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Executive Summary

The “Workshop on Blue Whiting Recruitment” (WKBLUR) met to examine potential mechanisms that may drive the recruitment to the Blue Whiting stock and assess whether forecasting recruitment in this stock is feasible. Blue Whiting year-class strength has shown dramatic changes in recent years, increasing by five-six times after 1995 and suddenly returning to pre-1995 levels after 2005. Recent work has shown that the North Atlantic Subpolar Gyre has a strong influence on the ecosystem in this region, including the spawning distribution of Blue Whiting, and the post-1995 increase in recruitment is coincident with a rapid weakening and westwards retreat of the gyre. WKBLUR therefore interpreted this temporal correlation of events as suggesting a possible causal linkage between the gyre and recruitment.

The workshop questioned the reliability of the recruitment estimates produced by the stock-assessment. The historical performance of the assessment is poor and recent work has highlighted that the management unit employed does not match biological and oceanographic evidence of structure within the stock. The upcoming benchmark assessment of this stock is expected to address these concerns in more detail.

The group developed two major hypotheses (shown schematically in Figure E1) that may account for the hypothesized linkage between the Subpolar Gyre and the recruitment dynamics. The “predation” hypothesis is centred upon the role of mackerel predation upon blue whiting: gyre-driven changes in the spawning distribution change the distribution of spawning products and thus the overlap of adult mackerel and blue whiting larvae, and hence the severity of larval-predation. Alternatively, the “food” hypothesis suggests that changes in the oceanographic conditions may change the amount, type and availability of food for larvae and juveniles, ultimately impacting growth, survival and recruitment. The workshop was not able to accept or reject either of these hypotheses directly: instead, the hypotheses presented form a framework for future research.

WKBLUR concluded that in the current absence of mechanistic understanding, it is not currently possible to make recruitment forecasts. Resolving the hypotheses developed above, however, may still render such forecasts feasible.

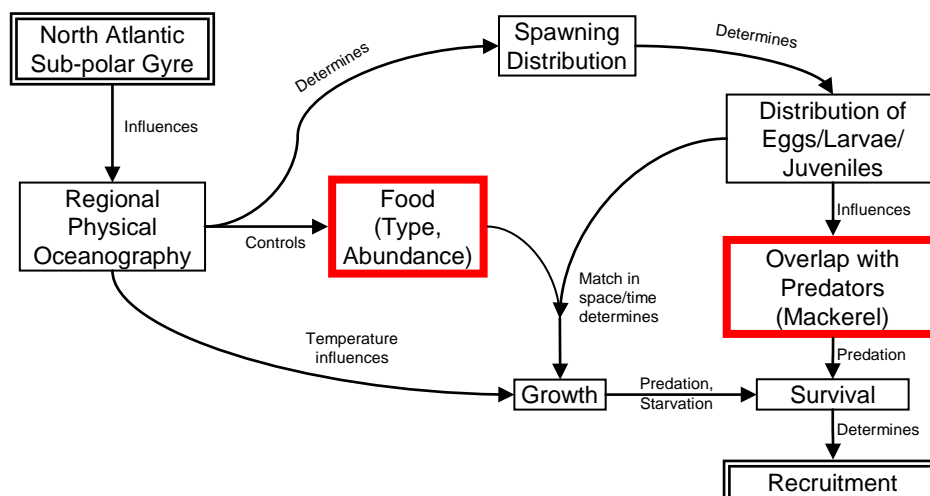


Figure E1. Summary of the proposed mechanisms giving rise to the observed correlation between the Subpolar Gyre and recruitment of blue whiting. The two key testable hypotheses developed in this work are highlighted within the red boxes.

1 Introduction

Blue whiting (*Micromesistius poutassou* Risso) is a pelagic planktivorous gadoid found throughout the Northeast Atlantic. The species ranges from the Iberian Peninsula and the western Mediterranean in the south to the Barents Sea in the north, from the North Sea to the Mid-Atlantic Ridge and even as far as the east coast of North America. However, despite the extremely wide geographic range, the species is currently managed as a single stock based around spawning grounds along the continental-shelf edge west of the British Isles (Bainbridge 1973; Bailey 1982 and references therein).

In recent years, recruitment to this stock has varied widely (Figure 1.1). From early 1990 weak year-classes of around 10 billion individuals, large year-classes were produced in 1996 (~50 billion individuals) and particularly in the period 2000–2003 (~50–60 billion individuals). However, in recent times (the 2005 year-class and onwards) the recruitment has returned abruptly to pre-1995 levels (ICES, 2009).

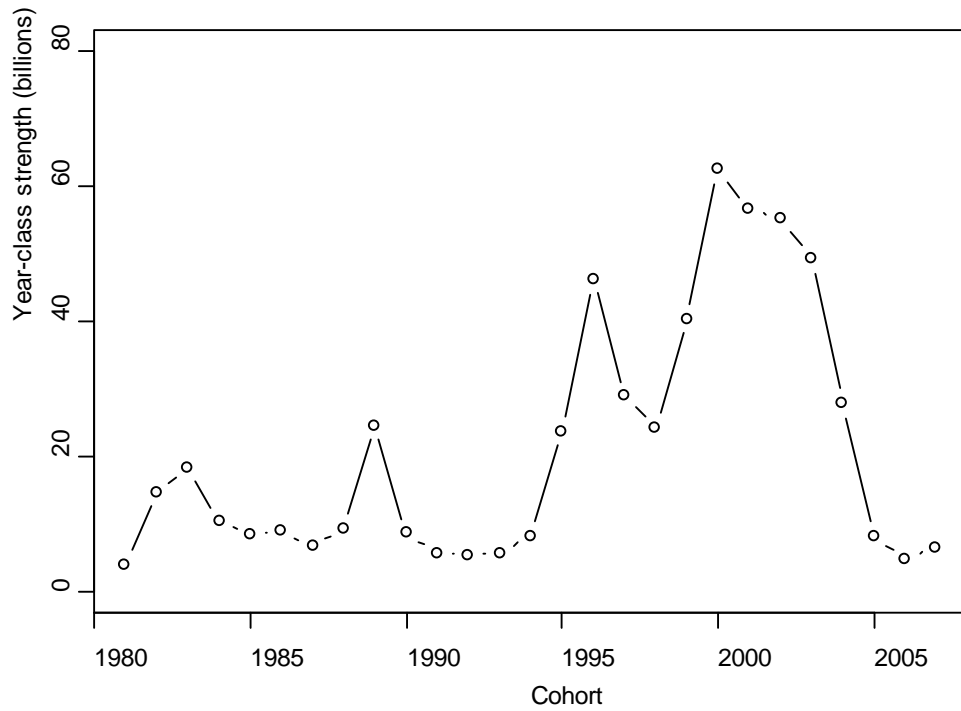
Such dramatic changes pose both severe management challenges and interesting scientific questions. The fishery upon this stock, riding on the back of the strong year-classes, expanded rapidly in the late 1990s and catches peaked at nearly 2500 tonnes in 2004, making it one of the largest fisheries in the world at that time. However, the return to pre-1995 recruitment levels after 2005 meant that the fishery could not be sustained, ultimately requiring drastic reductions in the fishery (ICES, 2009). If the mechanisms driving such changes were understood, and if shifts between such high and low recruitment regimes could be predicted in advance, management of this stock could potentially be optimized to avoid such difficulties.

Two recent papers have suggested that such prediction may be possible. The first of these papers, Hatun *et al.* (2009b), showed a link between the spawning distribution of this stock and the dynamics of the North Atlantic Subpolar Gyre: these distributional changes were seen in observations of larvae, in the spatial distribution of catches and in scientific acoustic surveys covering this region. The second paper, Hatun *et al.* (2009a), looked at the biogeography of the North-east Atlantic more generally, and was able to demonstrate the influence of the Subpolar Gyre across four different trophic levels, from phytoplankton through zooplankton and blue whiting all the way up to pilot whales. This work contributed further to our understanding of blue whiting dynamics, demonstrating the post-spawning distribution of fish varied in agreement with the Subpolar Gyre.

These results suggest that the Subpolar Gyre has a strong, and possibly determining, influence on the dynamics of the North Atlantic ecosystem, including blue whiting. Furthermore, we note that the rapid increase in recruitment to this stock in the mid-1990s is coincident with an equally dramatic change in the Subpolar Gyre (Figure 1.2). However, in more recent years, the recruitment appears to have collapsed, whilst the post-2005 increase in the gyre index was modestly compared to the pre-1995 values.

In this work, we review the current state of knowledge regarding the recruitment dynamics to the North Atlantic blue whiting stock, and attempt to establish whether recruitment prediction is scientifically feasible for this stock. This report reflects the three main lines of enquiry followed. In Section 2, we first examine the quality of the stock assessment, with a view to checking whether the recruitment time-series is “believable”, or simply an artefact of the assessment methodology. The diagnostics produced by the assessment method are examined and the results are compared with

other, independent, observations of year-class strength. Sections 3 and 4 examine potential hypotheses that could explain the wide range of recruitment dynamics: Section 3 examines the physical processes involved and sets the scene in terms of changes in oceanography and the Subpolar Gyre, whereas section 4 examines the potential biological mechanisms that could affect recruitment. Section 5 draws these strands together by considering how such recruitment forecasts might be performed, and examining several simple short-term forecast models. Finally, section 6 draws conclusions regarding whether forecasting recruitment in this stock is possible, and what further elements would be required to permit such a system.



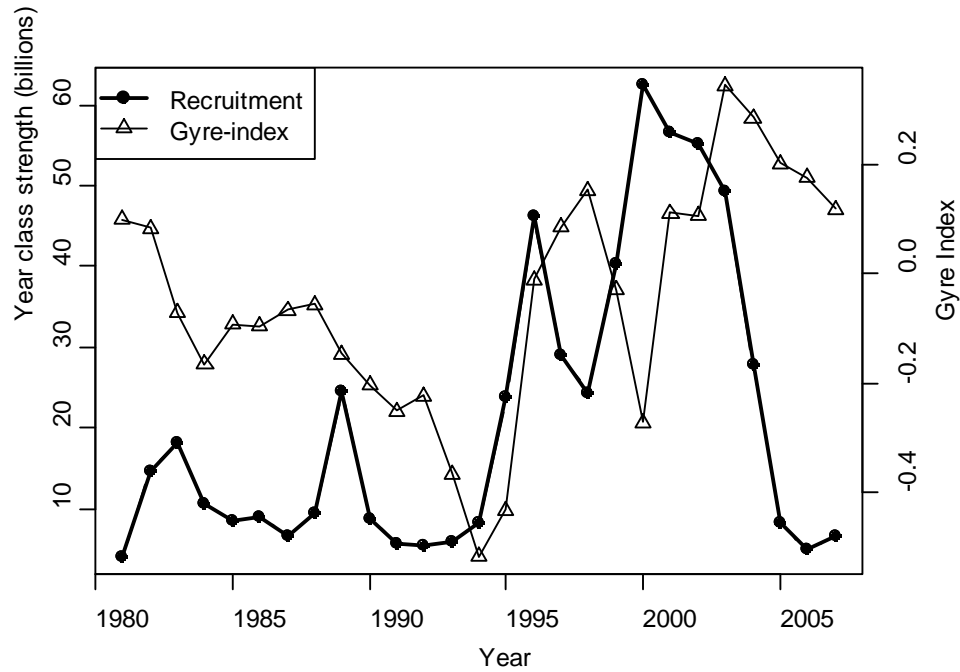


Figure 1.2. Comparison of blue whiting recruitment dynamics with those of the North Atlantic Subpolar Gyre. The year-class strength at-age 1 (filled circles, heavy line) is plotted as a function of the year in which that cohort was spawned, whilst the gyre index (open triangles, lighter line) is plotted as the average value during that year. The gyre index is inverted compared to Hatun (2005) - positive values correspond to a weak gyre. For more information regarding the gyre, see Section 3.

2 Reliability of the recruitment estimates

Before considering potential mechanisms influencing the recruitment to this stock, we first examine the robustness of the recruitment estimates. In particular, we examine the quality of the stock assessment, and attempt to assess whether the recruitment time-series generated by the assessment model is supported by other, independent, sources of information.

2.1 Stock Identity

Prior to 1993, for the purposes of assessment, it was assumed that blue whiting had two components, a northern and a southern component. The Northern stock was known to feed in the Norwegian Sea and spawn to the west of the British Isles. The Southern stock was found along the continental shelf off the coast of Spain and Portugal with the main spawning areas towards the Porcupine Bank. The Porcupine Bank is considered a transitional area between the two main stocks (ICES, 1990). In 1993 it was argued that there was no strong evidence to maintain this division between the two stocks. Results from an otolith age reading workshop at that time showed no significant difference in mean annual ring diameter between northern and southern stocks. It was agreed by ACFM in 1993 that the two stocks should be combined for assessment purposes (ICES, 1995). Since then this stock has been assessed as one unit (ICES, 2008).

Several approaches have been employed to investigate the stock structure of blue whiting. The details of studies relating to genetics have been published by Mork and Giaever, 1995, Giaever and Stein, 1998, Ryan *et al.*, 2005 and Was *et al.*, 2008.

Oceanographic modelling has been used to examine the advection of blue whiting eggs and larvae. Larval drift is thought to be an important factor in recruitment. Skogen *et al.*, 1999 proposed that the southern stock will spawn in an area where the eggs and larvae are likely to drift southwards and the northern stock where the eggs and larvae will drift northwards. Based on modelled drift patterns, they found that a possible separation line was located at 54.5°N but this was subject to significant interannual variability over the twenty years studied. Work conducted by Bartsch and Coombs (1997) used a three-dimensional baroclinic model and suggested that particles released on the Porcupine Bank drifted southwards with a separation at about 53–54°N. This work gave some additional information about stock separation but suggested that the division might be more southerly. Additional testing of this approach was recommended.

An investigation of larval growth histories was carried out in 2007 (Brophy and King, 2007). Groups that are spatially or temporally distinct after hatching are expected to show measurable differences in the larval portion of the otolith. This study showed that larvae from the Bay of Biscay grow faster than those from more northerly spawning areas. It also confirmed that fish spawning to the west of Ireland and Scotland does not form a randomly mixing unit and that subunits within this aggregation have experienced different conditions during the larval phase. The dispersal of larvae influences the subsequent dispersal of spawning adults. The fish that are found in the feeding assemblages throughout the distribution range do not contribute equally to the spawning assemblages in the north and south of the spawning grounds. There is therefore growing evidence from these studies that there may be several components in the North east Atlantic blue whiting stock.

Furthermore, in 2009, the Stock Identification Methods Working Group (SIMWG) stated that the perception of blue whiting in the NE Atlantic as a single unit stock is not consistent with recently observed differences in genetics and growth and should be revised. They recommended that a precautionary approach should initially treat blue whiting populations in areas VIIk and VIIj and further south as a separate unit from all other NE populations. This group also suggested that a large, interdisciplinary project on this species is needed in order to comprehensively understand blue whiting stock structure in the NE Atlantic so that more robust advice may be provided (ICES, 2009).

Such recommendations obviously present problems when trying to understand the recruitment of Blue Whiting in terms of a single stock. However, splitting the stock assessment into two separate units is a complex and time consuming task, not readily performed with the scope of such a meeting. Given these difficulties, WKBLUR therefore chose to continue in the single-stock paradigm where necessary, but to recognize these potential problems and bear them in mind as appropriate.

2.2 Assessment Methods

The Blue Whiting stock-assessment has been explored using different assessment models in the past including ICA (Integrated catch at-age analysis), AMCI (Assessment model combining information from various sources), XSA (extended survivors analysis), ISVPA (Instantaneous Separable VPA) and SMS (Stochastic Multi Species mode). For the last four years, SMS has been selected as the final model. SMS (Lewy and Vinther, 2004) is an age structured assessment model based on a separable VPA designed to handle multispecies interactions: however, it can be reduced to operate with one species only. In "single species mode", an objective function for catch-at-age (in numbers) and the time-series of survey indices-at-age are minimized assuming a

lognormal error distribution for all data sources. The expected catch is calculated from the catch equation and F at-age, which is assumed to be separable into an age selection and a year effect. SMS weights the various data sources automatically as part of the fitting procedure (ICES, 2006).

The assessment uses catch data from 1981–2008 and is tuned by three survey time-series:

- 1) The Norwegian acoustic survey, 1991–2003, ages 3–8.
- 2) The International ecosystem survey in the Norwegian Sea, 2000- 2009, ages 1 and 2.
- 3) The International blue whiting spawning stock survey 2004–2009, ages 3–8.

At the 2007 working group, five different assessment models were used to explore blue whiting data. The assessments presented were considered as very uncertain. As can be seen in Figure 2.2.1, the estimated spawning stock and fishing mortality varied considerably between the different models that were run. The difference between the models lies mostly in different weighting of data. It was concluded that the problem for all types of models seemed to be conflicting information from the catch and survey data, in combination with a relatively high uncertainty of the acoustic estimates of the stock size (ICES, 2007). Since 2007 the number of models to explore the data has been reduced with only XSA, ISVPA and SMS used in 2009.

A benchmark assessment has not yet been conducted for Blue Whiting. This stock is scheduled for benchmark in 2011. In the following sections, we examine the quality and suitability of these inputs, and the resulting assessment.

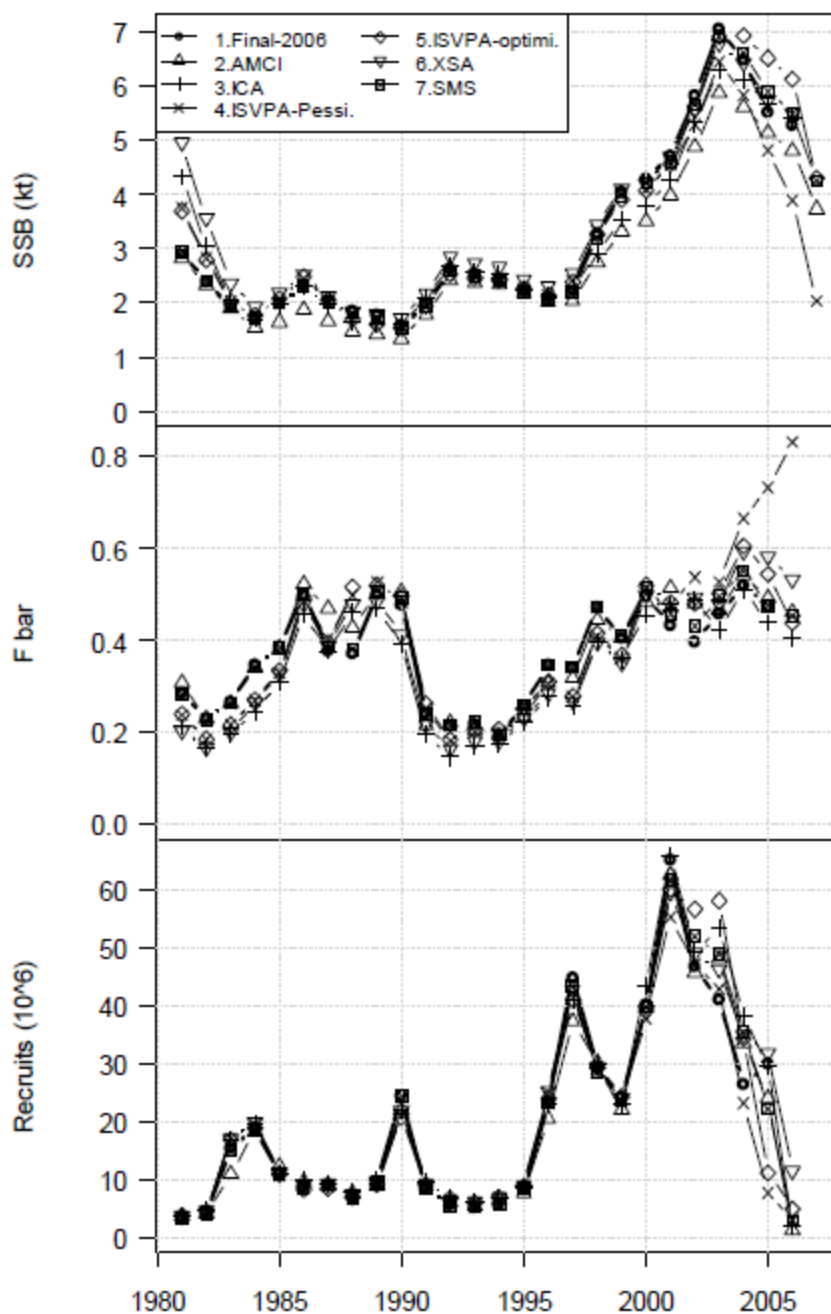


Figure 2.2.1. Comparisons between final exploratory AMCI, ISVPA (pessimistic and optimistic) , ICA, XSA and SMS assessments in 2007 (ICES, 2007).

2.3 Quality of the Research Surveys

2.3.1 Spatial and temporal coverage

It could be questioned whether the spawning-stock survey coverage been the same and has it covered the whole distribution area of the stock each year. The survey timings have fluctuated in time each year, and this could also create fluctuations in the interpretations of the results (Table 2.3.1).

The survey coverage during the historical surveys has mostly been confined to the shelf edge area from Porcupine to the Hebrides, and only occasionally west towards the Rockall Plateau. This makes drawing any inference about spawning distribution on the Rockall Bank difficult. In recent years (from 2004 onwards) the coverage has been more or less the same each year also covering the Rockall Plateau.

It could also be questioned whether the results from the surveys are representative of the stock, the age distribution, and the maturation. In the assessment, the stock is divided into a mature part (spawning-stock biomass, SSB) and an immature part based on the proportion mature at each age. One problem that could influence the estimate of the adult (mature) biomass from the acoustic surveys is a maturation ogive that is biased as a consequence of poor sampling or erroneous classification of maturity stage, during the spawning survey.

A further source of variability could be the age reading of the otoliths. If not all countries participating in the survey (as well as in the fishery) do not interpret the age rings in the otoliths in the same way, this would introduce errors in the age disaggregated survey estimates, and also in catch at-age data in the assessment.

Table 2.3.1. Timing of the surveys (day-month) in the spawning stock surveys west of the British Isles, March–April 1981 to 2009. Prior to 1996 the surveys were performed by Norway and Russia, then by Norway until 2004, where five nations participated in the international surveys coordinated by the ICES PGNAPES.

