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Variations in the distribution of blue whiting in the Barents Sea: climatic influences or year class effects?

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Blue whiting (*Micromesistius poutassou*) in the Barents Sea represent the north-eastern fringe of the distribution of the species in the Atlantic. Distribution and abundance of blue whiting in the Barents Sea have fluctuated markedly over the past 20 years: in some years, the species appears to be very common and widespread, whereas in other years it is much more scarce and its range appears to become contracted. These variations have at least two potential explanations. First, increases in abundance may be related to variations in the influx or distribution of warm Atlantic water in the area. Second, rich year classes may temporarily expand the distribution area of blue whiting in the Barents Sea (either through direct density effects or climate-recruitment interactions). We investigate these explanations using data from scientific surveys conducted by the Institute of Marine Research during the period 1982-2002. Because of differences in survey coverage, we restrict the analysis to the south-western Barents Sea. Variations in abundance and distribution are correlated with both recruitment and oceanographic conditions. Regression analyses suggest that the variations in abundance are dominated by variations in year class strength, strong year classes leading to high abundance of blue whiting in the study area one or two years later. However, also salinity in the Fugløya-Bear Island –section during the previous year has a significant effect, suggesting that strong inflow of Atlantic water promotes high abundance of blue whiting. Warm years are associated with the centre of gravity of the distribution being more northern and western than during cold years.

Keywords: climate, distribution, recruitment

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1. Introduction

Blue whiting (*Micromesistius poutassou*) is a mesopelagic gadoid that is common and widespread in the north-east Atlantic (Zilanov 1968a, Bailey 1982, Monstad 1990, Heino & Godø 2002). Blue whiting in the north-east Atlantic and in the adjacent seas are currently assessed as a single stock (ICES 2003a). The main spawning areas are along the continental shelf edge west of the British Isles, from where the eggs and larvae are distributed by currents towards north and south. Blue whiting in the Norwegian and Barents Seas are believed mostly to originate from these spawning areas, although the presence of larvae and juveniles shows that spawning also occurs along the coast of Norway (Lahn-Johannesen 1968, Zilanov 1968b).

The Barents Sea represents the northeastern border of the distribution of the species. Population genetic studies suggest the presence of local reproductive units in the Barents Sea (Giæver & Stien 1998). It is, however, poorly understood to what extent blue whiting in the Barents Sea represent local peripheral population(s), or originate from the main spawning areas off the British Isles. Evidence to support the possibility that the latter component is important comes from the fact that unusually high levels of recruitment in the main stock in recent years (ICES 2003a) coincided with relatively high abundance of the species in the Barents Sea (e.g. Aglen et al. 2002). It has also been noted that the distribution of blue whiting is influenced by temperature, cold conditions leading to a westward contraction of the range (Zilanov 1968a).

In this paper we investigate variations in abundance and distribution of blue whiting in the Barents Sea. In particular, we aim at gaining insight on the relative importance of recruitment from the main north-east Atlantic stock and of regional climatic conditions on the occurrence of blue whiting in the Barents Sea.

2. Material and Methods

This study is based on material from "winter surveys" conducted by the Institute of Marine Research (Bergen) in the Barents Sea (Fig. 1). The methods and results of this survey are published annually (e.g. Dalen et al. 1982, Aglen et al. 2002), and have been reviewed by Jakobsen et al. (1997). The survey is a combined acoustic and bottom trawl survey, carried out by 2-3 vessels during a period of 4-6 weeks in late January-early March. Since 2000 also a Russian research vessel has participated in the survey, but these data are not included here. The winter survey is primarily designed to estimate abundance of cod and haddock, but all fish in the trawl samples are sorted, identified to species and weighed and/or counted. In some cases catch weight or numbers of blue whiting were missing; the missing value was then filled by assuming that the fish had weight equal to the average individual weight in the whole data (96 g). The length distributions of blue whiting in the catch have often been measured, but other individual data were seldom collected (in particular, blue whiting have not been aged).

