOE survey has been standardized from 1987 onwards, but moved into the Celtic Sea at a later date. For the Iberian coast, the Portuguese data should only be used from 2005, but it should be noted that they are currently awaiting a new vessel and their gear type is likely to change with the new vessel to be more comparable to adjacent surveys. The Spanish data submitted to DATRAS contain only a standard species list, and it would be unwise to use these data to infer a southern range for species not "present" in these data as this may not be correct given that all of the species are not reported. Each of these surveys use different gear types and most are not directly comparable to each other. There are similar issues with the Beam Trawl surveys, the "BTS" data contains information on five national surveys, three different surveys from England and one from the Netherlands and one from Germany. Each of these surveys have a unique gear type and different temporal and spatial scales, so should not be combined without comparisons and calibrations. Care should be taken on using any of these surveys without prior quality control on the DATRAS data such as that in Moriarty and Greenstreet (in preparation).