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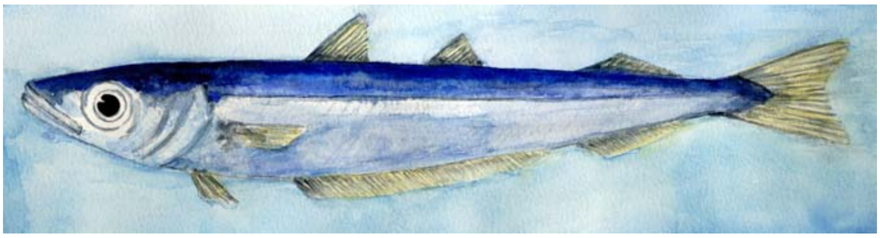

BLUE WHITING SURVEY DURING SPRING 2005

by

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Introduction

During the period March 11–April 15 R/V G. O. Sars surveyed the main spawning areas of blue whiting (*Micromesistius poutassou*) west of the British Isles. The survey is a continuation of a series of surveys that goes back to the 1970's. The Northern Pelagic and Blue Whiting Fisheries Working Group (and its predecessors) has used the data from 1981 onwards for tuning the stock assessment (e.g., ICES 2004a). This survey represents the longest continuous time series (only broken by a couple of years) on abundance and distribution of this stock, and as such, is also an important contributor to knowledge and information about stock dynamics in general.

The Norwegian blue whiting survey in 2005, as in the previous year, was part of the international blue whiting spawning stock survey. In addition to G. O. Sars, five other vessels participated in the survey: R/V Atlantniro (AtlantNIRO, Kaliningrad, Russia), R/V Celtic Explorer (Marine Institute, Ireland), R/V Fridtjof Nansen (PINRO, Murmansk, Russia), R/V Magnus Heinason (Faroese Fisheries Laboratory, the Faroes) and R/V Tridens (Netherlands Fisheries Research Institute, the Netherlands). The results of the international survey, including inter-calibrations among vessels, are presented in a separate report (see Heino at al. 2005).

Coordination of the international blue whiting spawning stock survey was initiated in the meeting of the Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys (PGNAPES; formerly Planning Group on Surveys on Pelagic Fish in the Norwegian Sea) in August 2004 (ICES 2004b). In the recent years the Norwegian survey has been providing the only regularly updated tuning time series in the blue whiting assessment. Too drastic changes in this survey could jeopardize the value of this survey in tuning the stock assessment, and the coverage of the Norwegian survey was therefore kept broadly similar. We can therefore consider the survey in 2005 being comparable to the earlier Norwegian blue whiting surveys.

The main purpose of the survey is to assess the abundance of blue whiting in the surveyed area using acoustic assessment methodology. This report documents the main results of the survey with the focus on the assessment of stock abundance and hydrography. The special task this year was to continue investigations on acoustic target strength of blue whiting started in 2002. Overview of target strength measurements as well as other investigations that are not part of the regular survey are presented in appendices.

Material and methods

The cruise tracks of G. O. Sars are shown in Figure 1. Starting from 2004, the traditional zig-zag design along the shelf edge has been replaced with a more systematic approach. In comparison to most earlier years, coverage in the south was more restricted and coverage in the west–northwest more extensive. Bad weather during the first week of the survey lead to slight reduction in the coverage in the south, while bad weather towards the end of the survey hampered the work with target strength measurements.

The acoustic survey was conducted with Simrad EK 60 echosounder using 38 kHz as the primary frequency and 18 kHz as secondary frequency; also data from 70, 120 and 200 kHz transducers were logged. 38 kHz sounder was controlled by a standard sphere calibration (Foote et al. 1987) some 2 weeks before the survey, and the calibration in the end of the survey revealed no significant changes. The 38 kHz echosounder was used for the assessment, and differences between the two frequencies were used during the scrutinizing process to improve separation of blue whiting from other acoustic scatters. The acoustic recordings were scrutinized once or twice a day using the Bergen Echo Integrator (BEI, Foote et al. 1991). Blue whiting was separated from other recordings using catch information, characteristics of the recordings, and frequency response between 18 and 38 kHz integration. The main settings of the acoustic instruments are given in Appendix 1.

The main sampling tool for identification of the acoustic recordings and for representative biological sampling of the population was a 486 m circumference pelagic trawl (Åkra trawl); this is the same pelagic trawl as used in earlier years. The rigging, detailed in Appendix 2, gave vertical opening of about 25-30 m at trawling speed of about 3.5 knots. In addition, a new, larger version of Åkra trawl with 586 m circumference was used on few stations. Large commercial blue whiting trawl (Egersund trawl) with 1200 m circumference was used on one station.

The normal pelagic trawl (486 m circumference Åkra trawl) was equipped with multi-sampler with three codends that could be opened consecutively. In most occasions, the multi-sampler was used to obtain two replicate samples from a single standard trawl haul by splitting the towing time in two periods. In some occasions, a third replicate sample was taken from either the same depth as the previous two or higher up from the water column.

Catch from the trawl hauls was sorted and weighed; fish were identified to species whenever possible and other taxa to higher taxonomic levels. Saithe and *Scopelogadus beanii* were measured for length and weight. Normally a sub-sample of 50 blue whiting were sexed, aged, and measured for length and weight, and their maturity status, stomach content, parasite load and liver size were estimated (Fotland et al. 2000). An additional sample of 50–150 fish was measured for length and weight. Special morphological measurements were carried out for the first 10 fish in a sample. Tissue samples for genetic analyses were taken during the first half of the cruise. All cephalopods were preserved and measured for weight and mantle length during or after the survey.

The acoustic data as well as the data from trawl hauls were analysed with BEAM (Totland and Godø 2001) to make estimates of total biomass and numbers of individuals by age and length in the whole survey area and within different sub-areas (i.e., the main areas in the terminology of BEAM). Strata of 1º latitude by 2º longitude were used. The area of a stratum was adjusted, when necessary, to correspond with the area that was covered representatively by the survey track. This was particularly important in the shelf break zone where high densities of blue whiting dropped quickly to zero at depths less than 200 m. The shallow areas were normally not covered, and these were then excluded from the analysis.

To obtain an estimate of length distribution within each stratum, samples from the focal stratum were used. If the focal stratum was not sampled representatively, also samples from the adjacent strata were used. In such cases, only samples that represented a similar kind of registration that dominated the focal stratum were included. Because this includes a degree of subjectivity, the sensitivity of the estimate with respect to the selected samples was crudely assessed by studying the influence of these samples on the length distribution in the stratum. In contrast to 2004, length frequency distributions from each sample were not weighted with the numbers of fish measured in that sample. The number of fish in the stratum is then calculated from the total acoustic density and the length composition of fish.

The methodology is in general terms described by Toresen et al. (1998). More information on this survey is given by, e.g., Anon. (1982) and Monstad (1986). Traditionally the following target strength (TS) function has been used:

$$TS = 21.8 \log L - 72.8 \text{ dB},$$

where L is fish length in centimetres. For conversion from acoustic density (s_A, m^2/n.mile^2) to fish density (ρ) the following relationship was used:

$$\rho = s_A / \langle\sigma\rangle,$$

where $\langle\sigma\rangle = 6.72 \cdot 10^{-7} L^{2.18}$ is the average acoustic backscattering cross section (m^2). The total estimated abundance by stratum is redistributed into length classes using the length distribution estimated from trawl samples. Biomass estimates and age-specific estimates are calculated for main areas using age-length and length-weight keys that are obtained by using estimated numbers in each length class within strata as the weighting variable of individual data.

BEAM does not distinguish between mature and immature individuals, and calculations dealing with only mature fish were therefore carried out separately after the final BEAM run. Proportions of mature individuals at length and age were estimated for each sub-area separately with logistic regression by weighting individual observations with estimated numbers within length class and stratum (variable 'popw' in the standard output dataset 'vgear' of BEAM). The estimates of spawning stock biomass and numbers of mature individuals by age and length were obtained by multiplying the numbers of individuals in each age and length class by estimated proportions of mature individuals. Spawning stock biomass is then obtained by multiplication of numbers at length by mean weight at length; this is valid assuming that immature and mature individuals have the same length-weight relationship.

We divided the surveyed area in four sub-areas similarly as in previous years (cf. Fig. 5).

The hydrographical situation in the surveyed area was mapped by a net of 91 CTD stations (Figure 2), including east–west sections at the western shelf edge of the Porcupine Bank at latitude 53° 30'N and between the Hebrides–Rockall at 57° 30'N, and a section from The Faroes to Shetland (i.e. the Nolsø–Flugga section). The salinity data presented in this report are not calibrated. The CTD data will be calibrated and subject to final quality control after the cruise. In addition, surface (~4m) temperature, salinity were recorded continuously along the complete track of the cruise using a ship-mounted thermosalinograph (SBE21).

To study the distribution and development of blue whiting larvae and eggs, plankton samples were collected at about every second CTD stations (Fig. 2) by use of a plankton dip-net (80 cm diameter) lowered to 200 m depth. The samples were immediately fixed in 4 % buffered formaldehyde. Eggs and larvae were counted and identified to species. Blue whiting, mackerel and horse mackerel eggs were classified into developmental stages and larvae were measured for length; for blue whiting the classification of developmental stages followed the scheme adopted from Seaton & Bailey (1971).

Results

Fish and cephalopod taxa recorded during the survey are listed in respectively Appendix 3 and Appendix 4. Comparisons between different pelagic survey trawls on G. O. Sars as well as between two commercial fishing vessels are presented in Appendix 5. Appendix 6 gives a brief analysis of variability in length distribution between replicate samples obtained with the multi-sampler. Results from the target strength investigations are presented in Appendix 7.

Distribution of blue whiting

Blue whiting were recorded in most of the survey area that covered about 93,000 square nautical miles (Fig. 3). The highest concentrations were recorded in a very rich aggregation southwest from the Rosemary Bank. Apart from this patch, aggregations were generally relatively small, and no areas of continuous good registrations were encountered. The shelf break off Hebrides, an area that traditionally has hosted rich aggregations, had only moderate to low densities of blue whiting. The highest recordings were observed at depths of 450–600 m, sometimes extending to around 300 m depth on the slope areas and north from the Wyville–Thompson Ridge. Loose layers of blue whiting in the upper parts of the water column (mostly juveniles) were observed only in the eastern parts of the Faroes sub-area.

When interpreting the results on the distribution and abundance, one should bear in mind that distribution of blue whiting is highly dynamic because of migrations in to and out from the spawning area. The survey in 2005 took place rather early, about one week earlier than in most years recently, but more than two weeks earlier than in 2003. This might explain why densities were relatively low in the Faroes/Shetland area where large aggregations are often found after spawning is completed.

Stock size

The estimated total abundance of blue whiting for the 2005 Norwegian survey was 8.5 million tonnes, representing an abundance of 95×10^9 individuals (Table 1). The geographical distribution of biomass by stratum is shown in Figure 4. The stock estimate obtained in 2005 is significantly smaller than in 2002–2004, both in terms of numbers and biomass. Virtually all fish were estimated to be mature, and the spawning stock is thus only marginally smaller than the total stock in the area.

The table below shows the Norwegian acoustic survey estimates of blue whiting in the spawning area since 1990. These numbers are not corrected for variation is spatial coverage.

Year	Abundance, 10^9 individuals		Biomass, mill. tonnes		Mean weight,	Mean length,
	total	spawning	total	spawning	g	cm
1990	63	56	6.3	5.7	101	27.1
1991	42	41	5.1	4.8	116	27.8
1992	38	37	4.3	4.2	111	27.5
1993	42	40	5.2	5.0	125	28.6
1994	27	26	4.1	4.1	153	31.1
1995	62	45	6.7	6.1	108	26.9
1996	52	36	5.1	4.5	94.9	25.5
1997						
1998	80	57	5.5	4.7	68.3	23.2
1999	120	110	8.9	8.5	74.4	25.0
2000	102	90	8.3	7.8	80.7	25.5
2001	97	72	6.7	5.6	69.0	24.1
2002	176	147	12.2	10.9	69.3	24.2
2003	160	132	11.4	10.4	71.6	24.6
2004	137	128	11.4	10.9	83.2	26.1
2005	95	93	8.5	8.5	90.2	27.0

The biomass estimates for the Hebrides sub-area were approximately unchanged with that sub-area hosting by far the largest part of the estimated stock biomass. However, the geographic distribution of the biomass within that sub-area was very different with relatively weak shelf break aggregations and one very large aggregation far offshore.

In the Faroes/Shetland area, biomass estimate was greatly reduced. This is probably a reflection of timing of the survey as it is the aggregations of post-spawning fish that make the largest contribution to the biomass in this sub-area. Would the Faroes/Shetland area have been covered some two weeks later, the aggregation off Rosemary Bank (in the Hebrides sub-area) would probably have moved to this sub-area (with the effect of reducing the estimate for the Hebrides sub-area).

Biomass estimate in the Rockall area in this year was somewhat less than in 2004. However, coverage in this area has varied greatly from year to year, making comparisons difficult. In most years, the area has been covered when the commercial fishery had moved away from the area. This year, there were still many vessels in the area, although they reported low catch rates. Earlier on in this season, good catch rates were reported further west.