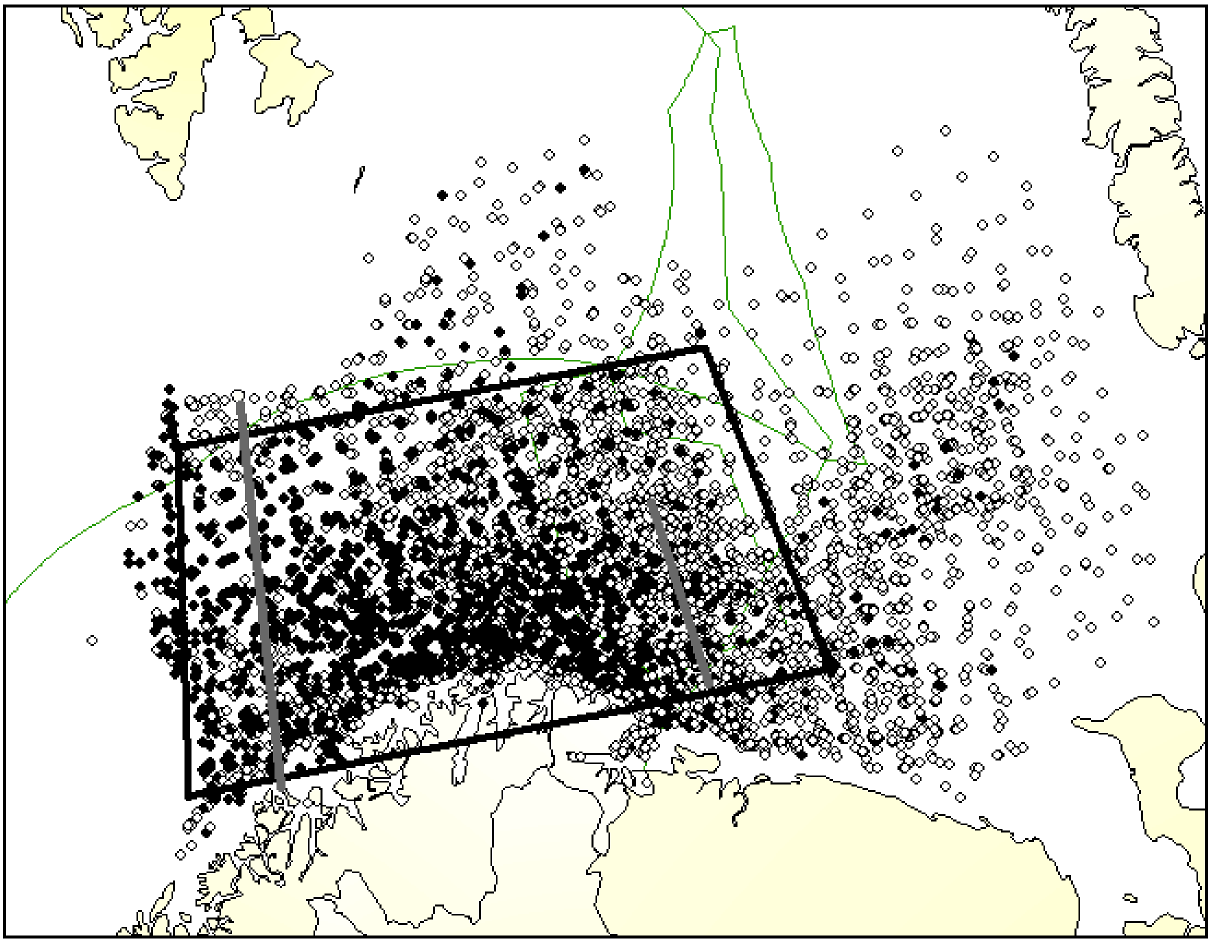

Figure 1. Distribution of survey trawl hauls. Open and closed circles denote trawl hauls without and with blue whiting. The polygon approximately shows the area that has been covered each year. The Fugløya-Bear Island and Kola hydrographic sections are shown in grey.

Here we utilize data from bottom trawl samples collected in 1982-2002. There have been a number of changes in the gear and survey design over this period (see Jakobsen et al. 1997, Aglen et al. 2002). Most notably, towing time (distance) was reduced from 60 min (3 nm) to 30 min (1.5 nm) in 1986, bobbins gear was replaced by rockhopper ground gear in 1989, and mesh size (stretched) in cod-end was reduced from 35-40 mm to 22 mm in 1994. The sampling width has been controlled by "strapping" in some hauls in 1993-1997 and in all hauls later on (see Jakobsen et al. 1997, Aglen et al. 2002). The survey area was expanded northwards in 1993, and the coverage of the Russian zone has been variable.