YEAR	SURVEY TIMING					
	NORWAY		RUSSIA		INTERNATIONAL/COMBINED	
	START	STOP	START	STOP	START	STOP
1981	09-03	04-04				
1982						
1983	01-04	15-04	15-04	15-05		
1984	26-03	17-04				
1985			01-04	15-04		
1986	01-04	19-04				
1987	16-03	11-03				
1988	25-03	24-04	28-03	21-04		
1989	30-03	24-04				
1990						
1991	18-03	16-04	17-03	12-04	17-03	16-04
1992	17-03	28-03			17-03	28-03
1993	12-03	03-04	21-03	11-04	12-03	11-04
1994	25-03	15-04				
1995						
1996	20-03	22-04	01-04	15-04		
1997						
1998	24-03	26-04				
1999	24-03	22-04				
2000	22-03	24-04				
2001	21-03	23-04				
2002	23-03	25-04				
2003	29-03	27-04				
2004					17-03	18-04

	SURVEY TIMING		
	NORWAY	RUSSIA	INTERNATIONAL/COMBINED
2005			10-03 14-04
2006			03-03 15-04
2007			09-03 12-04
2008			17-03 16-04
2009			17-03 16-04

2.3.2 Target Strength

There have been suggestions that the conversion factor (Target strength; TS) for blue whiting is too low, resulting in a too high biomass from the acoustic surveys. Furthermore, it is not clear whether a linear relationship with length is correct for larger blue whiting, i.e. the TS might not be linear function for all fish lengths. As blue whiting is a physoclist gadoid (i.e. with a closed gas filled swimbladder), it might be suspected that the TS changes with the fat content of the fish. The gas filled swimbladder represents most of the acoustic backscattering energy (echo) and any changes in the volume of the swimbladder would thus affect the echo.

A study by Jacobsen *et al.* (2002) showed that the total fat content of blue whiting varies significantly during the year, being at a minimum in April/May after spawning (just above 2%) after spawning, where most of the resources have been used for gonad development (Figure 2.3.1). The fish rapidly gain fat after spawning and reaches a maximum fat content in August (nearly 9%), which remains high in the remainder of the year (Figure 2.3.1).

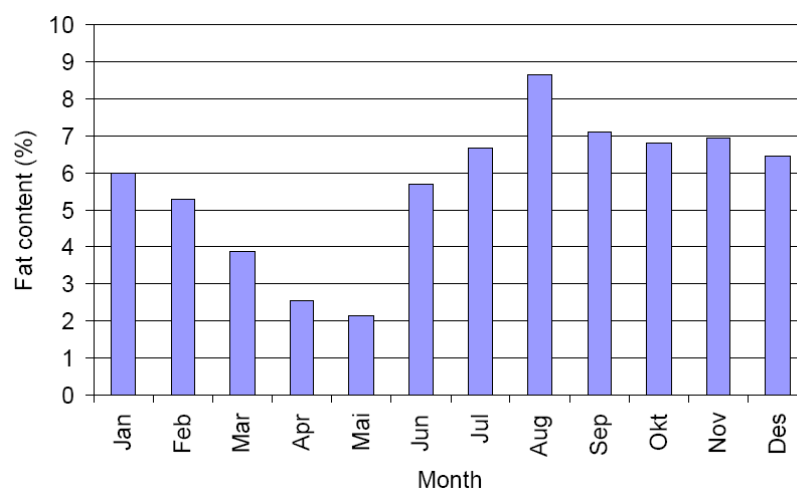


Figure 2.3.1. Fat content (%) in blue whiting by month from the Faroese commercial landings during 2001. The fish was sampled at Havsbrún fishmeal factory in Fuglafjørð, Faroe Islands (Jacobsen 2002).

Does the TS of blue whiting changes before and after spawning? When the fish is full of roe and milk the fat content of the fish is high (which has a lower specific density than seawater) reducing the need for a full swimbladder to keep the fish at neutral buoyancy at depth and thereby reducing its TS at length. Conversely, after spawning the fish is thin and slender, with low fat content and therefore needs to fill the gas bladder to compensate for the loss of buoyancy making the TS too large for its length, resulting in an overestimation in an acoustic survey.

By simple modelling of the swimbladder, Jacobsen et al. (2002) found an inverse relationship between the acoustic target strength and fat content, and further that a seasonal variations in fat content of 7% might lead to a bias of up to 12% in acoustic biomass estimates, if they were measured in the low-fat and high-fat period.

2.3.3 Survey direction

During the period 1983–1996, two research vessels, one Norwegian and one Russian, performed acoustic surveys for blue whiting in the spawning area in spring. In some of the years large discrepancies in the biomass estimates between the two vessels were observed (Table 2.3.3). The ratio of the spawning stocks estimates between Russia and Norway ranged from 0.46 to 2.8 with the Russian estimates being lower than the Norwegian in 8 out of 12 years (Table 2.3.3). During many of these surveys the two vessels used to cover the spawning area in opposite direction, the Russian progressing from the north to the south and the Norwegian from the south to the North. The blue whiting from the Porcupine Bank area and north of that area is thought to migrate northwards after spawning. This is the same direction as the survey progresses, and as the Norwegian vessel surveyed the area during 1983–1996. This could lead to double counting of fish if the migration rate is faster than the northward progression of the survey, and conversely to an underestimation by a southward progression. Furthermore, the survey tracks are east-west covering the whole deep from Porcupine across to Rockall Bank. Therefore a further source for mismatch when several vessels take part in the northward coverage could arise, if e.g. a vessel is taking over or continuing a track from another vessel and reaches the starting point with a time gap between both vessels, again causing the fish migration to overtake the survey progression.

Table 2.3.3. Biomass estimates (total stock and spawning stock) of blue whiting in the spawning stock surveys west of the British Isles, March–April 1983 to 1996. Russian surveys and Norwegian surveys and the RU/NO ratio of the SSBs.

YEAR	BIOMASS ESTIMATES				RATIO
	RUSSIA		NORWAY		RU/NO
	TB	SSB	TB	SSB	SSB %
1983	3.6	3.6	4.7	4.4	0.8
1984	3.4	2.7	2.8	2.1	1.3
1985	2.8	2.7			
1986	6.4	5.6	2.6	2.0	2.8
1987	5.4	5.1	4.3	4.1	1.2
1988	3.7	3.1	7.1	6.8	0.5
1989	6.3	5.7	7.0	6.1	0.9
1990	5.4	5.1	6.3	5.7	0.9
1991	4.6	4.2	5.1	4.8	0.9
1992	3.6	3.3	4.3	4.2	0.8
1993	3.8	3.7	5.2	5.0	0.7
1994			4.1	4.1	
1995	6.8	6.0	6.7	6.1	1.0
1996	7.1	5.8	5.1	4.5	1.3
Mean	4.8	4.4	5.0	4.6	1.1

2.3.4 How big proportion migrates southward?

This question could also cause a bias in the spawning stock survey if the proportion is variable (Brophy and King, 2007), i.e. if it depends on the amount spawning at a certain location as a consequence of environmental conditions that vary from year to year, causing a varying proportion of the stock migrating north or south after spawning. Current understanding of the relative dynamics of the northern/southern components is insufficient to assess the importance of such a phenomenon.

2.3.5 New improved survey to monitor post-spawning migration

A new approach to monitoring the post-spawning migration of blue whiting may improve the precision of the biomass estimate. A stationary survey is suggested, where the axis from Shetland to Iceland across the Faroes is surveyed continuously in the period after spawning (April-May), with one vessel in the Iceland-Faroe Ridge and one in the Faroe-Shetland Channel continuously crossing back and forth. Such a survey might be less in space and better in timing than the current international survey covering the "whole" spawning area from 52 to 61 N.

2.4 Quality of the catch data

Catch data are essential in the assessment of year-class strength in blue whiting. In general, the catch data on blue whiting are not regarded as uncertain, i.e. there are no suspicions about misreporting, discarding etc. However, changes in the nature of the fishery itself may influence the assessment. The model used to perform the blue whiting assessment (the stochastic multispecies model, SMS) assumes that the catchability of the fishery is constant in time and therefore, for example, the catches of juveniles (1–2 years) are representative for the abundance of these year classes. Hence, a relative increase of these age groups in the catch would have a direct effect on the estimated year-class abundance coming out of the model. This is not necessarily correct, however, as the spatio-temporal distribution of the fishery may change over time, exploiting the juveniles differently from year to year. For example, when the large year classes recruited after 1995, there was doubt in the early assessments whether these changes were real or simply a change in the fishery targeting juveniles in the Norwegian Sea. The SMS assessment estimates a high variance for catches of 1 and 2 year old fish, indicating that the fishery on these year classes does not reflect the year-class strength very precisely.

However, the potential uncertainty in the abundance of juveniles' only counts for the 1–4 last years in the model runs. The precision of the year-class strength estimates increases further back in time as more observations are incorporated into the model.

To conclude, it is not expected that problems with catch data will have significant effects on the estimated recruitment.

2.5 Quality of the Assessment

Recruitment, as determined by the stock assessment, incorporates information from surveys and catch data. Both sources show that the abundance of 1 year old blue whiting has decreased to a very low level in the period 2006–2009. Extremely low age-2 abundance was observed in the surveys the following year for the same year class, confirming the very low abundance of juveniles in the survey area. It is not possible to estimate the exact level of recruitment in the most recent years, but there is no doubt that recruitment is very low (ICES, 2009).

Most assessment models used for blue whiting assume that selection pattern of the fishery remains at least approximately constant over several years. In reality, selection pattern can change significantly and blur recruitment signals from catch data. For example, periods of increased exploitation in the Norwegian Sea (see Figure 8.3.1.2 in ICES, 2009) where more juvenile blue whiting are caught than in the spawning fishery will positively bias recruitment estimates when constant selection pattern is assumed,

SMS estimates of the uncertainty in recruitment are presented in Figure 2.5.1. A consistent CV of less than 10% can be seen from 1984 until 2003. From 2004 the CV increases until it reaches its highest point of over 40% in the terminal year. This result is consistent with our understanding of the way in which stock assessment models work (i.e. that the least accuracy estimated values are the most recent) and suggests that the model has a reasonable degree of confidence in all recruitment estimates except the most recent (the 2007 year class, first observed/estimated in 2008).

In 2009 the assessment settings were changed with more weight given to the International spawning stock survey results. The weighting factors used this year were internally estimated within the modelling framework. These changes in assessment model settings changed the perception of the stock and led to an increase in the estimate of SSB. The 2008 SSB estimate derived from the 2008 assessment was 3.39 mt, whereas the 2009 assessment revised this 2008 estimate up to 4.18 mt. The International spawning stock survey has a time-series of only six years and shows a large interannual variation in the age-structured indices.

2.5.1 Historical Retrospective

A historical retrospective analysis for blue whiting from 2003–2008 is presented in Figure 2.5.2. Over this time, both the assessment model itself and the model settings have changed appreciably. In contrast to the CVs estimated by the model, the historical assessment pattern indicates a very uncertain and inconsistent assessment. Recruitment estimates were generally revised upwards during the early 2000s at the height of the recruitment boom, in some cases by a factor of six times or more. However, in recent years the assessment has generally agreed much better both on the magnitude and general trend in recruitment.

The assessments clearly underestimated SSB and overestimated fishing mortality (F) at the beginning of the “high” recruitment period. In recent years, the assessments have suggested a rapid decrease in the stock size, although each successive assessment appears to delay the time at which this starts to occur.

2.5.2 Recruitment Estimates used in the Forecasts

Different methods have been used to derive the recruitment estimates for input to the short-term forecasts. The geometric mean value, the lowest observed and the recruitment values obtained from the RCT3 estimates have been used in different years. The revision either upwards or downwards of the recruitment estimates illustrates the uncertainties in these estimates, but does not give an indication of any potential bias (ICES, 2009).

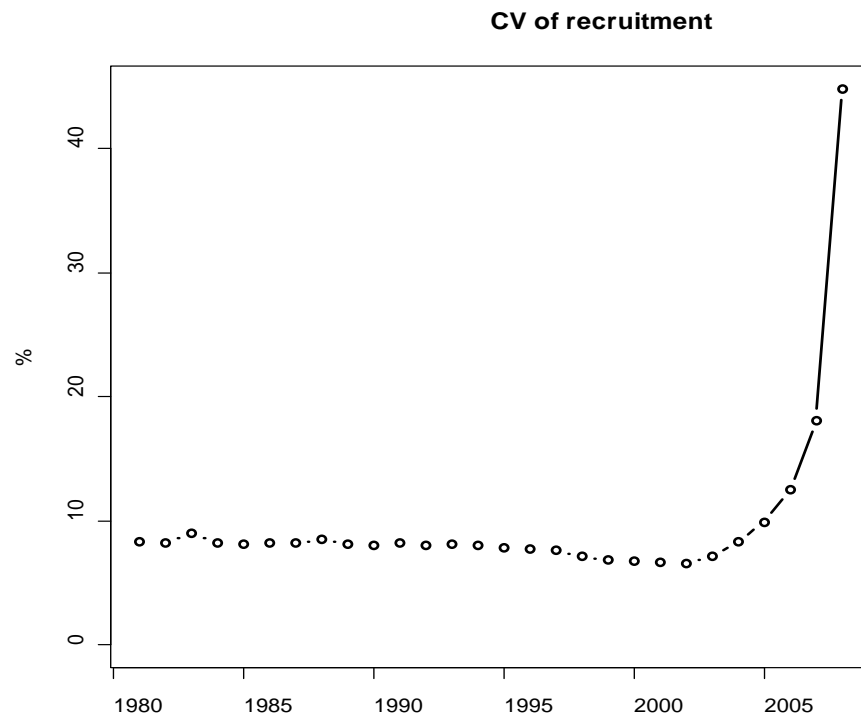


Figure 2.5.1. SMS estimates of CV on recruitment.

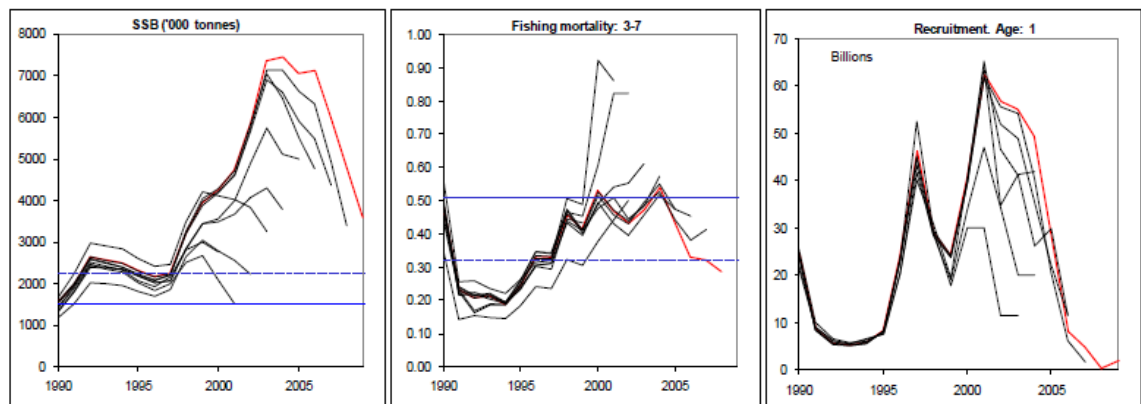


Figure 2.5.2. Historical Retrospective of the blue whiting assessment. The red line gives the most recent assessment results.

2.6 Comparison of recruitment from the assessment with other data sources

There are several sources of information about the recruitment that are independent of the stock assessment and can act as additional information sources: of specific interest are surveys carried out in the Nordic Sea and the Barents Sea (ICES, 2009b). These time-series confirm that the year classes 2005–2008 are at the very low end of the historical recruitments.

Figure 2.6.1 shows how age 1 estimates from the final SMS assessment relates to age 1 indices from the two surveys. The correlation between the Barents Sea index and the SMS recruitment predictions seems to be relatively robust and are statistically significant. In contrast, the correlation between predicted recruitment and the Nordic Sea survey are driven by the last three years.

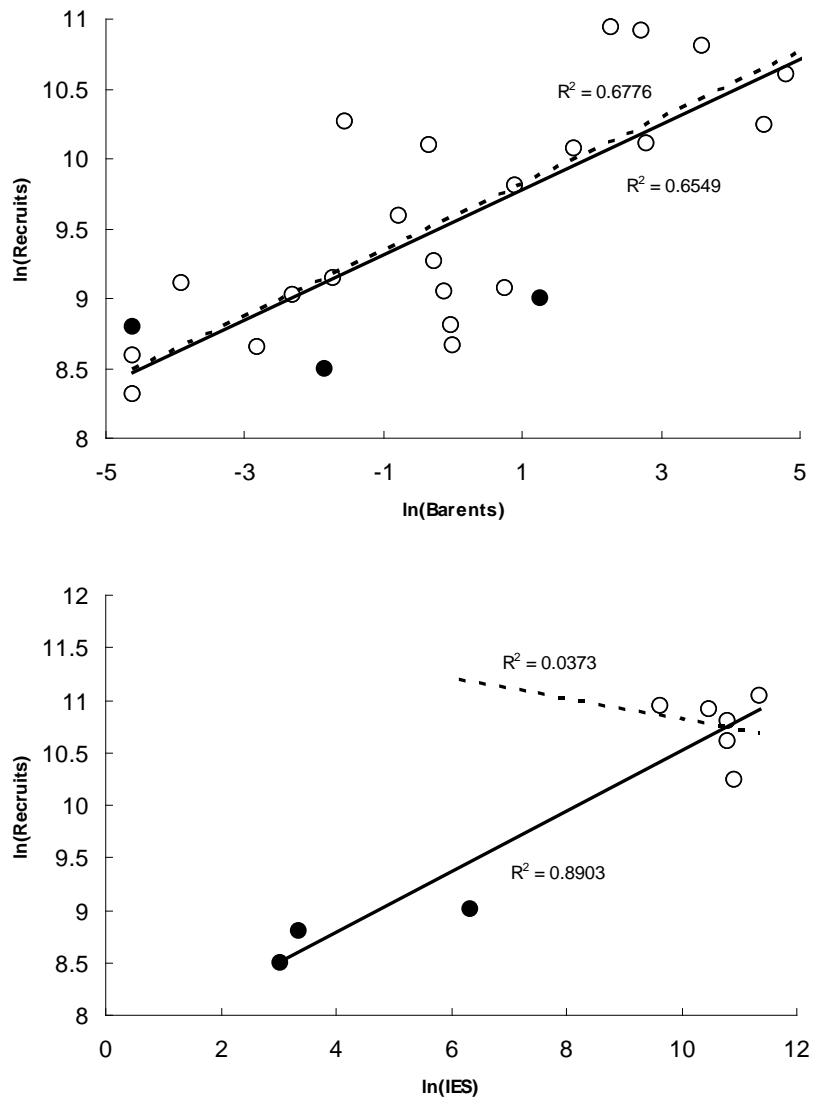


Figure 2.6.1. Recruitment (age 1, thousands) from the SMS assessment and age 1 indices from the Barents Sea bottom-trawl survey (upper panel) and the International ecosystem survey in the Nordic Seas (IES) standard area (lower panel), both on log-scale. Fitted regression lines are drawn for all data (solid lines) and excluding the last 3 years (open circles, dashed line).

A recent investigation published by Heino *et al.* (2008) provides further support that the data from the Barents Sea survey may be used to give a first reliable recruitment index. Abundance of juvenile blue whiting in the Barents Sea – measured either as incidence or mean catch rate – was found to be correlated with recruitment in the Northeast Atlantic stock. This was confirmed by a positive correlation between recruitment in the Atlantic and measures of juvenile abundance in the Barents Sea (Table 2.6.1). The correlations also suggested that high levels of recruitment in the Atlantic resulted in a more northerly distribution of blue whiting in the Barents Sea with a 2 year time-lag.

Survey catch rates of <19 cm blue whiting in the Barents Sea provide a proxy for the year-class strength in the stock as a whole (Figure 2.6.2). The relationship was tight, but also highly non-linear: strong year classes appeared disproportionately strong in the Barents Sea. On log–log scale, the relationship between estimated recruitment and

the survey index was approximately linear, with correlation coefficient of 0.89 (Figure 2.6.2).

The results of Heino *et al.* (2008) also suggest that distribution and abundance of blue whiting in the Barents Sea is affected by local climate conditions (Figure 2.6.3). Overall abundance of blue whiting, measured either as incidence or mean catch rate, is positively affected by recruitment in the Atlantic stock as well as strong inflow of warm and saline Atlantic water (Hátún *et al.*, 2009). Overall, effect of recruitment on abundance of blue whiting in the Barents Sea appears larger than that of environment, as evidenced by correlation analyses. Nonetheless, of the analysed environmental variables, salinity had the strongest effect. Because high salinity is the fingerprint of the Atlantic water, this suggests that the occurrence of blue whiting is primarily influenced by strong inflow of warm Atlantic water, rather than temperature *per se*. Based on their results, Heino *et al.* (2008) propose that strong inflow of Atlantic water facilitates transport of juvenile blue whiting from the Norwegian into the Barents Sea.

Table 2.6.1. Correlations between recruitment of blue whiting in the Atlantic and abundance in the Barents Sea (Taken from Heino *et al.*, 2008).

	Raw data			Detrended data		
	Incidence	Catch rate		Incidence	Catch rate	
		Ind. nm ⁻¹	Kg nm ⁻¹		Ind. nm ⁻¹	Kg nm ⁻¹
Recruitment, year						
<i>t</i>	0.57	0.72	0.59	0.23	0.46	0.30
<i>t</i> - 1	0.53	0.62	0.59	0.43	0.48	0.46
<i>t</i> - 2	0.37	0.46	0.50	0.35	0.24	0.35

Correlations different from zero at $P < 0.05$ are shown in bold; no adjustments for multiple comparisons are made in these exploratory analyses. Detrending refers to detrending of log-transformed recruitment time series. $N = 22$.