The amount of blue whiting in the Porcupine Bank sub-area was rather low, in particular when compared to 2004 when almost three times as much biomass was recorded with a similar spatial coverage. In comparison to earlier years, the estimate is rather low but not unusual.

Stock composition

Year class 2000 (age 5 years) continues, albeit with a narrow margin, to be the most abundant year class in the stock, both in terms of biomass and numbers (Table 2, Fig. 5). This was also the dominant year class in 2002–2004, and appears for fourth year in row as the strongest one in record for its age. Its abundance has been reduced by some 37% from 2004, the year when it presumably was fully recruited to the spawning stock. Year class 2001 is currently almost as abundant as year class 2000, although much less abundant than that year class at the same age. Blue whiting of age 3 years makes also a significant contribution (~17%) although it is relatively weak for its age. Year classes 1999 and before lumped together make a similar contribution.

There is considerable variability in age structure among the four sub-areas (Figure 6). Year class 2000 is dominating by a small margin in the Hebrides, whereas year class 2001 is equally abundant in the Rockall sub-area and is dominant in the Faroes/Shetland sub-area. In the Porcupine Bank sub-area it is year class 2002 that dominates. This picture is consistent with the one observed in 2003–2004, with the Hebrides sub-area hosting the oldest fish and the Faroes/Shetland and Porcupine Bank sub-areas the youngest.

Mean length and weight of blue whiting in the survey area continue to increase (see the text table above), largely reflecting the increase in the average age and the continued dominance of year class 2000. Condition of young blue whiting was somewhat worse and that of old fish somewhat better than in 2004 (Table 2). These changes are mostly caused by changes in weight-at-age.

Eggs and larvae

Plankton samples were taken on 50 stations. Blue whiting was the most numerous species among both fish larvae and eggs. Distribution of blue whiting eggs shows no obvious spatial patterns (Fig. 7). Eggs in all developmental stages were encountered without obvious dominance of any stage.

Sample distributions were highly skewed with a few samples containing most of the individuals. Mean numbers of eggs and larvae per sample (with standard deviations) measured in 2001–2005 are the following:

Year	Blue whiting		Mackerel		Horse mackerel	
	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
2001	6.7 (37)	**72.9** (207)	**23.8** (62)	0.20 (0.78)	0.46 (1.4)	0.049 (0.31)
2002	1.7 (4.6)	**21.9** (48)	**27.8** (98)	0.34 (1.2)	5.3 (30)	0.054 (0.30)
2003	**16.5** (67)	**176** (703)	**20.3** (50)	7.5 (30.3)	2.7 (7.2)	0.043 (0.21)
2004	4.5 (11)	**9.8** (29)	1.5 (8.8)	0 (0)	0.14 (0.77)	0.023 (0.15)
2005	3.7 (18.4)	0.38 (1.4)	3.7 (19)	0 (0)	0 (0)	0 (0)

Boldface is here used to mark abundances that are significantly ($p<0.05$) different from the abundance in 2005 as estimated by generalized linear models with logarithmic link and negative binomial error functions.

Abundance of blue whiting larvae was the lowest one recorded in this short time series. In comparison to years 2001—2004, this difference is statistically significant. The number of eggs was low but not as low as in 2002. The numbers of mackerel eggs were low, and not a single mackerel larva or horse mackerel egg or larva was observed. However, interpretation of these changes is difficult because of the short time series, variation in timing of the surveys, and highly aggregated distribution of ichthyoplankton. That all components of ichthyoplankton were rare suggests a common explanation. In terms of hydrography (see the Hydrography section below), 2005 is not very different from 2004 or years before. A plausible explanation is timing of the survey. The survey in 2005 was conducted rather early, in particular when compared to the record year 2003 when the survey was very late (the difference is about two weeks). No reliable, independent information exists on the strength of these year classes at later stages. It is thus not possible to say whether the observed rarity of ichthyoplankton is genuine, or caused by changes in sampling in relation to season or distribution of ichthyoplankton.

Cephalopods

During the period March 29 to April 15, 40 specimens of squid and octopods were caught by means of multisampler and medium-sized Åkra-trawl (species list see Appendix 4). More than 40 % of the specimens caught were however retrieved from meshes of the fore net rather than the codend.

Most specimens were identified to species and morphological measurements i.e. dorsal mantle length (DML, mm) and weight (g) were recorded. Of the 11 species identified the majority of specimens (48 %, n = 18) belonged to species *Histioteuthis hoylei*. This species is more commonly reported from tropical and subtropical waters but has previously been found in boreal waters associated with the Gulf Stream. The North Atlantic current, which is fed by the Gulf Stream, strongly influences the investigation area and might be responsible for the occurrence of *H. hoylei* in present catches.

Todarodes sagittatus and *Gonatus* sp. are common species in North East Atlantic waters and are frequently encountered in mesopelagic layers off the continental shelf. All remaining species have previously been found in Northern Atlantic waters in small numbers.

Two species of octopods and three juvenile specimens of squid remain to date unidentified but will be sent out to specialists for possible identification.

Muscle tissue samples of all squid collected will be analysed for stable isotope ratios in connection with a feeding study on sperm whales in North Atlantic waters. Stable isotopes of cephalopod beaks will be measured to gain further information on habitat use of midwater cephalopod species.

Hydrography

The horizontal distribution of temperature at 10 and 400 meters depths are shown in Figures 8 and 9, respectively. The maps are based on data collected on board G. O. Sars (Figure 2) and CTD data kindly provided by the scientists on board R/V Fridtjof Nansen who were running simultaneous surveys in the area. The cooperation has given a much better horizontal coverage of the area.

The Wyville Thompson ridge (~60°N) divides the survey area into two very different hydrographic regimes. South of the Wyville Thompson ridge the vertical gradients in temperature are small. In this area the differences in the temperature between 10m and 400m are less than 1°C. At 1000m depth the temperatures are between 6°C and 9°C, with the lowest temperatures at the Porcupine section (Figure 10) and in the north west. In the Faroe–Shetland channel the situation is very different with a strong thermocline around 500m depth separating a layer of warm saline Atlantic water overlying cold (~ -0.5°C), deep waters originating in the Norwegian Sea (See Figure 11, Faroe–Shetland section).

Also the horizontal gradients are generally very small in the area south of the Wyville Thompson ridge, in particular, the north–south gradient is very small. In the Rockall Through the temperature drops by less than 2°C from 50°N to 60°N both at 10m and 400m depths (Figures 8 and 9). Due to a northward flowing shelf edge current, it is along the shelf edge that the warm saline penetrates furthest to the north.

Just as the last few years, this year's temperatures were above 11°C in the southern part of the area. Both this year and in 2004 the 10°C isotherm extended north to about 58°N. The warmest water in the Faroe–Shetland channel was just above 9°C. At 400m depth south of the Wyville Thompson ridge, the horizontal temperature distribution shows a cooling trend compared to last year (the 10°C isotherm extends north to about 58°N this year compared to 60°N in 2004.)

At the Porcupine section (Figure 10) the temperature is quite homogeneous down to about 500m with a gradual change in the thermocline between 500m and 1000m. The most conspicuous feature this year is the intrusion of fairly low salinity water at the outermost station on the section (station 152). The salinities are about 0.2 lower than on the neighbouring station down to about 1000m, and this is a large difference.

On the Faroe–Shetland section (Figure 11) there is a characteristic wedge shaped core of Atlantic water on the eastern slope, but the Atlantic water occupies the upper hundred meters across the whole channel. Below the Atlantic water, cold and low salinity (S<34.90) intermediate (S<34.90) water of Norwegian Sea origin extending up to about 500m. The 0°C isotherm is found at 600m depth at the western side, 500m central in the channel and it slopes downward to nearly 700m at the eastern side. This is about the same depth as last year, but shallower than in 2003. The temperature and salinity (S<34.4) in the core of the Atlantic water are lower than last year, and this a continuation of a cooling and freshening seen last year compared to the record warm and saline water in 2003.

Based on the hydrographic observations obtained during the blue whiting surveys, the mean temperature and salinity from 50 to 600m of all the stations in deep water (bottom depth>600m) in 2° latitude times 2° longitude boxes has been calculated for each survey. The box with limits 52° to 54°N and 16° to 14°W had few gaps, and the time series of mean temperature and salinity for this box is shown in figure 12. The pattern seen is that after some years with temperatures around 10.1°C in the 1980s, it dropped to a minimum in 1994 (~9.8°C). After 1994 an increase in temperature is seen, and in 1998 temperature reached a local maximum (~10.5°C) with the three following years a few tenths of a degree colder. 2002 was a warm year with ~10.7°C, and in 2003 the temperature dropped to (~10.5°C). In 2004 was the warmest on record (~10.8°C), but this year (~10.4°C) is colder than the three preceding years. This is above the long-term average, but about average for the last 10 years.

2004 was the first year with mean salinity in the box off Porcupine Bank with salinity above 35.50. This year it dropped to 35.45, which is above the long-term average, but similar to the average for the last 10 years. Similar changes are seen in the other boxes, indicating that the box discussed above is representative for the region along the continental slope south of the Wyville Thompson ridge.

Concluding remarks

It is important to emphasize that the acoustic estimates of blue whiting stock, although traditionally expressed in individual numbers and biomass, should be understood as relative indices rather than absolute measures of stock abundance. The estimates are based on a target strength relationship that is known to give too low values. As a consequence, the biomass estimate for the survey area is too high (the actual bias is not accurately known but may be as high as about 40%, see Godø et al. 2002, Heino et al. 2003 and Appendix 7). On the other hand, it is clear that the coverage of the spawning stock by the survey is not complete. Some other sources of uncertainty in this survey are discussed in Heino (2004c).

The survey results in spring 2005 suggest significant decreases in both numbers (about 30%) and biomass (about 25%) of blue whiting compared to years 2002–2004. This decrease should be judged against changes in survey coverage, which in 2005 was about 20% less than in 2004. To make the numbers more comparable, next we compare only those survey strata that were covered in both years and adjust for relative coverage within each stratum. In 2005, the total stock biomass estimate in those strata that were covered in 2004 is 8.4 million tonnes. Adjusting for slightly smaller coverage within each stratum in 2005 than in 2004, the corrected estimate is 8.7 million tonnes. This estimate has to be compared with the estimate obtained in 2004 for the same strata, 10.9 million tonnes. The coverage-corrected decrease in total stock biomass is thus about 20%.

There is also a significant change in the age structure of the spawning stock that reflects ageing of dominant year classes. The year class 2000, the strongest year class in record, continues to dominate the spawning stock: 36% of spawning stock biomass is attributed to this year class. The year class 2001 is also abundant (31% of SSB) and, although nowhere as strong as year class 2000, relatively strong in comparison to most recent year classes. In addition, year class 2002 has a share of 17%, but this year class is rather weak for its age. Year classes 2003–2004 appear very weak in the survey area. Although lack of bottom trawl sampling may have contributed to the rarity of young fish in the samples, in a similar situation in 2003 large numbers of young fish were sampled

It is importance to appreciate that the spawning stock biomass is to an increasing degree maintained by growth of mature fish in the stock, as opposed to rich new recruiting year classes—which was the case in 2001–2003 when year classes 1999 and 2000 were recruiting to the spawning stock.

Norwegian survey in 2005 was carried out in co-operation with five other vessels (one from the Faroes, Ireland and the Netherlands, and two from Russia). The results from this second survey with broad international participation show an even larger decrease in the stock from 2004 to 2005, despite a larger area covered this year (Heino et al. 2005). The international survey shows the dominance of the same year classes as Norwegian survey, but a somewhat higher proportion of young blue whiting. In conclusion, the results of the international survey are consistent with the ones from Norwegian alone, giving increased confidence to the results presented here.

After three years with relatively stable stock biomass but ageing stock, a clear reduction in the blue whiting stock can be observed. The recorded decrease in stock abundance is an inevitable consequence of weaker recruiting year classes and high exploitation rate. The numbers of young blue whiting (ages 1–3 years) in the survey this year were particularly low. Unless fishing pressure is considerable decreased or the recruiting year classes prove to be considerable stronger than present data suggest, a reduction in stock abundance that is at least as large as the one observed this year is likely.

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Table 1. Assessment factors of blue whiting, spring 2005.

Sub-area			Numbers (millions)			Biomass (1000 tonnes)			Mean weight	Mean length	Density
		n.mile^2	Mature	Total	%mature	Mature	Total	%mature	g	cm	t/n.mile^2
II	Porcupine Bank	17550	5340	5370	99.4	428	430	99.6	80.0	26.3	24
III	Hebrides	33839	69400	70000	99.0	6440	6470	99.6	92.3	27.0	191
IV	Faroes/Shetland	20246	6770	7100	95.4	610	626	97.6	88.1	26.7	31
V	Rockall	21148	11800	12000	98.3	999	1005	99.4	83.9	27.1	48
Total		92783	93200	94500	98.7	8480	8530	99.5	90.2	27.0	92

Table 2. Stock estimate of blue whiting, spring 2005.