A large part of the bottom trawl hauls were made in pre-determined positions, whereas the rest were taken more opportunistically to identify acoustic recordings, or in the context of gear experiments or vessel comparisons. We have excluded the latter when they were identifiable in the database. We have also excluded all trawl hauls with abnormal towing distance or problems with the gear. Because original sampling designs are not easily reconstructed, we assume that within the area considered sampling has been effectively random with respect to blue whiting, and calculate abundance measures as simple averages. Individual samples were weighted with catch rates in weight when calculating annual values for mean length and geographic position.

To account for variations in the distribution of effort, we only use data from a geographical rectangle that has been covered every year during the period 1982-2002 (Fig. 1). Within this rectangle the mean sampling position (i.e., mean latitude and longitude of the trawl hauls included in the data) has, nevertheless, varied substantially over the years, between 71.5 °N-72.3 °N and 25.8 °E-29.6 °E. The data selected for the analyses included 4149 trawl hauls. Blue whiting were present in 1878 hauls, and length distributions were available in 1437 in hauls.

Data on recruitment from the "main" north-east Atlantic stock of blue whiting are taken from ICES (2003a,b), where recruitment is given as numbers at the age of 1 year. Recruitment in 2001 is highly uncertain and an estimate for 2002 is not yet available. Variables describing oceanic climate are extracted from databases of the Institute of Marine Research; these data are partly described by Loeng et al. (2003). Temperature and salinity values from the Fugløya-Bear Island –section are annual averages in the 50-200 m depth layer. Kola temperature is an annual average in the 0-200 m depth layer. Ice index describes ice conditions during winter and summer; large positive values indicate limited ice cover.

Model selection in regression analyses was performed by starting from a model with all considered explanatory variables but with no interactions. For example, for catch rates a model of the following form was considered:

log(catch rate)~Environment1+Environment2+…+Recruitment

An automatic selection procedure (function stepAIC by Venables & Ripley 2002) was then used to find the model that minimized the Akaike Information Criterion (AIC). This generally yielded a simpler model that contained parameters that could be removed without making the fit significantly (P>0.05) worse as judged by F-test comparing nested models. Such parameters were eliminated, one by one, by removing the parameter that resulted in the lowest increase in AIC. For catch rate in numbers, the resultant model was:

$\log(\text{catch rate}_{\text{year } t}) \sim \text{Salinity}_{\text{year } t-1} + \text{Recruitment}_{\text{year } t}$

Finally, it was checked whether adding interactions would improve the fit. The adequacy of the resultant models was checked using usual model checking procedures (Venables & Ripley 2002)

3. Results

Abundance and distribution

Catch rate per nautical mile aggregated over the whole data is 2.12 kg/nm or 45.5 individuals/nm. The incidence of blue whiting in the trawl catches (i.e., proportion of catches with blue whiting) is about 45%. There are large annual fluctuations that overlay a weak but statistically significant positive trend (Fig. 2). Catch rates in terms of both numbers and biomass display more marked increasing trends (Fig. 3). However, there are also strong fluctuations that appear periodic. For reference, recruitment in the Atlantic stock of blue whiting is shown in Fig. 2.

We measure distribution of blue whiting by calculating the centre of gravity of the distribution, with sampling positions weighed with catch rates (in kg/nm). Blue whiting show a marginally more southern and substantially more western distribution than the sampling effort: the centre of gravity for blue whiting is at 71.8 °N and 22.9 °E, and for sampling at 72.0 °N and 28.0 °E. The centre of gravity displays strong annual variations, ranging between 18.1 °E and 27.9 °E in the east-west direction and between 71.2 °N and 73.1 °N in the north-south direction (Fig. 4). These variations are stronger than those in the distribution of effort (71.6 °N-72.3 °N and 25.8 °E-29.6 °E).

