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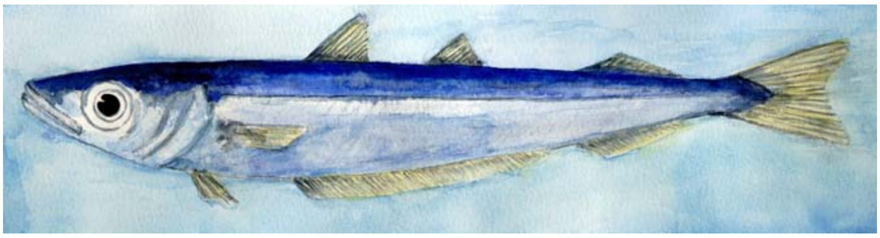

BLUE WHITING SURVEY DURING SPRING 2006

by

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Introduction

During the period March 15–April 16 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 has used the data from 1981 onwards for tuning the stock assessment (e.g., ICES 2005a). 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.

Starting from 2004, the Norwegian blue whiting survey has been part of the international blue whiting spawning stock survey. In this year, in addition to G. O. Sars, four other vessels participated in the survey: R/V Atlantniro (AtlantNIRO, Kaliningrad, Russia), R/V Celtic Explorer (Marine Institute, Ireland), 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. 2006).

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 2005 (ICES 2005b). 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 2006 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, with focus on small blue whiting in particular. 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. The overall coverage was similar to the coverage in recent years. However, bad weather during the second leg of the survey lead to long period with no sampling and acoustic records of suboptimal quality. Target strength measurements were carried out in

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) in January before the survey. This transducer has proven to be stable and therefore this calibration was considered sufficient. In addition, the intercalibration with R/V Magnus Heinason did not indicate any anomalies. 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 586 m circumference pelagic trawl (Åkra trawl); this is a slightly larger version of the standard Åkra trawl with 486 m circumference used in earlier years. The rigging, detailed in Appendix 2, gave vertical opening of about 30-40m m at trawling speed of about 3.5 knots. The higher value corresponds to the first part of the survey during which the use of trawl sonar increased the opening. In addition, a bottom trawl with 4 x 18 m opening equipped with a Rock-hopper ground gear was used on some shallower areas.

During the first part of the survey, the pelagic trawl was equipped with multi-sampler with three codends that could be opened consecutively. The multi-sampler was used to obtain two replicate samples from a single standard trawl haul by splitting the towing time in two (occasionally three) periods of roughly equal length.

Catch from the trawl hauls was sorted and weighed; fish were identified to species whenever possible and other taxa to higher taxonomic levels. Saithe, mackerel, dealfish 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, gonad weight 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.

Because of bad weather, no samples were obtained from a largish area in the northwest part of the survey area (Figure 1). As R/V Celtic Explorer was working in this area just shortly before us, and their sampling procedures and age readings are similar to ours, data from this vessel was used in the estimate.

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 1° latitude by 2° 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. As in 2005 but 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 $<\sigma> = 6.72 \cdot 10^{-7} L^{2.18}$ 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. 4); the southern part of the Porcupine Bank (sub-area I) was not covered.

The hydrographical situation in the surveyed area was mapped by a net of 76 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° 40'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 (~6.5m) temperature and 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. One net was lost and another damaged, after which a smaller dip-net (55 cm diameter) had to be used starting from station 579. 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 taxa recorded during the survey are listed in Appendix 3. Catch comparison between commercial fishing vessel and G. O. Sars is presented in Appendix 4 and the results from inter-calibration with Magnus Heinason in Appendix 6. Appendix 5 gives a brief analysis of variability in length distribution between replicate samples obtained with the multi-sampler. An overview of the work with target strength measurements and some preliminary results are in Appendix 7.

Distribution of blue whiting

Blue whiting were recorded in most of the survey area that covered about 104,000 square nautical miles (Fig. 3). The highest concentrations were recorded in along the shelf edge from the Hebrides towards the Faroe Bank; the bulk of the biomass was distributed much more evenly than in 2005. The densest single school, however, was recorded between the Rockall Bank and Anton Dohrn Sea Mount. The observed densities were rather low west of the Porcupine Bank, north of Rockall, and particularly east of the Wyville-Thompson Ridge. The highest recordings were observed at depths of 450–600 m, sometimes extending to around 2-300 m depth on the slope areas and north from the

Wyville–Thompson Ridge. Overall, the distribution pattern of blue whiting in the survey area can be considered as rather typical except for the low densities in the north.

Stock size

The estimated total abundance of blue whiting for the 2005 Norwegian survey was 8.2 million tonnes, representing an abundance of 92x10^9 individuals (Table 1). The geographical distribution of biomass by stratum is shown in Figure 5. The stock estimate obtained in 2006 is marginally smaller than in 2005 but significantly smaller than in 2002–2004, both in terms of numbers and biomass. As usual, the majority of fish were estimated to be mature, and the spawning stock is thus only little 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
2006	91	86	8.2	8.1	90.1	26.6

The biomass estimate for the Hebrides sub-area was some 15% lower than in 2005. This area hosts about two thirds of the stock (Table 1). Also in the Faroes/Shetland area, the biomass estimate was lower than in 2005, here by some 30%. The estimate of this year is very low in comparison to recent years.

In contrast, biomass estimate in both the Porcupine Bank and Rockall sub-areas in this year was about 50% higher than in 2005 and similar to estimates from 2003.

Stock composition

Year class 2002 (age 4 years) was the most abundant year class in the stock by a wide margin, and stronger than earlier surveys have indicated. (Table 2, Fig. 5). Together with year classes 2003 and 2001 (respectively ages 3 and 5 years), these year classes make 82% of the spawning stock Age class 2000 is forth largest. This is the first year since 2001 when the stock is *not* dominated by year class 2000; at age 6 years now, it is still abundant for its age, but not breaking record as in 2002-2005. It's abundance is only 25% of the observed abundance in 2005, suggesting either very high mortality, low catchability of blue whiting this large, or both.

The age structure is similar in central and northern sub-areas (Hebrides, Rockall, and Faroes/Shetland), with age 4 years blue whiting dominating (Figure 6). In the Porcupine bank sub-area, age class 3 years dominated; this is consistent with earlier years although the sampling in this area was poor this year.

Mean length and weight of blue whiting in the survey area are similar to the estimates from 2005; the increasing trend observed during the last five years has thus halted (see the text table above) Condition of blue whiting was somewhat better than in 2005 except for age class 1 year (Table 2).

Eggs and larvae

Plankton samples were taken on 31 stations. Blue whiting was the most numerous species among both fish larvae and eggs. Most blue whiting eggs were encountered between the Rockall Bank and the mainland (Fig. 7). Eggs in all developmental stages were encountered with dominance of stages III-IV.

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 2001–2006 are the following, with the observed numbers multiplied with the ratio of mouth areas of the standard (80cm diameter) and small (55cm diameter) net, about 3.2, when the small net was used:

Year	Blue whiting		Mackerel		Horse mackerel	
	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
2001	6.7 (37)	**73** (207)	**24** (62)	0.20 (0.78)	0.46 (1.4)	0.049 (0.31)
2002	**1.7** (4.6)	**22** (48)	**28** (98)	0.34 (1.2)	**5.3** (30)	0.054 (0.30)
2003	17 (67)	**176** (703)	**20** (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)
2006	7.9 (14.8)	0.26 (0.82)	4.2 (22)	0 (0)	0.16 (0.52)	0 (0)

Boldface is here used to mark abundances that are significantly ($p<0.05$) different from the abundance in 2006 as estimated by generalized linear models with logarithmic link and negative binomial error functions and relative mouth area of the net used as an offset variable.

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 somewhat higher than the long-term average (6.7). The numbers of mackerel and horse mackerel eggs were low, and not a single mackerel 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. Survey timing, in particular, is likely to be important. The survey in 2006 was conducted rather early, in particular when compared to the record year 2003 when the survey was very late (the difference is almost 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.

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 CTD and salinograph data collected on board G. O. Sars (Figure 2) and CTD data kindly provided by the scientists on board R/V Atlantniro, R/V Celtic Explorer, R/V Magnus Heinason and R/V Tridens 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 8°C. 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 53°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 water 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, but this year the 11°C isotherm extends far into the Rockall Through, to 57°N. Both this year and in 2005 the 10°C isotherm extended north to about 58°N, but a larger area is occupied with water above 10°C. Whereas last year a temperature decrease was observed compared to 2004, this years temperatures are higher than 2004. 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 also shows a warming compared to last year.

At the Porcupine section (Figure 10) the temperature is very homogeneous (11-11.5°C) down to about 500m with a gradual change in the thermocline between 500m and 1000m.

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 water of Norwegian Sea origin is extending up to about 500m. The 0°C isotherm is found at between 500 and 700m, shallowest in the west. This is about the same depth as the two preceding years, but shallower than in 2003. The temperature and salinity (S<35.4) in the core of the Atlantic water are about the same as last year, thus the cooling and freshening observed the two preceding years has stopped.

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. In the period 2002-2004 the temperature was above 10.5°C, with 2004 the warmest on record (~10.8°C). Last year we saw a drop to ~10.4°C. This year a new record has been set with 11.3°C, which is 0.5°C warmer than the previous record. 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.

The mean salinity in the box off Porcupine Bank is 35.51 this year. This is the highest value in the more than 20 years long time series.

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). 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 (2004).

The survey results in spring 2006 suggest negligible decreases in both numbers (about 3%) and biomass (about 4%) of blue whiting compared to year 2005, but large decreases compared to years 2002–2004. This decrease should be judged against changes in survey coverage, which in 2006 was about 12% more than in 2005. 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 2006, the total stock biomass estimate in those strata that were covered in 2005 is 7.7 million tonnes (as opposed to 8.2 million tonnes in the whole survey area). Adjusting for slightly smaller coverage within each stratum in 2006 than in 2005, the corrected total estimate is 7.9 million tonnes. This estimate has to be compared with the estimate obtained in 2005 for the same strata, 8.4 million tonnes. The coverage-corrected decrease in total stock biomass is about 6%, a somewhat larger reduction than the direct comparison would suggest.