Length	Age in years (year class)										Numbers	Biomass	Mean	Mature
	1	2	3	4	5	6	7	8	9	10				
(cm)	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	(10^6)	(10^6 kg)	weight (g)	%
14.0 - 15.0	16	0	0	0	0	0	0	0	0	0	16	0.2	14	0
15.0 - 16.0	48	0	0	0	0	0	0	0	0	0	48	0.8	16.8	0
16.0 - 17.0	41	0	0	0	0	0	0	0	0	0	41	0.8	19	0
17.0 - 18.0	11	0	0	0	0	0	0	0	0	0	11	0.3	24.2	0
18.0 - 19.0	98	26	0	0	0	0	0	0	0	0	124	3.4	27.1	0
19.0 - 20.0	95	109	0	0	0	0	0	0	0	0	203	6.4	31.6	11
20.0 - 21.0	23	602	0	0	0	0	0	0	0	0	624	21	34.1	14
21.0 - 22.0	23	78	103	0	0	0	0	0	0	0	204	9.4	46	54
22.0 - 23.0	15	0	534	0	0	0	0	0	0	0	549	28	50.7	94
23.0 - 24.0	0	409	2822	384	13	0	0	0	0	0	3627	215	59.3	98
24.0 - 25.0	0	124	4918	2439	1876	0	0	0	0	0	9356	618	66.1	99
25.0 - 26.0	0	110	6309	7595	3801	734	0	0	0	0	18549	1385	74.7	100
26.0 - 27.0	0	0	2764	8872	8126	344	0	0	0	0	20105	1664	82.8	100
27.0 - 28.0	0	0	1798	5806	6301	976	26	0	0	0	14907	1384	92.8	100
28.0 - 29.0	0	0	571	3367	4246	1254	425	165	0	0	10028	1052	104.9	100
29.0 - 30.0	0	0	150	1657	4325	1560	372	36	0	0	8100	938	115.8	100
30.0 - 31.0	0	0	0	206	1613	907	37	343	0	0	3106	401	129	100
31.0 - 32.0	0	0	0	29	1318	979	286	16	29	0	2658	384	144.4	100
32.0 - 33.0	0	0	0	103	39	233	413	0	25	0	813	131	161.5	100
33.0 - 34.0	0	0	0	0	37	230	113	132	0	0	512	92	179	100
34.0 - 35.0	0	0	0	0	0	16	295	2	189	15	516	99	190.7	100
35.0 - 36.0	0	0	0	0	0	12	3	0	91	0	106	23	216.3	100
36.0 - 37.0	0	0	0	0	14	175	14	13	0	0	215	48	220.8	100
37.0 - 38.0	0	0	0	0	0	0	0	0	0	0	0	0	.	
38.0 - 39.0	0	0	0	0	0	27	7	38	0	0	71	20	285	100
39.0 - 40.0	0	0	0	0	0	8	2	2	0	0	12	3.1	262.6	100
40.0 - 41.0	0	0	0	0	0	1	0	0	0	0	1	0.4	410	100
TSN (10^6)	370	1456	19968	30459	31708	7455	1993	747	333	15	94503			
TSB (10^6 kg)	11	69	1469	2608	3025	882	287	107	64	2.9	8527			
Mean length (cm)	18.4	22	25.3	26.7	27.6	29.4	31.3	31.1	34.4	34.5	27.0			
Mean weight (g)	29.4	47.5	73.6	85.6	95.4	118.4	143.9	143.3	193.5	191.9	90.2			
Condition	4.7	4.5	4.5	4.5	4.5	4.7	4.7	4.8	4.8	4.7	4.6			
% mature	10	50	99	100	100	100	100	100	100	100	99.5			
% of SSB	0	0	17	31	36	10	3	1	1	0				

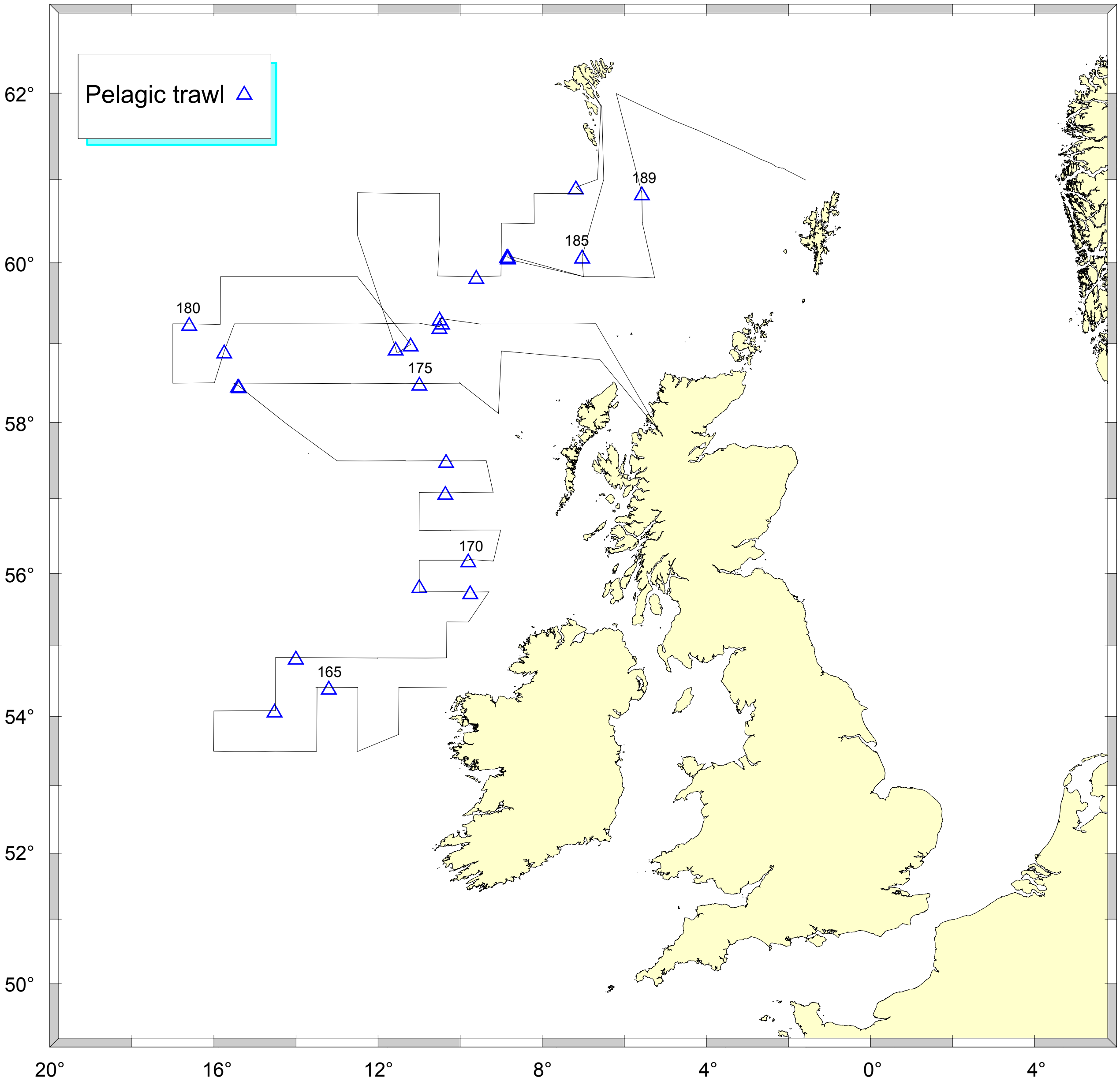


Figure 1. Cruise tracks with trawl stations, R.V. "G. O. Sars" 11 March–15 April 2005.

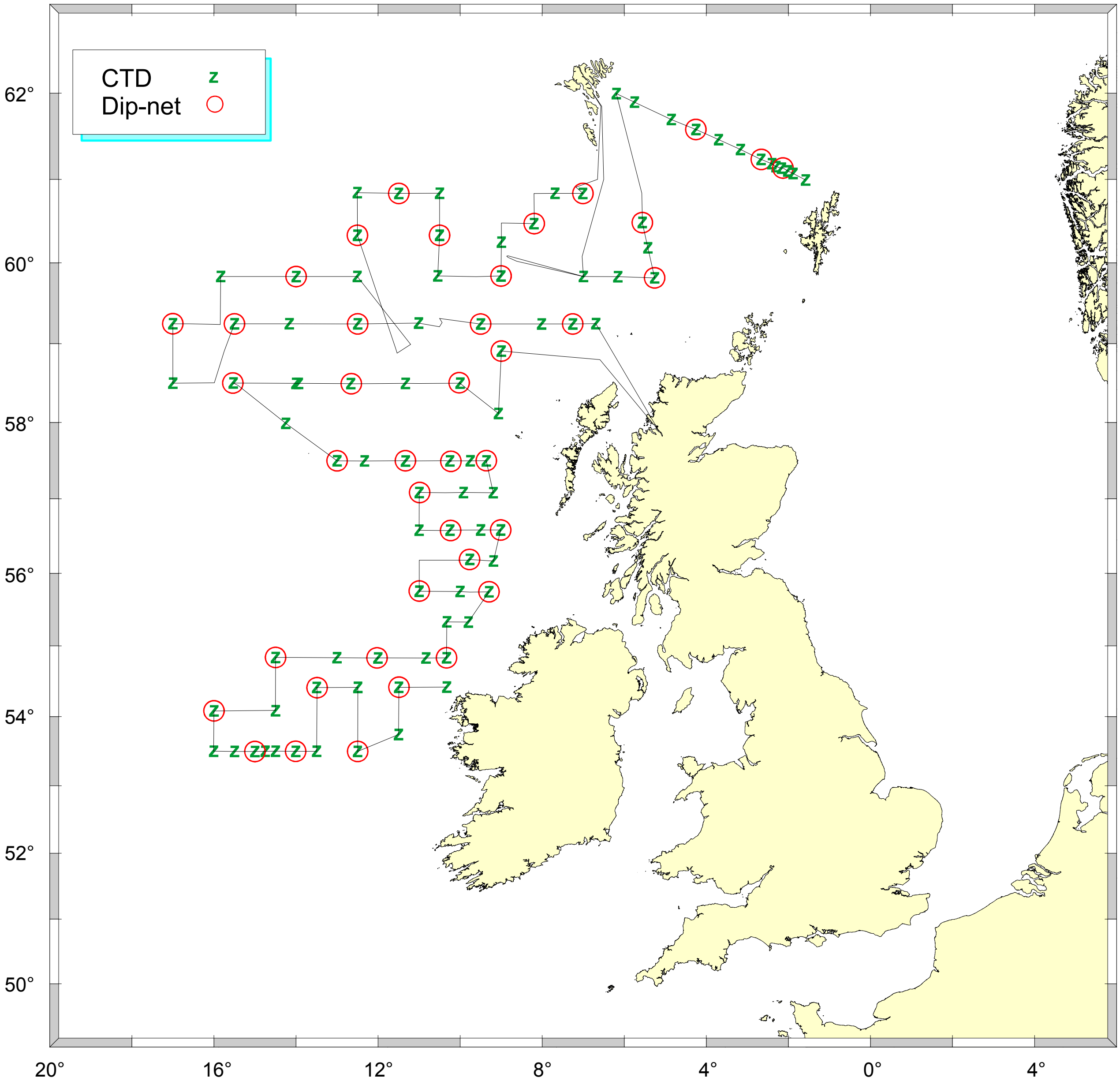


Figure 2. Cruise tracks with CTD and plankton stations, R.V. “G. O. Sars” 11 March–15 April 2005.