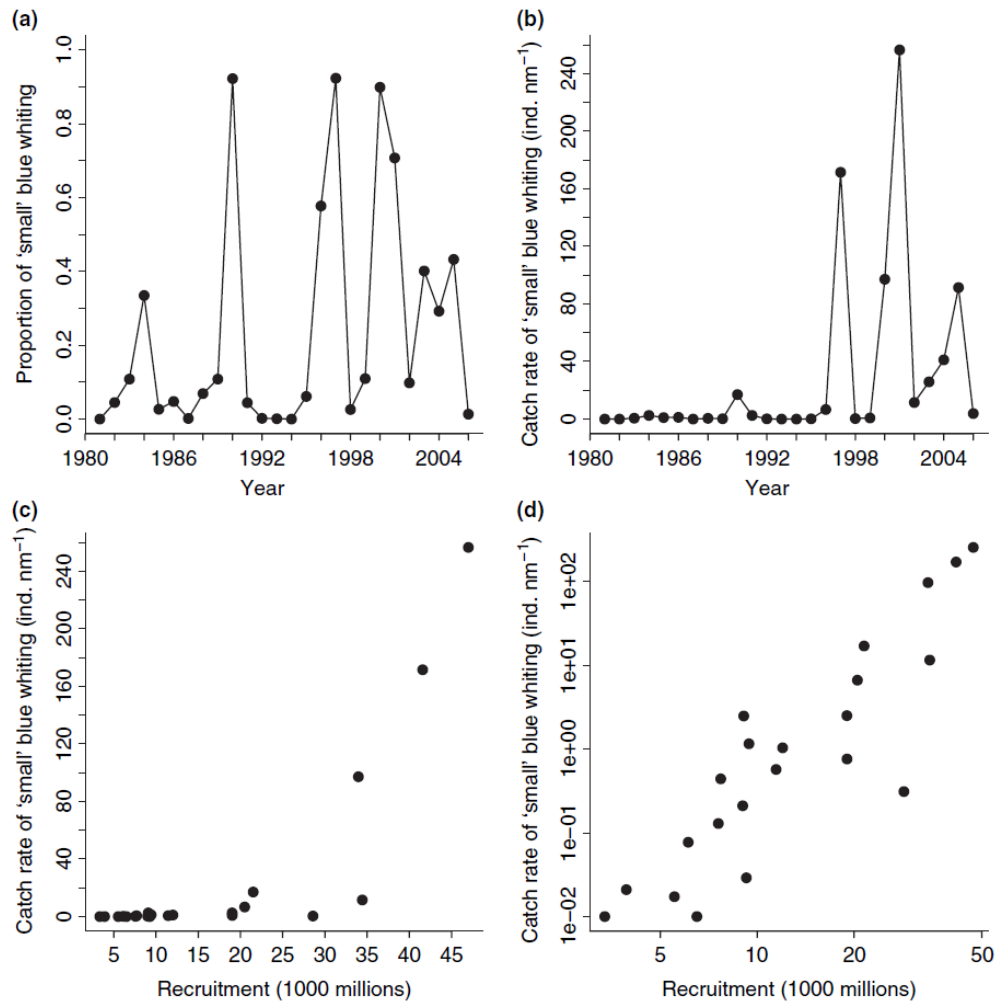


Figure 2.6.2 (a) Proportion of blue whiting of total length less than 19 cm (assumed conservative maximum length of age 1 blue whiting) in Barents Sea survey hauls. (b) Catch rate of <19 cm blue whiting in survey hauls. (c) Relationship between recruitment in the 'main' Atlantic stock of blue whiting in 1981–2002 (from ICES WGWIDE) and the catch rate of <19 cm blue whiting in Barents Sea survey hauls. (d) After log-transformation, the relationship is approximately linear, with correlation coefficient $r_p = 0.89$. (After Heino et al., 2008).

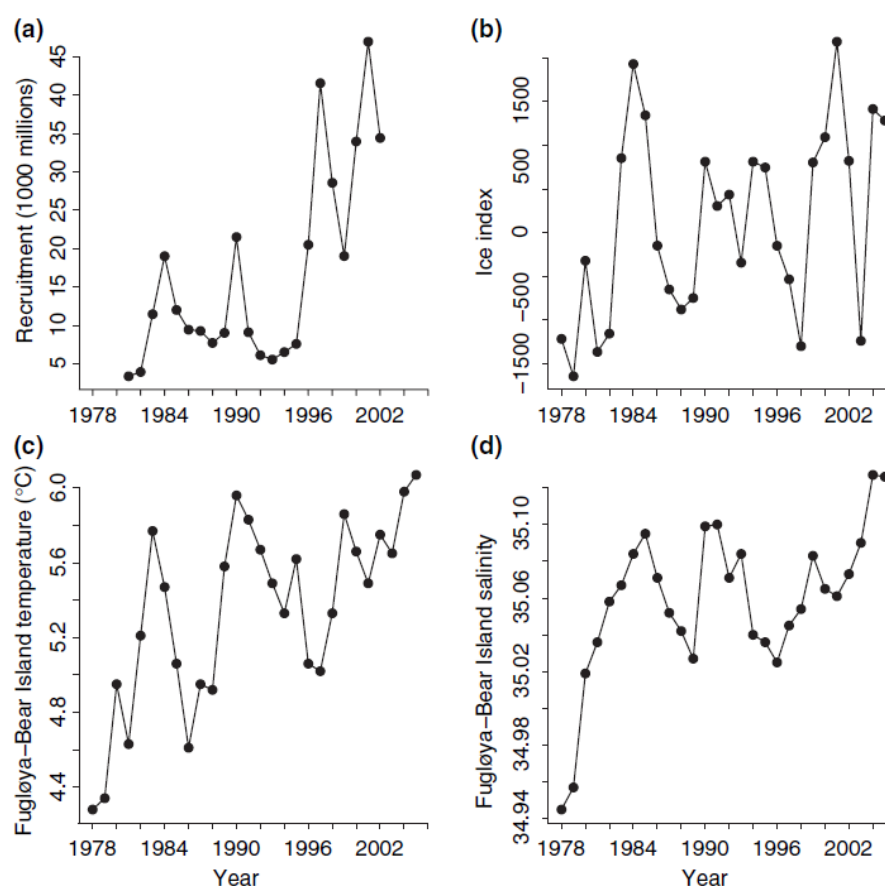


Figure 2.6.3 (a) Time series of recruitment of blue whiting and variables describing the environment. Recruitment is the estimated recruitment (age 1 year) as reported by ICES WGWiDE. (b) The ice index measures the difference between summer minimum and winter maximum of ice cover in the Barents Sea; positive values indicate little ice. (c) Temperature and (d) salinity are annual means from the Fugløya–Bear Island section. (After Heino *et al.*, 2008).

Additionally to the surveys conducted in the Barents Sea and Norwegian Sea, there are other surveys where 0- and 1-group blue whiting are caught. For instance the North Sea – Norwegian Deep shrimp survey (Tveite, 2000) regularly catches blue whiting. However, there are difficulties with this survey with regards to changes in gear and survey timing over the years. The survey started in 1984 as a 4th quarter survey. The same vessel was used up until 2002 bottom-trawl. More importantly, the survey time was shifted to the 2nd quarter for the years 2004 and 2005, and to the 1st quarter since 2006. Unfortunately, no 0-group blue whiting are encountered during the first half of the year. Up until 2005, blue whiting were present in about 80% of all hauls (Figure 2.6.4). At that time, catch rates dropped dramatically. It is still not clear whether this is just a survey timing effect. Until 1996, all strong blue whiting year classes were also represented in the North Sea – Norwegian Deep shrimp survey, however, this was not the case thereafter.

The International Bottom Trawl Survey conducted in the North Sea also catches blue whiting, especially in the northern North Sea and areas close to the Norwegian Trench. The 1st quarter IBTS (coverage of the northern North Sea since 1974) usually catches blue whiting first as 1-group, whereas the 3rd quarter IBTS (since 1991) catches them first as 0-group. Fish of less than 21 cm are classified into the 1-group, and those less than 19 cm are classified into 0-group. The strong 1989 year class was missing in the 1st quarter survey, however the time-series shows the first strong recruitment

period in the 1970s (Figure 2.6.5). Absolute catch rates are higher in the 3rd quarter survey, indicating that this survey covers a period when the younger 0-group fish are especially abundant. Both surveys highlight again that recruitment in the past 4 years was very poor.

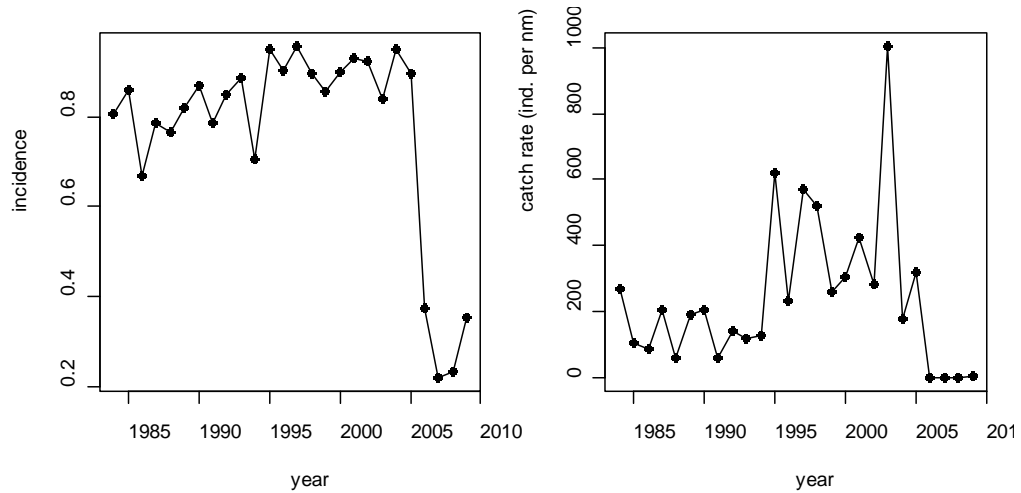


Figure 2.6.4. Encountered blue whiting in the North Sea – Norwegian Deep shrimp survey in terms of relative occurrence in survey hauls (left panel) and catch rate in individuals caught per nautical mile (right panel).

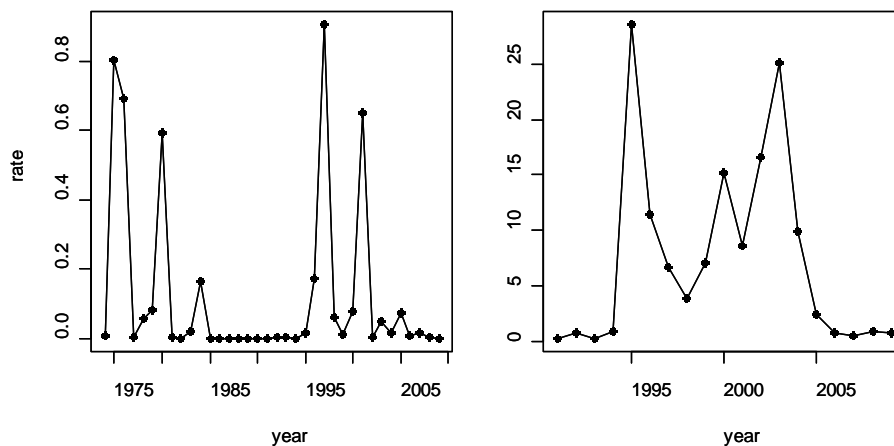


Figure 2.6.5. Catch rates of blue whiting caught in the 1st (left panel) and 3rd (right panel) quarter IBTS in the North Sea. Units on the y-axes are in individuals per nautical mile.

Another survey that encounters young blue whiting and that might be used to provide a recruitment index is the 4th quarter French groundfish survey conducted in the Bay of Biscay. This survey was only standardized in 1997; however, earlier surveys do exist. Figure 2.6.6 shows that blue whiting are regularly caught and occurred in about 90% of all trawl hauls. The blue whiting encountered are a mixture of 0- and 1-group. The strong signal observed in 2006 is in agreement with observations of Skogen *et al.* 1999, suggesting a split of the blue whiting stock into a northern and southern component with different recruitment trends.

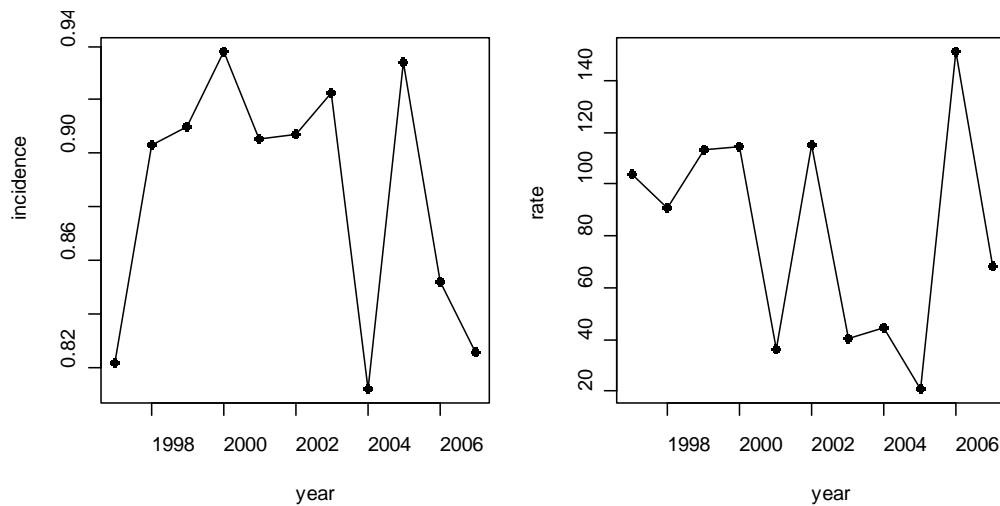


Figure 2.6.6. Encountered blue whiting in the French groundfish survey conducted in the Bay of Biscay. Relative occurrence in survey hauls (left panel) and catch rate in individuals caught per nautical mile (right panel) are given.

Of course, surveys that specifically target Blue whiting at-age 1 will be vital to produce reliable indices of recruitment. Alternatively, recruitment indices could be derived from already existing data. For instance, before the early 1970's, larvae of fish species sampled by the Continuous Plankton Recorder (CPR) survey were identified in the analysis process. Available data of sampled fish larvae indicate that Blue whiting made up about 10% of all identified fish species in the CPR data (Corten and Lindley, 2003). However, afterwards, identification of fish larvae down to species level was discontinued. Given the broad spatial coverage of the CPR tows and the fact that Blue whiting larvae were sampled, there may be merit in analysing CPR records to build-up a larvae abundance index time-series. Availability of early life stage data will assist recruitment estimation (cf. assessment of North Sea herring, ICES, 2009a). Further, modelling studies may be used to investigate abundances at later life stages if egg and/or larvae data would be available.

2.7 Conclusions

In conclusion, there are several major problems with this assessment. The most important of these revolve around questions of stock-identity, and in particular the treatment of this as a single stock. Although the assessment model tends to suggest a relatively high degree of confidence in the results it generates, this is not borne out by the historical retrospective plot, which shows a low precision and systematic bias in estimates of recruitment. There are also significant concerns about the spawning stock surveys. However, the basic conclusion that recruitment in this stock increased in the late 1990s and has collapsed recently appears to be borne out, both by the assessment (sufficient time has passed that the estimation of most year classes can be considered reliable) and alternative data sources (e.g. the Barents Sea index). For the purposes of this work, we therefore assume that the recruitment time-series has some validity: nevertheless, significant questions remain and should be addressed by future work.

2.8 References

Brophy, D., and King, P.A. 2007. Larval otolith growth histories show evidence of stock structure in Northeast Atlantic blue whiting (*Micromesistius poutassou*). ICES J.Mar.Sci. 64:1136–1144.

- Giæver, M., Stien, J. 1998. Population genetic substructure in blue whiting based on allozyme data. *Journal of fish biology* (1998) 52, 782–795.
- ICES. 1990. Report of the Blue Whiting Assessment Working Group. ICES CM/Assess: 3.
- ICES. 1995. Report of the Blue Whiting Assessment Working Group. ICES CM/Assess: 7.
- ICES. 2006. Report of the Northern Pelagic and Blue Whiting Working Group (WGNPBW) ICES 2006 CM/ACFM:34.
- ICES. 2007. Report of the Northern Pelagic and Blue Whiting Working Group (WGNPBW) ICES 2007 CM/ACFM:29.
- ICES. 2008. Report of the Working Group on Widely Distributed Stocks (WGWIDE) ICES CM 2008/ACOM:13.
- ICES. 2009. Report of the Stock Identification Methods Working Group (SIMWG) ICES CM 2009 LRC:12.
- ICES (2009) Report of the Working Group for Widely Distributed Stocks (WGWIDE) ICES 2009 CM/ACOM:12.
- J. A. Jacobsen, S. H. í Jákupsstovu, M. Poulsen, and G. Vang. 2002. Does the seasonal variation of fat content of blue whiting affect the acoustic conversion factor (TS)? ICES CM 2002/O:15: 8 pp.
- Lewy, P., M. Vinther, 2004. A stochastic age-length-structured multispecies model applied to North Sea Stocks ICES CM 2004/ FF:2.
- Mork, J., Giæver, M. 1995. Genetic variation at isozyme loci in blue whiting from the north-east Atlantic. *Journal of Fish Biology* (1995), 46, 462–468.
- Skogen, M., Monstad, T., Svendsen, E. 1999. A possible separation between a northern and a southern stock of northeast Atlantic blue whiting. *Fisheries Research* 41 (1999) 119–131.
- Ryan, A., Mattiangeli, V., Mork, J. 2005. Genetic differentiation of blue whiting (*Micromesistius poutassou* Risso) populations at the extremes of the species range and at the Hebrides – Porcupine Bank spawning grounds. *ICES Journal of Marine Science*, 62: 948–955.
- Was, A., Gosling, E., McCrann, K., and Mork, J. 2008. Evidence for population structuring of blue whiting (*Micromesistius poutassou*) in the Northeast Atlantic. *ICES Journal of Marine Science*, 65: 216–225.

3 The Physical Environment

3.1 Background

The marine climate (temperature, salinity currents etc.) in the spawning area is highly variable and provides the background against which changes in the dynamics of blue whiting recruitment have occurred. The physical processes acting on the different regions within the spawning area (the European continental shelf, open-ocean, the Rockall Plateau and the other oceanic banks) differ and the variability which characterizes the subregions is therefore also different. Here we examine the physical dynamics of each region as a way to set the stage for a later examination of the biological environment (Section 4).

3.2 The main signals

3.2.1 Long-term trend

The entire North Atlantic region is influenced by the increasing northern hemisphere Temperature trend (Beaugrand *et al.*, 2002b), which is related to ongoing global warming (Intergovernmental Panel on Climate Change 2007). This hemispheric/global trend has a stronger influence on the relatively shallow European Shelf Seas and on the waters near the continental shelf than it has on the much deeper oceanic regions. This type of variability (the first mode) has previously been linked to increases in sea surface temperature (SST) and phytoplankton (Edwards *et al.*, 2002) and a decline in *C. finmarchicus* (Planque and Fromentin, 1996) in the North Sea (Figure 3.2.1).

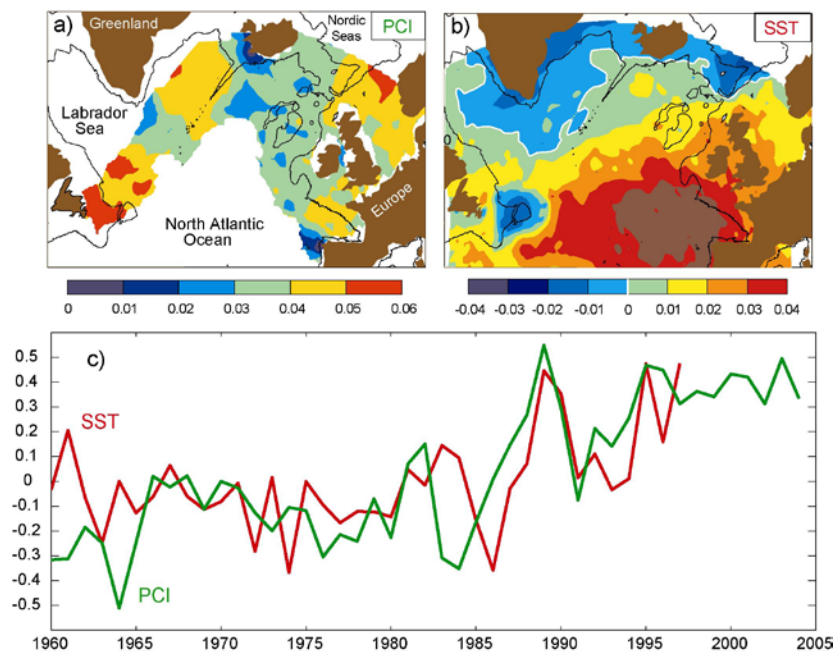


Figure 3.2.1. Variability modes related to northern hemisphere Temperature. Spatial patterns of () the first Phytoplankton Colour Index mode (PCI), and () the first SST mode. () The corresponding time-series (principal components; Hátún 2009a).

3.2.2 Large oceanic shifts (decadal to multidecadal)

The Rockall Trough, the Rockall and Hatton banks and the Iceland Basin are characterized by decadal to multidecadal shifts (Figure 3.2.2). Three very different types of

source water masses mix in these regions. Very saline water from the intergyre-Biscay region in the south, water from the North Atlantic Current of intermediate salinity and the much fresher contribution from the Subpolar Gyre. Variability of the dynamics (size and circulation strength) of the gyre regulates the relative contribution of these water masses to the spawning regions. This type of variability is represented by the so-called *gyre index*. The atmosphere regulates the decadal component of this variability through sea-air heat loss in the Irminger-Labrador Seas and through windstress curl in the Rockall region (Eden and Willebrand, 2001). The multidecadal component is probably driven by internal oceanic dynamics (Kushnir, 1994).

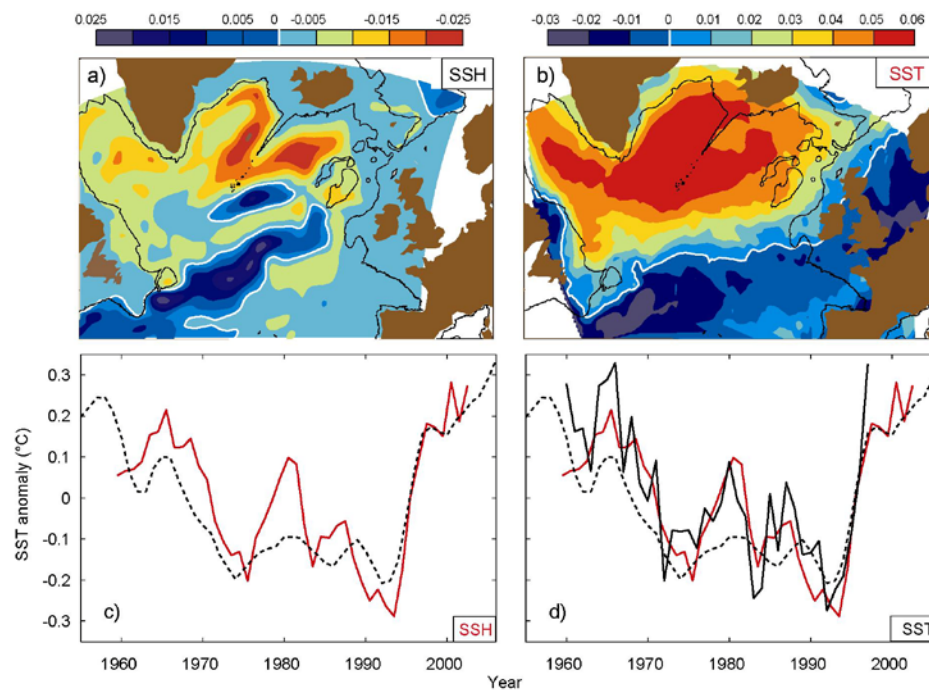


Figure 3.2.2. The gyre mode of variability. (a) and (b) show the spatial patterns of simulated sea surface height (SSH; Hátún 2005), and sea surface temperature (SST; Beaugrand 2002b), respectively. (c) and (d) show the associated time-series. (c) The SSH principal component (inverted gyre index, red), and the northeastern North Atlantic SST (black dashed). These time-series are also shown in (d), and the units refer to the SST series. (d) A previously reported SST principal component (thick black line) based on PCA of observed SST (Beaugrand 2002b).