There is also a significant change in the age structure of the spawning stock. Estimated abundance of year class 2000, the strongest year class in record, has decreased dramatically (by about 75%). After being the dominant year class for four years, this year class was only fourth most abundant this year. While the heavy fishing must diminish the numbers of this year class, another factor contributing to this unexpectedly drastic decrease is size selectivity of the pelagic trawl used during this survey: the trawl does not catch large individuals well, as evidenced by the comparisons with commercial fishing vessel during this survey (see Appendix 4). Unexpectedly, the dominant year class was the one from 2002 (age 4 years). This year class has been below average in earlier years, but estimate this year above average, and almost twice as high as its strength the year before. Whether this is caused by late recruitment to the spawning stock or underestimation earlier on (or overestimation this year) is unclear. Young blue whiting was more abundant than in 2005, but still relatively scarce in comparison to earlier years. For Porcupine Bank this largely reflects inadequate sampling, but this factor alone is not sufficient to explain the low numbers.

Norwegian survey in 2006 was carried out in co-operation with four other vessels (from the Faroes, Ireland, the Netherlands, and Russia). The results from this third international, ICES-coordinated survey (Heino et al. 2006) yield a total stock estimate that is larger than the Norwegian estimate, with most of the difference arising from the more extended coverage in the western areas (west of 16°W). On the other hand, areas in the very south and north that were not covered by G.O. Sars contribute little to the total stock. In contrast to the Norwegian survey, the international survey suggests a significant increase in the stock. This is mostly caused by the western areas not covered by G.O. Sars, but also a significant increase in the Hebrides sub-area was measured. The lower estimate by G.O. Sars this year as compared to 2005 may be explained by possible overestimation in 2005 caused a single huge school of blue whiting that was overrepresented in the acoustics. Both surveys show similar age structure, with the dominance of age classes 2002 and 2003. Considering the differences in spatial coverage, the results are in fairly good agreement, but the international survey yielding a more optimistic picture.

The relatively stability of the stock estimate in comparison to estimate from 2005 suggests that recruitment to the spawning stock has compensated for loss of individuals through fishing and natural mortality. We are not aware of any obvious factors biasing the current estimate relative to the earlier estimates. However, stock numbers at age suggest rapid disappearance of fish older than 4 years in age. The spawning stock is thus dependent on good recruitment. The current survey yields unexpectedly positive view on the strength of year class 2002. In contrast, later year classes appear weak. This calls for cautious exploitation of the stock.

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Table 1. Assessment factors of blue whiting, spring 2006.

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	18014	7680	7680	100	618	618	100	80.5	26.3	34
III	Hebrides	34564	58000	62800	92.3	5480	5620	97.6	89.5	26.6	163
IV	Faroes/Shetland	20383	5100	5300	96.1	439	445	98.5	84.0	26.2	22
V	Rockall	31064	15200	15500	98.6	1540	1540	99.7	99.7	27.0	50
Total		104025	86000	91200	94.2	8070	8220	98.2	90.1	26.6	79

Table 2. Stock estimate of blue whiting, spring 2006.

Length	Age in years (year class)										Numbers	Biomass	Mean weight	Mature
	1	2	3	4	5	6	7	8	9	10+				
(cm)	2005	2004	2003	2002	2001	2000	1999	1998	1997	-1996	(10^6)	(10^6 kg)	(g)	%
15.0 - 16.0	238	0	0	0	0	0	0	0	0	0	238	4	16.3	0
16.0 - 17.0	1636	0	0	0	0	0	0	0	0	0	1636	32	19.4	1
17.0 - 18.0	1104	6	0	0	0	0	0	0	0	0	1111	26	23.0	4
18.0 - 19.0	857	20	0	0	0	0	0	0	0	0	877	23	26.6	16
19.0 - 20.0	458	222	0	0	0	0	0	0	0	0	680	22	31.8	16
20.0 - 21.0	384	535	0	0	0	0	0	0	0	0	919	37	40.7	51
21.0 - 22.0	113	422	27	0	0	0	0	0	0	0	562	26	46.3	65
22.0 - 23.0	103	372	149	48	0	0	0	0	0	0	672	38	56.6	82
23.0 - 24.0	0	814	1142	840	0	0	0	0	0	0	2796	178	63.7	90
24.0 - 25.0	0	619	3533	2135	0	254	0	0	0	0	6540	457	69.8	100
25.0 - 26.0	0	252	6791	8083	1820	229	0	0	0	0	17175	1314	76.5	100
26.0 - 27.0	0	577	3328	8573	2551	1549	0	0	0	0	16578	1390	83.8	100
27.0 - 28.0	0	0	2689	7740	3683	1025	0	0	0	0	15137	1410	93.2	100
28.0 - 29.0	0	0	895	5446	2862	1600	4	0	0	0	10806	1136	105	100
29.0 - 30.0	0	0	813	2239	2357	1217	401	0	0	0	7027	832	118	100
30.0 - 31.0	0	0	0	867	1408	873	352	156	0	0	3656	489	134	100
31.0 - 32.0	0	0	79	487	328	890	288	0	0	0	2072	299	144	100
32.0 - 33.0	0	0	0	10	845	279	244	17	0	0	1395	231	165	100
33.0 - 34.0	0	0	0	143	90	49	241	264	0	0	786	153	194	100
34.0 - 35.0	0	0	0	7	55	0	42	29	89	0	221	47	214	100
35.0 - 36.0	0	0	0	0	0	201	6	0	7	0	214	48	225	100
36.0 - 37.0	0	0	0	0	0	0	14	0	32	32	78	16	211	100
37.0 - 38.0	0	0	0	0	0	0	0	0	2	8	10	3	248	100
38.0 - 39.0	0	0	0	0	0	0	0	0	0	0	0	0	.	.
39.0 - 40.0	0	0	0	0	0	0	0	0	0	0	0	0	.	.
40.0 - 41.0	0	0	0	0	0	0	0	0	0	0	0	0	.	.
41.0 - 42.0	0	0	0	0	0	0	0	0	0	0	0	0	.	.
42.0 - 43.0	0	0	0	0	0	0	0	0	0	35	35	12	356	100
TSN (10^6)	4893	3839	19446	36617	15998	8167	1592	466	129	75	91221			
TSB (10^6 kg)	125	232	1577	3326	1677	917	240	81	26	21	8221			
Length (cm)	17.9	23.2	26	27	28.3	28.8	31.4	32.5	35.1	39.4	26.6			
Weight (g)	25.5	60.4	81.1	90.8	105	112	151	174	203	281	90.1			
Condition	4.4	4.8	4.6	4.6	4.6	4.7	4.9	5.1	4.7	4.6	4.8			
% mature	10	78	100	100	100	100	100	100	100	100	94.2			
% of SSB	0	2	20	41	21	11	3	1	0	0				

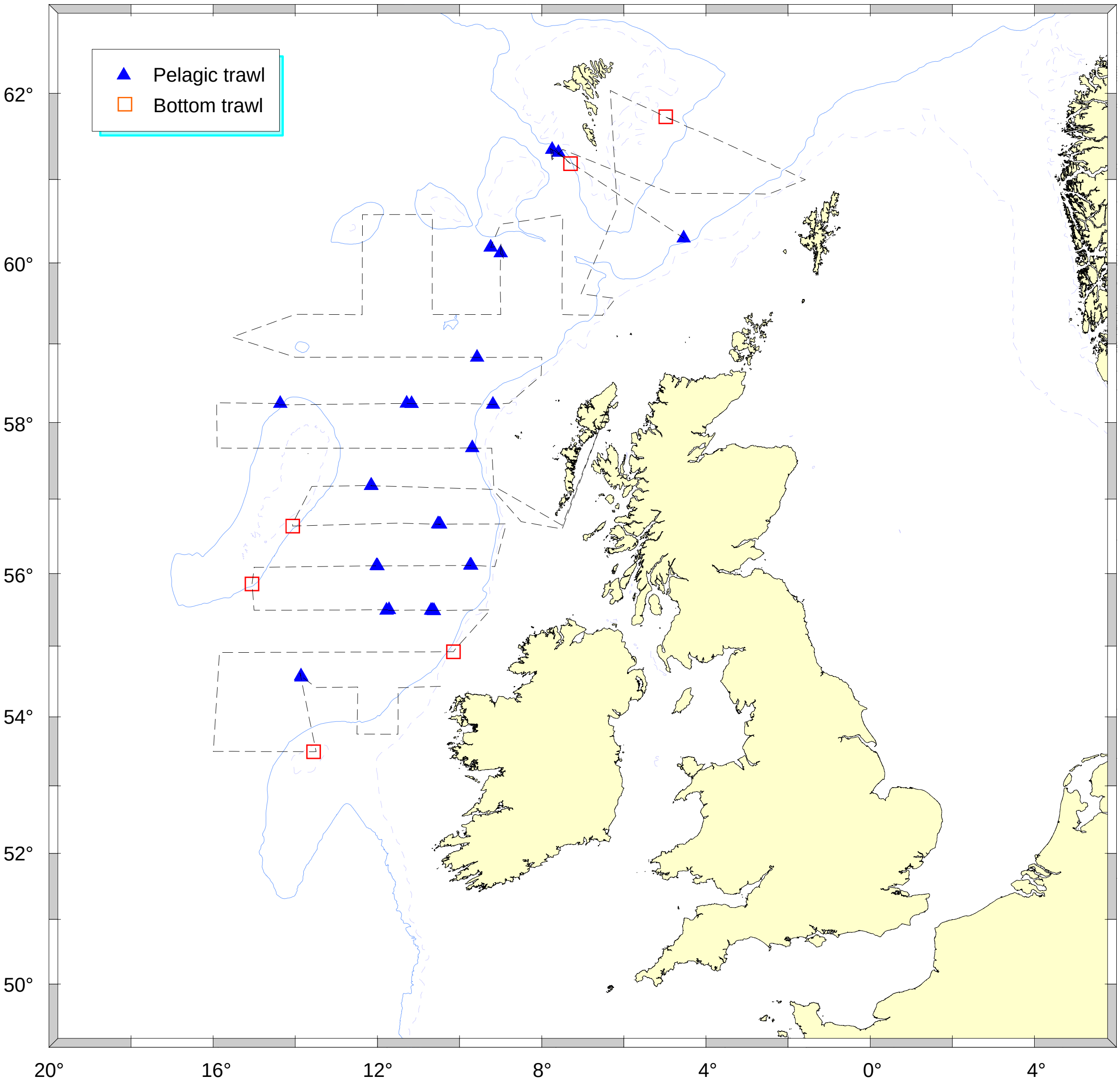


Figure 1. Cruise tracks with trawl stations, R.V. "G. O. Sars" 15 March–16 April 2006.