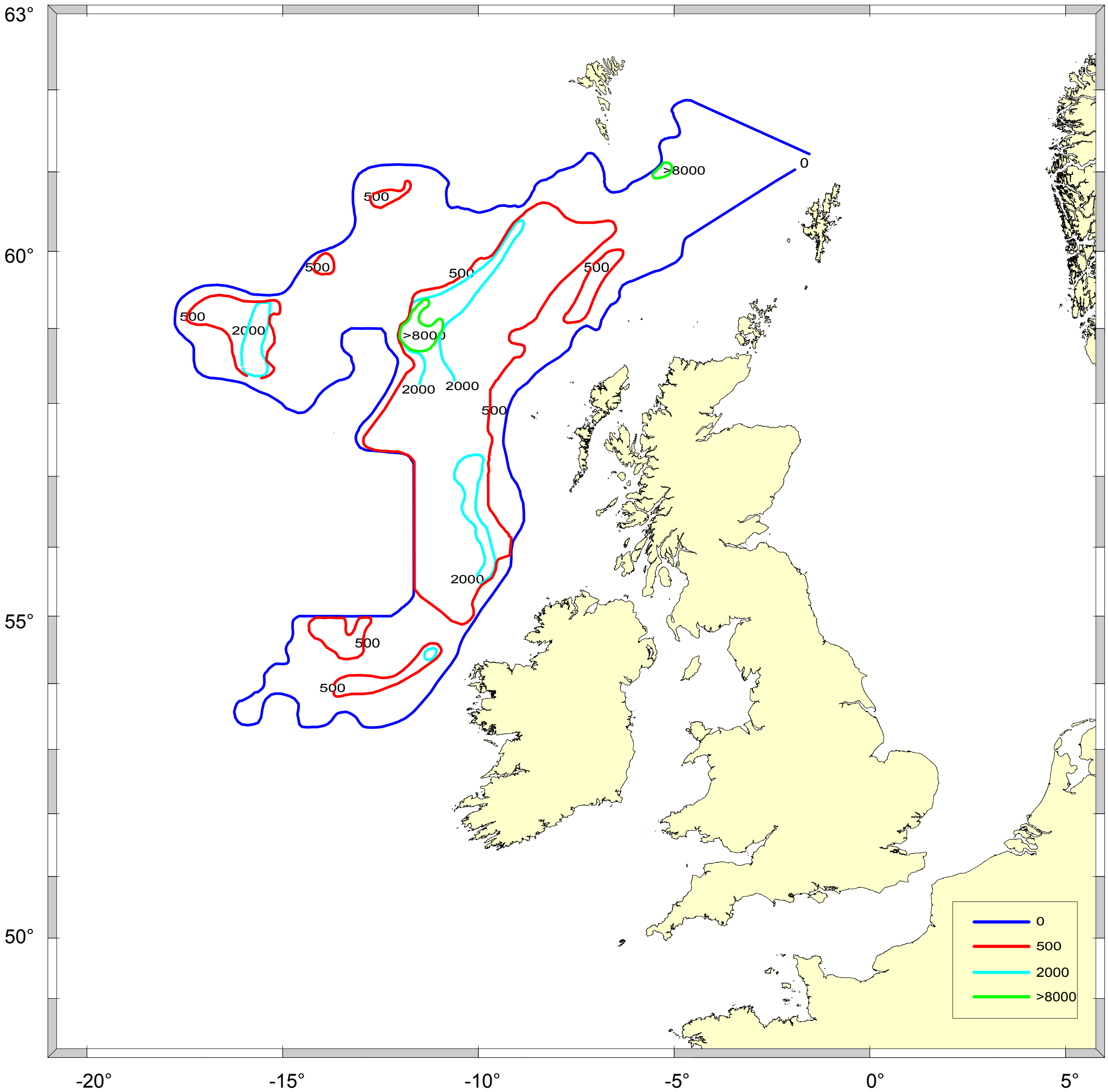


Figure 3. Distribution of blue whiting in spring 2005 in terms of echo intensity (s_A-values, $m^2/n.mile^2$). The map is primarily based on observed echo intensities along the cruise track (see Fig. 1) and knowledge on bottom topography and its influence on distribution of blue whiting.

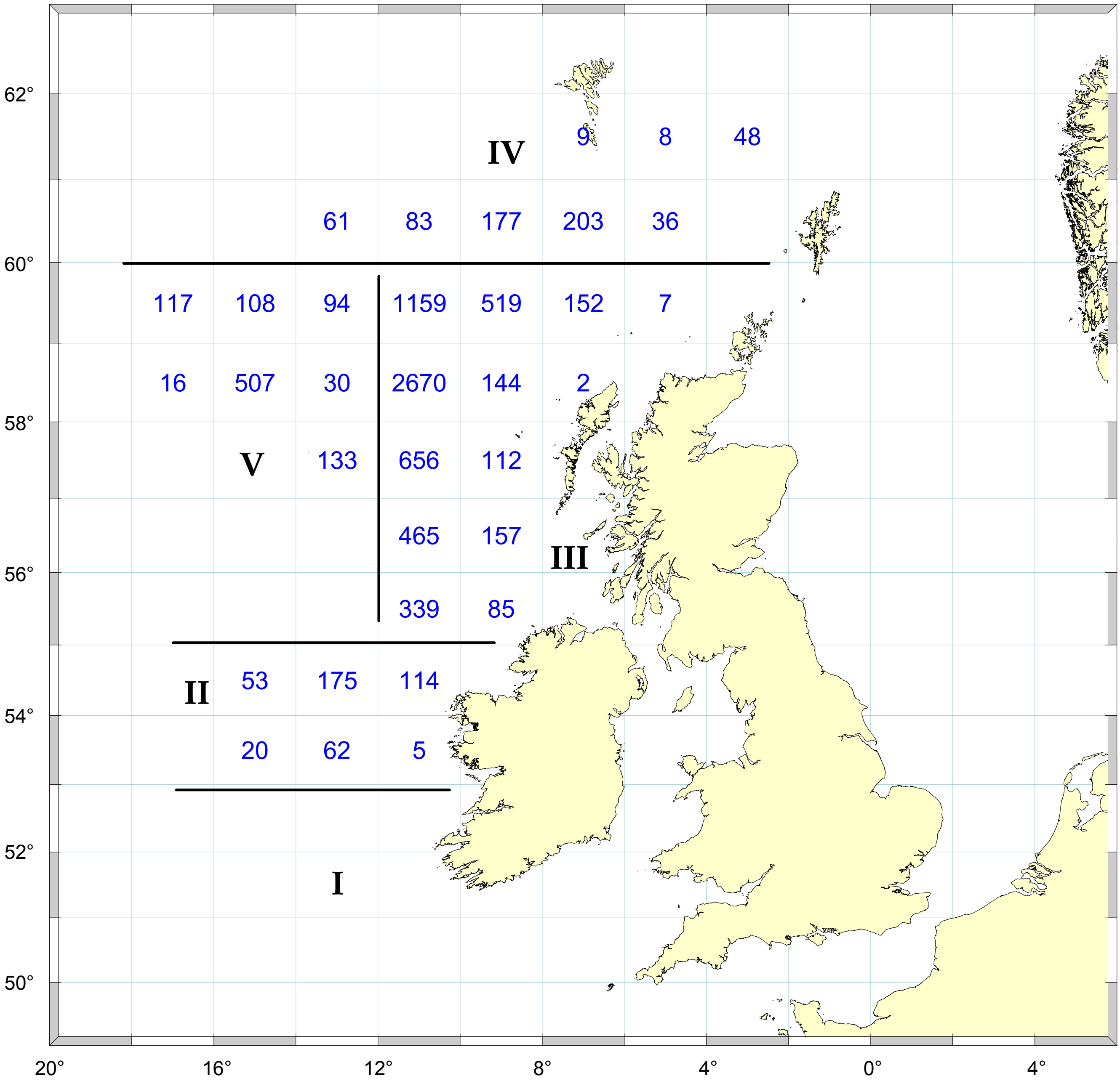


Figure 4. Blue whiting biomass in 1000 tonnes, spring 2005. Marking of sub-areas I-V used in assessment.

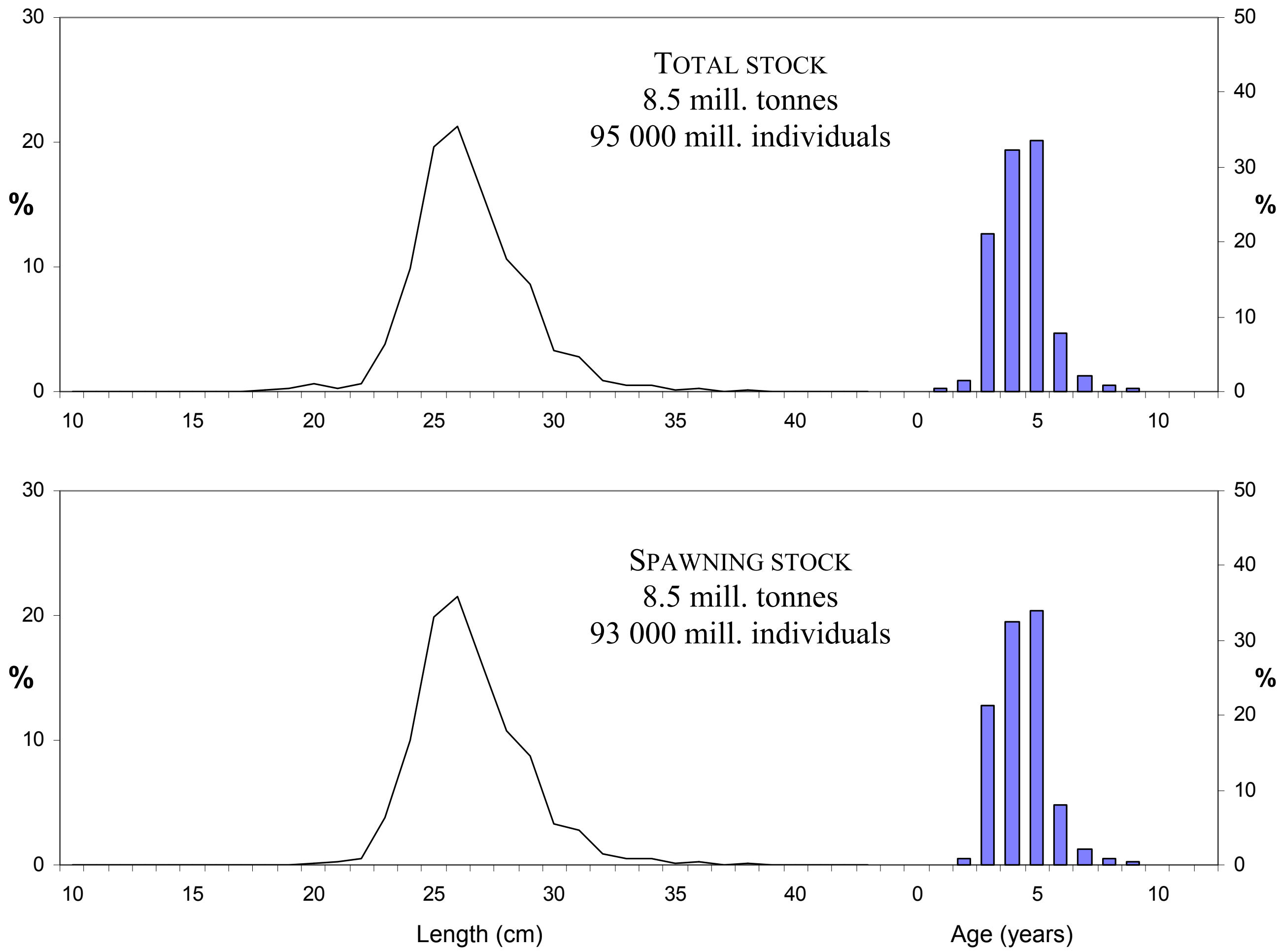


Figure 5. Length and age distribution in the total and spawning stock of blue whiting in the area to the west of the British Isles, spring 2005.

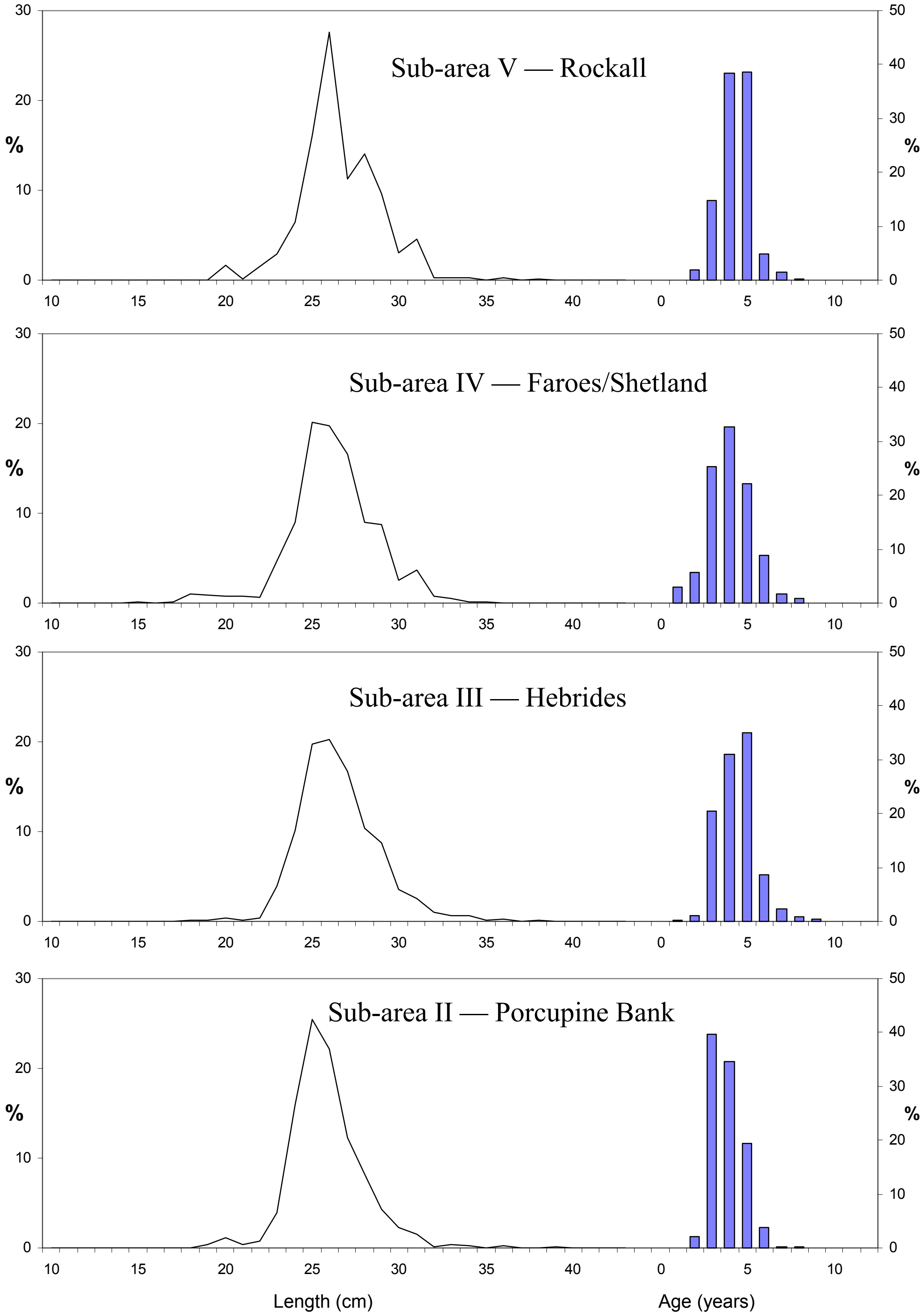


Figure 6. Length and age distribution of blue whiting by sub-areas (II-V), spring 2005.