3.2.3 Sub-decadal oscillations

Clear sub-decadal oscillations ride on the slower longer term trend characterized by the gyre index (Figure 3.2.3). This type of variability can be identified in the gyre index more readily if it is calculated from satellite altimetry data, rather than derived by simulation. In order to emphasize the sub-decadal oscillations (SDO) and to identify the spatial imprint of these on the oceans, the sea surface height (SSH) EOF-analysis by (Häkkinen and Rhines, 2004) has been redone, but after a linear trend has been subtracted from each data point (Figure 3.2.4). The SDO appear as the first mode of variability, which demonstrates that this has been the most coherent pattern of SSH, and thus, hydrographic variability of the North Atlantic Ocean since the early 1990s – disregarding the slower trend. The spatial imprint associated with the SDO (Figure 3.2.4a) is shifted northwards and eastwards towards the Nordic Seas, compared to the spatial imprint associated with gyre index, where the focus area is found

in the Irminger Sea (Figure 3.2.3a). The principal component time-series (Figure 3.2.4) clearly illustrates the SDO.

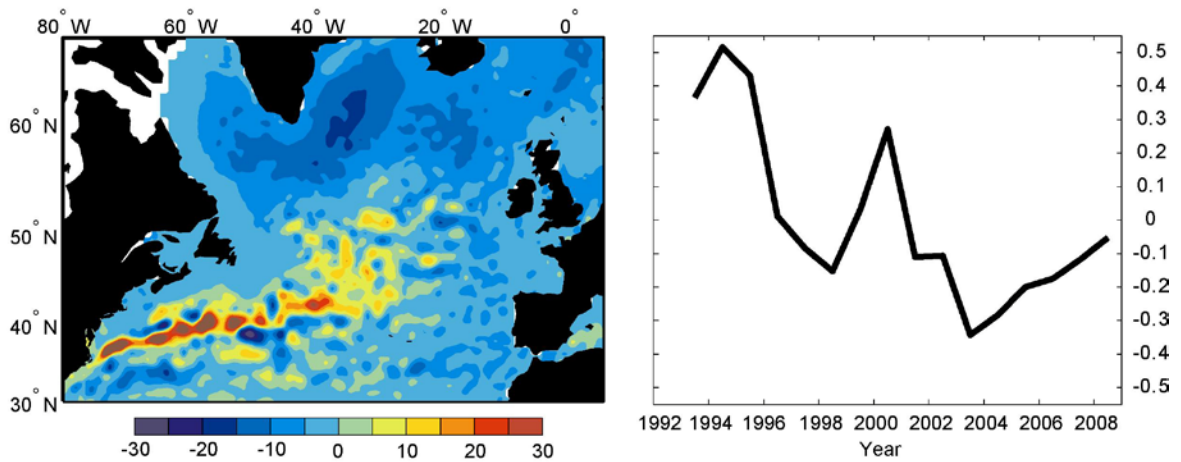


Figure 3.2.3. The previously documented ‘gyre mode’ obtained by applying a PCA to the sea surface height (SSH) field in the northern North Atlantic (Häkkinen and Rhines, 2004; Hátún 2005). The gyre index is the first principal component (time-series) from this analysis (right panel). The gyre mode is associated with especially large SSH changes, and thereby changes in circulation, in the Iceland-Irminger basins (left panel)). Dominance of cold and fresh Subarctic water in the Iceland Basin is associated with a high index value (implying a strong gyre circulation) and dominance of warmer and more saline water of subtropical origin is associated with a low index (weak gyre). The gyre index is plotted inverted.

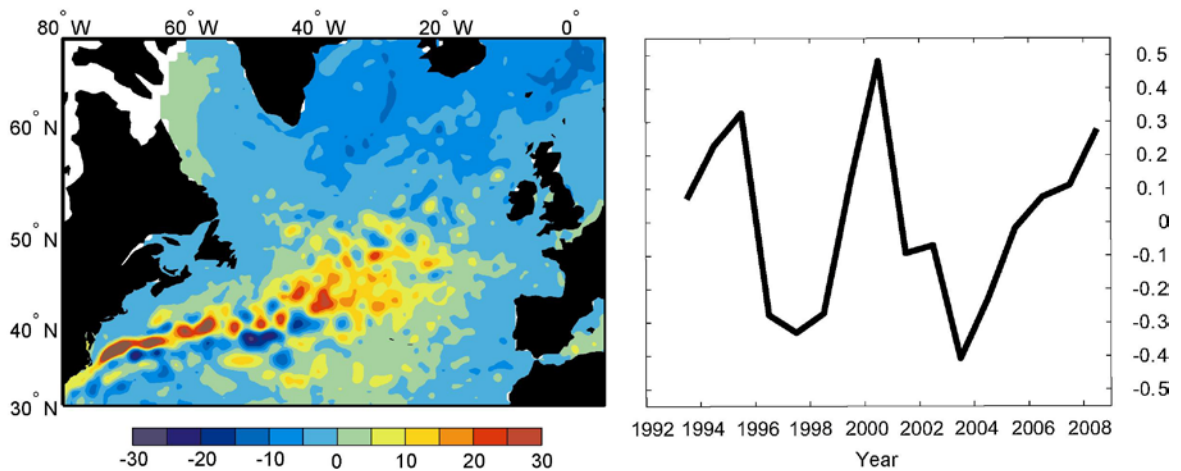


Figure 3.2.4. Shorter term climatic fluctuation between ‘Subarctic’ and ‘subtropical’ states. This has been obtained as described in Figure 3.2.3, but after a linear trend has been removed from each data-point. This type of variability is especially pronounced in the northeastern Irminger Sea, the southern Norwegian Sea and the Iceland Basin (dark bluish colors in the left panel).

This type of variability is mainly driven by regional atmospheric forcing, whereof the sea-air heat loss is an important component (Figure 3.2.5)

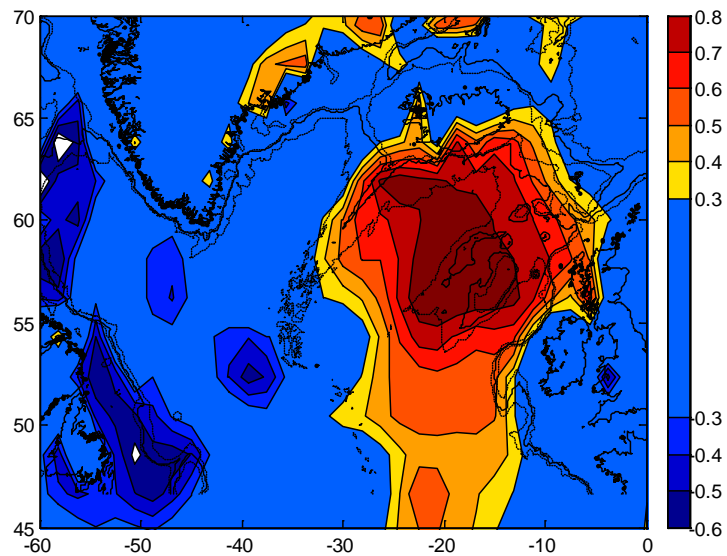


Figure 3.2.5. Point wise correlations between the SDO time-series (Figure 3.2.4) and the heat loss from ocean. Atmospheric data from NCAR/NCEP reanalysis project (Kalnay et al., 1996) are used.

3.2.4 Pulses along the European continental shelf

The hydrography in the spawning region is not only regulated by the relative contribution of the source water masses, but also by the characteristics of the source waters themselves. The salinity of the Eastern North Atlantic Water (ENAW) from the south is influenced by the variable influence of highly saline water from the Mediterranean Ocean (Ellett *et al.*, 1986; Holliday *et al.*, 2000). Variability of the ENAW has a stronger influence on the waters near the European continental shelf than it has on the open-ocean region farther west. The hydrography along the continental shelf is characterized by strong pulses, or northward intrusions, of saline waters (Figure 3.2.6). This type of variability is less clear in the oceanic regions. The driving mechanism behind this type of variability is not well understood.

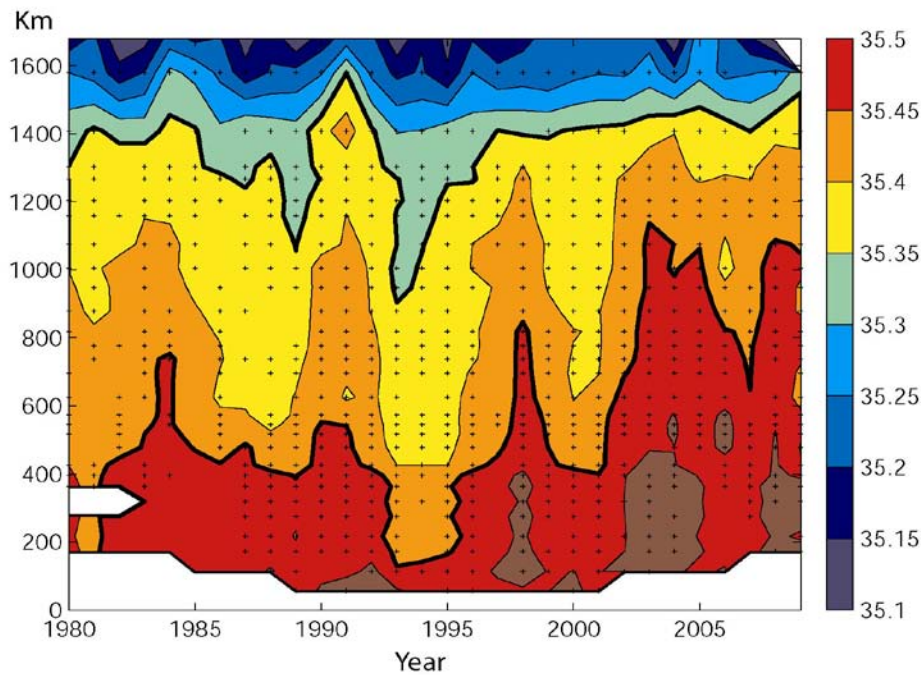


Figure 3.2.6. Time-latitude/distance (Hovmüller) plot of salinity at 300-m depths along the continental shelf edge from Porcupine Bank northwards. Only data from March to June have been included. The salinity envelope 35.35–35.45 psu is emphasized with thick black lines. Available data points are illustrated with small crosses. Updated from (Hátún , 2009b).

3.3 Splitting at Rockall

The interface between the Subarctic waters and the Atlantic water masses defines the Subarctic front and thus the flow path of the North Atlantic Current (NAC) (green solid arrows in Figure 3.3.1). The quantity of Subarctic water south of the southern tip of the Rockall Plateau varies from nil to significant (Wade *et al.*, 1997). When Subarctic water is present at this location, a large proportion of the NAC flows into the Rockall Trough and along the eastern side of the Rockall Plateau, embedding the plateau in Subarctic water masses (Figure 3.3.1a). When, on the other hand, the Subarctic boundary is located farther west and the NAC mainly flows along the western side of the Rockall Plateau, both the plateau and the region south of Iceland are flooded with warmer and more saline Modified North Atlantic Water (MNAW) (Hansen and Østerhus 2000; Figure 3.3.1b). Because of the splitting of the NAC around the Rockall Plateau, subtle changes in its flow path can cause large and rapid shifts in the marine climate on and around the Rockall Plateau and in the Iceland Basin.

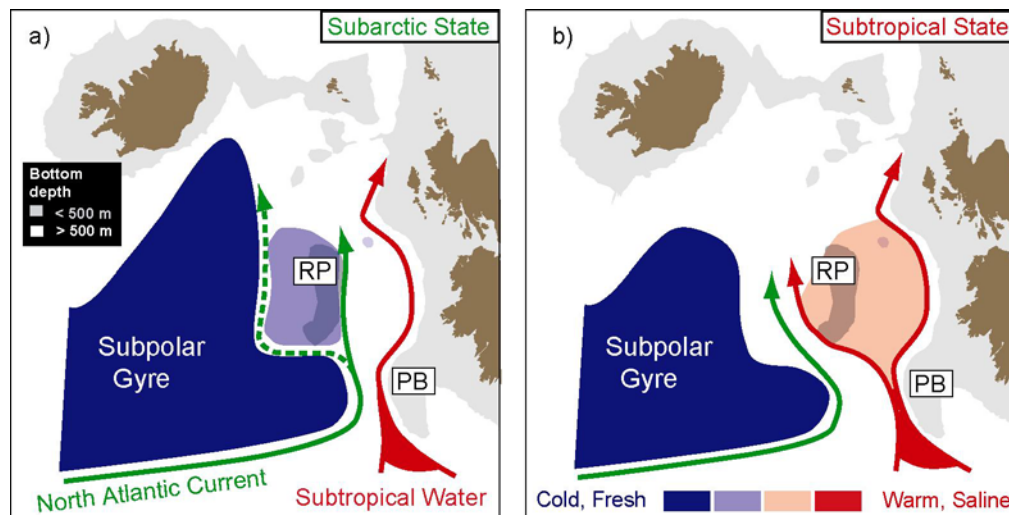


Figure 3.3.1. Simplified illustration of the source flows to the Rockall Region. () A strong Subpolar Gyre results in strong influence of cold Subarctic water near the Rockall Plateau (Subarctic state). () A weak gyre results in a warm subtropical anomaly near the plateau (based on Hatun *et al.*, 2005; subtropical state). Abbreviations - RP: Rockall Plateau and PB: Porcupine Bank.

3.3.1 Retention

The splitting mechanism of the NAC south of the Rockall Plateau is also probably very important for the degree of retention around Rockall. A strong influx from the NAC into the Rockall Trough might wash the Rockall Bank with oceanic water, and thus break down the retention system (Dooley, 1984). This is highly important for the young stages of fish.

3.4 Recent changes

In recent years, the gyre index shows that northeastern Atlantic and the Nordic Seas have moved towards a more Subarctic state after 2004. This is verified as a decrease in temperatures and salinity at several other locations in the Northern North Atlantic (Holliday *et al.*, 2009).

There was a sudden salinity increase in the Rockall Trough in 2008, but the slight post-2004 temperature decline has continued (Holliday *et al.*, 2009). This is rather unusual, since salinity and temperature changes have typically been in synchrony.

An updated analysis from Hátún *et al.*, 2009 shows that after the post-2003 freshening a new salinity pulse appeared in 2008 (Figure 3.2.6). This was caused by a strong episode of Iberian Poleward Current advecting saltier waters than those observed in December 2006 and January 2007 (Holliday *et al.*, 2009). The pulse has subsequently spread to Icelandic and Faroese waters (Holliday *et al.*, 2009).

3.5 References

- Dooley, H. D. 1984. Aspects of oceanographic variability on Scottish fishing grounds. PhD. Thesis. 1 - 154. University of Aberdeen,
- Eden, C., and Willebrand, J. 2001. Mechanism of interannual to decadal variability of the North Atlantic circulation. *J. Clim.*, **14**: 2266–2280.
- Ellett, D. J., Edwards, A., and Bowers, R. 1986. The Hydrography of the Rockall Channel - An Overview. *Proceedings of the Royal Society of Edinburgh Section B-Biological Sciences*, **88**: 61–81.

- Häkkinen, S., and Rhines, P. B. 2004. Decline of subpolar North Atlantic circulation during the 1990s. *Science*, **304**: 555–559.
- Hansen, B., and Østerhus, S. 2000. North Atlantic-Nordic Seas exchanges. *Prog. Oceanogr.*, **45**: 109–208.
- Hátún, H., Payne, M., Beaugrand, G., Reid, P. C., Sandø, A. B., Drange, H., Hansen, B., Jacobsen, J. A., and Bloch, D. 2009a. Large bio-geographical shifts in the north-eastern Atlantic Ocean: From the subpolar gyre, via plankton, to blue whiting and pilot whales. *Prog. Oceanogr.*, **80**: 149–162.
- Hátún, H., Payne, M. R., and Jacobsen, J. A. 2009b. The North Atlantic subpolar gyre regulates the spawning distribution of blue whiting (*Micromesistius poutassou*). *Canadian Journal of Fisheries and Aquatic Sciences*, **66**: 759–770.
- Holliday, N. P., Hughes, S., and Beszczynska-Moller, A. 2009. ICES report on ocean climate 2008. ICES Cooperative Research Report, **298**: 1–66.
- Holliday, N. P., Pollard, R. T., Read, J. F., and Leach, H. 2000. Water mass properties and fluxes in the Rockall Trough, 1975–1998. *Deep-Sea Res.*, **47**: 1303–1332.
- Intergovernmental Panel on Climate Change, W. I. 2007. *Climate Change 2007: The Physical Science Basis, summary for policymakers*. (Cambridge University Press, Cambridge, 2007).
- Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., and Joseph, D. 1996. The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc.*, **77**: 437–471.
- Kushnir, Y. 1994. Interdecadal Variations in North-Atlantic Sea-Surface Temperature and Associated Atmospheric Conditions. *J. Clim.*, **7**: 141–157.

4 Biological processes potentially influencing recruitment of Blue whiting

4.1 Complexity of the system

The general inability of the academic community to predict recruitment stems from the complexity of the process, which is affected by both the number of offspring (eggs) produced as well as the overall effect of density-independent and density-dependent processes on all prerecruit stages (Figure 4.1.1). Density-dependent processes include competition for food with conspecifics and/or offspring of other species, the predation by other species and the possibility of cannibalism. Included here are also the potential effects of changes in stock structure; e.g. proportion of older, repeat spawners in the population, which may affect both egg quality and spawning time, and thereby indirectly the recruitment. Density-independent factors include all the physical forces influencing prerecruits and their prey, hereunder changes in temperature, salinity and currents.

The link to predicting recruitment lies in the understanding of the actual processes regulating recruitment, and how they are influenced by the external forces. There is always a need to investigate all potential processes, both density-dependent and density-independent. Changes in the physical environment may be predicted by models, and if the link to recruitment processes is known, it may be possible to predict the recruitment.

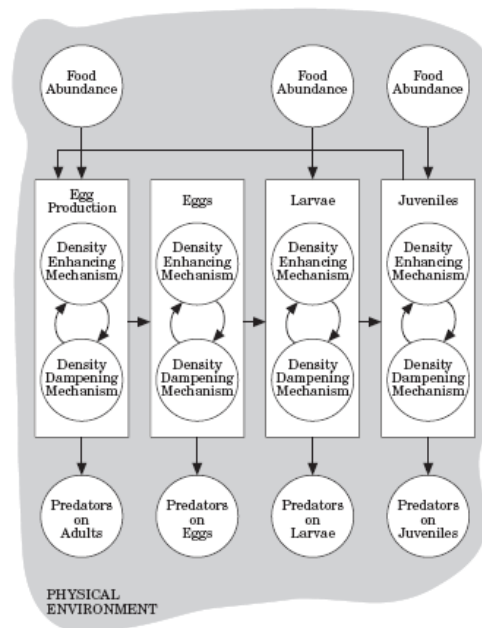


Figure 4.1.1. Conceptual model of the population-dynamics process (from Rothschild, 2000). Each of the four stabilizing modules consists of density enhancing and density-dampening mechanisms. Food abundance transmits information to the population on its own abundance affecting the density-enhancing response. Population density is transmitted to predators. If predators respond by changing their efficiency, then predation is density-dependent. The model suggests redundancy, in as much as food resources and predators are different at each life-history stage. The physical environment may influence all processes.

4.2 The early life stages

Year-class strength in fish is frequently determined during the early life stages (Hjort, 1914). Here we review the current state of knowledge regarding the early life stages of blue whiting.

Blue whiting spawning takes place at depths of 300 – 600m. The spawning period extends from January/February to April/May. Spawning starts in the south (with the main spawning during March and April (Skogen, 1999)). Spawning takes place along the shelf edge and banks west of the British Isles. Juveniles are abundant in many areas, with the main nursery area believed to be the Norwegian Sea. The highest concentrations of blue whiting spawners and larvae have previously been found in the vicinity of the Porcupine Bank (Hillgruber *et al.*, 1995). Since then, larger concentrations are observed farther north, especially west of the Hebrides.

There are currently no directed surveys conducted for blue whiting eggs and larvae. SAFOS have analysed CPR (Continuous Plankton Recorder) samples and worked up data up until 1972. Significant quantities of blue whiting larvae are present in CPR samples (Corten, 2003). A project is underway to analyse samples after 1972, but results will first be available after a year or two from now.

Several studies have been carried out to examine the movements of blue whiting eggs and larvae. Ådlandsvik *et al.* (2001) used a mathematical model of the vertical distribution of fish eggs and larvae in response to changes in their buoyancy and applied this to blue whiting. Observations on the vertical distributions of eggs and larvae of blue whiting were presented, together with experimental measurements of their buoyancy. The modelling results show that this change in blue whiting egg density results in the eggs being positively buoyant initially and rising through the water

column, and then during the latter half of development they descend. This maintains the eggs as bathypelagic until hatching. After hatching the larvae ascend towards the surface. During this ascent, functional eyes and jaws develop. By the time the larvae reach the surface layers, where suitable food items are found, they are capable of feeding exogenously. Larvae are found in the upper 60m of the water column indicating some combination of passive rising or active vertical migration of the larvae from the depth of spawning. In the particular case of the spawning area for blue whiting, vertical stratification of the water column is weak during spring, and consequently a small change in egg buoyancy or water density will have a large influence on the vertical distribution of the eggs.

Larval drift is an important factor for recruitment and several studies using numerical circulation models for simulation of larval drift have been carried out. The possible importance of the variability of the drift pattern for the recruitment of blue whiting has been studied by Svendsen *et al.* (1996) They showed that large variations in the drift patterns were seen from year to year, but generally much larger amounts of larvae than expected drifted southward from the Porcupine Bank area west of Ireland to the Bay of Biscay. Typically larvae hatched on the northern side of the Porcupine Bank drift northwards through the Faroe-Shetland Channel, and most of these larvae are located on the shelf.