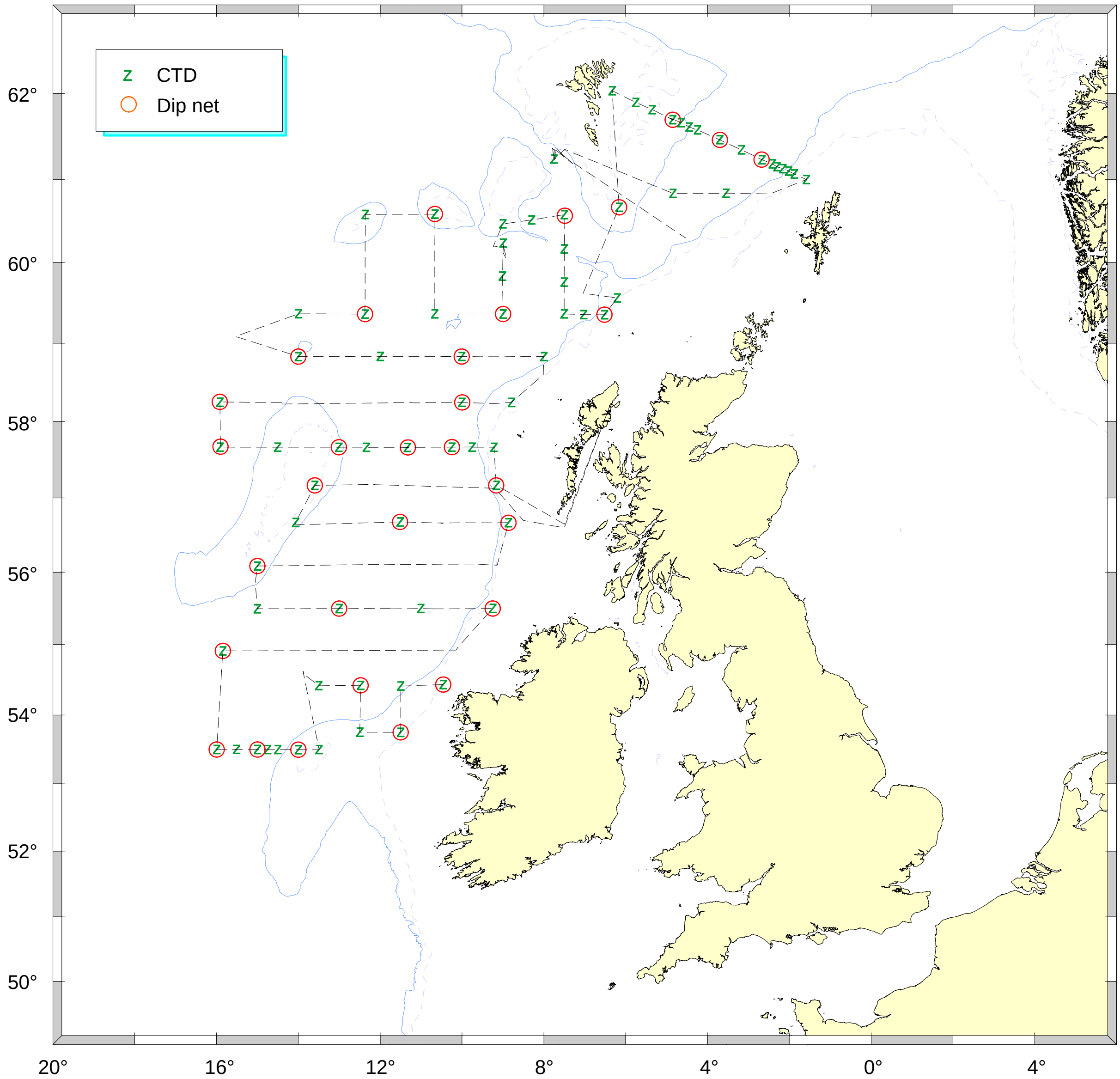


Figure 2. Cruise tracks with CTD and plankton stations, R.V. “G. O. Sars” 15 March–16 April 2006.

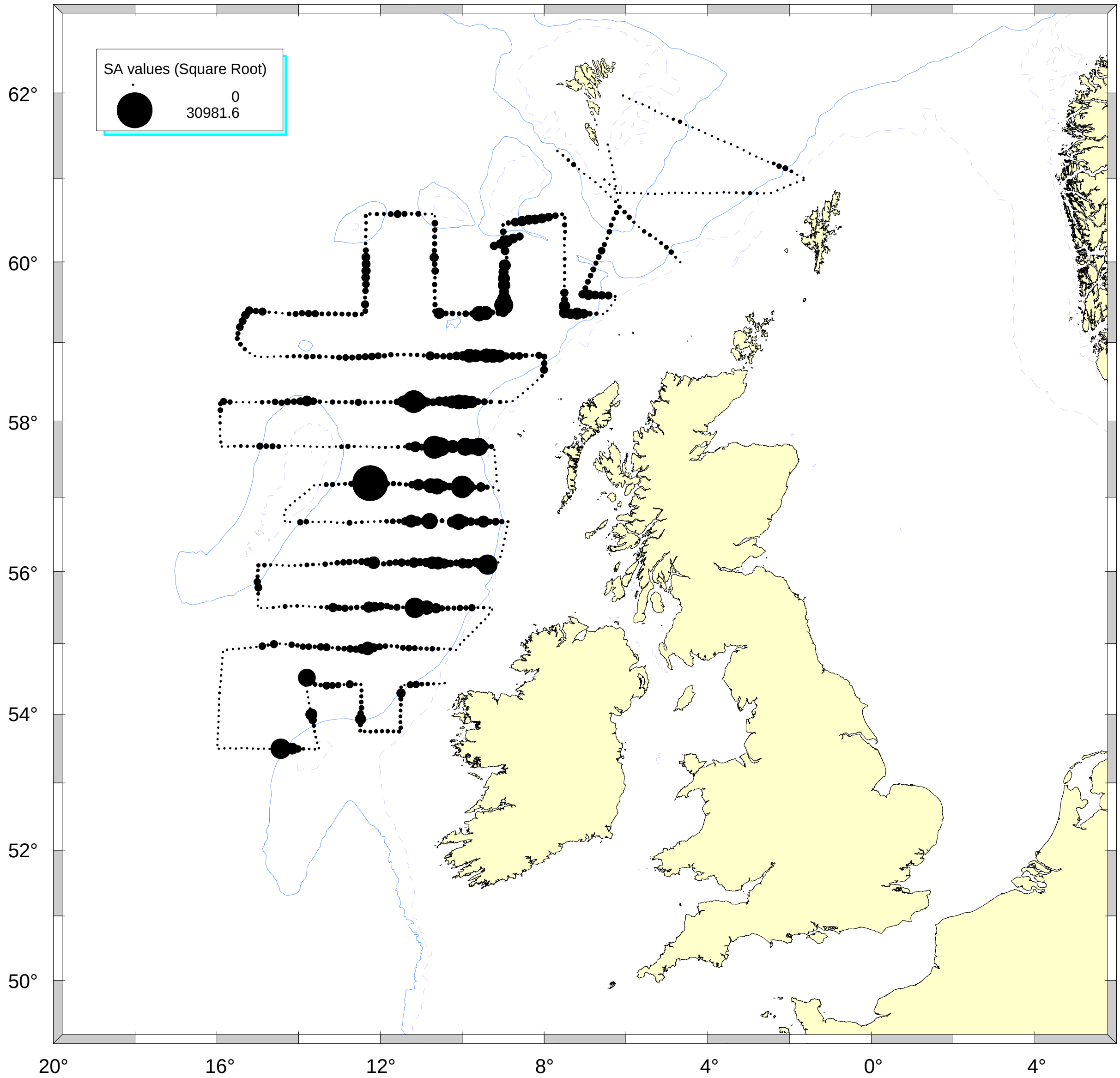


Figure 3. Distribution of blue whiting in spring 2006 in terms of echo intensity (s_A-values, $m^2/n.mile^2$). The map is primarily based on observed echo intensities along the cruise track (see Fig. 1) and knowledge on bottom topography and its influence on distribution of blue whiting.