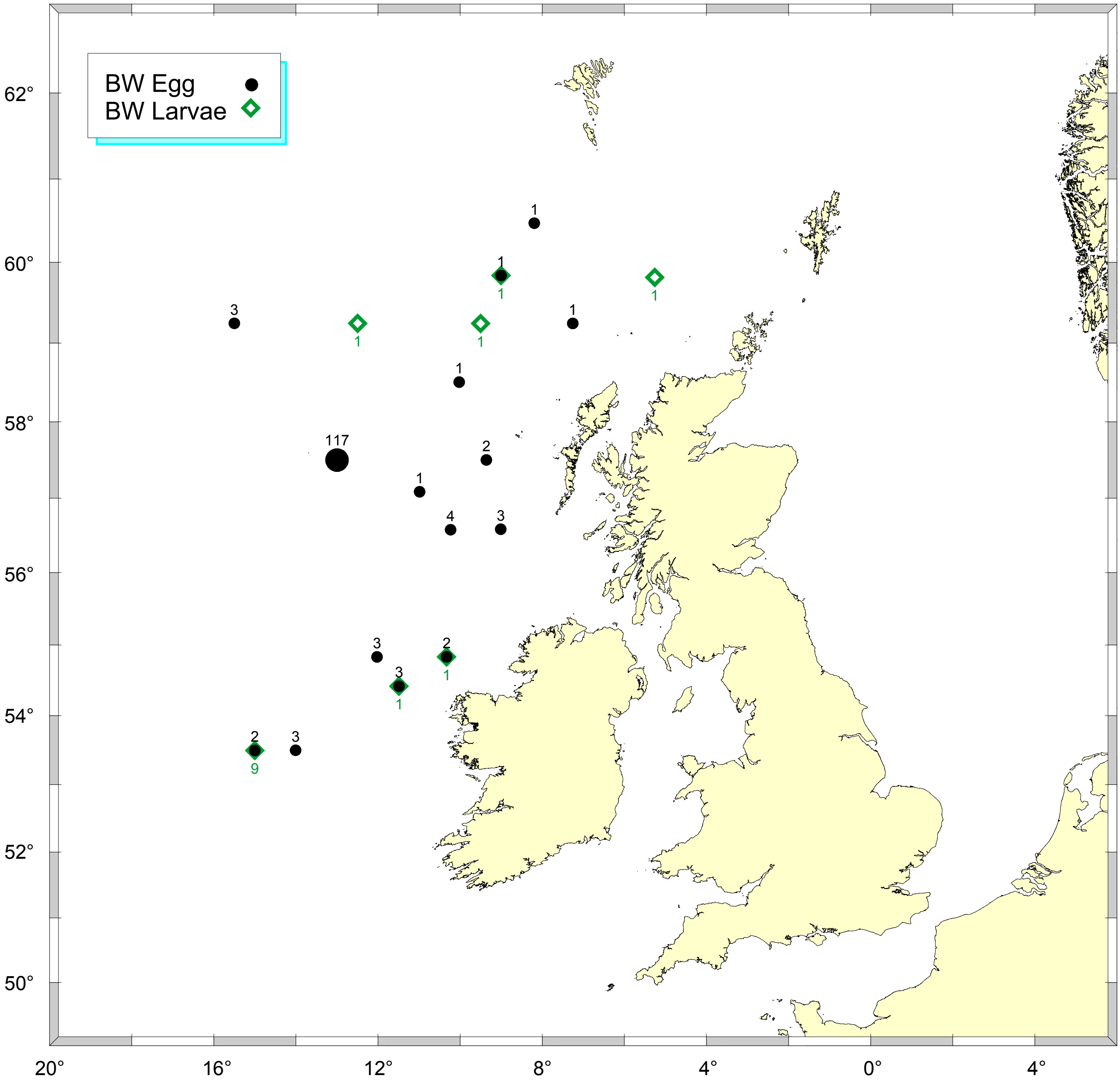


Figure 7. Distribution of blue whiting eggs and larvae in spring 2005. Number of individuals is also inserted (eggs on the top, larvae on the bottom).

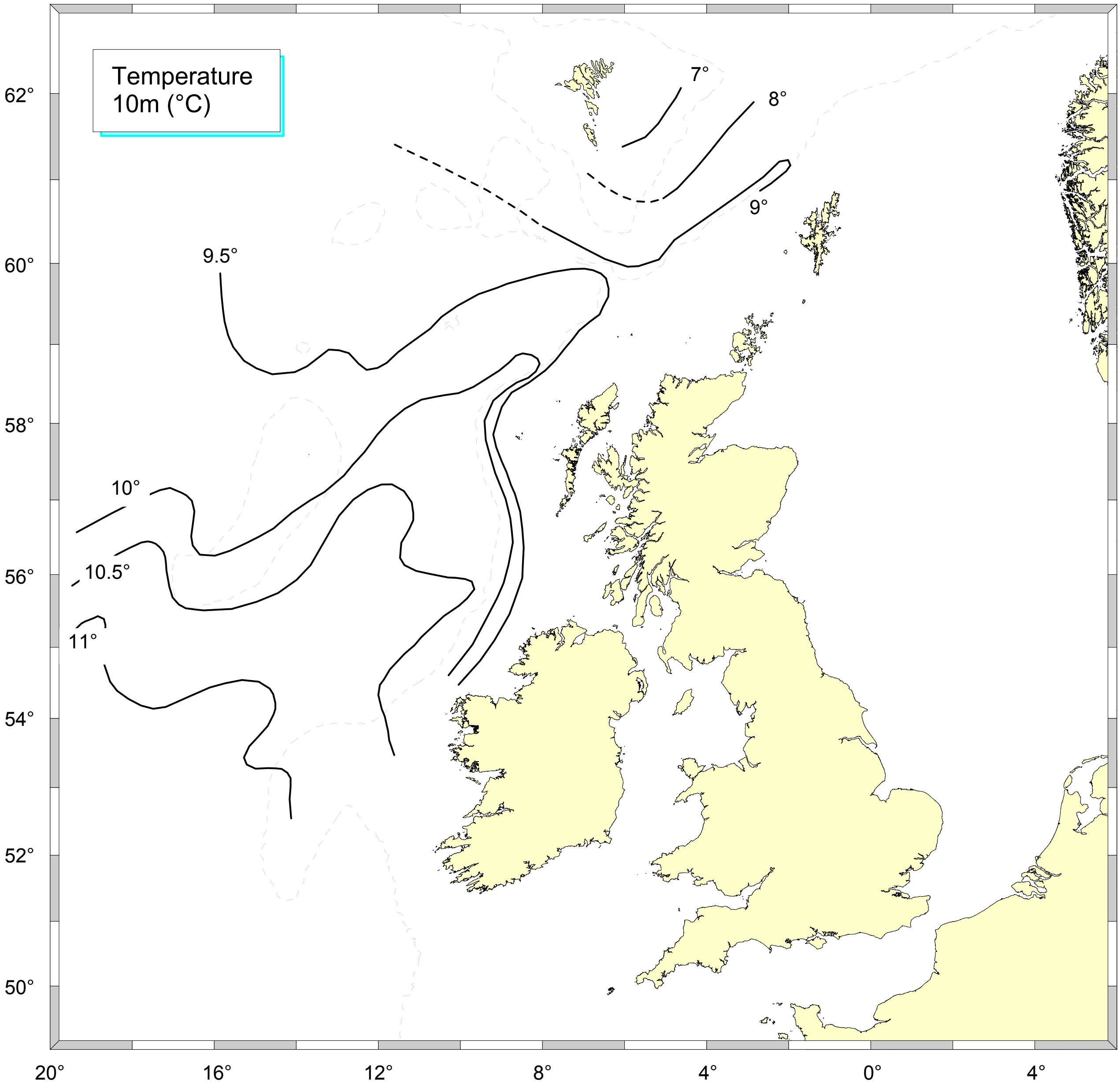


Figure 8. Horizontal temperature (°C) distribution at 10m depth.

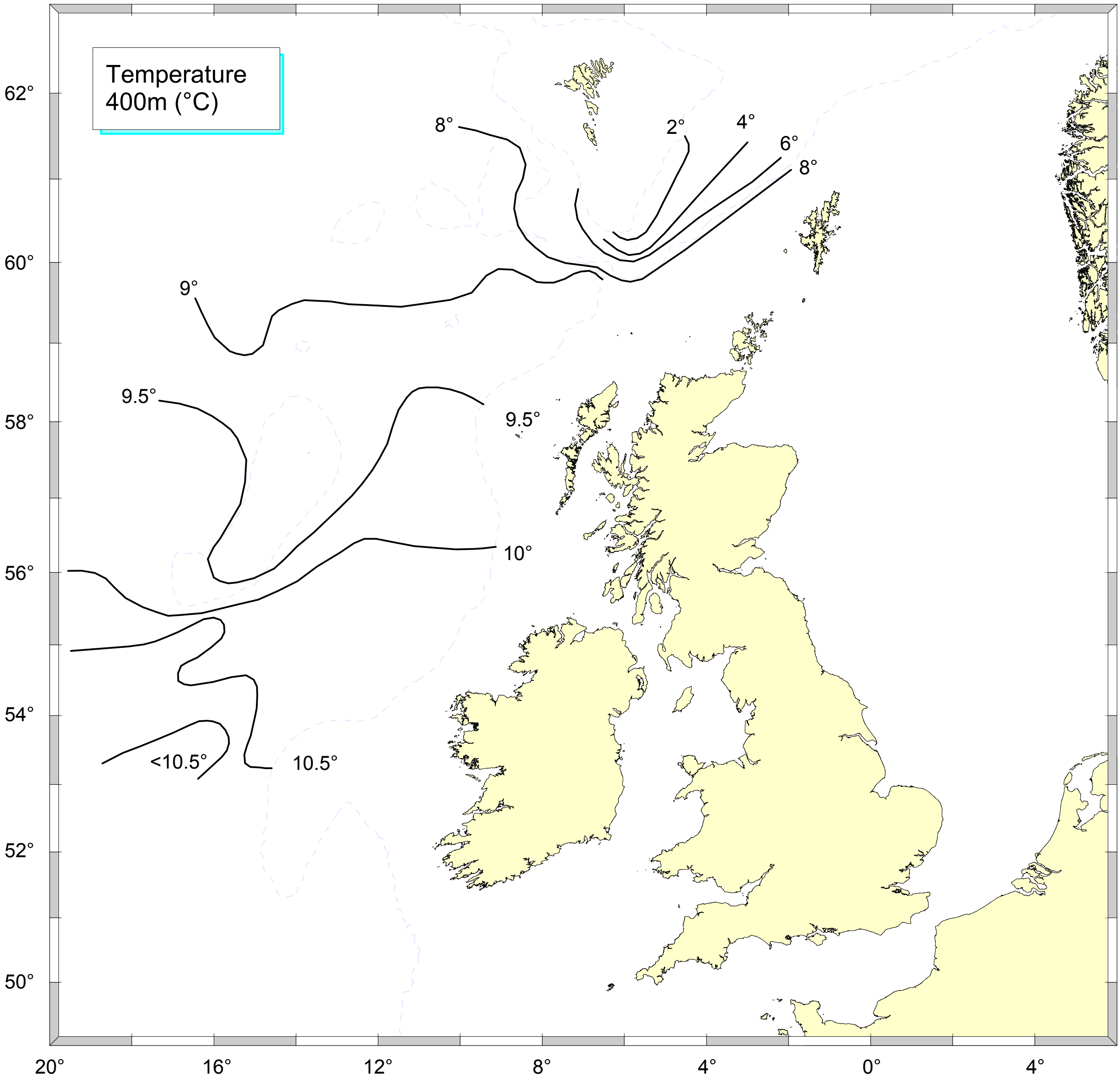


Figure 9. Horizontal temperature (°C) distribution at 400m depth.