Oceanographic modelling has been used to examine movements of blue whiting eggs and larvae by Skogen *et al.* (1999). A hypothesis put forward was that the southern stock will spawn in an area where the eggs and larvae are likely to drift southwards and the northern stock where the eggs and larvae will drift northwards. Based on modelled drift patterns they found that a possible separation line was located at 54.5°N but this was subject to significant interannual variability over the twenty years studied.

Work conducted by Bartsch and Coombs (1997) using a three-dimensional model suggests that particles released on the Porcupine Bank drifted southwards with a separation at about 53–54°N. Eggs and larvae from species that spawn on the shelf edge are vulnerable to advection into areas of unsuitable larval food supply, increased predation risk or to subsequent inappropriate nursery grounds. Mortality may be high during these early life stages. Behavioural characteristics of the post-larvae such as shoaling and vertical migration will also influence subsequent dispersal as the increased motility of the late larval stages makes them less influenced by passive planktonic drift.

An investigation of larval growth histories was carried out in 2007 (Brophy and King, 2007). Groups that are spatially or temporally distinct after hatching show measurable differences in the larval portion of the otolith. This study has shown that larvae from the Bay of Biscay grow faster than those from more northerly spawning areas showing that mixing of fish from these areas is limited. It also confirmed that fish spawning to the west of Ireland and Scotland, do not form a randomly mixing unit and that subunits within this aggregation have experienced differences during the larval phase. The dispersal of larvae influences the subsequent dispersal of spawning adults. The factors responsible for the variability that was observed in otolith growth were not tested by this study. It is likely that differences in larval otolith growth rate reflect variation in temperature and food supply along larval drift trajectories, and they may also be influenced by the timing of hatching and by selective mortality during the larval phase.

4.3 The role of food

4.3.1 Suitable prey for blue whiting larvae

Unfortunately, the precise prey requirements of blue whiting larvae are poorly known. The prime prey candidates, however, are the copepods *Pseudocalanus*, *Acartia* and *Oithona*. (Bailey, 1982).

4.3.2 Food availability can determine larval survival

The survival of larvae is determined by the availability of suitable prey items. Both the quantity and the quality of prey are important for larval survival. These factors could be the reason for the apparent higher survival of larvae when the currents floating across the Porcupine Bank and the Rockall Bank originate in the south containing larger proportions of suitable prey. On the other hand, the water masses coming from the west, when the Subpolar Gyre is strong, contain different fauna that may or may-not be suitable prey items (Hátún *et al.*, 2009b).

Recent findings indicate that the biomass of zooplankton (i.e. mostly *Calanus* spp.) in the Nordic Seas is decreasing, and that this could be partly due to increasing biomasses of the large pelagic stocks feeding in the area (herring and mackerel). It could also be postulated that the low plankton abundance would put a pressure on young (0 and 1 group) blue whiting feeding on small zooplankton in the area. Larger blue whiting usually feed in deeper waters on euphausiids (krill), however, there is very little information on biomass estimates.

4.3.3 Use of CPR data in analysis of prey

The work-up of historical CPR data should be prioritized. Since very few studies exist of feeding of blue whiting larvae, this would allow for an analysis of potential prey availability in the areas where blue whiting larvae drift after spawning. One problem with CPR data are that they do not catch the larger zooplankton, such as krill and larger amphipods. But young stages of krill have been reported, and therefore there is a potential to identify krill abundance during the early part of summer when young stages grow up.

4.4 The role of growth

Many recruitment studies are based on the premise that there is a single, clearly identifiable factor responsible for the annual production of marine fish. Authors have often focused on density independent factors affecting recruitment, involving biological responses to physical processes. The major hypotheses are the following: (1) Starvation (incl. growth-mortality hypothesis) (2) Predation (3) Physical dispersal (4) Disease. Anderson (1988) suggested that the hypothesis that survival is a direct function of growth provides a rational theoretical framework for recruitment research and was suggested as a basis for future work.

In the growth-mortality hypothesis (Ware, 1975; Shepherd and Cushing, 1980), it is hypothesized that predation decreases with increasing size, (Folkvord and Hunter, 1986; Pepin 1991). Higher growth rates therefore enhance the chance of survival by reducing the length of the predation window, i.e. the time the larvae is "small" and an easy target for predators. Conditions that determine growth rate during larval phase, such as food availability (direct) and increased ambient temperature (indirect) leading to faster growth, will therefore ultimately determine survival. Pepin *et al.* (1987) have demonstrated this is generally true for vertebrate and invertebrate marine predators.

There are unfortunately no known studies that have examined the relationship between growth rates and survival/mortality in blue whiting. Nevertheless, by extension from other species, this hypothesis could be expected to play a significant role in the survival of the early life stages blue whiting.

4.5 The role of predation

Predation is a complex factor in the survival of larvae that is poorly understood (Bailey and Houde, 1989; Fuiman, 1994). At the late larval stage, predation by invertebrates generally decreases substantially, whereas the predation pressure exerted by fish increases (Fuiman and Gamble, 1989). The mechanism behind better survival has been described by reduced overlap with predators (Fortier and Quinonez-Velazquez, 1998; Lapolla and Buckley, 2005; Nishimura *et al.*, 2007; Husebø *et al.*, 2009).

There are no known studies focusing on the predation on blue whiting eggs and larvae. However, potentially there may be several predators, and mackerel is one that has the clear potential to graze down the blue whiting eggs and larvae. Olaso *et al.* (2005) demonstrated a shift in the mackerel diet from over 90% krill to over 90% blue whiting from spring to autumn off northern Spain (Figure 4.5.1 and Figure 4.5.2). Sabral and Murta (2002) also found that blue whiting was the main prey in mackerel stomachs off Portugal.

Hence, mackerel may feed on the eggs and larvae of blue whiting, thus affecting blue whiting recruitment negatively. Mackerel also are also to be found in the blue whiting spawning region: Figure 4.5.3 shows the results of mackerel egg counts in the period 7 May to 3 June 2007 (ICES WGMEGGS 2007), where the eggs are found rather far west and north off the Hebrides, indicating an extension of the historical spawning distribution (ICES WGMEGGS 2007). Predation by mackerel upon the early life-stages of blue whiting therefore appears feasible in terms of both diet considerations and spatial/temporal overlap.

Furthermore, the degree of spatial overlap in the spawning distribution of blue whiting with mackerel varies (Figure 4.5.4), with overlap being reduced in years with good blue whiting recruitment. The hypothesis of mackerel predation is therefore consistent with the observations obtained this far. Initiatives for stomach sampling of mackerel on the blue whiting spawning grounds and along the drift trajectories should therefore be taken in order to further explore this hypothesis.

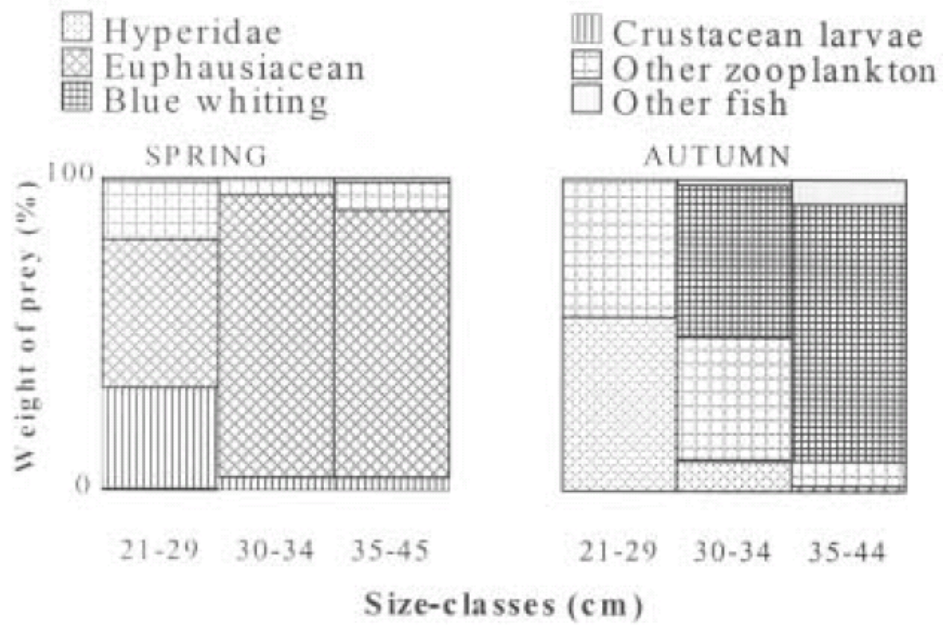


Figure 4.5.1. Mackerel diet in terms of weight of prey in per cent off northern Spain in spring and autumn by length group (Olaso *et al.*, 2005).

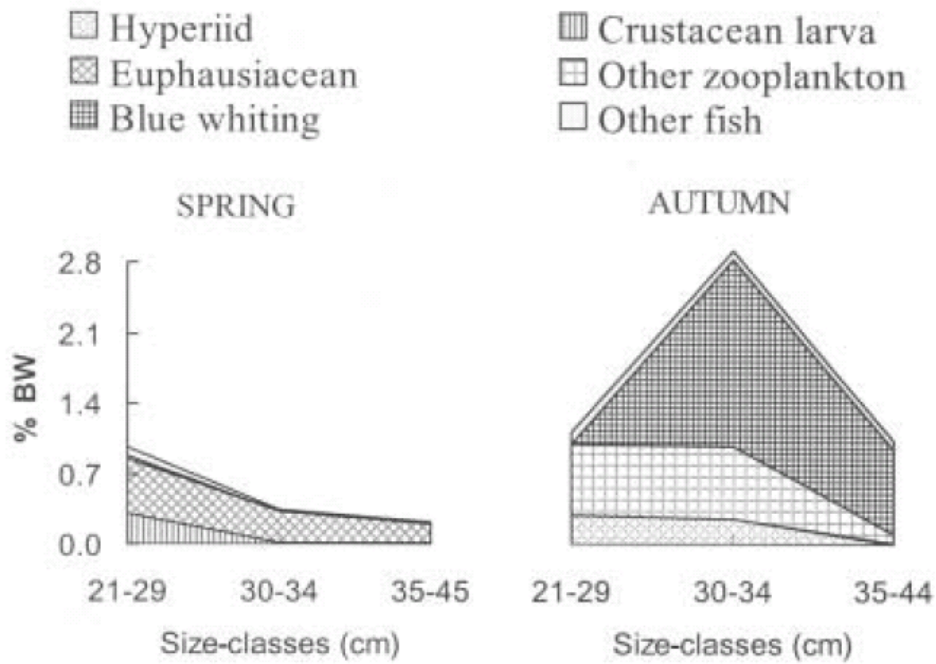


Figure 4.5.2. Mackerel diet in terms of weight of prey in % of body weight off northern Spain in spring and autumn by length group (Olaso *et al.*, 2005).

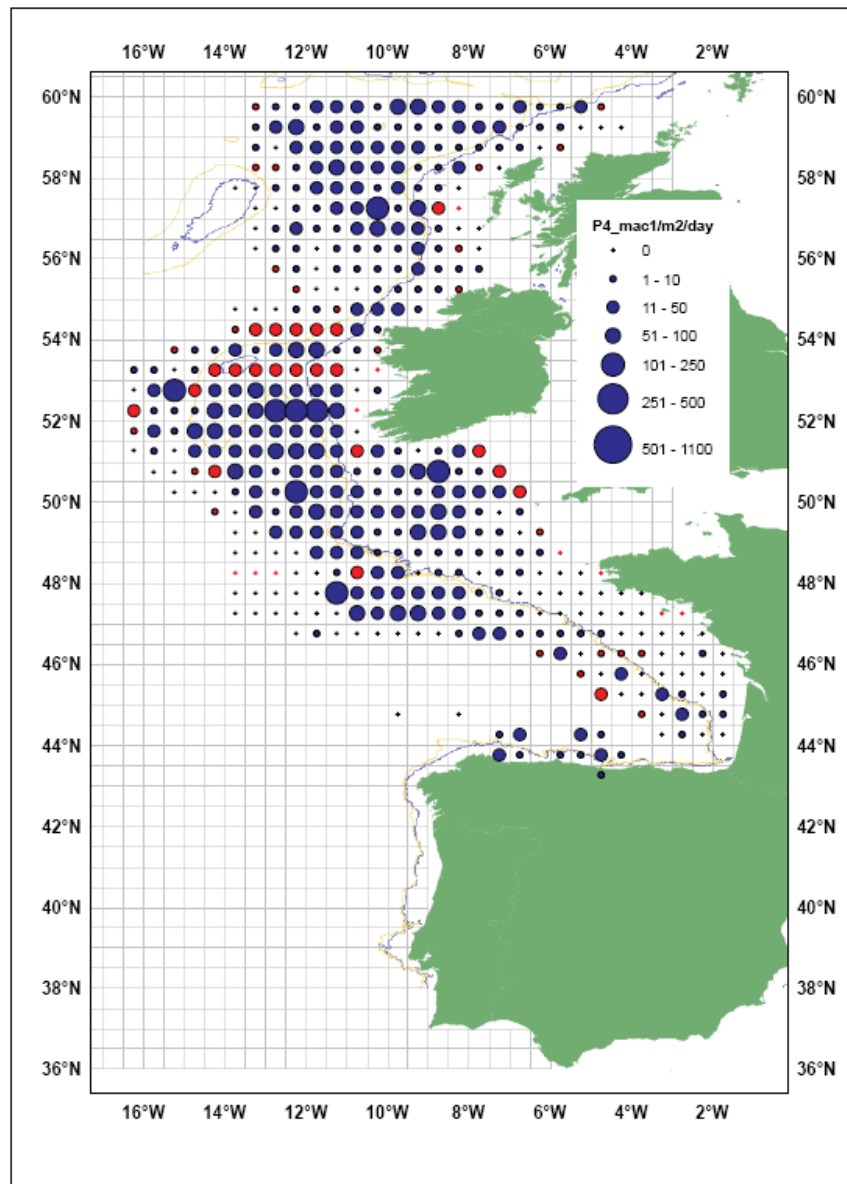


Figure 4.5.3. Mackerel egg production by half rectangle for survey period 4 (7 May – 3 June 2005). Filled blue circles represent observed values, filled red circles represent interpolated values, black crosses represent observed zeroes, red crosses interpolated zeroes.

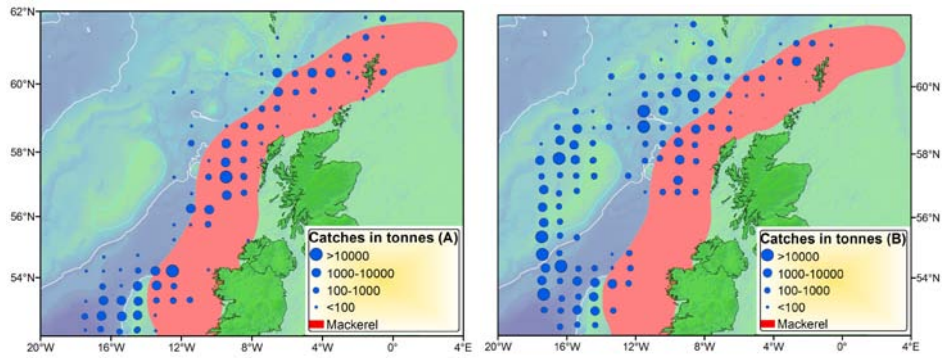


Figure 4.5.4. Maps showing mean catch of blue whiting by ICES squares in the prespawning period (quarter 1) during a period with low recruitment (a) 1989–1996, and a period of high recruitment (b) 1997–2005 (Hatun , 2009b), and the overlap with mackerel (based on catch distribution in 2005; Figure taken from Loeng 2009).

4.6 The role of competition

Since all large fish stocks in the Norwegian Sea are pelagic, the fish–fish interactions appear much less pronounced than in areas, where there are both large demersal stocks, as well as pelagics. However, it is known that blue whiting feed upon mesopelagic fish, and when available, 0-group herring (Monstad, 2004). A diet overlap between herring and juvenile blue whiting is also found. Both species prey on *Calanus finnmarchicus* (Bjelland and Monstad 1997). Prokopchuk and Sentyabov (2006) demonstrated a diet overlap between all the large pelagic stocks in the Norwegian Sea: herring, mackerel and Blue whiting (Figure 4.6.1). The diet of Atlantic salmon (*Salmo salar* L.) in the Norwegian Sea consists of a wide range of different food items, but they seem to prefer fish if available. Herring, redfish (*Sebastes* spp.) and blue whiting are known prey items (Holm *et al.*, 2004); however, the biomass of salmon is very low compared to the other pelagic stocks in the area, thus the effect is probably minimal as to how much the feeding by salmon influences other stocks (Holm *et al.*, 2004).

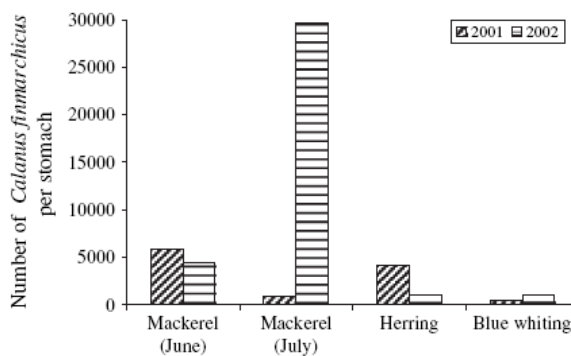


Figure 4.6.1. Average abundance of *Calanus finnmarchicus* (number in stomach) in the diet of mackerel, herring, and blue whiting in the Norwegian Sea in 2001–2002. From Prokopchuk and Sentyabov (2006).

4.6.1 Biomass, Production and Consumption

To compare the different trophic levels within the Norwegian Sea, one of the main feeding areas for adult blue whiting, published estimates of biomass, production and consumption have been used. The consumption estimates are what each trophic level

eats, not how much of the trophic level is eaten. The Norwegian Sea estimates have been taken from Skjoldal *et al.* (2004), except for seabirds, which were obtained from Anker-Nilssen and Lorentsen (2004). For the Norwegian Sea production estimates, the wet weight production was divided by total area times the conversion factor from wet weight to carbon (i.e. 10, as assumed by Skjoldal *et al.*, 2004).

Zooplankton dominates the biomass spectra with over 10 times greater biomass than that of phytoplankton in the Norwegian Sea (Figure 4.6.2). In the Norwegian Sea the estimated consumption by zooplankton exceeds the production of phytoplankton, even after taking into account carnivorous zooplankton. The estimates of primary production assumed that regenerated production was two times the new production. If the regenerated production is three times the new production, then there is a closer fit between the estimates of primary production and consumption by herbivorous zooplankton (Skjoldal *et al.*, 2004). This indicates the level of uncertainty in such estimates. The highest consumption to production levels occur for seabirds and marine mammals, so although their biomass and production are relatively minor in comparison with the other trophic levels, their consumption is still important due to their relatively high metabolic maintenance costs.

While such estimates, especially of production and consumption, require many assumptions, are highly uncertain, and must be interpreted with extreme caution, they do provide a means for comparison within regions. Such exercises in future for the Norwegian Sea and other relevant areas should focus on using similar species and assumptions.

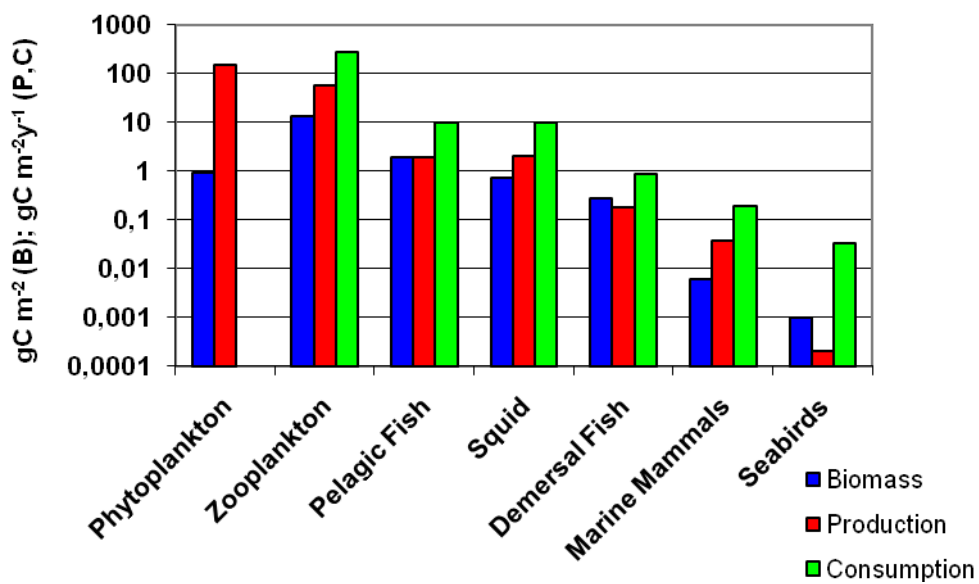


Figure 4.6.2. The estimated biomass, production and consumption by trophic level in the Norwegian Sea. Descriptions of the data sources are provided in the text. The vertical axis is in gCm⁻² for biomass and in gCm⁻² y⁻¹ for production and consumption (Loeng and Drinkwater, 2007).

Larvae and young blue whiting feed on zooplankton in the Norwegian Sea and Figure 4.6.2 clearly indicates that the Norwegian Sea produces enough zooplankton to feed the large amount of pelagic fish that live there. However, Figure 4.6.3 clearly shows that the biomass of zooplankton in the Norwegian Sea and adjacent areas has decreased during the last fifteen years. In parallel, the biomass of pelagic fish (blue whiting, mackerel and Norwegian spring-spawning herring) has increased. The ques-

tion therefore becomes: is there enough food in the Norwegian Sea to feed almost 30 million tonnes of pelagic fish and have the pelagic stocks reached a size where they negatively affect their own recruitment through overgrazing of their food resources?

An increasing mean water temperature in the feeding area shifted the southern distribution edge of an important prey item for adult blue whiting (*Calanus finmarchicus*) northwards (ICES, 2008). In addition, the average biomass of zooplankton in the Norwegian Sea has shown a steadily decreasing trend since 2002 (Figure 4.6.3). Thus large changes in the plankton abundance and species composition have occurred the last several years in the main feeding area for blue whiting. More detailed studies are needed to quantify these effects and their implications for the blue whiting stock.