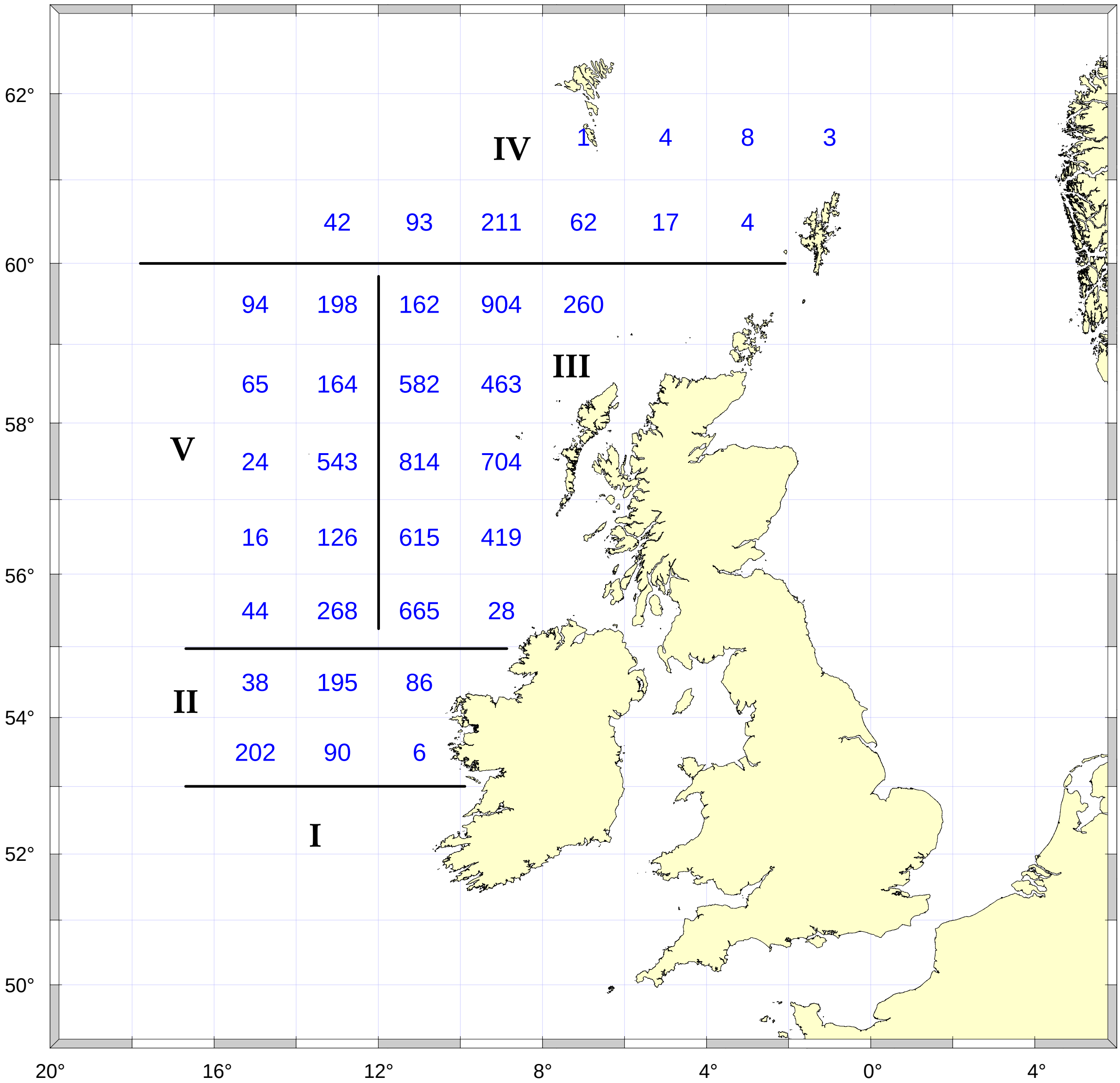


Figure 4. Blue whiting biomass in 1000 tonnes, spring 2006. Marking of sub-areas I-V used in assessment.

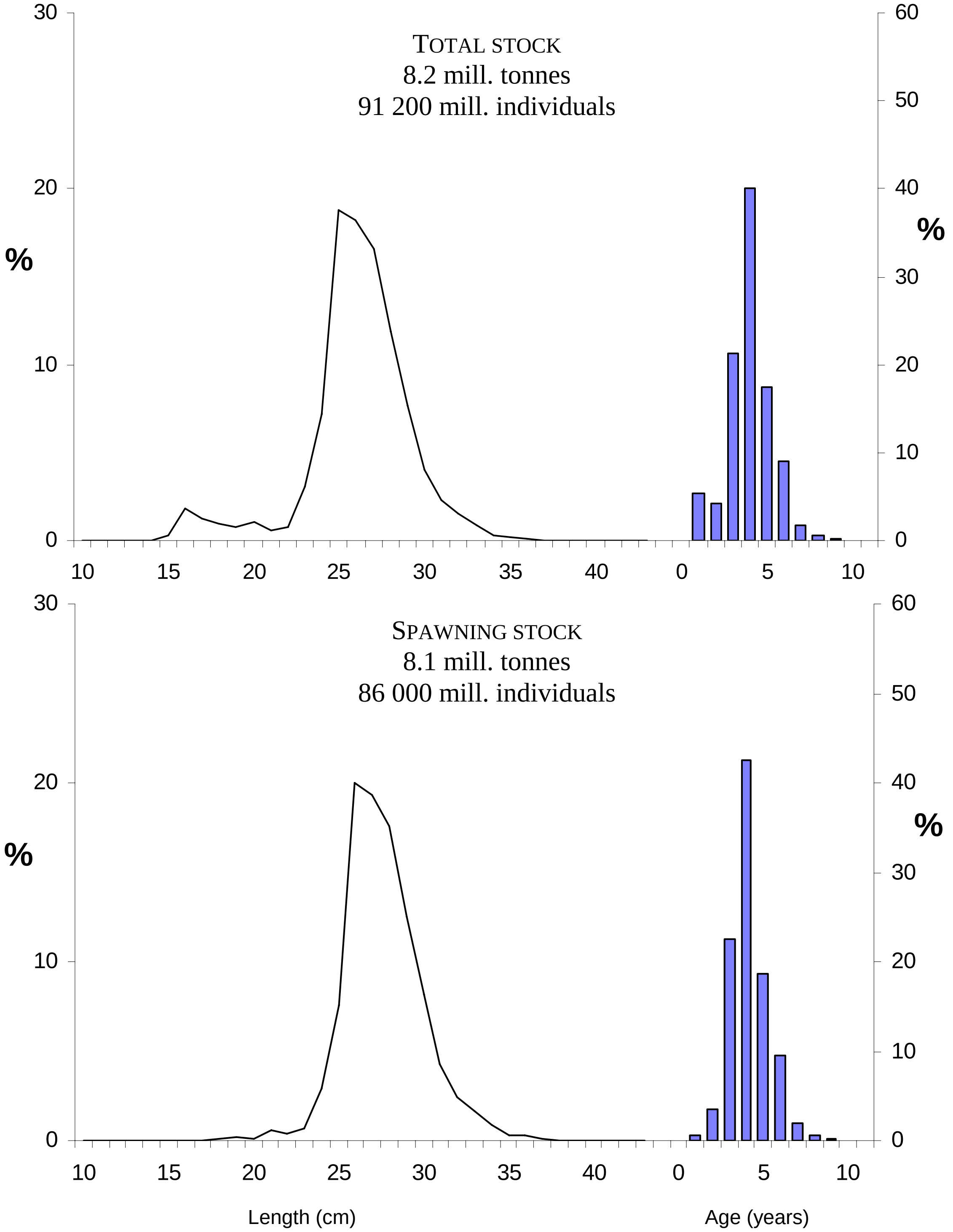


Figure 5. Length and age distribution in the total and spawning stock of blue whiting in the area to the west of the British Isles, spring 2006.