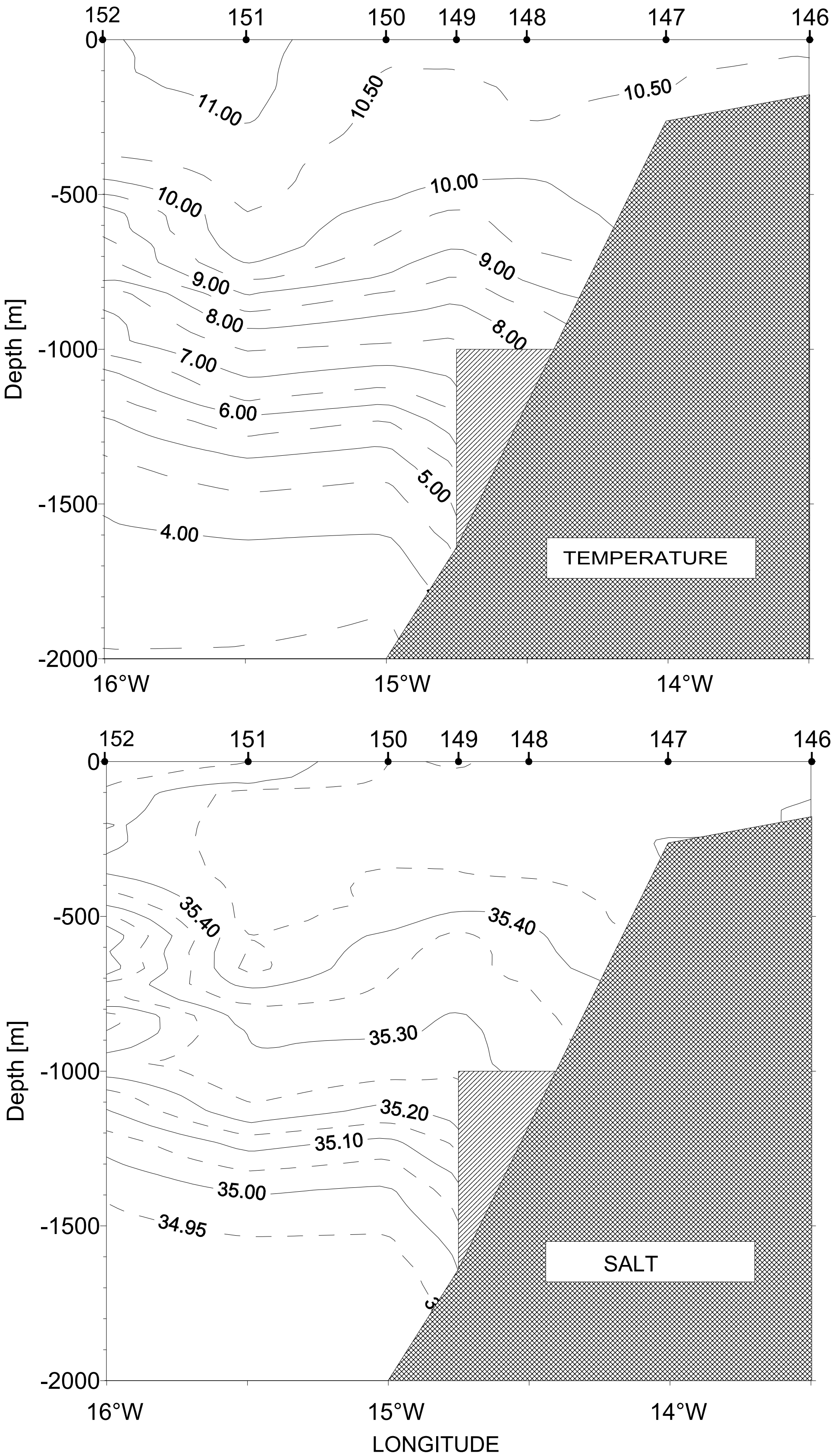


Figure 10. Vertical distribution of temperature (°C) and salinity in a section at the shelf edge at the Porcupine Bank at 53° 30'N. Station numbers at the top of the panels. The triangle indicates missing data due to two stations erroneously taken to only 1000 m depth.

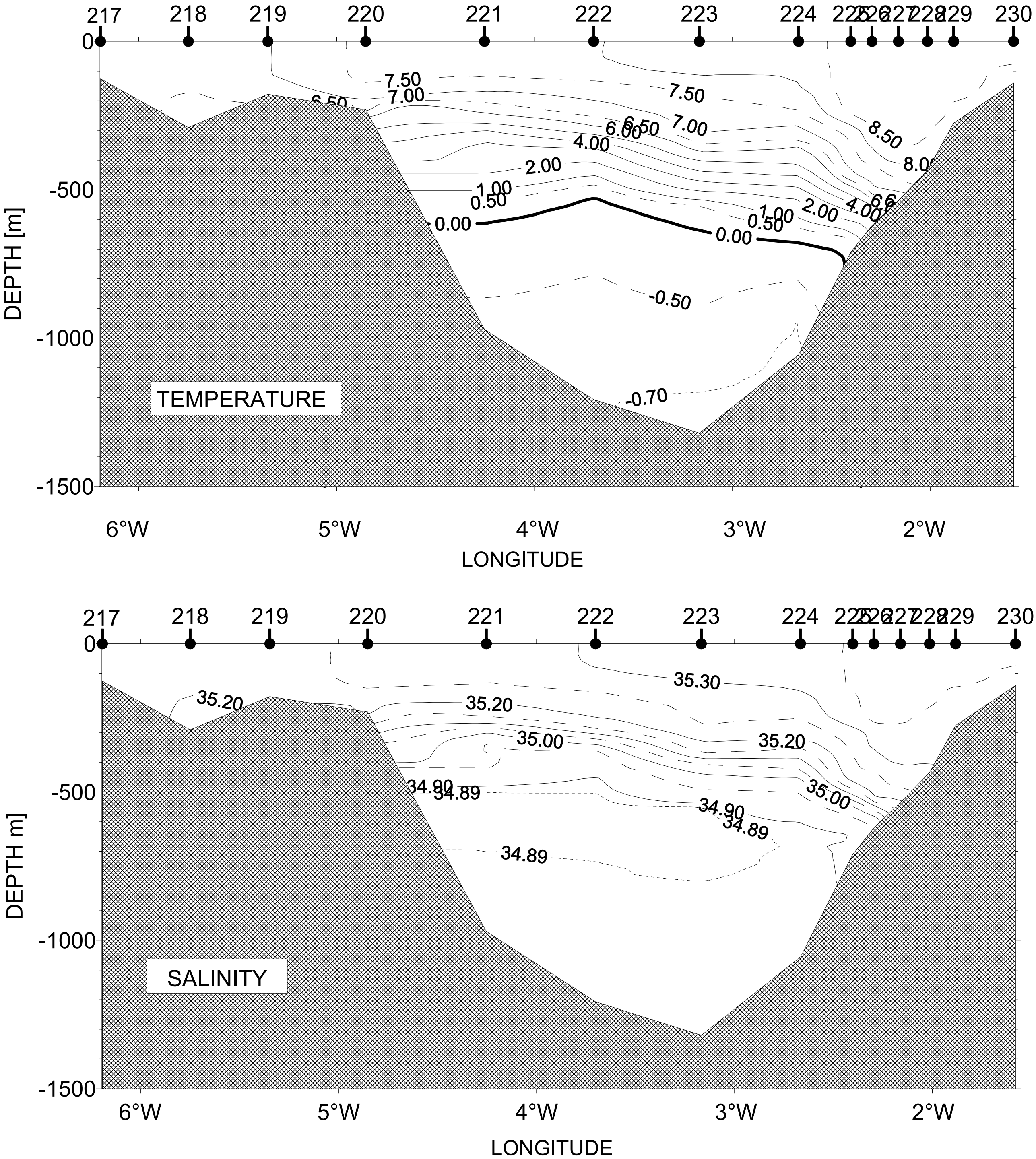


Figure 11. Vertical distribution of temperature (°C) and salinity in a section from the Faroes to Shetland (Nolsø-Flugga). Station numbers at the top of the panels.

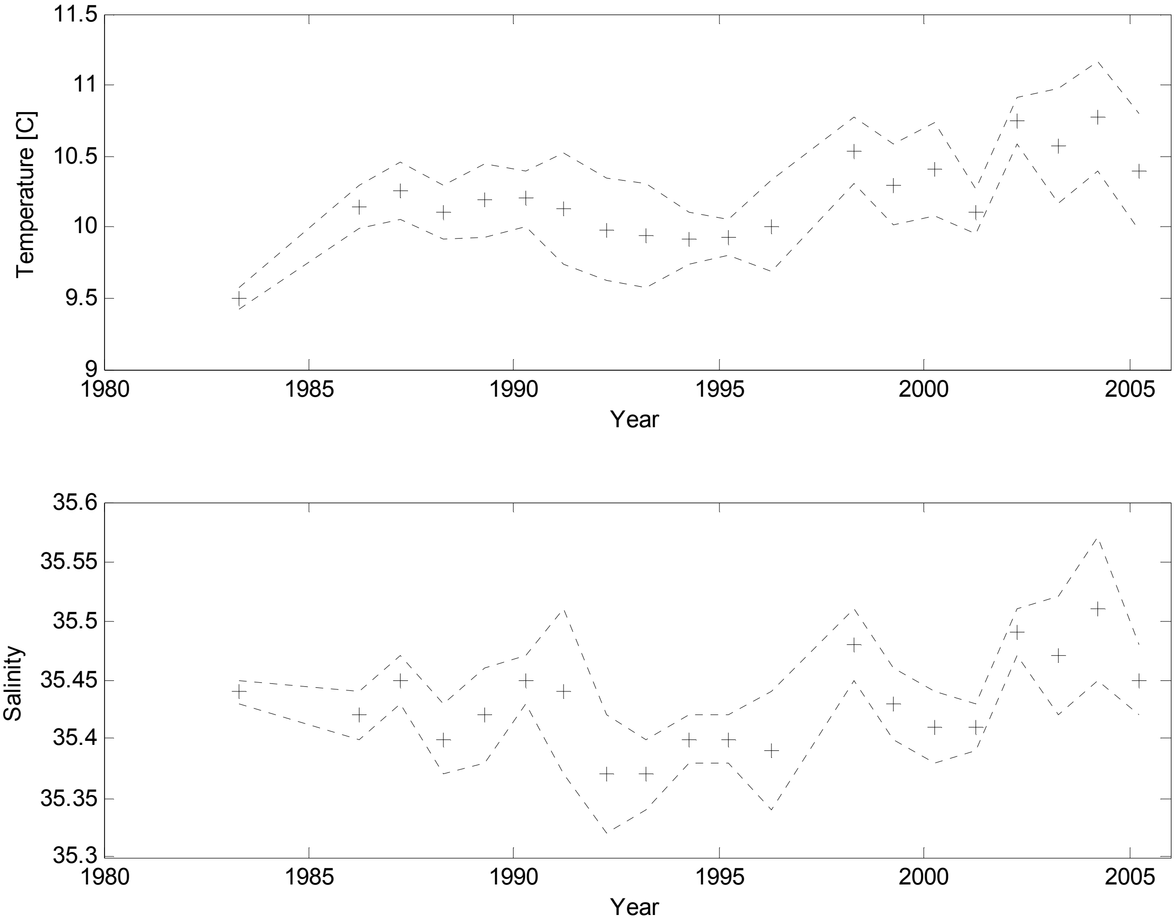


Figure 12. Yearly mean temperature and salinity from 50-600 m (crosses) of all stations in a box with bottom depth >600 m, west of the Porcupine bank bounded by 52° to 54°N and 16 to 14°W. Dotted lines are drawn at ±1 standard deviation of all observations in each box, each year.

Appendix 1. Acoustic equipment and settings

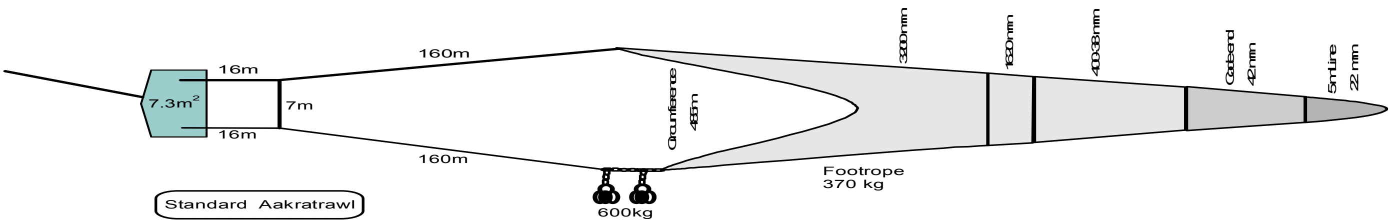
Acoustic equipment and settings for the primary frequency on the R/V "G. O. Sars", 11 March–15 April 2005.