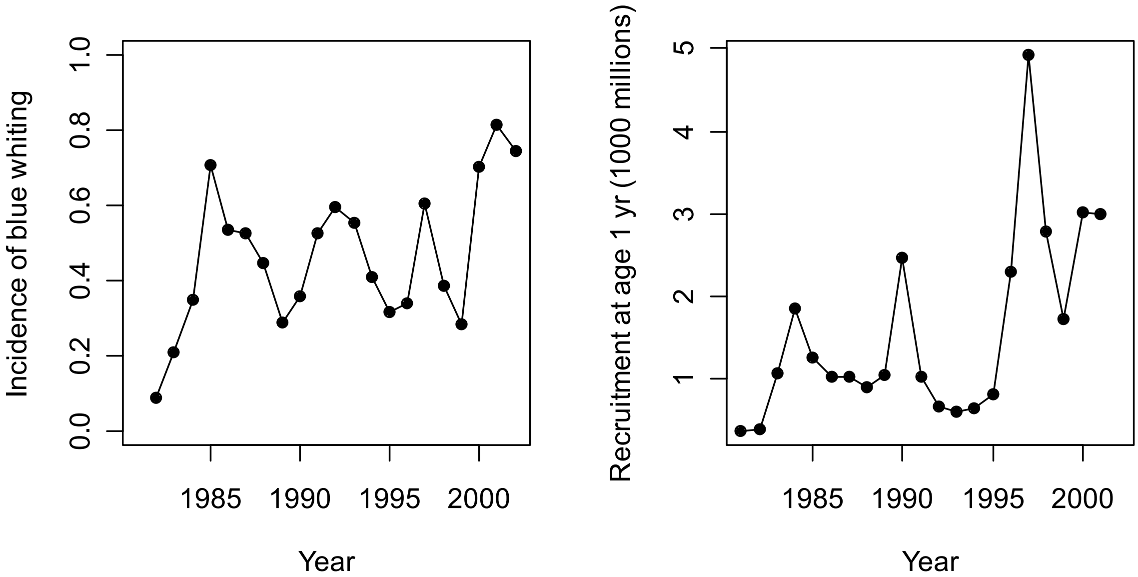

Figure 2. Incidence of blue whiting in trawl catches. Panel on the right shows recruitment in the Atlantic stock of blue whiting in 1981-2001 as given in ICES (2003a,b).

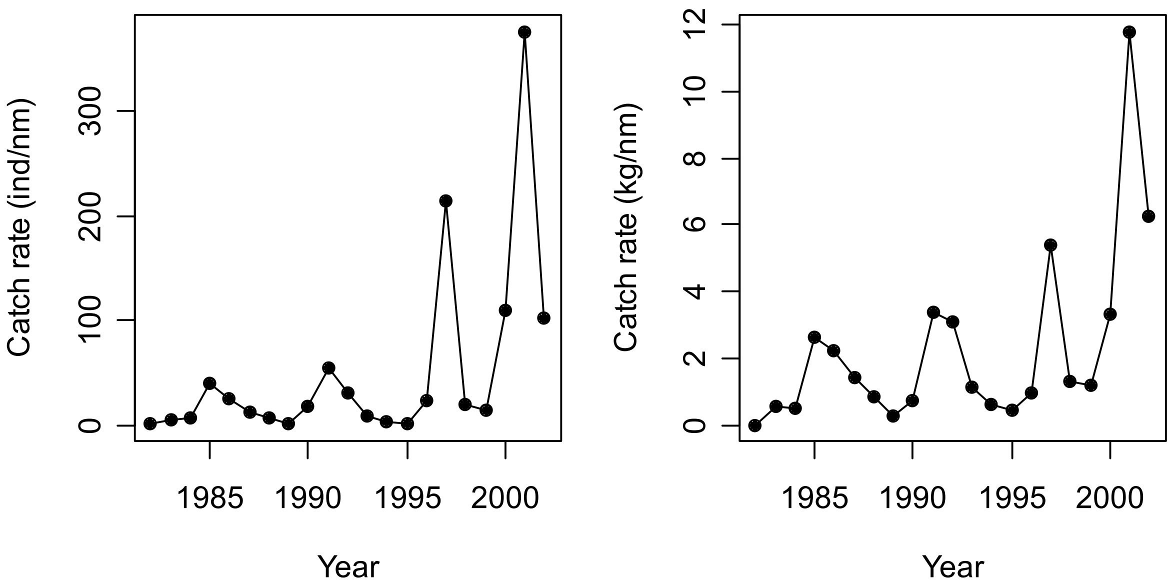

Figure 3. Average catch rates of blue whiting in bottom trawl hauls.