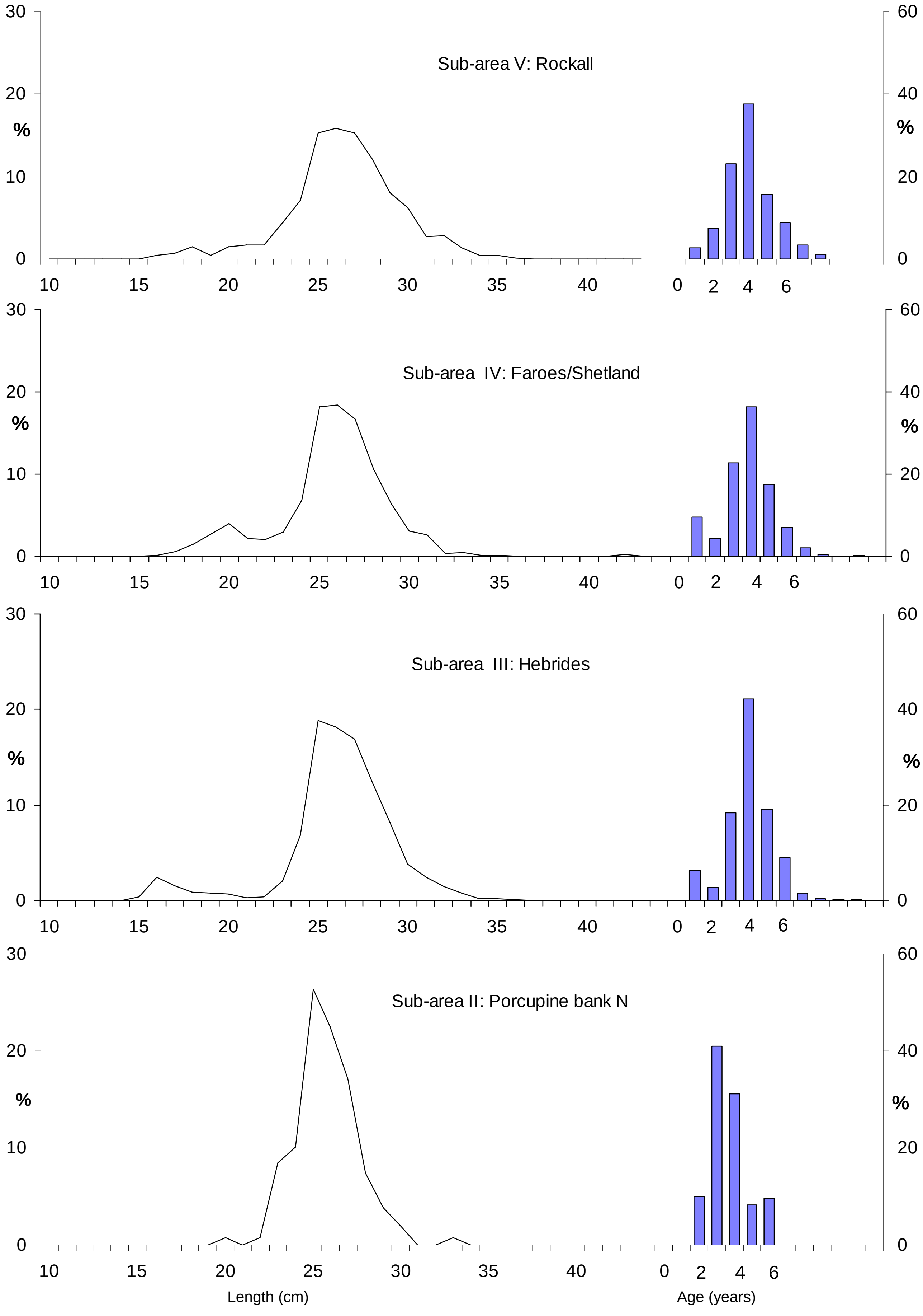


Figure 6. Length and age distribution of blue whiting by sub-areas (II-V), spring 2006.

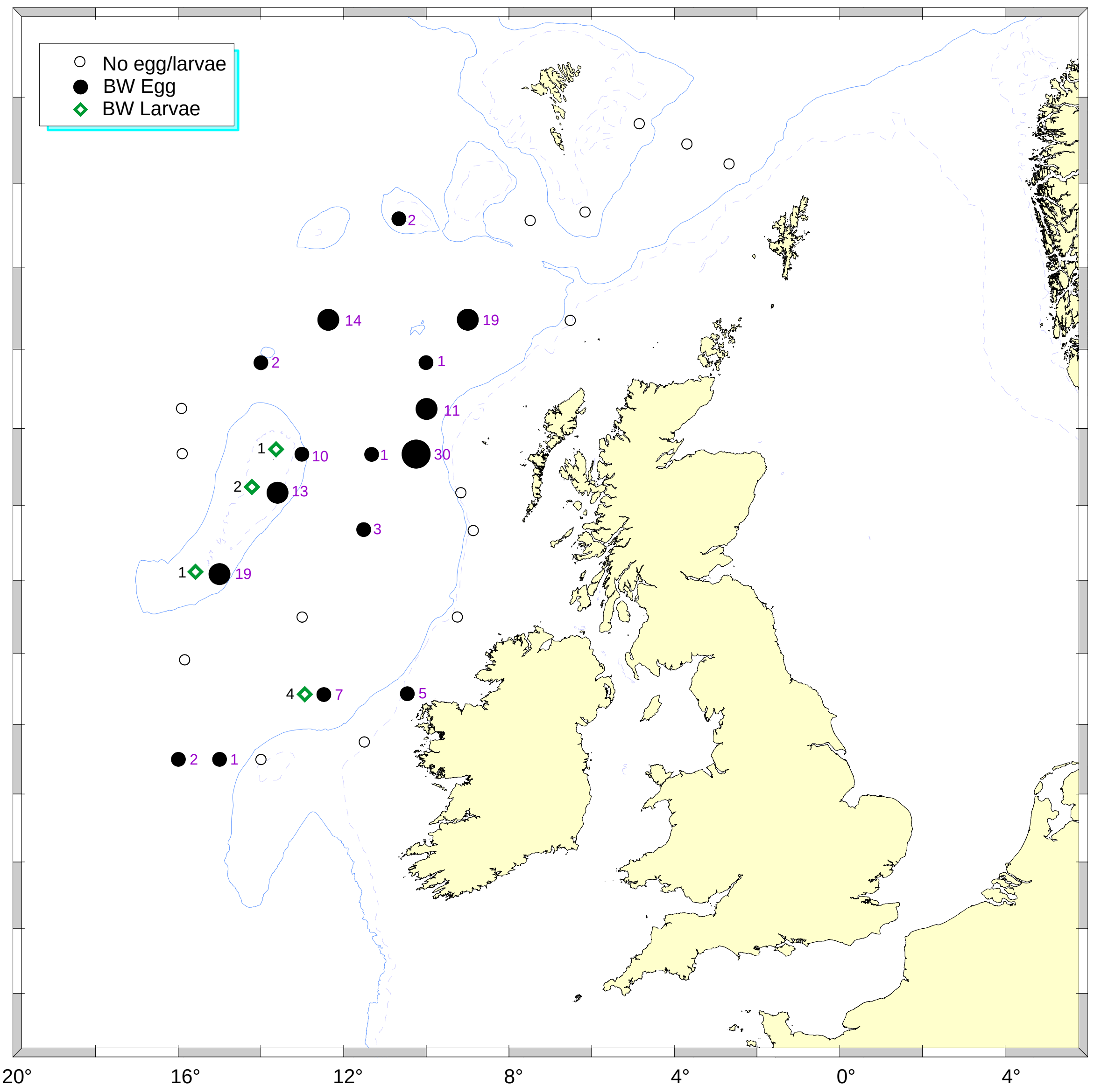


Figure 7. Distribution of blue whiting eggs and larvae in spring 2006. Number of individuals is also inserted (eggs on the right, larvae on the left).

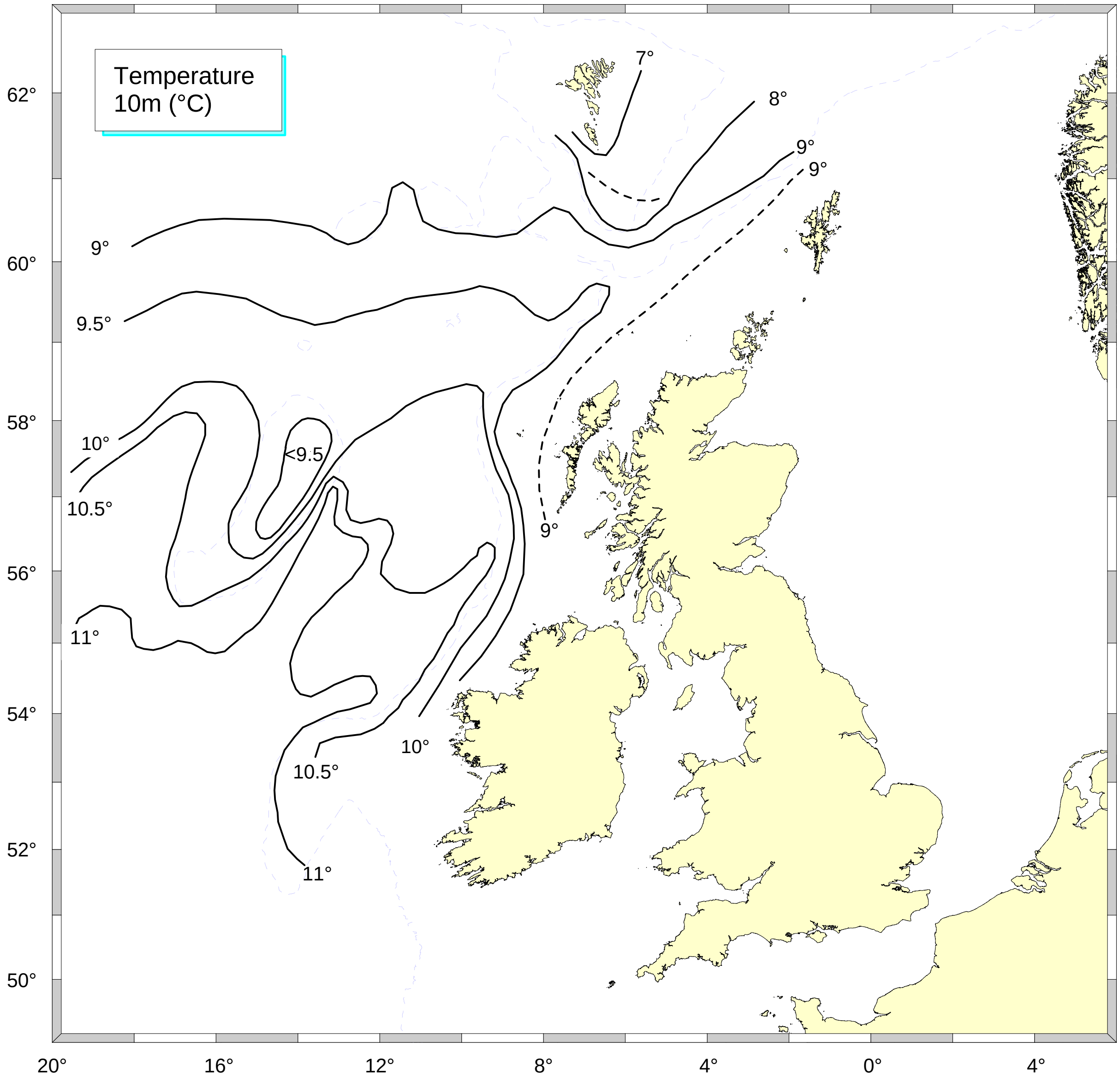


Figure 8. Horizontal temperature (°C) distribution at 10m depth.