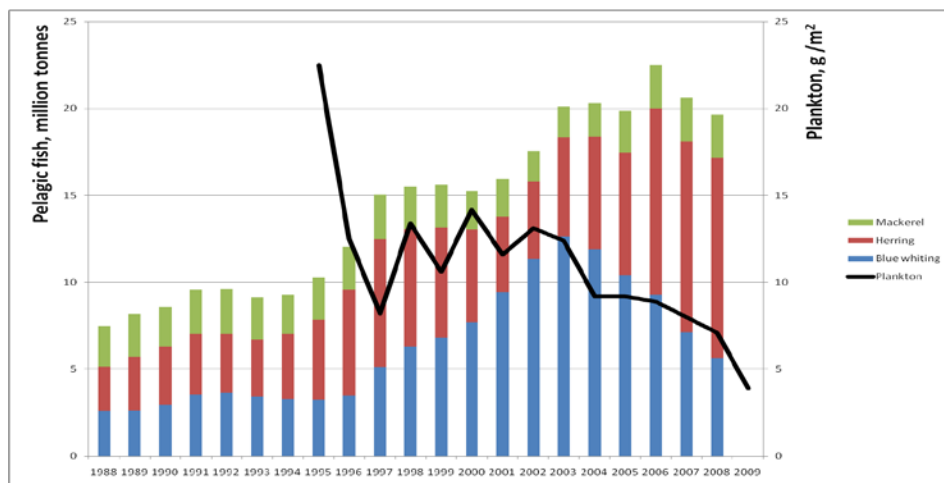


Figure 4.6.3. Fluctuations in total biomass of pelagic fish and zooplankton in the Norwegian Sea (Loeng, 2009).

The decrease in zooplankton is also demonstrated in Figure 4.6.4. From 2000 to 2005, most of the decrease took place in the central Norwegian Sea, while there were small changes northeast of Iceland. In 2009 the zooplankton biomass was low all over the area.

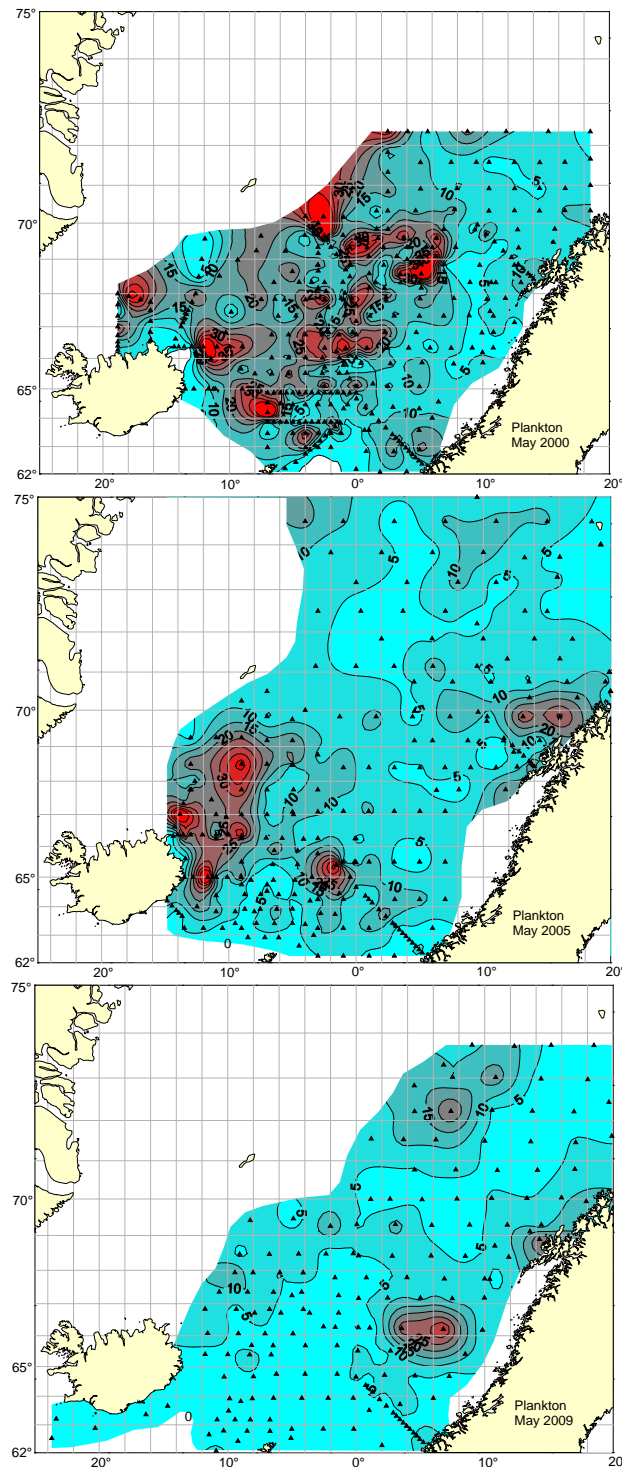
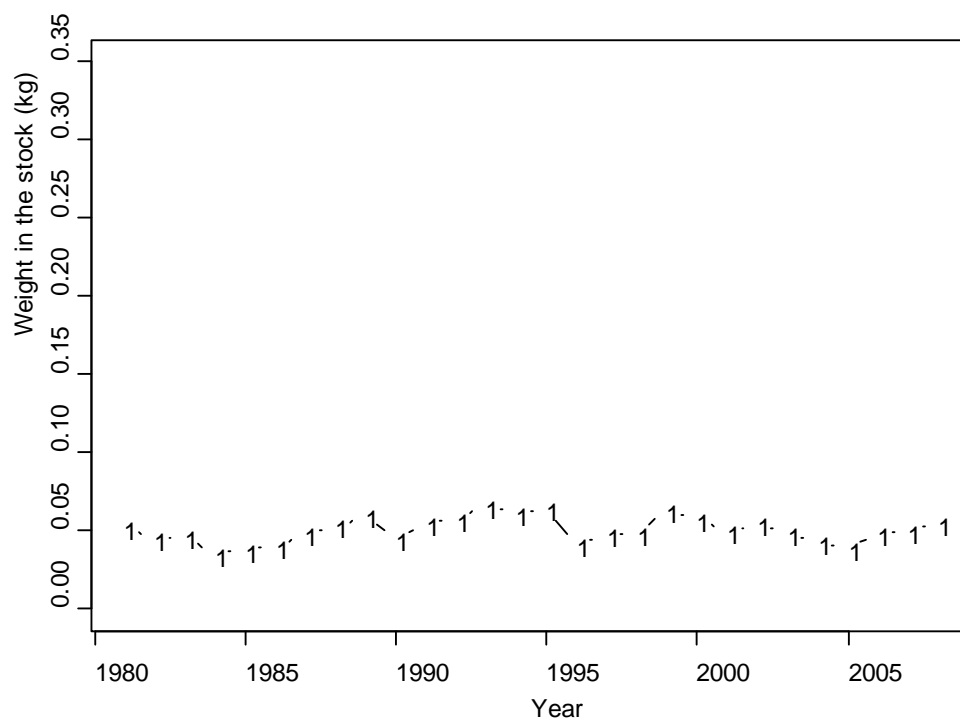
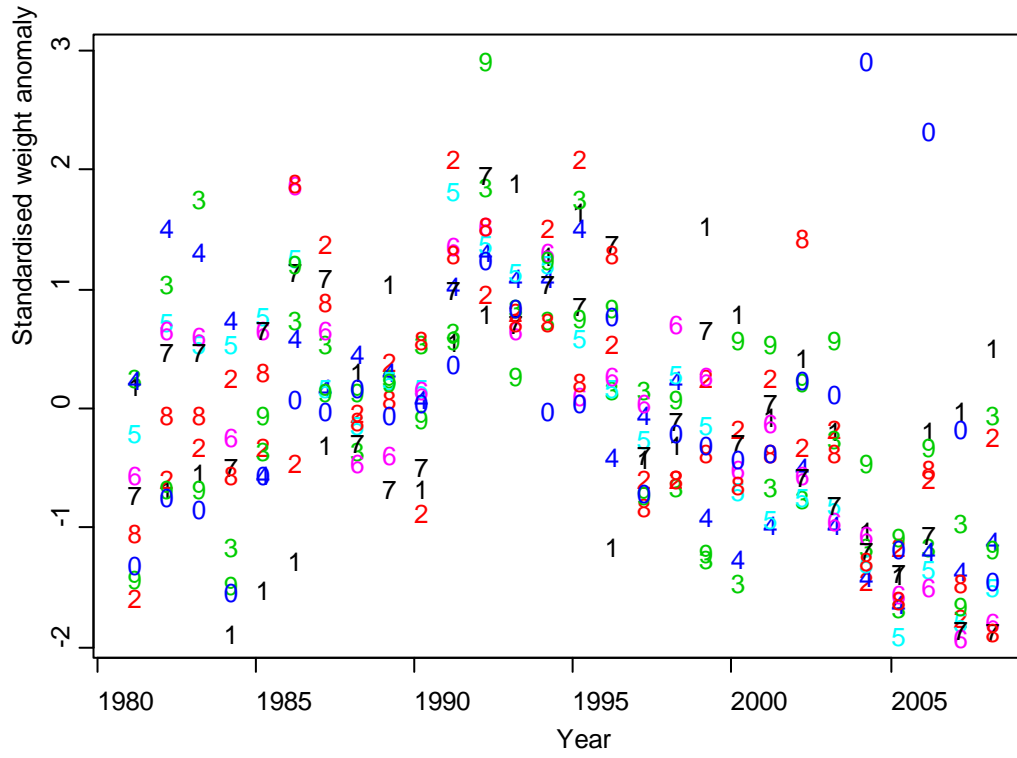


Figure 4.6.4. Zooplankton biomass in the Norwegian Sea in (top panel) May 2000, (middle panel) May 2005 and (bottom panel) May 2009 (Source: PGNAPES reports 2000, 2005 and 2009).

Another indication of the low availability of prey may be seen in Figure 4.6.5 and 4.6.6, which show changes in the catch weight at-age since 1980. Since the early 1990s, the average weight at-age for fish older than three years has been decreasing. The report from WGwide (2008) stated that “there are several possible explanations for the overall negative trend in mean weight at-age, and hence growth, through the last 15 years”. However, they underline that “...an in depth analysis of the causes, which would be needed for any kind of forecast, is outside the scope of working group.”





rate biological information in context of the physical system, it must be emphasized to have an overview over the physical variability taking place in the different locations during the relevant period (see Section 3). Important spatial dimensions, judging from physical and biological variability and from data availability, will be discussed separately.

4.7.2 North and south (of the Porcupine Bank)

Blue whiting (*Micromesistius poutassou*) in the Northeast Atlantic system probably consists of several stocks. For assessment purposes two main components, one spawning along the slope north of and one along the slope south of the Porcupine Bank, have been assumed. The Porcupine Bank area has been considered a transition zone.

4.7.3 Along the European continental shelf (the s-axis)

The densest concentrations of spawning blue whiting are typically found along the European continental shelf and the data coverage is also highest along this dimension (Figure 4.7.1). Large north-south shifts in the spawning distribution along this dimension have been related to changes in the Subpolar Gyre: strong gyre and cold conditions – southerly position; and vice versa for a weak gyre. The largest concentrations of spawning blue whiting are found within relatively narrow ranges of salinity (35.35–35.45 psu) and temperature (9–10°C) ((Hátún *et al.*, 2008; Hátún *et al.*, 2009b; Henderson 1957; Schmidt 1909; Figure 4.7.2).

The spawning distribution in 2008 and 2009 was at a very northerly position, in agreement with the northward salinity intrusion (Figure 4.7.2). So the linkage between spawning distribution and hydrography seems to be more linked to salinity than to temperature.

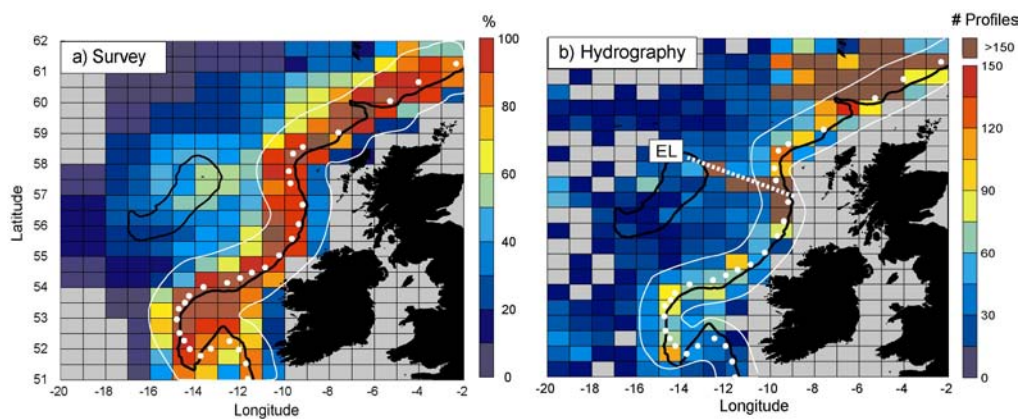


Figure 4.7.1. Data coverage and the s-axis. (a) Spatial coverage of acoustic surveys (1981–2007) showing the fraction coverage of each 0.5° latitude \times 0.5° longitude square and (b) number of hydrographic stations with available data at 300 meter depths during the 1981–2007 period, binned into the same geographical squares. Squares with no acoustical data or fewer than five hydrographic stations are colored grey. The s-axis is shown with the dots and the truncation radius (a) is illustrated with white thin lines. EL: Ellett Line.

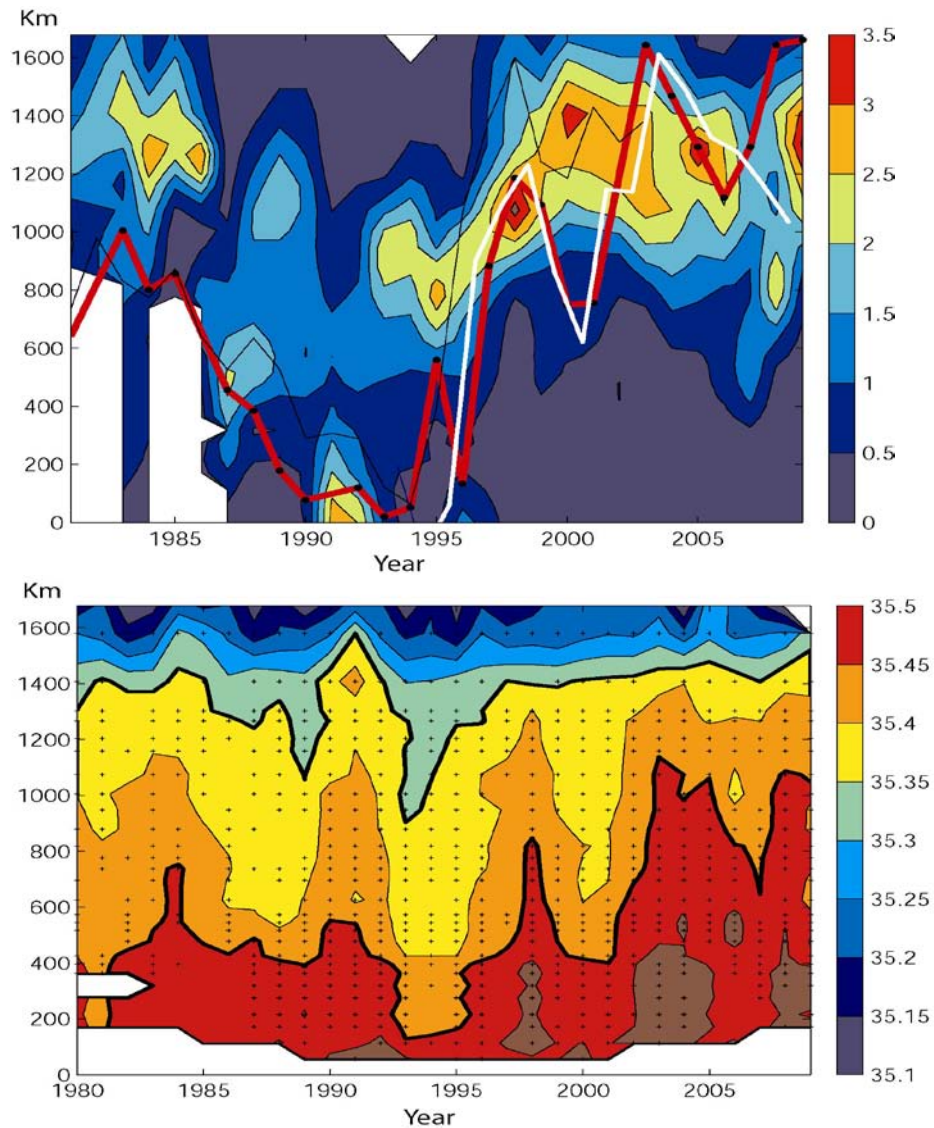


Figure 4.7.2 () Time-latitude/distance (Hovmüller) plot of normalized biomass density of blue whiting along the European Continental Slope (-axis, see Figure 4.7.1). The thin black curve shows a gyre index based on the simulated sea surface height in the northeastern Atlantic, and the white line shows an extension of this index based on satellite altimetry (Hakkinen and Rhines 2004, updated). The red curve shows salinity averaged over depth range 0–800 m at the Ellett Line (Holliday , 2000; see Figure 4.7.1). White areas indicate absence of survey data. () Hovmüller plot of salinity at 300-m depths along the -axis. Only data from March to June have been included. The salinity range (35.35–35.45) encompassing the densest blue whiting observations in () is emphasized with thick black lines. Available data points are illustrated with small crosses. Updated from (Hátún , 2009b).

The peaks in the recruitment time-series appear to be linked to the shorter term salinity pulses that appear along the s-axis (see section 3.2.4), but which are not evident in the gyre index (Figure 4.7.3). The recruitment peaks appear to start at the onset of salinity pulses.

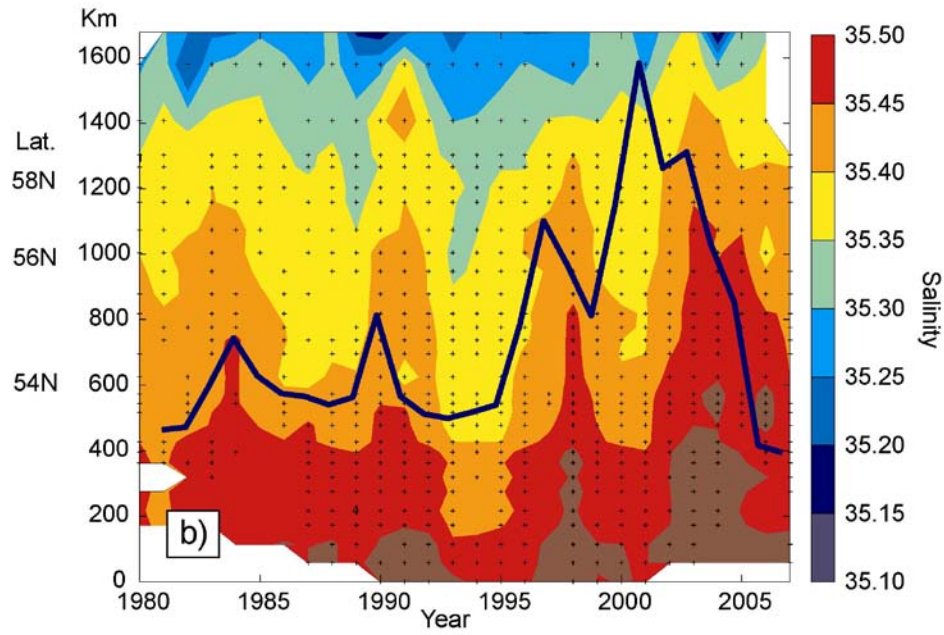


Figure 4.7.3. Hovmüller plot of salinity at 300-m depths along the -axis and the recruitment time-series (not to scale).

4.7.4 On-off Rockall

The temperature/salinity sensitivity of spawning blue whiting and large hydrographic changes around the Rockall Plateau indicate that the east-west/on-off Rockall dimension is highly important. Large on-off Rockall shifts in the spawning distribution along this dimension have been related to changes in the Subpolar Gyre: strong gyre and cold conditions – off Rockall, weak gyre and warm conditions – on Rockall.

Blue whiting larvae data from the Continuous Plankton Recorder (1951–1970) along this dimension support this on-off Rockall hypothesis (Figure 4.7.4).

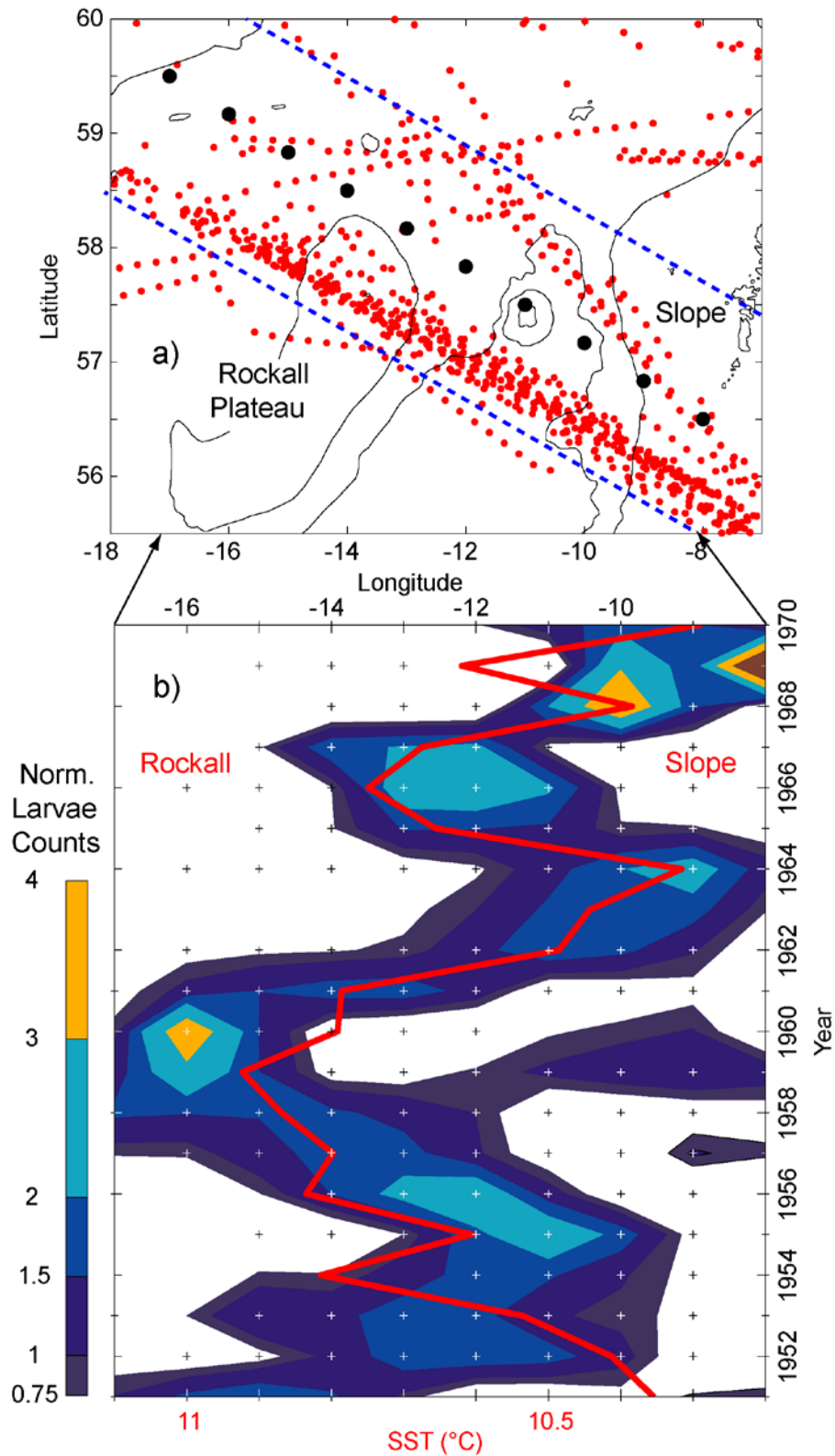


Figure 4.7.4. The \dots -axis (black dots) and positions with larvae data from the CPR (red dots) during the period from 1951 to 1970. The truncation radius () (Hátún et al. 2009b) is shown with the blue dashed lines. () Longitude-time (Hovmöller) plot of the normalized larvae counts. The red line shows the sea surface temperature (SST). Available data points are shown with the crosses.