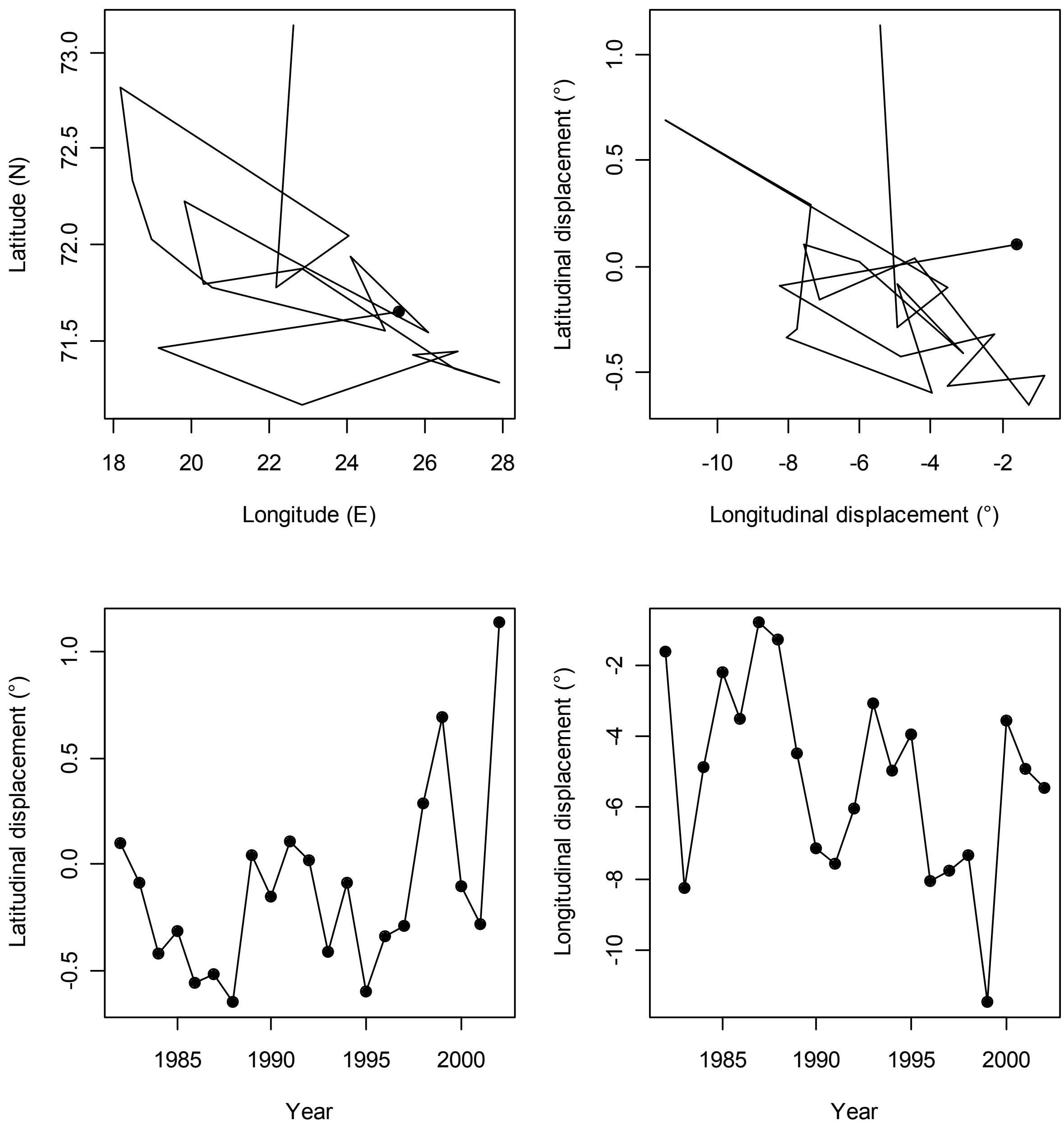

Figure 4. Centre of gravity of distribution of blue whiting, and the position of this centre relative to the centre of gravity of sampling (top row). The point corresponding to the first year in the time series is shown with a dot. The bottom row shows annual displacements.