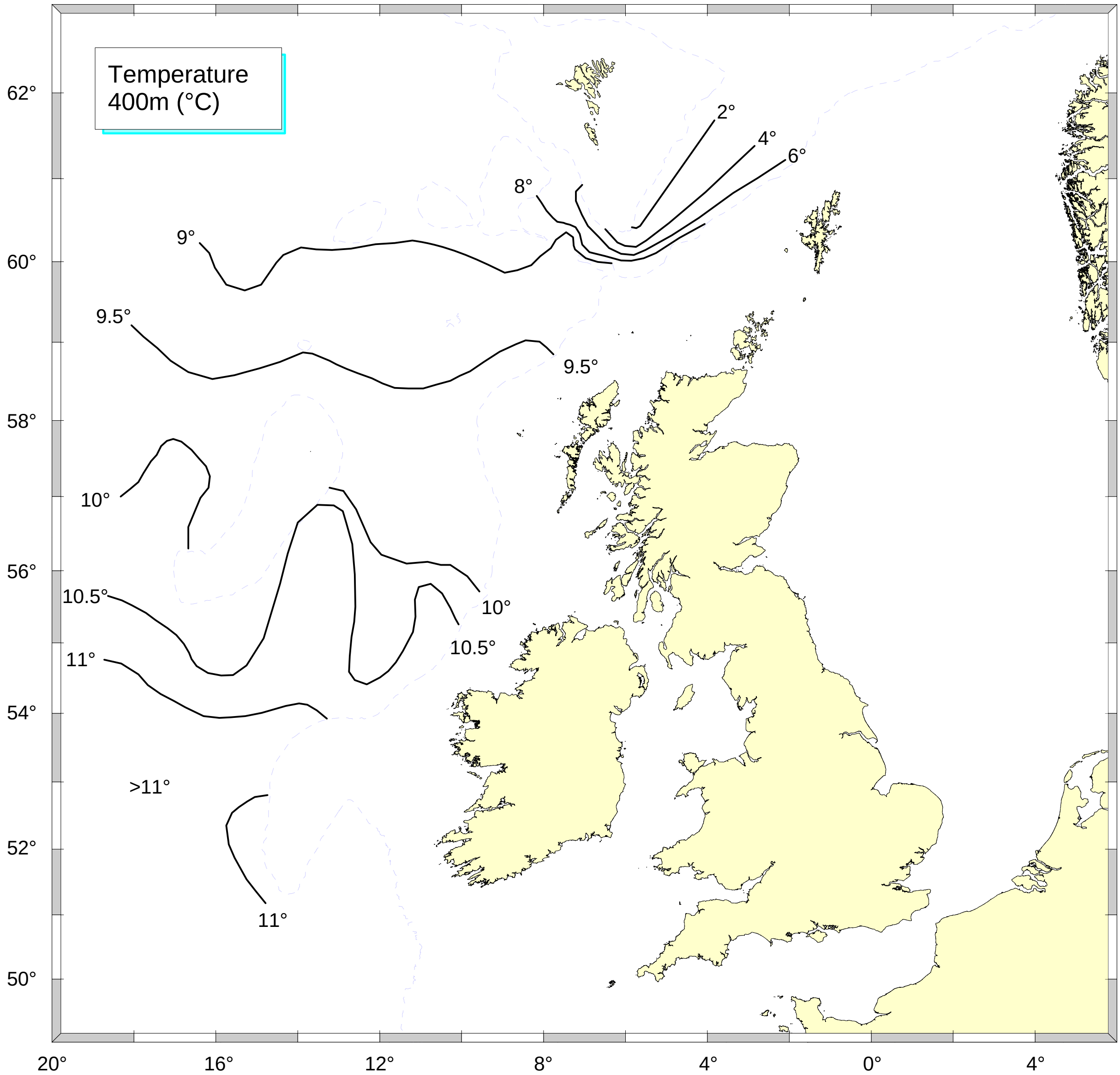
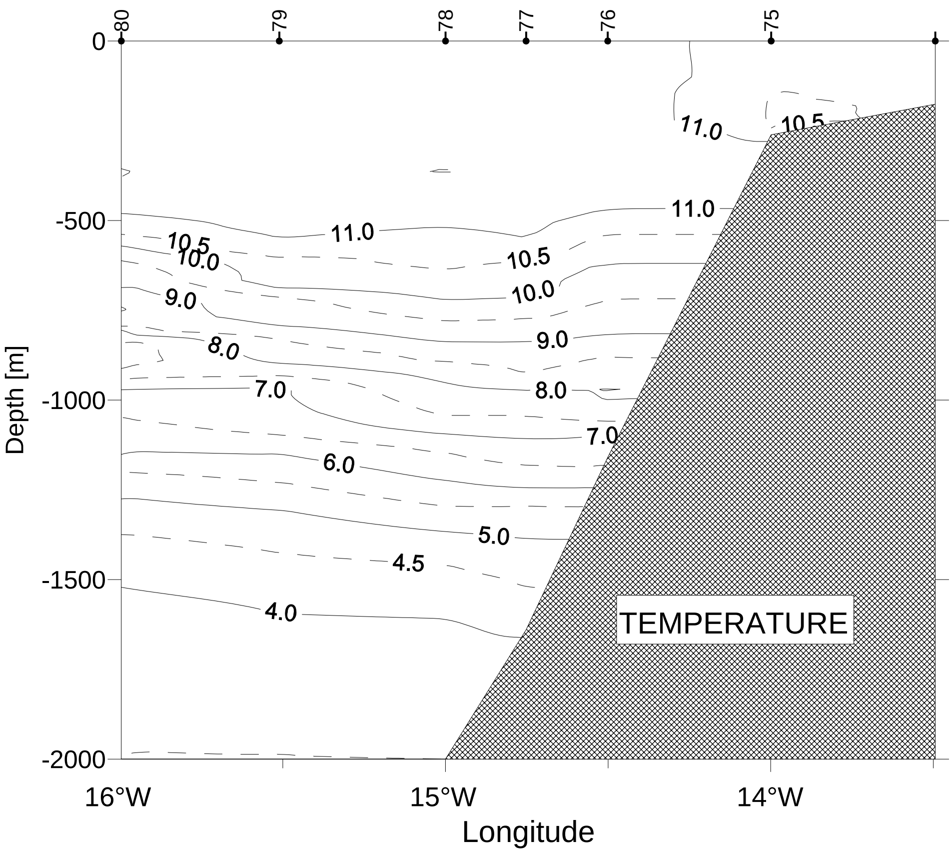


Figure 9. Horizontal temperature (°C) distribution at 400m depth.



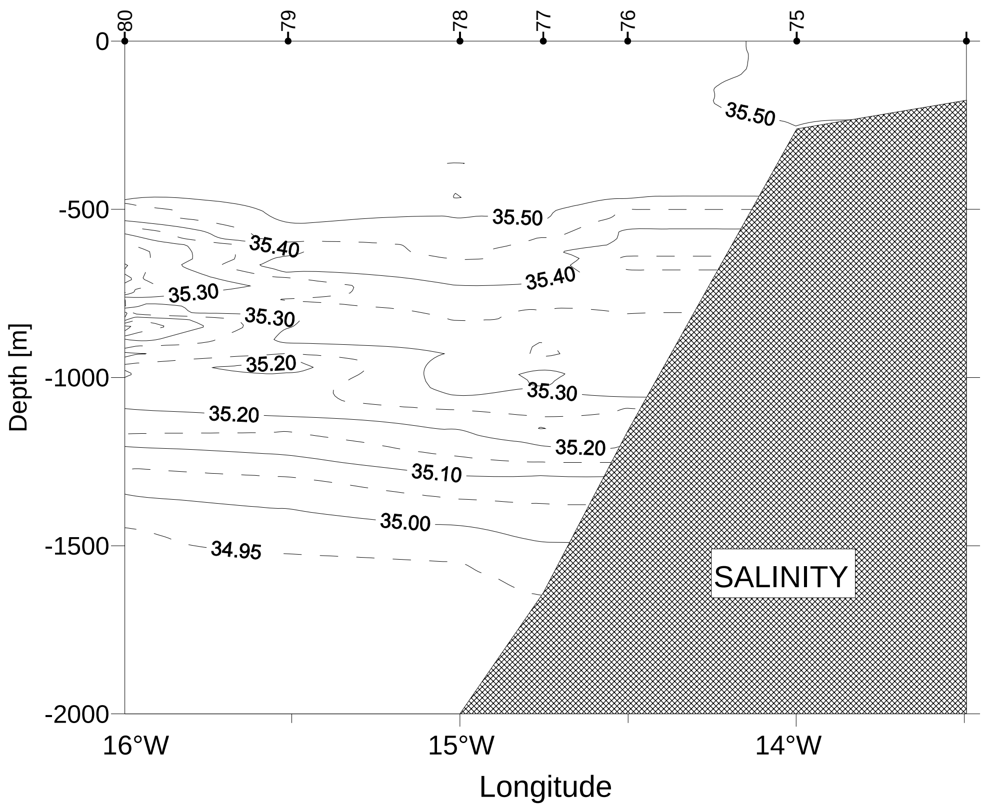


Figure 10. Vertical distribution of temperature (°C) and salinity in a section at the shelf edge at the Porcupine Bank at 53° 30'N. Station numbers at the top of the panels.