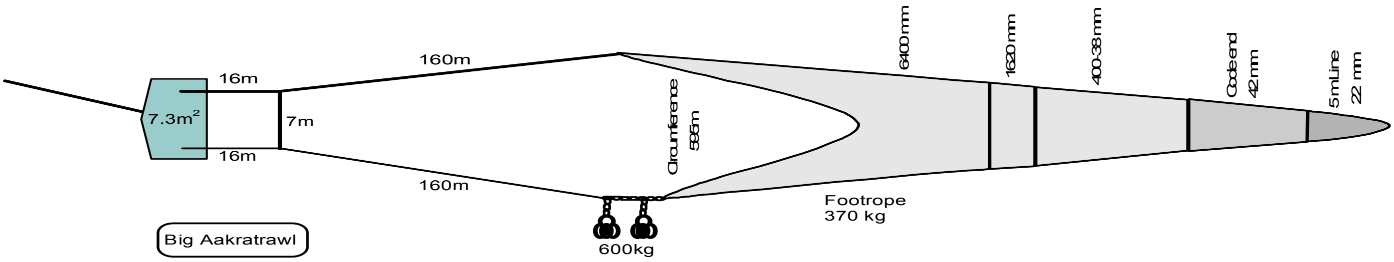
Echo sounder:	Simrad EK 60
Primary frequency:	38 kHz
transducer:	ES38B – SK
Other frequencies:	18, 70, 120, 200 kHz
transducers:	ES18-11, 70-7C, 120-7C, 200-7C
Absorption coefficient:	9.785 dB/km
Pulse length:	1ms
Band width:	2.425 kHz
Transmitter power:	2000 W
Angle sensitivity:	21.9 dB
2-way beam angle:	-20.8 dB
Ts Transducer gain:	25.71 dB*
s_A correction	-0.66 dB
3 dB beam width	
along ship:	6.98 °
athw. ship:	6.97 °
Range:	750 m

* Calibration in the end of the survey gave a value 25.68 dB.

Appendix 2. Configuration of the pelagic trawls

The figure below gives details of the configuration of the "standard" large pelagic trawl (Åkratrål) used to collect most of the biological samples during the blue whiting survey in spring 2005. A new, larger version of this trawl was used on some occasions.





Appendix 3. Fish taxa encountered during the blue whiting survey in spring 2005.

Scientific name	English name	Norwegian name
Nemichthyidae	Snipe-eels	Sneppeålfamilien
Nemichthys scolopaceus	Slender snipe-eel	Sneppeål
Ophistoproctidae	Spookfishes	
Opisthoproctus soleatus	Barreleye, Spookfish	Flatbuket kikkertfisk
Alepocephalidae	Smooth-heads	Glatthodefiskfamilien
Xenodermichthys copei	Bluntsnout smooth-head	Kortsnutet glatthodefisk
Platytroctidae (Searsidae)	Searsids	
Maulisia sp.		
Sagamichthys schnakenbecki	Schnakenbeck's searsid	
Searsia koefoedi	Koefoed's searsid	
Microstomatidae (Argentinidae)	Argentines	(Vassildfamilien)
Nansenia groenlandica	Greenland argentine	
Nansenia oblita	Forgotten argentine	
Gonostomatidae	Lightfishes	Lysfiskfamilien
Cyclothone	Bristlemouth	
Gonostoma elongatum	Elongated bristlemouth fish	
Gonostoma bathyphilum		
Sternoptychidae	Hatchetfishes	Perlemorsfiskfamilien
Argyropelecus hemigymnus	Axefish	Flekket perlemorsfisk
Argyropelecus olfersi	Silver hatchetfish	Stor perlemorsfisk
Maurolicus muelleri	Pearlside	Laksesild
Stomiidae	Scaly dragonfishes	Dragekjeftfamilien
Stomias boa ferox	Boa dragonfish	Boafisk, Storkjeft
Chauliodus sloani	Sloane's viperfish	Segltannfisk
Melanostomiidae	Scaleless dragonfishes	(Dragekjeftfamilien)
Melanostomias bartonbeani		
Notosudidae	Waryfishes	
Scoleposaurus lepidus	Blackfin waryfish	
Paralepididae	Barracudinas	Laksetobisfamilien
Arctozenus (Notolepis) rissoi	White barracudina	Liten laksetobis
Paralepis sp.		
Scopelarchidae	Pearleye fishes	
Benthalbella infans	Zugmayer's pearleye	
Myctophidae	Lanternfishes	Lysprikkfiskfamilien
Trachipteridae	Deal fishes	Sølvkveitefamilien
Trachipterus arcticus	Deal fish	Sølvkveite

Melamphaidae	Bigscale fishes, Ridgeheads	
Scopelogadus beanii		
Gadidae	Cod fishes	Torskefamilien
Micromesistius poutassou	Blue whiting	Kolmule
Pollachius virens	Saithe	Sei
Syngnathidae	Hippocampes	Nålefiskfamilien
Percichthyidae	Temperate basses	
Howella sherborni		
Chiasmodontidae	Swallowers	
Chiasmodon niger	Black swallower	
Scombridae	Mackerels, Tunas	Makrelfamilien
Scomber scombrus	Atlantic mackerel	Makrell
Bramidae	Breams	Havbrasmefamilien
Pterycombus brama	Atlantic fanfish	Sølvbrasme
Ceratiidae	Sea devils	

Appendix 4. Cephalopods encountered during the second leg of the blue whiting survey in spring 2005.

Date	Station	Serial	Species	Dorsal mantle length (mm)	Weight (g)	Comments	Outside net = 1 Inside net = 2
30/03/05	176	23024	*Gonatus* sp.	120	34		1
30/03/05	177	23027	*Histioteuthis hoylei*	65	193	no tentacles	2
30/03/05	178	23028	*H. hoylei*	65	170		1
30/03/05	178	23028	*Todarodes sagittatus*	60	8		1
30/03/05	178	23028	*T. sagittatus*	185	126		2
31/03/05	179	23029	*Chiroteuthis veranyi*	150	269		1
31/03/05	179	23029	*Taonius pavo*	105	18		2
31/03/05	179	23029	*T. pavo*	120	21		2
31/03/05	179	23029	*H. hoylei*	55	99	no tentacles	2
31/03/05	179	23029	*H. hoylei*	55	121	no tentacles	2
31/03/05	179	23029	*H. hoylei*	55	133	no tentacles	2
31/03/05	179	23029	*H. hoylei*	45	66		2
31/03/05	179	23029	*H. hoylei*	55	121	no tentacles	2
31/03/05	179	23029	2 octopods to be identified				2
01/04/05	180	23030	H. *hoylei*	60	77		1
01/04/05	180	23030	*H. hoylei*	65	100		1
01/04/05	180	23030	*H. hoylei*	55	75		1
01/04/05	180	23030	*H. hoylei*	70	155		1
01/04/05	180	23030	*H. hoylei*	45	39		1
01/04/05	180	23030	*H. hoylei*	70	181		1
01/04/05	180	23030	*H. hoylei*	60	86		1
01/04/05	180	23030	*H. hoylei*		60	head only	1
01/04/05	180	23030	*H. hoylei*		151	head + digestive gland	1

(table continued)

Date	Station	Serial	Species	Dorsal mantle length (mm)	Weight (g)	Comments	Outside net = 1 Inside net = 2
01/04/05	180	23030	*H. hoylei*		95	head + digestive gland	1
01/04/05	180	23030	*H. hoylei*		75	head + digestive gland	1
01/04/05	180	23030	*H. hoylei*	60	15	mantle only	2
01/04/05	180	23030	*T. pavo*	120	7	mantle only	1
01/04/05	180	23030	*Brachioteuthis* sp.	85	14		1
01/04/05	180	23030	*Brachioteuthis* sp.	75	12	no tentacles	1
01/04/05	180	23030	T. *pavo*	95	12		2
01/04/05	180	23030	*Octopoteuthis danae*	80	56	no tentacles	2
01/04/05	180	23030	Juvenile squid to be identified	35	3		
01/04/05	180	23031	*Pholidoteuthis* boschmai	65	10	Identification to be confirmed	2
01/04/05	180	23032	Juvenile squid to be identified	45	4		2
01/04/05	180	23032	*Octopoteuthis* danae	60	18	no tentacles	2
03/04/05	181	23034	*Octopoteuthis sicula*	80	53		2
03/04/05	181	23034	Taoniinae spp.	180	159		2
03/04/05	181	23034	Juvenile squid to be identified	35	3		2
06/04/05	184	23038	*Gonatus* sp.	145	45		2
08/04/05	185	23039	*Histioteuthis* sp.	50	58	no tentacles, no eyes	1

Appendix 5. Comparisons of pelagic trawls

Methods and results

A comparison between three large pelagic trawls on G. O. Sars ("normal" Åkra trawl, large Åkra trawl and Egersund trawl, a commercial blue whiting trawl – see page 3) was carried on March 30 7:50-17:40 UTC on the western flank of Rosemary Bank. Blue whiting was distributed in depths between 450-600 metres. The spatial structure was heterogeneous with registrations varying from dense clumps to diffuse layers. One trawl haul was taken with each trawl. Multi-sampler in Åkra trawl was used to get two sub-samples from the main layer as well as one sample 50 m higher up.

Length distributions in all catches were quite similar (Figure 1, Table 1). Taking the combined normal Åkra trawl sample from the main layer as the reference, only the length distribution in the sample taken with the same trawl 50 metres higher up is significantly different (p=0.03), although the difference is quantitatively small (0.6 cm). In fact, there is already as much difference between the two first cod-ends in the normal Åkra trawl (difference in mean length 0.4 cm) as between different trawls (differences in mean length between 0.4–0.5 cm).

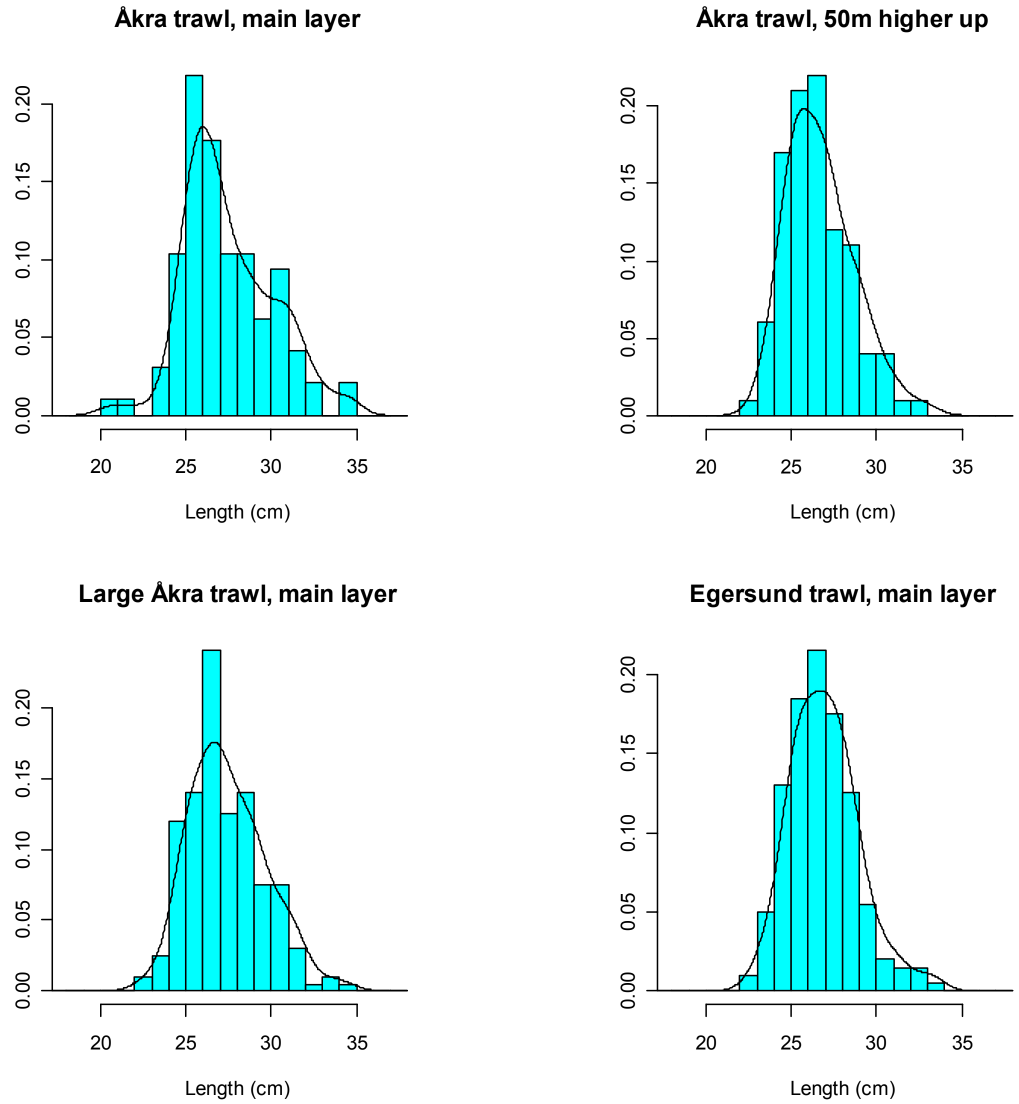


Figure 1. Length distributions from the trawls hauls with three different trawls on the western flank of Rosemary Bank. See Table 1 for sample sizes.