Abundance and distribution in relation to recruitment

Abundance of blue whiting in the Barents Sea and recruitment in the north-east Atlantic stock both display positive trends. Therefore it is not unexpected that there tends to be a significant positive correlation between recruitment in the Atlantic and measures of abundance in the Barents Sea (Table 1). For catch rates the correlation is strongest without a time lag. In the detrended data, the correlations are smaller and generally insignificant, except for the correlation between recruitment and catch rate in numbers.

Correlations suggest that high levels of recruitment in the Atlantic are associated with a more northern distribution in the Barents Sea at a time lag of two years (Table 2). There is also a slight indication that high levels of recruitment are associated with a more western distribution.

In absence of age measurements, data on length distributions can give information on age structure. Mean length weighted with catch rate in weight displays strong fluctuations, often characterised by a sudden drop in mean length followed by a more gradual increase (Fig. 5). The minima in mean length correspond to years of strong recruitment in the Atlantic stock, and the time series shows a strong negative correlation (raw and detrended data: r_p=-0.769 and r_p=-0.721, respectively).

Table 1. Correlations (r_p) between recruitment of blue whiting in the Atlantic and abundance in the Barents Sea. Correlations different from zero at P<0.05 are shown in bold.

	Raw data			Detrended data		
	Incidence	Catch rate		Incidence	Catch rate	
		ind./nm	kg/nm		ind./nm	kg/nm
Recruitment, year t	0.36	**0.66**	**0.52**	0.18	**0.51**	0.34
Recruitment, year t-1	0.41	**0.45**	**0.52**	0.17	0.19	0.27
Recruitment, year t-2	0.23	0.12	0.24	0.03	0.19	-0.08

Table 2. Correlations (r_p) between recruitment of blue whiting in the Atlantic and displacement of the distribution in the Barents Sea relative to the sampling effort. Correlations different from zero at P<0.05 are shown in bold.

	Raw data		Detrended data	
	Displacement		Displacement	
	Latitudinal	Longitudinal	Latitudinal	Longitudinal
Recruitment, year t	0.07	-0.40	-0.11	-0.21
Recruitment, year t-1	**0.52**	-0.38	0.35	-0.19
Recruitment, year t-2	**0.68**	-0.33	**0.55**	-0.19

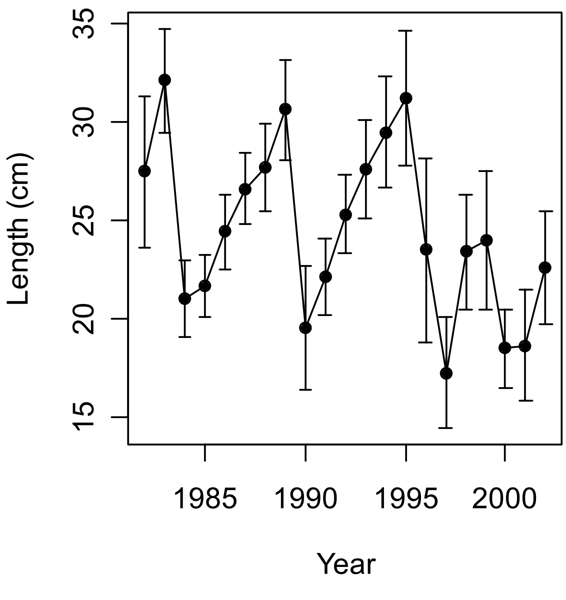

Figure 5. Mean length of blue whiting in survey hauls weighted with catch rate in weight. Vertical bars show mean standard deviation of length in individual hauls.