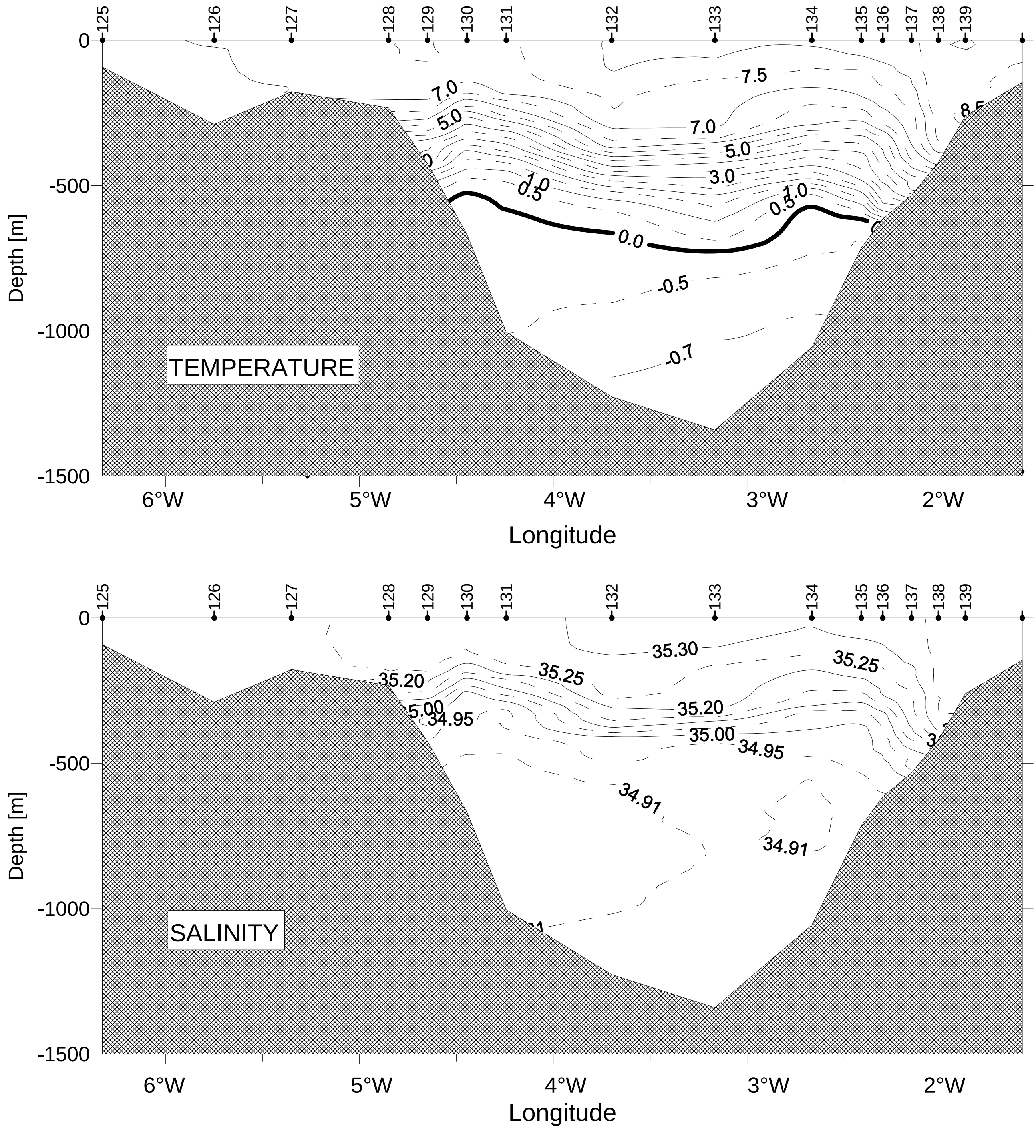


Figure 11. Vertical distribution of temperature (°C) and salinity in a section from the Faroes to Shetland (Nolsø-Flugga). Station numbers at the top of the panels.

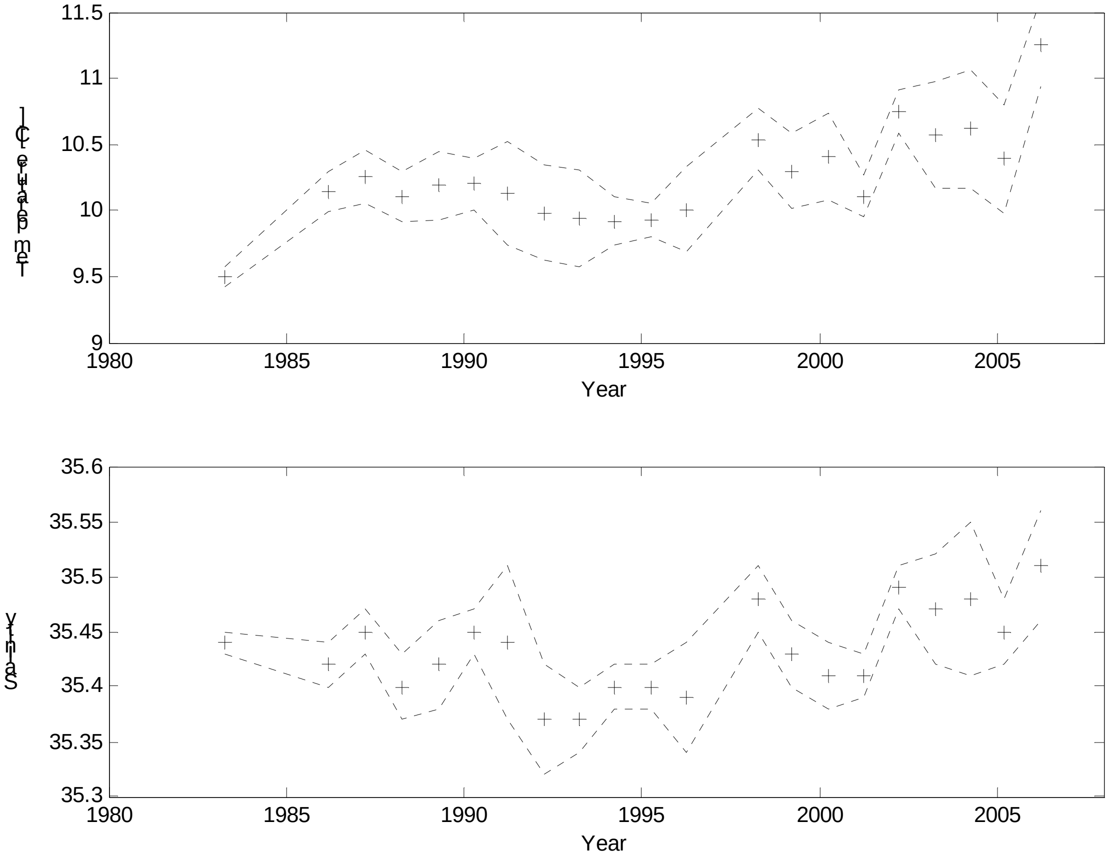


Figure 12. Yearly mean temperature and salinity from 50-600 m (crosses) of all stations in a box with bottom depth >600 m, west of the Porcupine bank bounded by 52° to 54°N and 16 to 14°W. Dotted lines are drawn at ±1 standard deviation of all observations in each box, each year.

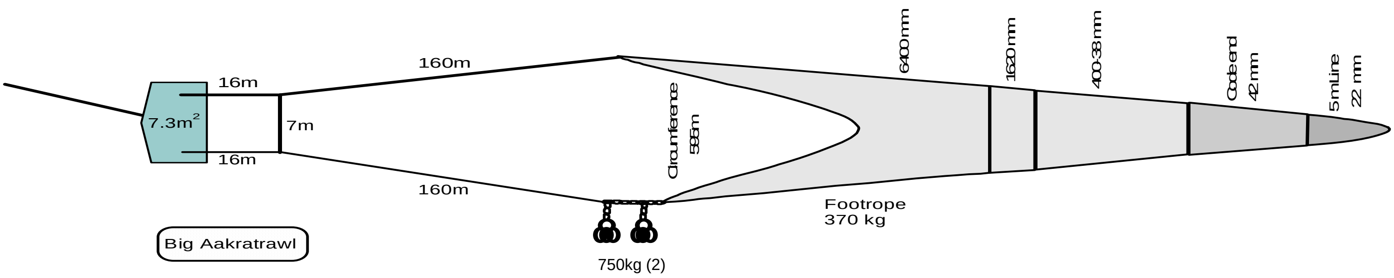
Appendix 1. Acoustic equipment and settings

Acoustic equipment and settings for the primary frequency on the R/V "G. O. Sars", 15 March–16 April 2006

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:	25.55 dB
s_A correction	-0.65 dB
3 dB beam width	
along ship:	7.05 °
athw. ship:	7.06 °
Range:	750 m

Appendix 2. Configuration of the pelagic trawl

The figure below gives details of the configuration of the large pelagic trawl (Åkratrål) used to collect most of the biological samples during the blue whiting survey in spring 2006.