Fisheries data also support this hypothesis (although such data should be treated with care due to political regulations) (Hátún *et al.*, 2009b).

We have previously suggested the following possible causal relations between recruitment and the on-off Rockall shifts: Firstly, that eggs and fry starting on the plateau will follow different drift paths from those starting on the shelf, which would enlarge and diversify their nursery area and thereby improve growth/survival opportunities of the larvae. Secondly, that a potentially strong retention of water masses near the Rockall Bank during warm low-gyre index years (Dooley 1984) might provide good local growth conditions. Thirdly, that larval development near Rockall might be in closer synchrony with production cycles of key prey types (zooplankton), than nearer the continental slope (Bainbridge and Cooper, 1973).

Differentiating between these competing hypotheses is a challenging task which should be validated by i) applying hydrographic drift modelling to investigate how the initial position of eggs and larvae might influence the downstream spread of larvae and the environment they encounter, ii) establishing regular field studies to sample larvae growth/size and feeding intensity/food content simultaneously in the spawning areas and in the downstream larval feeding areas, and relate this to the ambient prey availability and the hydrographic environment

4.7.5 East (North Sea) – West (Iceland)

Clear east-west shifts have been demonstrated for the post-spawning migration pattern of blue whiting (Hátún *et al.*, 2009a). These shifts co-vary with the dynamics of the Subpolar Gyre:

Strong gyre and cold conditions give rise to an easterly migration pathway, while weak gyre and warm conditions result in a westerly migration pathway (Figure 4.7.5).

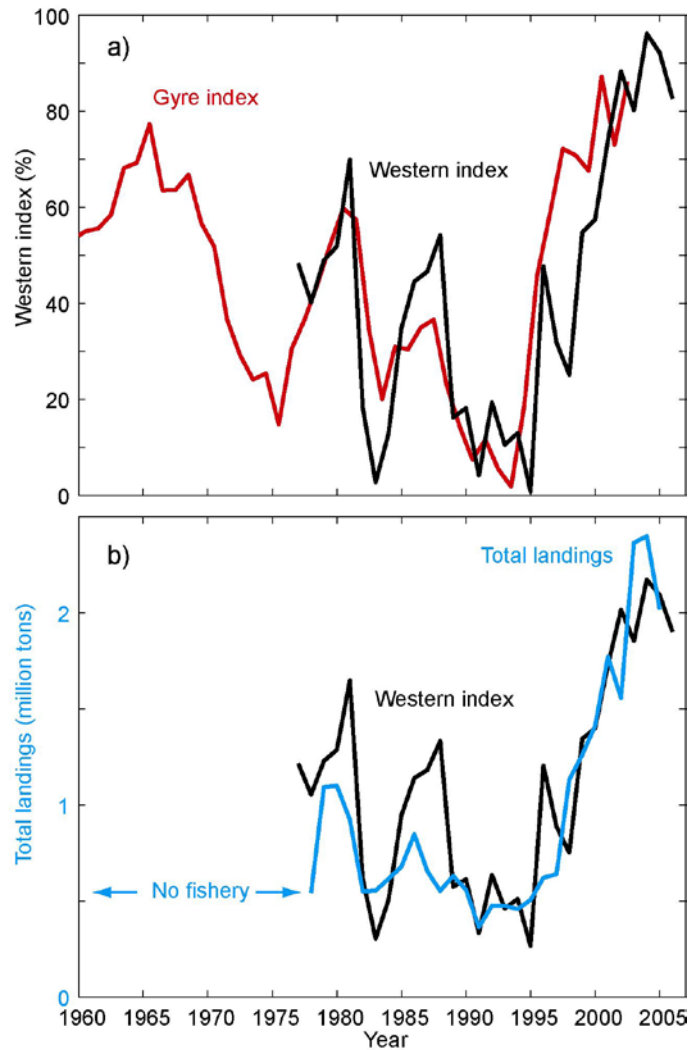


Figure. 4.7.5. The western index for blue whiting catches (black) plotted together with () the inverted gyre index and () the total annually averaged blue whiting landings by all fleets (Hátún , 2009a).

This east-west dynamics has been linked to the on-off Rockall shift in spawning distribution.

4.7.6 The fringes (north/west Iceland and the Barents Sea)

The fringe areas of the distribution might experience a “spillover” effect. The influence of marine climate on the stock dynamics might therefore be especially clear in these areas.

Two hypotheses are put forward: to explain the fluctuations in the Barents Sea. First, rich year-classes in the main Atlantic stock of blue whiting may contribute to increased abundance in the Barents Sea. Second, variations in hydrography, such as influx of warm Atlantic water, may be particularly important in this fringe area (Heino *et al.*, 2008).

4.8 The role of stock structure

Changes in stock structure can have a considerable influence on the reproductive potential of a stock and this in turn could contribute to the recruitment variability (Trippel, 1999). The compositions of the spawning stock, whether size or age struc-

tured, along with individual fish condition are of importance for the stock reproductive potential (Marshall *et al.*, 1998, 2000; Trippel, 1998). Moreover, it is quite common in fish that first-time spawners spawn later in the season than the repeat spawners (Slotte *et al.*, 2000). Hence, the proportion of recruits among the spawners may have a significant effect on spawning time, thereby indirectly affecting the survival since hatching time is found to be significant factor influencing recruitment in fish (Fortier and Quinonez-Velazquez, 1998; Lapolla and Buckley, 2005; Nishimura *et al.*, 2007; Husebø *et al.*, 2009).

Given the large changes in recruitment observed in this stock, it is reasonable to expect that there have been correspondingly large changes in the stock structure. Such changes would have been especially important at the start of the high-recruitment period (spawning stock dominated by first time spawners) and the end (spawning dominated by repeat spawners). However, the dramatic changes in recruitment appear to that have induced changes in the stock structure (rather than *vice versa*) and therefore it would appear that this is, at most, a second order effect.

4.9 References

- Ådlandsvik, B., Coombs, S. Sundby, S., Temple, G. (2001) Buoyancy and vertical distribution of eggs and larvae of blue whiting (*Micromesistius poutassou*): observations and modelling. Fisheries Research 50 (2001) 59–72.
- Anderson, J.T. 1988. A review of size dependent survival during pre-recruit stages of fishes in relation to recruitment. J.Northw.Atl.Fish.Sci. 8:55–66.
- Anker-Nilssen, T., Lorentsen, S.-H., 2004. Seabirds in the Norwegian Sea. In: Skjoldal, H.R. (Ed.), The Norwegian Sea Ecosystem. Tapir Academic Press, Trondheim, pp. 435–446.
- Bailey, K. M., and Houde, E. D. 1989. Predation on eggs and larvae of marine fishes and the recruitment problem. Advances in Marine Biology, 25: 1–83.
- Bainbridge, V., and Cooper, G. 1973. The distribution and abundance of the larvae of the blue whiting, *Micromesistius poutassou* (Risso), in the north-east Atlantic, 1948–1970. Bulletins of Marine Ecology, 8: 99–114.
- Bjelland, O., and Monstad, T. 2007. Blue whiting in the Norwegian Sea, spring and summer 1995 and 1996. ICES-CM-1997/CC:15, 25 pp.
- Brophy, D., and King, P.A. 2007. Larval otolith growth histories show evidence of stock structure in Northeast Atlantic blue whiting (*Micromesistius poutassou*) ICES Journal of Marine Science, 64: 1136–1144.
- Cabral H. N. and Murta, A. G. 2002. The diet of blue whiting, hake, horse mackerel and mackerel of Portugal. J. Appl. Ichthyol. 18 (2002), 14–23.
- Conway, D.V.P., 1980. The food of larval blue whiting, *Micromesistius poutassou* (Risso), in the Rockall area. J. Fish. Biol. 16, 709–723.
- Dooley, H. D. 1984. Aspects of oceanographic variability on Scottish fishing grounds. PhD. Thesis. 1 - 154. University of Aberdeen,
- Folkvord, A., and Hunter, J. R. 1986. Size-specific vulnerability of northern anchovy *Engraulis mordax* larvae to predation by fishes. Fishery Bulletin (U.S.), 84: 859–869.
- Fortier, L., and Quinonez-Velazquez, C. 1998. Dependence of survival on growth in larval pollock *Pollachius virens* and haddock *Melanogrammus aeglefinus*: a field study based on individual hatch dates. Marine Ecology Progress Series, 174: 1–12.
- Fuiman, L. A. 1994. The interplay of ontogeny and scaling in the interactions of fish larvae and their predators. Journal of Fish Biology, 45: 55–79.

- Fuiman, L. A., and Gamble, J. C. 1989. Influence of experimental manipulations on predation of herring larvae by juvenile herring in large enclosures. *Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer*, 191: 359–365.
- Hátún, H., Payne, M., Beaugrand, G., Reid, P. C., Sandø, A. B., Drange, H., Hansen, B., Jacobsen, J. A., and Bloch, D. 2009a. Large bio-geographical shifts in the north-eastern Atlantic Ocean: From the subpolar gyre, via plankton, to blue whiting and pilot whales. *Prog. Oceanogr.*, 80: 149–162.
- Hátún, H., Payne, M. R., and Jacobsen, J. A. 2009b. The North Atlantic subpolar gyre regulates the spawning distribution of blue whiting (*Micromesistius poutas-sou*). *Canadian Journal of Fisheries and Aquatic Sciences*, 66: 759–770.
- Heino, M., Engelhard, G. H., and Godo, O. R. 2008. Migrations and hydrography de-termines the abundance fluctuations of blue whiting (*Micromesistius poutas-sou*) in the Barents Sea. *Fisheries Oceanography*, 17: 153–163.
- Henderson, G. T. D. 1957. Continuous plankton records: the distribution of young *Gadus poutassou* (Risso). *Bulletins of Marine Ecology*, 4: 179–202.
- Hillgruber, N., Kloppmann, M., Westernhagen, H. von., (1995) Distribution of blue whiting *Micromesistius poutassou* larvae in the Porcupine Bank area, west of Ireland, in relation to hydrography and the feeding environment. ICES C.M.1995/H:27.
- Holm, M., Hansen, L.P., Holst, J.C., Jacobsen, J.A., 2004. Atlantic salmon (*Salmo salar* L.). In: Skjoldal, H.R. (Ed.), *The Norwegian Sea Ecosystem*. Tapir Academic Press, Trondheim, pp. 315–356.
- Husebø, Å., Stenevik, E.K., Slotte, A., Vikebø, F., Fossum, P. and Folkvord, A. 2009 Early hatching time in Norwegian spring spawning herring (*Clupea harengus* L.) results in increased survival, *ICES Marine Science Symposia*, 66:1710–1717.
- ICES. 2008. Report of the Working Group on Mackerel and Horse Mackerel Egg Surveys (WGMEGS). ICES CM 2008/LRC:09.
- Lapolla, A., and Buckeley, L. J. 2005. Hatch date distributions of young-of-year haddock *Melanogrammus aeglefinus* in the Gulf of Maine/Georges Bank region: implications for recruitment. *Marine Ecology Progress Series*, 290: 239–249.
- Loeng, H. and Drinkwater, K. 2007. An overview of the ecosystems of the Barents and Norwegian Seas and their response to climate variability. *Deep-Sea Research II* 54 (2007) 2478–2500
- Loeng, H., Holst, J. CHR., Slotte, A., and Höines, Å. 2009. The rise and fall of the blue whiting stock. Poster, ICES CM 2009, E:35, Berlin, Germany September 2009
- Monstad, T. 2004. Blue whiting. In: Skjoldal, H.R. (Ed.), *The Norwegian Sea Ecosystem*. Tapir Academic Press, Trondheim, pp. 263–288.
- Marshall, C.T., O'Brien, L., Tomkiewicz, J., Marteinsdóttir, G., Morgan, M.J., Saborido-Rey, F., Köster, F.W., Blanchard, J.L., Secor, D.H., Kraus, F., Wright, P., Mukhina, N.V., and Björnsson, H. 2003. Developing alternative indices of reproductive potential for use in fisheries management: case studies for stocks spanning an information gradient. *Journal of Northwest Atlantic Fishery Science*, 33: 161–190.
- Marshall, C.T., Needle, C.L., Thorsen, A., Kjesbu, O.S., and Yaragina, N.A. 2006. Systematic bias in estimates of reproductive potential of an Atlantic cod (*Gadus morhua*) stock: implications for stock–recruit theory and management. *Canadian Journal of Fisheries and Aquatic Sciences*, 63: 980–994.
- Pepin, P., S. Jr. Spearre, and J. A. Koslow. 1987. Predation on larval fish by Atlantic mackerel, *Scomber scombrus*, with comparison of predation by zooplankton. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 2012–18.

- Pepin, P. 1991. The effect of temperature and size on development, mortality and survival rates of the pelagic early life stages of marine fishes. *Canadian Journal of Fisheries and Aquatic Sciences*, 48: 503–518.
- Nishimura, A., Hamatsu, T., Shida, O., Mihara, I., and Mutoh, T. 2007. Interannual variability in hatching period and early growth of juvenile walleye Pollock, *Theragra chalcogramma*, in the Pacific coastal area of Hokkaido. *Fisheries Oceanography*, 16: 229–239.
- Olaso, T., Gutierrez, J. L., Villamor, B. Carrera, P. Valdes, L., Abaunza, P. Seasonal changes in the north-eastern Atlantic mackerel diet (*Scomber scombrus*) in the north of Spain (ICES Division VIIIc). 2005. *Journal of the Marine Biological Association of the UK* 85 (2): 415–418.
- Prokopchuk, I., and Sentyabov, E. 2006. Diets of herring, mackerel, and blue whiting in the Norwegian Sea in relation to *Calanus finmarchicus* distribution and temperature conditions. *ICES Journal of Marine Science*, 63: 117–127.
- Rothschild, B. J. 2000. "Fish stocks and recruitment": the past thirty years. – *ICES Journal of Marine Science*, 57: 191–201.
- Schmidt, S. 1909. The distribution of the pelagic fry and the spawning regions of the gadoids in the North Atlantic from Iceland to Spain. *Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer*, 10: 1–229.
- Shepherd, J. G., and Cushing, D. H. 1980. A mechanism for density dependent survival of larval fish as the basis of a stock–recruitment relationship. *Journal du Conseil International pour l'Exploration de la Mer*, 39: 160–167.
- Skjoldal, H.R., Dalpadado, P., Dommasnes, A., 2004. Food webs and trophic interactions. *In*: Skjoldal, H.R. (Ed.), *The Norwegian Sea Ecosystem*. Tapir Academic Press, Trondheim, pp. 447–506.
- Slotte, A., Johannessen, A., and Kjesbu, O. S. 2000. Effects of fish size on spawning time in Norwegian spring spawning herring (*Clupea harengus* L.). *Journal of Fish Biology*, 56: 295–310.
- Trippel, E.A. 1998. Egg size and viability and seasonal offspring production of young Atlantic cod. *Transactions of the American Fisheries Society*, 127: 339–359.
- Ware, D. M. 1975. Relation between egg size, growth and natural mortality of larval fish. *Journal of the Fisheries Research Board of Canada*, 32: 2503–2512.

5 Potential for Prediction

“Prediction is very difficult, especially about the future.” - Niels Bohr

The previous section examined a range of different hypothesized mechanisms that are potential candidate mechanisms that may account for the wide range of recruitment observed in the blue whiting stock in recent times. Under the assumption that all of these hypothesized mechanisms are (or could be) understood, there is therefore the (theoretical) potential for making predictions over differing time-scales regarding the recruitment to this stock. Here we examine the possibilities for making such a projection. In doing so, we distinguish between recruitment variability (i.e. the variance of recruitment about a mean value) and the variability of the recruitment (i.e. changes in the mean recruitment value). Given that accounting for the recruitment variability requires a full characterization of both the mean value and the associated distribution, and thus is significantly more complex, here we choose to focus solely on the potential for predicting the recruitment (i.e. the mean value) as a function of time.

In doing so, however, we must take great care with the basis for making such a prediction. In order to make such a prediction, it is first necessary that we understand the system at hand, and particularly the processes driving it. The break-down of recruitment-environment correlations several years after their publication is a well known and documented phenomenon in the fisheries literature (Myers, 1998). Given the uncertainty in our current state of biological knowledge (Section 4), we therefore apply Niels Bohr’s wisdom and avoid making outright predictions. Instead, here we discuss the possibilities of, and necessary conditions for, making such predictions.

5.1 Short-term predictions

5.1.1 Baseline

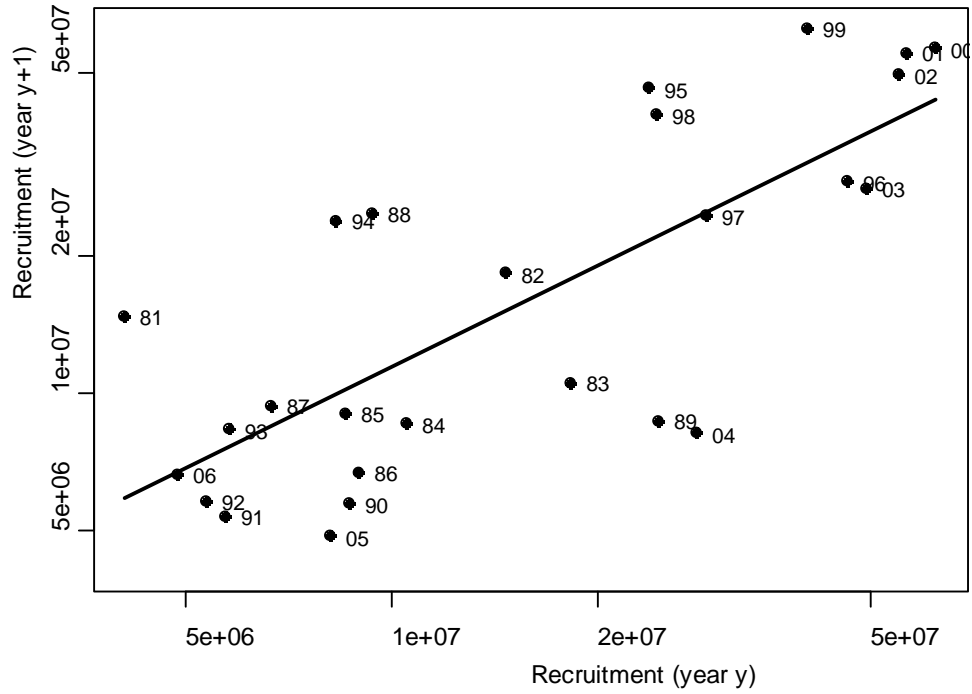
When considering any form of statistical prediction, it is useful to have a baseline prediction model against which to compare other models: only in cases where the proposed prediction scheme can be shown to statistically outperform the baseline case should the newer scheme be considered. One can envisage many such baseline cases, many of which will perform reasonably well (e.g. drawing cards with “high”, “middle”, or “low” from a hat). As a baseline prediction model here, we note the high degree of autocorrelation visually apparent in the time-series of recruitment, and therefore propose the following baseline model:

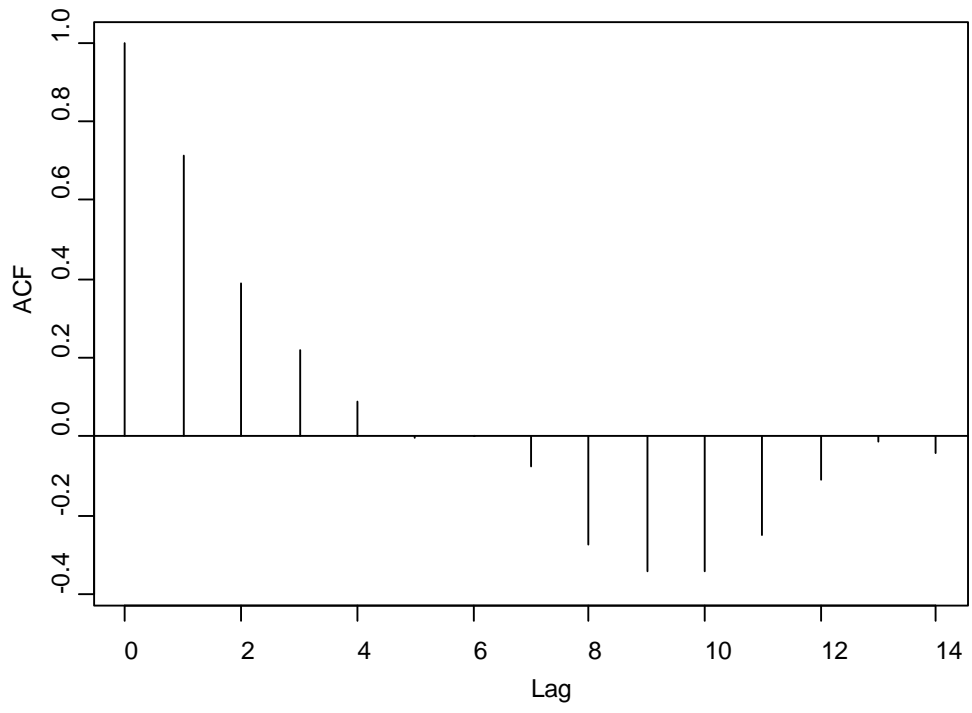
“Recruitment next year will be the same as this year”

The correlation between recruitments in successive years is highly significant ($p < 0.001$, $r^2 = 0.547$, Figure 5.1.1), suggesting strong support for this baseline model. Furthermore, we can generalize this result further by examining the autocorrelation function for the (log) recruitment time-series i.e. the correlation between values separated by various lags (Figure 5.1.2). The autocorrelation is found to be significant at a lag of two years (albeit marginally), but the autocorrelation breaks down for longer lags. This suggests a significant potential prediction mechanism two years into the future by simply assuming that recruitment is the same as the previous year.