Abundance and distribution in relation to environment

Variables describing climatic conditions 1-2 years earlier show positive correlations with measures on the abundance of blue whiting (Table 3). The correlations are generally the strongest with incidence, while the correlations with catch rate in numbers are low and mostly insignificant. All correlations suggest that warm conditions are associated with high abundance. Warm temperatures on the Fugløya-Bear Island –section are correlated with more northerly and more westerly distribution in the same year (Table 3).

Table 3. Correlations between environmental variables and blue whiting abundance.

	Incidence	Catch rate		Displacement	
		ind./nm	kg/nm	Latitudinal	Longitudinal
Fugløya-Bear Island temperature, year t	0.09	0.02	0.06	**0.54**	**-0.52**
Fugløya-Bear Island temperature, year t-1	0.42	0.22	0.30	0.11	-0.34
Fugløya-Bear Island temperature, year t-2	**0.69**	**0.44**	**0.55**	0.03	0.02
Fugløya-Bear Island salinity, year t	-0.09	-0.01	0.12	0.22	-0.16
Fugløya-Bear Island salinity, year t-1	**0.48**	-0.02	0.17	-0.04	0.21
Fugløya-Bear Island salinity, year t-2	**0.48**	0.07	0.19	-0.38	**0.49**
Kola temperature, year t	0.25	0.17	0.22	0.33	-0.34
Kola temperature, year t-1	**0.54**	0.33	**0.44**	0.07	-0.18
Kola temperature, year t-2	**0.65**	0.29	**0.45**	0.09	0.09
Ice index, year t	0.42	0.39	**0.47**	0.16	-0.19
Ice index, year t-1	**0.74**	0.33	**0.50**	-0.05	0.23
Ice index, year t-2	**0.49**	0.24	0.37	-0.11	0.27

Regression models on abundance and distribution

To simplify model selection, we consider only a subset of potential explanatory variables. We omit the Kola temperature because it is strongly correlated with temperature in the Fugløya-Bear Island –section. For regression models explaining abundance, we consider only recruitment at the year of observation and one year earlier, and climatic variables one and two years earlier, as correlation analyses suggested that other delays are less relevant. For regression models explaining distribution, we consider recruitment at the year of observation and 1 and 2 years earlier, and climatic variables at the year of observation.

The final regression models for abundance include recruitment in the Atlantic stock and salinity in the Fugløya-Bear Island –section for all three measures of abundance (Table 4). The quantitative effect of recruitment is stronger than that of salinity. All models can explain large proportions of variability in the abundance data. Displacement of the centre of gravity in blue whiting distribution is explained by temperature in the Fugløya-Bear Island –section, and for latitudinal displacement, also by recruitment two years earlier (Table 5). The regression model captures the variations in latitudinal distribution reasonably well, but a larger part of variability in longitudinal displacement remains unexplained.

Table 4. Regression models on blue whiting abundance. Model on incidence is a logistic regression. Catch rates were log-transformed. R^2 gives the proportion of variability in abundance data that is explained by the model either in terms of deviance (D) or sum of squares (SS). b refers to parameter estimates, assuming that recruitment is measured in 10^{12} individuals and salinity in ppt.

	Incidence			Catch rate, ind./nm			Catch rate, kg/nm		
	D	b	P	SS	b	P	SS	b	P
Recruitment, year t	366	0.057	<0.001	45.4	0.147	<0.001	21.2	0.103	<0.001
Salinity, year t-1	247	20.5	<0.001	21.6	48.8	<0.001	9.04	34.3	<0.001
Salinity, year t-2	223	16.5	<0.001				3.10	18.2	0.018
R^2 (adjusted)	82.1%			82.8% (80.8%)			79.9% (76.1%)		

Table 5. Regression models on blue whiting distribution, measured relative to the sampling effort. Displacement is measured in degrees. For other explanations, see Table 4.

	Latitudinal displacement			Longitudinal displacement		
	SS	b	P	SS	b	P
Temperature, year t	0.427	0.424	0.006	36.2	-3.81	0.022
Recruitment, year t-2	0.604	0.017	0.002			
R^2 (adjusted)	65.4% (61.1%)			27.1% (22.8%)		

4. *Discussion*

Our results show that the distribution and abundance of blue whiting in the Barents Sea is significantly influenced both by recruitment in the Atlantic stock and by climatic conditions. The overall abundance is more strongly affected by recruitment than by climate, whereas the picture is less clear-cut with respect to the distribution. Our results also suggest that blue whiting from the “main” Atlantic stock numerically overshadow the possible local stock components in the study area covering south-western parts of the Barents Sea.