Table 1. Results of trawl comparisons on the western flank of Rosemary Bank.

Trawl, layer, cod-end	Tow time (min)	Catch (kg)	Average length ± S.D. (cm)	Sample size
Åkra trawl, main layer, cod-end #1-2 combined	26	105	27.3 ±2.4	197
Cod-end #1	13	75	27.1 ±2.1	100
Cod-end #2	13	30	27.5 ±2.6	97
Åkra trawl, 50m higher above, cod-end #3	11	20	26.7 ±2.0	100
Large Åkra trawl, main layer	57	130	27.5 ±2.2	200
Egersund trawl, main layer	46	1000	27.0 ±2.0	200

In two occasions, we had an opportunity to obtain a blue whiting sample from a commercial fishing vessel that had trawled in the same area as G. O. Sars (Table 2, Figure 2). The first one occurred northwest of Rockall where a large number of Norwegian fishing vessels were trawling on blue whiting. Blue whiting occurred a well-defined layer of some 50-100 m in thickness in the depth of 500-600 metres. G. O. Sars took a haul with the large Åkra trawl at 17h UTC. A sample was obtained from a Norwegian vessel that had been towing for 25 hours (catching 50 tonnes) in the same area. The difference in length distributions is quantitatively rather small (1.0 cm) but statistically significant ($p<0.001$).

The second comparison between a commercial trawler and G. O. Sars was conducted southwest of Rosemary Bank where a large number of Norwegian and some Dutch fishing vessels were trawling on blue whiting. Blue whiting occurred in a well-defined layer of some 50-100 m in thickness in the depth of 500-600 metres. G. O. Sars took a haul with the large Åkra trawl at 11h UTC. A sample was obtained from a Norwegian vessel that had been towing in the same area. The difference in length distributions is larger (1.5 cm) than in the comparison near Rockall and statistically significant ($p<0.001$).

Conclusions

The differences between three large pelagic trawls on G. O. Sars suggest similar selection properties under the conditions encountered on the Rosemary Bank. In fact, there is already as much difference between the two first cod-ends in the normal Åkra trawl (difference in mean length 0.4 cm) as among trawls (differences in mean length between 0.4–0.5 cm). Contrary to prior expectations, the largest trawl did not yield the largest blue whiting. In fact, the opposite is true if only the hauls from the main layer are compared. The generality of these conclusions remain unknown as further trawl comparisons were hampered by either the multi-sampler failing to operate or adverse weather leading to abortion of trawling after one haul.

Commercial fishing vessels continue to fish larger blue whiting than an IMR vessel using an Åkra trawl, although the difference is not very large (1.0–1.5 cm). In 2003, a similar difference (1.2 cm) was observed (Heino *et al.* 2003), whereas in 2002 an alarmingly large difference of 4.0 cm was observed. The consistent sign of this difference suggests that its origin is a pure selective effect due to the difference in the size of gear, even though in any single comparison the effect of spatial heterogeneity cannot be ruled out.

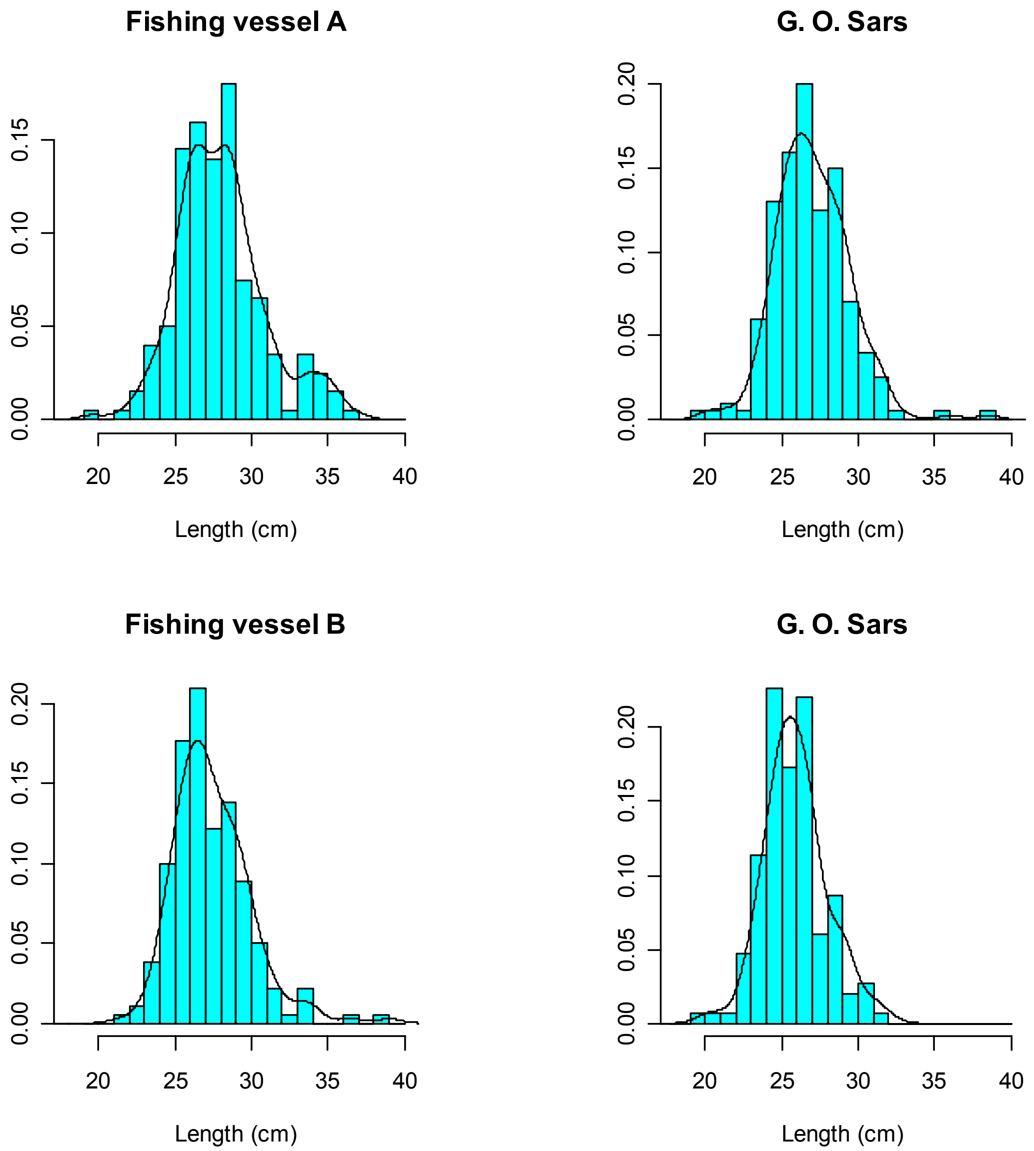


Figure 1. Length distributions from trawl hauls from a commercial fishing vessel and G. O. Sars from the same area, near Rockall in the top and near Rosemary Bank in the bottom row. See Table 2 for sample sizes.

Table 2. Results of comparisons between the large Åkra trawl on G. O. Sars and two commercial fishing vessels.

Area and date	Vessel	Tow time (min)	Catch (kg)	Average length ± S.D. (cm)	Sample size
NW of Rockall 30/3/2005	Commercial fishing vessel	55	40	28.0 ±2.9	200
	G. O. Sars with large Åkra trawl	1500	50,000	27.1 ±2.4	200
SW of Rosemary bank 3/4/2005	Commercial fishing vessel	some hours	~300,000	27.4 ±2.5	181
	G. O. Sars with large Åkra trawl	90	330	25.9 ±2.0	200

Appendix 6. Variability among trawl hauls and among replicate samples with single hauls.

Multiple samples were obtained from 14 trawl hauls. In eight of these, both codends had at least 50 blue whiting measured, a number taken here as the criterion for a representative sample. Mean length of blue whiting in these hauls (with standard deviation inserted below) from these hauls are given below, with those with less 50 blue whiting in at least one codend coloured gray:

Station	165	166	167	168	169	170	171	172	175	176	180	181	183	185
1st codend	26.3	26.9	27.1	27.2	27.2	26.6	26.9	27.0	26.4	27.1	27.3	26.9	26.3	27.1
	1.8	2.4	2.2	2.2	2.4	2.1	2.5	2.7	1.8	2.1	1.8	2.2	2.0	2.4
2nd codend	25.5	25.6	26.7	26.8	26.5	26.4	27.1	25.5	26.1	27.5	26.5	27.2	27.2	26.6
	1.0	3.5	3.4	2.2	2.5	2.1	2.7	3.6	2.1	2.6		2.3	2.4	3.0

The results of an analysis of variance applied to the data from station with "good" samples is shown below:

Factor	D.f.	Mean square	F	p
Station	7	22.3	4.08	<0.001
Codend	1	1.7	0.30	0.583
Station*codend	7	12.1	2.22	0.031
Residual	1483	5.5		

As expected, more variance can be attributed to the variability between stations than between sub-samples. However, within-station variability among sub-samples is smaller only by a factor less than two. Thus, the variability encountered at the spatial scale of few nautical miles is only slightly smaller than variability encountered at the spatial scale of tens of nautical miles! Reassuringly, there is no consistent difference between first and second codend.

Appendix 7. *In situ* target strength measurements of blue whiting using a towed body and an "acoustic lander"

Introduction

Acoustic abundance estimates of blue whiting have always tended to be considerably higher than analytic estimates based on catch data. The reason is believed to be that the currently used relationship mapping fish length to its target strength (TS) gives too low TS and thus overestimates fish numbers. In order to obtain a more realistic relationship, TS measurements were conducted during blue whiting surveys in 2002–2003 with a stationary transducer lowered above a layer of blue whiting (Godø *et al.* 2002; Heino *et al.* 2003). The results confirm the view that the current TS equation results in overestimation of fish, but the results were not definitive enough to give a new, reliable TS equation because of limited sampling effort and problems with avoidance reaction of fish to the transducer. In order to resolve the ambiguity on the "true" TS of blue whiting, collection of target strength data was continued during the blue whiting cruise with the R/V G. O. Sars, this time using a towed body and an "acoustic lander".

Material and methods

Biological data

Trawl hauls were taken before (and sometimes also after) each TS station in order to confirm the species and length composition.

Towed body

The towed body is equipped with a Simrad EK60 echo sounder operating at 38 kHz and 120 kHz. During the TS measurements the towed body was towed at 2-3 knots, depending on the speed and direction of the current relative to the ship's heading, and placed at depths of about 500 m, i.e., placing the towed body directly above or within the blue whiting layer. Nine experiments with the towed body were performed, with effective measuring time of 1-2 hours each. Short range and high pulse repetition frequency was used in order to resolve individual targets. Stability of the towed body in regard to speed and tilt/roll was a slight problem due to varying weather conditions, with wind speeds ranging from 6 to 20 knots. Six experiments have so far been deemed appropriate for TS analysis.

Fish avoidance to the towed body is a subject that requires thorough analysis. Visual inspection of the vessels 18 kHz and the towed body's echo sounder seems to be matching. Target strength measurements seem to be difficult during dawn, possible due to avoidance.

Acoustic lander

An "acoustic lander" equipped with a Simrad EK60 echo sounder and an ES38D split-beam transducer, with identical settings as the towed body (Table 1), was deployed three times during the cruise. It ran for a period of almost 24 hours in each experiment.

Calibrations

The echo sounders were calibrated in dock (Nykirkekaien) on 11.03.05, in accordance with recommended procedures (Foote *et al*. 1987). The transducers were calibrated with a tungsten-carbide sphere of diameter 38.1 mm (WC38.1), with nominal target strengths of –42.2 dB re $1m^2$ (38 kHz) and –39.56 dB re $1m^2$ (120 kHz) at a sound speed of 1470 m/s. Depth calibration was performed in Bjørnafjorden, 14.04.05, by positioning the sphere near the acoustic axis at 15 m (38 kHz) below the towed-body. The body was then lowered to 500 m in steps of 50 m.

Data analysis

The filtering and selection of target strength data were performed in accordance with methodology described by Ona (1990). Target strength analysis is performed on "raw" target strength values, and after filtering using a target tracking approach (Handegard *et al.* 2003).

Preliminary results

Accurate results are not available at this time due to the fact that depth results from the depth calibrations are not yet analysed. Nevertheless, preliminary analyses indicate matching results from previous cruises (Godø *et al.* 2002; Heino *et al.* 2003) with a bimodal distribution, although the lower mode is often higher compared with 2003 results.

Table 1. Echo sounder settings and characteristics.

Frequency	38 kHz	120 kHz
Type	ES38DD	ES120-7DD
Power [W]	2000	500
Pulse length [ms]	1.0	1.0
Band width [kHz]	2.4	3.0
Two-way eqv. beam angle [dB]	-20.6	-20.8

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