Such a result is not surprising: visual examination of the recruitment time-series suggests a high degree of autocorrelation, essentially switching between high and low recruitment regimes and remaining at those levels for some time. Such a model, however, is of little use in predicting when the changes between states occur. Further-

more, in the absence of any real process understanding, the long-term robustness of such a model is unclear. Nevertheless, it provides a useful baseline against which other models can be tested.





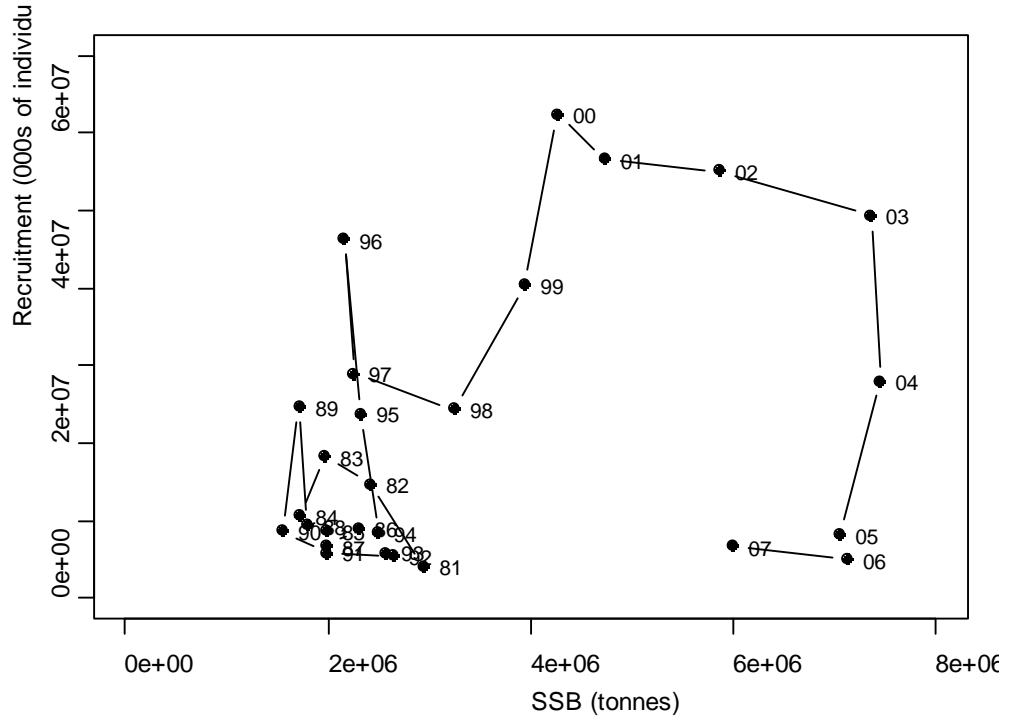
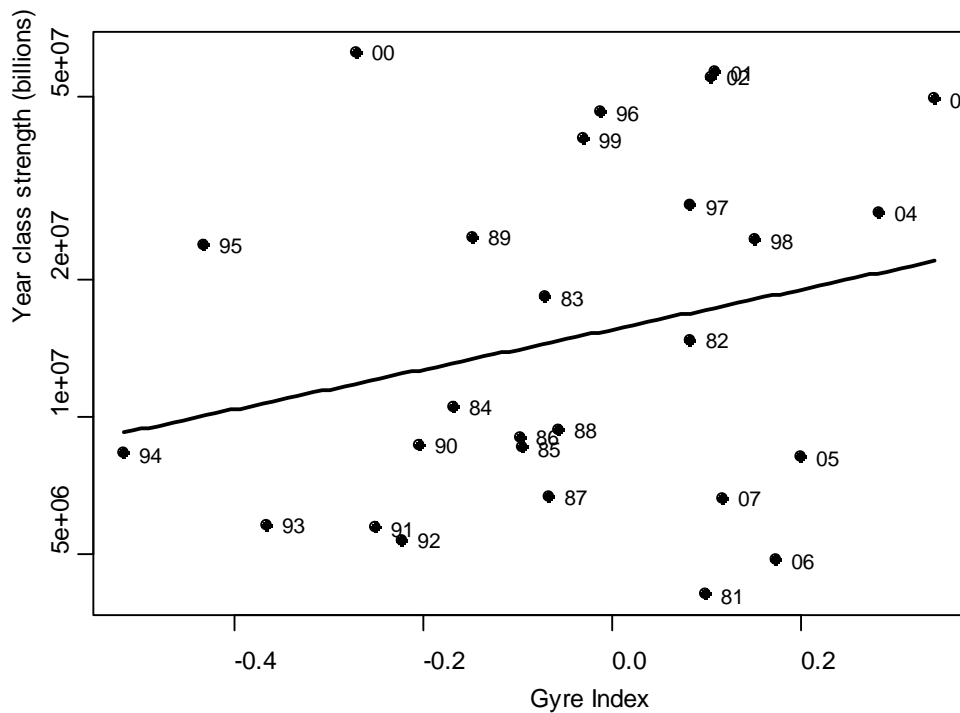
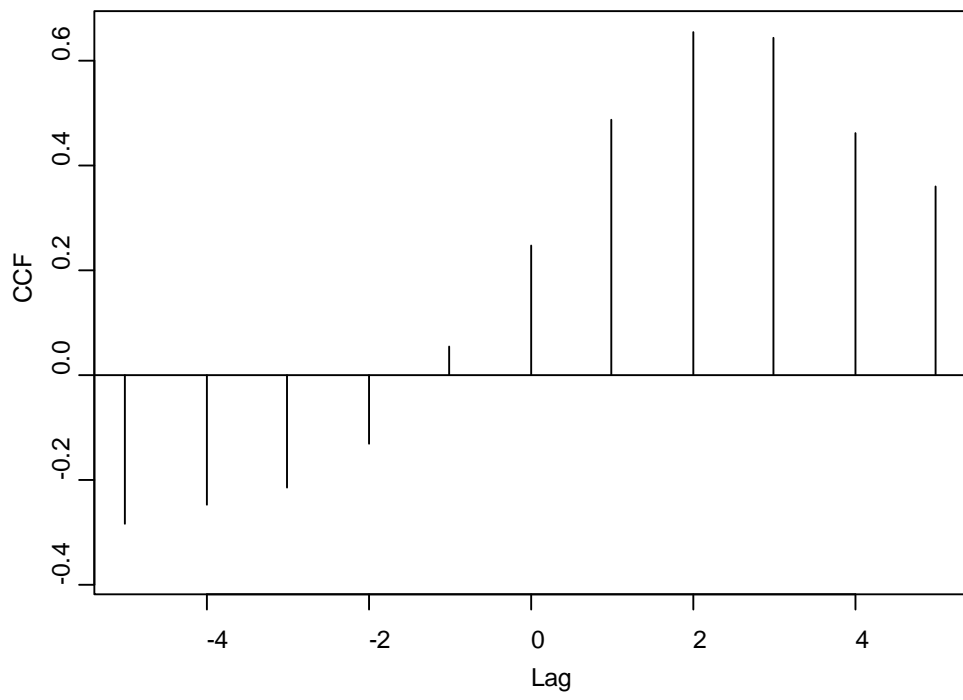


exhibit dramatic changes during the mid 1990s, whilst the time-series appear to have diverged in the most recent one-two years (note, for example, the 2005–07 cohorts in Figure 5.1.4). Lag analysis involves shifting the time-series with respect to each other and as a result, both time-series are essentially truncated (due to the lack of overlap at the start and end of the series): whilst this may not be a problem in very long time-series, in this situation the effect is to disregard the data points at either end of the time-series. However, these are also the points that show the greatest disagreement between the time-series (e.g. the 2005–2007 cohorts) and therefore it is not surprising that removing them in this manner improves the correlation. Similar mechanisms can be envisaged for the recruits-per-spawner. This phenomenon, therefore, acts to obfuscate the possible existence of any time-lagged mechanisms in this system.

Furthermore, we note that none of these models, even if we were to believe in them fully, are capable of making predictions with a high degree of reliability – the best of these, $\log(\text{recruitment})$ is a linear function of the gyre index with a lag of 2 years, ($r^2 = 0.42$) is still inferior to the baseline model.





is impacted, suggests that two to three-year predictions of ecosystem change may be feasible. Model experiments promise the potential for medium-term forecasts (5–10 years) of the development of the Subpolar Gyre (Lohmann *et al.*, 2008a; Lohmann *et al.*, 2008b).

The internal oceanic dynamics in the North Atlantic Ocean has a relatively long 'memory'. Such changes that have been referred to as the Thermo-Haline mode (Kushnir, 1994) have characteristic multidecadal oscillations (i.e. the Atlantic Multidecadal Oscillation). If the oscillations are persistent, they might be used for medium-term predictions.

5.3 Long-term prediction

Long-term prediction requires input from Global Circulations Models (GCM). However, for a more regional scale, downscaling is necessary. One way to go might be to select the models that reproduce the circulation in the area best up to present, and use the output from these models as input for the regional models and run the models for the period from now and to 2100 (as in the IPCC). This will give indications on how some typical feature, like the Subpolar Gyre, will behave in future. We might get indication on when and how often we should expect strong or weak gyre. By using this information in biological models or using biophysical models, we could get information on periods with strong and weak recruitment of e.g. blue whiting. However, we would never be able to identify single years of good recruitment in a period where we in general have poor recruitment. An example on to link input from GMC-models with regional biophysical modelling was done for plankton production in the Barents Sea by Ellingsen *et al.* (2008)

5.3.1 Need for different types of models

Climate models use quantitative methods to simulate the interaction of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the climate system to projections of future climate. The results may be used as input in biophysical models. Dynamics of the Subpolar Gyre has been studied with numerical models. Hatun *et al.* (2005) have defined a regional gyre index based on simulated sea surface height using the MICOM model, while Mauritzen *et al.* (2006) have used a 50-year time-series of the same model to relate positioning and strength of the gyre to the exchange of water across the Greenland-Scotland ridge. The spawning products are transported from spawning to nursery areas with the ocean currents. This can be simulated using particle tracking and circulation models. Variability and sensitivity of this drift to shifts in the spawning distribution could easily be simulated by perturbations of the release positions (in both space and time) of the particles in the model.

Biological models are conceptual representations of biological processes. In general, these are expressed numerically, i.e. we aim to capture the essence of biological phenomena as formulae or equations. Biological models may be as simple as a general relationship between food and growth, or as complex as a description of the detailed interactions within a highly structured ecosystem. No matter how simple or complicated a model is, it will always be an abstraction of the natural process it is trying to replicate. The challenge is to identify and retain the most relevant elements. Zooplankton production and variability of the Norwegian Sea have been modelled by e.g. Slagstad using the SINMOD model. At IMR an individual based model (IBM) of the copepod *Calanus finmarchicus* have been implemented (Hjøllo, Huse, Skogen, in prep.) and coupled to the circulation model ROMS and primary production model

NORWECOM to study production and stock dynamics of *C. finmarchicus* in the Nordic Seas. This model will further be used to investigate the interannual variability of primary and secondary production in the area over the last 20–30 years. There is also an ongoing project (INFERNO) to couple a fish (mackerel, herring, blue whiting) migration model (Utne, Huse *et al.*, in prep.) to the *C. finmarchicus* model.

Bio-physical models combine the physical and biological models, and may be used to explain the long-term trends in abundance of phyto- and zooplankton and fish species as a function of ecological and climate change, and their population dynamics in the actual area. Bio-physical models might be used to identify linkages between physical conditions and fish populations' parameters like recruitment, drift of spawning products and distribution. Huse *et al.* (2008) investigated the indications of a negative impact of herring recruitment of Norway pout in the North Sea. Using a Lagrangian particle tracking model in combination with IBTS data of herring and Norway pout, the drift of Norway pout larvae was simulated and potential predation of the larvae from herring implemented. The analyses indicate a negative impact by herring on recruitment on Norway pout, with a Beverton–Holt model improved fit from $r^2=0.04$ (without herring predation) to $r^2=0.31$ when herring was considered. An analogous approach may yield similar improvements in understand and predictive power in the case of blue whiting.

5.4 References

- Eden, C., and Willebrand, J. 2001. Mechanism of interannual to decadal variability of the North Atlantic circulation. *J. Clim.*, 14: 2266–2280.
- Ellingsen, I. H., Dalpadado, P., Slagstad, D., and Loeng, H. 2008. Impact of climatic change on the biological production in the Barents Sea. *Climatic Change* (2008) 87:155–175 DOI 10.1007/s10584-007-9369-6.
- Hátún, H., Sando, A. B., Drange, H., Hansen, B., and Valdimarsson, H. 2005. Influence of the Atlantic subpolar gyre on the thermohaline circulation. *Science*, 309: 1841–1844.
- Huse, G., Salthaug, A., and Skogen, M. D. 2008. Indications of a negative impact of herring on recruitment of Norway pout. – *ICES Journal of Marine Science*, 65.
- Kushnir, Y. 1994. Interdecadal Variations in North-Atlantic Sea-Surface Temperature and Associated Atmospheric Conditions. *J. Clim.*, 7: 141–157.
- Lohmann, K., Drange, H., and Bentsen, M. 2008a. Response of the North Atlantic subpolar gyre to persistent North Atlantic Oscillation like forcing. *Clim. Dyn.*, doi: 10.1007/s00382-008-0467-6
- Lohmann, K., Drange, H., and Bentsen, M. 2008b. What caused the strong weakening of the North Atlantic subpolar gyre post 1995? *Geophys. Res. Lett.*, Submitted.
- Mauritzen, C., S. S. Hjøllø, and A. B. Sandø (2006), Passive tracers and active dynamics: A model study of hydrography and circulation in the northern North Atlantic, *J. Geophys. Res.*, 111, C08014, doi:10.1029/2005JC003252.
- Meyers, R.A. 1998. When do environment recruitment correlations work? *Reviews in Fish Biology and Fisheries* 8:285-305.

6 Conclusions

In this work, we have examined the recruitment dynamics of blue whiting in the North Atlantic with a view to understanding whether it is possible to make recruitment forecasts on a short, medium or long-term basis.

Firstly, the WKBLUR workshop examined the reliability of the recruitment estimates produced by the stock-assessment. The assessment is of a relatively poor quality, and there are strong patterns observed in the historical retrospective analysis beyond the estimation uncertainties produced by the assessment method. Furthermore, recent work has highlighted that the management unit employed does not match biological and oceanographic evidence of structure within the stock. Additionally, while the “as-assessed” recruitment shows good correlation with other alternative recruitment indices (e.g. the Barents Sea indices), the relationship between these time-series in light of the aforementioned stock-identity issues is unclear. A benchmark assessment on this stock is scheduled for 2011 that will address these issues in more detail, including a potential division of the current stock into two separate components: in the absence of such new results, the workshop concluded that the quality of the recruitment time-series is unclear, and possibly poor, but addressed the remaining ToRs on the assumption that the assessed time-series represents the underlying dynamics of the stock.

The workshop reviewed and updated existing work on both the oceanography in the region and the distribution dynamics of blue whiting, particularly focusing on the most recent observations – there was no evidence to suggest that results regarding the spawning distribution recently reported in the literature have become invalidated.

The workshop examined a broad selection of hypothesized mechanisms that may explain the recruitment dynamics of this stock. The group focused on two potential mechanisms that may account for the hypothesized linkage between the oceanographic climate and the recruitment dynamics. The first of these (“the predation hypothesis”), is centred on the role of mackerel predation: changes in the spawning distribution, and therefore the distribution of spawning products, lead to changes in the mackerel-blue whiting larvae overlap, and therefore the degree of predation. The second hypothesis (“the food hypothesis”) centres on the amount and availability of food to the larvae and juveniles: changes in the oceanographic conditions may change the food availability, ultimately impacting larval/juvenile growth, survival and recruitment. The workshop was not able to accept or reject either of these hypotheses: more research is therefore required.

Finally, the workshop examined potential schemes that could be used for generating recruitment forecasts. A high-degree of autocorrelation is present in the time-series, and indeed the assumption that recruitment in the following year is the same as the recruitment in the previous year was found to give relatively good predictions ($r^2=0.57$). However, in the absence of a detailed process understanding, it was not possible to move beyond such basic schemes towards making genuine, knowledge-based, forecasts. Further research may resolve this issue, and the precise mechanics of how such a prediction scheme may work were discussed.

6.1 References

Corten, A., and Lindley, J.A. 2003. The use of CPR data in fisheries research. *Prog Oceanogr* 58:285–300.

- Heino, M., Engelhard, G.H., and Godø, O.R. 2008. Migrations and hydrography determine the abundance fluctuations of blue whiting (*Micromesistius poutassou*) in the Barents Sea. *Fish. Oceanogr.* 17: 153–163.
- ICES. 2009a. Report of the Herring Assessment Working Group for the Area South of 62 N. ICES CM/ACOM:03.
- ICES. 2009b. Report of the Working Group on Widely Distributed Stocks (WGWIDE). ICES CM/ACOM:12.
- Skogen, M. D., Monstad, T., and Svendsen, E. 1999. A possible separation between a northern and a southern stock of the northeast Atlantic blue whiting. *Fisheries Research*, 41: 119–131.
- Tveite, S. 2000. Suitability of a fixed station shrimp abundance survey in the Skagerrak-Norwegian Deeps for stock assessment and associated research. *Journal of Northwest Atlantic Fishery Science*, 27:177–182.

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Annex 2: The Subpolar Gyre Index

Many of the hypotheses presented here revolve around the North Atlantic Subpolar Gyre. The gyre consists of relatively cold and low-saline anticlockwise rotating Subarctic water masses. Such an oceanic structure on the northern hemisphere results in low sea level anomalies, compared to the geoid. When the gyre is anomalously cold, the peripheral fronts between the central Subarctic waters and the warmer surrounding waters of Atlantic origin become tighter – the anticlockwise circulation intensifies. The opposite happens when the gyre is relatively warm. The sea level anomaly (SLA) in the northern North Atlantic is therefore a good proxy for the water mass characteristics, circulation strength and shape of the Subpolar Gyre. By applying Empirical Orthogonal Function (EOF) (Preisendorfer, 1988) analysis to satellite-based SLA observations, Hakkinen and Rhines (2004) have previously demonstrated that the gyre declined throughout the 1990s. The same analysis, but based on simulated SLA data, showed that the 1990s decline was part of decadal to multidecadal variability of the gyre (Hátún *et al.*, 2005). Furthermore, it was shown that the hydrographic variability of the spawning region of blue whiting west of the British Isles was regulated by the strength/shape of the Subpolar Gyre (Hátún *et al.*, 2005).

The update time-series of the gyre index is constructed by merging the model-based and the satellite-based indices. The scaling of the indices is based on a regression analysis between the two time-series over their overlapping period, 1993 to 2003. The satellite-based time-series represents the merged series during this period.

Here we present an updated time-series of the gyre index for future reference.

YEAR	GYRE INDEX	REMARKS
1961	0.0663	Model output
1962	0.0704	Model output
1963	0.0887	Model output
1964	0.1543	Model output
1965	0.1618	Model output
1966	0.2153	Model output
1967	0.1235	Model output
1968	0.1239	Model output
1969	0.1451	Model output
1970	0.0779	Model output
1971	0.0452	Model output
1972	-0.0562	Model output
1973	-0.1055	Model output
1974	-0.1393	Model output
1975	-0.1309	Model output
1976	-0.2016	Model output
1977	-0.0967	Model output
1978	-0.0560	Model output
1979	-0.0064	Model output
1980	0.0491	Model output
1981	0.0985	Model output
1982	0.0823	Model output
1983	-0.0712	Model output

YEAR	GYRE INDEX	REMARKS
1984	-0.1666	Model output
1985	-0.0937	Model output
1986	-0.0975	Model output
1987	-0.0671	Model output
1988	-0.0562	Model output
1989	-0.1466	Model output
1990	-0.2045	Model output
1991	-0.2505	Model output
1992	-0.2228	Model output
1993	-0.3655	Satellite altimetry data scaled to model outputs
1994	-0.5160	Satellite altimetry data scaled to model outputs
1995	-0.4314	Satellite altimetry data scaled to model outputs
1996	-0.0113	Satellite altimetry data scaled to model outputs
1997	0.0839	Satellite altimetry data scaled to model outputs
1998	0.1525	Satellite altimetry data scaled to model outputs
1999	-0.0296	Satellite altimetry data scaled to model outputs
2000	-0.2714	Satellite altimetry data scaled to model outputs
2001	0.1106	Satellite altimetry data scaled to model outputs
2002	0.1060	Satellite altimetry data scaled to model outputs
2003	0.3430	Satellite altimetry data scaled to model outputs
2004	0.2838	Satellite altimetry data scaled to model outputs
2005	0.2002	Satellite altimetry data scaled to model outputs
2006	0.1751	Satellite altimetry data scaled to model outputs
2007	0.1177	
2008	0.0525	

References

- Hátún, H., Sando, A. B., Drange, H., Hansen, B., and Valdimarsson, H. 2005. Influence of the Atlantic subpolar gyre on the thermohaline circulation. *Science*, **309**: 1841–1844.
- Preisendorfer, R. 1988. *Principal Component Analysis in Meteorology and Oceanography*. Elsevier Science Publishing Company Inc., 425 pp.

Annex 3: Recommendations

The assessment model has changed and assessment settings have also been altered in recent years. A consistent assessment method with well defined settings is needed for this stock. This should be examined in detail by the benchmark assessment which is planned for 2011.

There is also a need to investigate other possible recruitment indices. The Barents Sea index shows close correlations with the recruitment estimates that are generated from the assessment. Other surveys which catch juvenile blue whiting should also be examined.