The interpretation of our results is potentially complicated by several changes in survey methodology (Jakobsen et al. 1997). As blue whiting is not closely associated with the sea bottom, the change from bobbins to rockhopper ground gear is unlikely to significantly affect the results here. The decrease in tow time in 1986 is likely lead to a modest underestimation of incidence of blue whiting relative to the earlier years as many trawl samples contain only single blue whiting. The decrease in mesh size in the cod-end in 1994 probably had an opposite effect by increasing retention of blue whiting. In summary, a number of changes in gear have taken place over the years, but it is impossible to evaluate the effect of these quantitatively. No abrupt changes in the studied time series seem to be associated with these changes.

The abundance of blue whiting seems to be strongly influenced by the strength of the year class one to two years earlier. The two first peaks in survey catch rates, 1985 and 1991, occurred one year after peaks in recruitment (and thus two years after the cohort was formed – recall that recruitment in blue whiting refers to age of one year). In 1997 there is a peak both in catch rates and in recruitment. The record-high peak in survey catch rates in 2001 cannot yet be compared to the recruitment estimate from the official ICES assessment (ICES 2003b), although an alternative assessment (ICES 2003a) and some other information suggest that recruitment was indeed very high in that year. Thus the two first peaks correspond to strong year classes entering the Barents Sea at the age of 2 years, whereas the two latter correspond to strong year classes entering the Barents Sea at the age of 1 year. Is this change in the time of entry to the Barents Sea real, or is it caused by the change to trawls with smaller mesh sizes after 1993? Examining the mean length of blue whiting supports the latter alternative (Fig. 5) – pronounced dips in mean length correspond to strong year classes the year before. It is, however, perplexing why the incoming strong year class did influence the mean length in 1984 and 1990, but did not significantly influence catch rates.

Of the environmental variables describing climatic conditions in the Barents Sea, salinity entered the final regression models explaining the abundance of blue whiting, but temperature or ice index did not. This suggests that, rather than temperature *per se*, the occurrence of blue whiting is more strongly influenced by strong inflow of warm Atlantic water with high salinity. Influence of ocean climate on dynamics of the fish resources in the Barents Sea is in general terms fairly well known (Loeng 1989, Helle & Pennington 1999, Ottersen & Loeng 2000), but our study is, to our knowledge, the first demonstration of such effects in blue whiting in the Barents Sea.

Our results that warm conditions are associated with a more westerly distribution seem to contradict earlier statements that cold conditions lead to a range contraction towards west (Zilanov 1968a). However, one should also note that we did not study the changes in range, but in centre of gravity of distribution – these two aspects of distribution need not to display similar dynamics. For example, it is possible that the centre of gravity is primarily determined by the occurrence of blue whiting from the "main" Atlantic stock in the study area. In years when those fish are present in low numbers, the centre of gravity may be more strongly influenced by "resident" blue whiting, which supposedly have a more eastern distribution. If this interpretation is correct, our results thus support the population genetic studies that indicate that the Barents Sea hosts a stock component that is partially separated from the main Atlantic stock (Giæver & Stien 1998). However, abundance fluctuations of blue whiting in the Barents Sea are largely determined by the presence of the Atlantic stock component, which seem to numerically overshadow the local stock component. These hypotheses could be explored by more detailed analyses on age- and spatial structure of blue whiting in the Barents Sea.

One of the problems in blue whiting assessment is the scarcity of data that could be used to estimate strength of year classes before they become vulnerable to the fishery. Our results here suggest that data from the winter survey in the Barents Sea conducted by Norway, recently jointly with Russia, could contribute to filling this gap. Both abundance estimates and length distributions appear to provide information on year class strength 1-2 years after spawning. Unfortunately current abundance data are not age-disaggregated. We will therefore encourage systematic age sampling in coming years for making age-disaggregated abundance estimates available for blue whiting assessments.

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