Appendix 3. Fish taxa encountered during the blue whiting survey in spring 2006

	Scientific name	Common name
1	*Aphanopus carbo*	black scabbardfish
2	*Argentina silus*	greater argentine
3	*Argentina sphyraena*	argentine
4	*Argyropelecus hemigymnus*	axefish
5	*Argyropelecus olfersi*	hatchet fish
6	*Arnoglossus imperialis*	imperial scaldfish
7	*Bathygadus*	grenadier
8	*Brosme brosme*	cusk
9	*Caelorinchus caelorhincus*	blackspot grenadier
10	*Callionymus lyra*	common dragonet
11	*Capros aper*	boarfish
12	*Chauliodus sloani*	sloane's viperfish
13	*Chiasmodon niger*	black swallower
14	Chimaeridae	rabbitfishes
15	Congridae	conger eels
16	*Cyclothone*	bristlemouth
17	*Diretmus argenteus*	
18	*Electrona rissoi*	lanternfish
19	*Entelurus aequerius*	snake pipe-fish
20	*Etmopterus spinax*	velvet belly
21	*Eutrigla gurnardus*	grey gurnard
22	*Gadiculus argenteus*	silvery pout
23	*Gaidropsarus vulgaris*	three-bearded rockling
24	*Galeus melastomus*	blackmouthed dogfish
25	*Glyptocephalus cynoglossu*	witch
26	*Gonostomatidae*	lightfishes
27	*Gonostoma elongatum*	
28	*Helicolenus dactylopterus*	blue-mouth redfish
29	*Hippoglossoides platessoides*	long rough dab
30	*Howella sherborni*	
31	*Labrus bimaculatus*	cuckoo wrasse
32	*Lampadena speculigera*	mirror lanterfish
33	*Lampanyctus macdonaldi*	lanternfish
34	*Lepidorhombus whiffiagoni*	megrim
35	*Limanda limanda*	dab
36	*Lophius piscatorius*	anglerfish (monk)
37	*Maurolicus muelleri*	pearlside
38	*Melanogrammus aeglefinus*	haddock
39	Melanostomidae	
40	*Melanostomias*	
41	*Merluccius merluccius*	hake
42	*Microchirus variegatus*	thickback sole

43	*Micromesistius poutassou*	blue whiting
44	*Microstomus kitt*	lemon sole
45	*Molva dypterygia*	blue ling
46	*Molva molva*	ling
47	Myctophidae	lanternfishes
48	*Nansenia groenlandica*	greenland argentine
49	*Nansenia oblita*	forgotten argentine
50	*Notolepis rissoi*	
51	*Notoscopelus kroeyeri*	
52	Opisthoproctidae	
53	Paralepididae	barracudinas
54	*Paralepis coregonoides*	
55	*Phycis blennoides*	greater fork-beard
56	Platytroctidae	
57	*Pseudoscopelus*	
58	*Raja montagui*	spotted ray
59	*Sagamichtys schnakenbecki*	
60	*Scomber scombrus*	mackerel
61	*Scopelogadus beanii*	
62	*Scopelosaurus lepidus*	
63	*Scyliorhinus canicula*	smallspotted catfish
64	*Searsia koefoedi*	
65	*Sebastes viviparus*	norway redfish
66	*Stomias boa ferox*	
67	*Trachipterus arcticus*	deal-fish
68	*Trachurus trachurus*	horse mackerel
69	*Trigla lucerna*	tub gurnard
70	*Trisopterus minutus*	poor-cod
71	*Xenodermichthys copei*	bluesnout smooth-head
72	*Zeus faber*	John Dory

Appendix 4. Comparison of trawl performance

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, north of the Porcupine Bank (Table 1, Figure 1); couple other Norwegian vessels were also fishing in the same area. Blue whiting occurred as a well-defined layer of some 50-100 m in thickness in the depth of 450-600 metres. The difference in length distributions is moderate (1.5 cm) and statistically significant ($p<0.001$). Notice that the modal length is the same in both samples, but large individuals (length >30cm) are largely missing from the sample of G.O. Sars. Commercial fishing vessels thus continue to fish larger blue whiting than an IMR vessel using an Åkra trawl. 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.

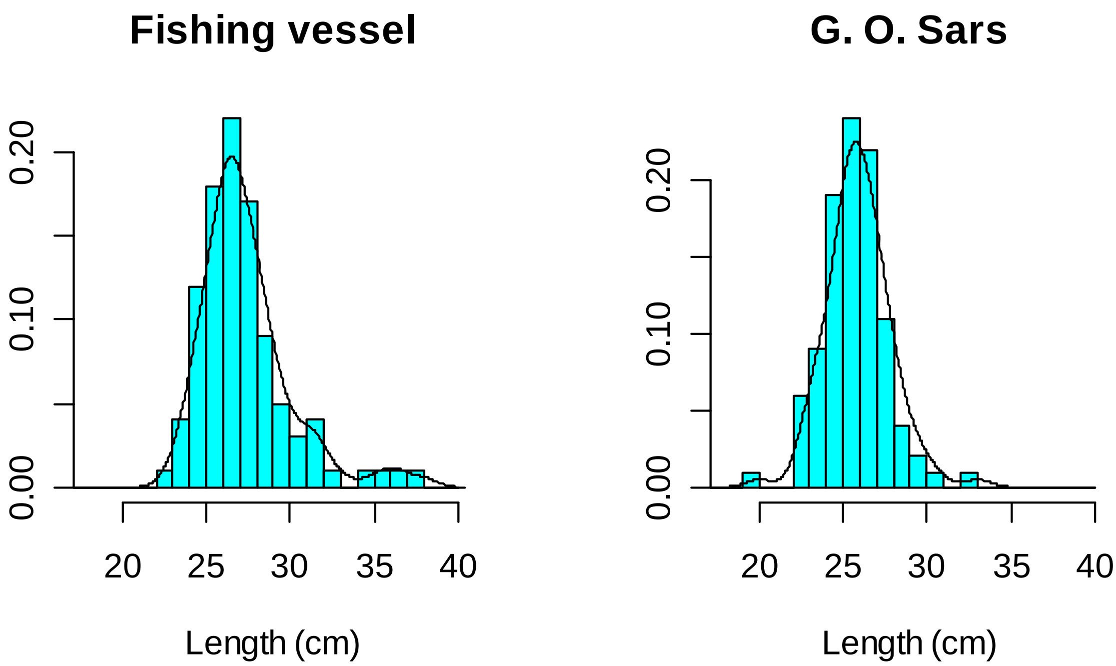


Figure 1. Length distributions from trawl hauls from a commercial fishing vessel and G. O. Sars from the same area. See Table 1 for sample sizes.

Table 1. Results of comparisons between the large Åkra trawl on G. O. Sars and a commercial fishing vessel.

Area and date	Vessel	Catch (kg)	Average length ± S.D. (cm)	Sample size
N of Porcupine Bank, 19/3/2006	Commercial fishing vessel	500,000	27.4 ±2.7	100
	G. O. Sars with large Åkra trawl	30	25.9 ±1.9	100

Appendix 5. Variability among trawl hauls and among replicate samples with single hauls.

Multiple samples were obtained from 6 trawl hauls. In all cases, "adequate" samples were obtained, the criterion being that the catch was at least 50 blue whiting. Mean length of blue whiting in these hauls from these hauls are given below:

Station	199	200	202	203	204	206
1st codend	26.0	27.4	27.0	27.3	26.7	28.4
2nd codend	26.4	26.9	26.3	27.6	27.5	28.3
3rd codend	27.0				27.6	

The results of an analysis of variance applied to the data is shown below:

Factor	D.f.	Mean square	F	p
Station	5	83.2	17.1	<0.001
Codend	2	22.0	4.5	0.011
Station*codend	6	11.0	2.3	0.035
Residual	1140	4.9		

As expected, more variance can be attributed to the variability between stations than between sub-samples. However, there are also significant contributions from variability between codends and the station*codend interaction. Fish in the second and third codend tend to be longer than fish in the first codend. This is in contrast to results obtained in 2005 when the codend effect was not significant.

The data for weight and condition factor (defined as weight/length^3) are as follows:

	Station	199	200	202	203	204	206
Weight	1st codend	84	94	112	96	102	120
	2nd codend	82	89	101	101	103	124
	3rd codend	87				102	
Condition factor	1st codend	4.75	4.48	5.53	4.61	5.09	5.11
	2nd codend	4.41	4.51	5.42	4.74	4.83	5.29
	3rd codend	4.39				4.73	

Analysis of variance applied to the data gives the following results (with weight log-transformed):

	Factor	D.f.	Mean square	F	p
Weight	Station	5	2.81	39.7	<0.001
	Codend	2	0.071	1.0	0.368
	Station*codend	6	0.11	1.6	0.143
	Residual	1139	0.071		
Condition factor	Station	5	28.0	131	<0.001
	Codend	2	2.5	11.7	<0.001
	Station*codend	6	1.5	6.8	<0.001
	Residual	1139	0.213		

Somewhat unexpectedly, only station has a significant effect on weight. However, all explanatory variables have highly significant effects on condition factor, with station having by far the strongest effect. Fish in the first codend tend to be in the best condition.

The results differ from those obtained in 2005: there is evidence of consistent differences between first and second codend, whereas the between stations heterogeneity in the codend effect (the interaction station*codend) is weaker. Nevertheless, there is significant level of spatial heterogeneity among already at the spatial scale of one nautical mile.

The results are at odds with the common wisdom that strongest fish can sustain swimming in front if the trawl longer before ending in the codend. A possible biological explanation is that the fish with best “condition” have large gonads that impair swimming, while post-spawners are better avoiding the trawl. Unfortunately full biological data were collected only from one codend per station. At the level of the whole blue whiting material from this cruise, condition factor is the highest among early maturing (stage 3) and ripe (stage 5) fish. After accounting for gonad weight, no maturity stage can be singled out as being characterised by higher condition. Thus the codend effect eludes this simple explanation.

Appendix 6. Inter-calibration between R/V Magnus Heinason and R/V G. O. Sars

Acoustic inter-calibration between R/V G. O. Sars and R/V Magnus Heinason was conducted on April 9 by the Ymir Ridge, south of the Faroes at N 60° 15' and W 9° 00'. The weather was fairly favourable with weak wind (10-15kt from NW) and moderate swell (significant wave height 4 metres) remaining from the strong gale the day before. The main acoustic features in the area were (1) a 100 m thick layer of blue whiting in depths between 450 and 600 metres that was strongest close to the Ymir Ridge, (2) a dense layer of presumed macro-zooplankton immediate below and partly mixed with the blue whiting layer, and (3) mesopelagics, probably mostly pearlside, in depths between 200 and 300 metres.

The inter-calibration was the run over 22 nautical miles between 13:48-16:06 GMT. Vessels were cruising southwest at parallel courses side by side at a distance of about 0.5 nm.

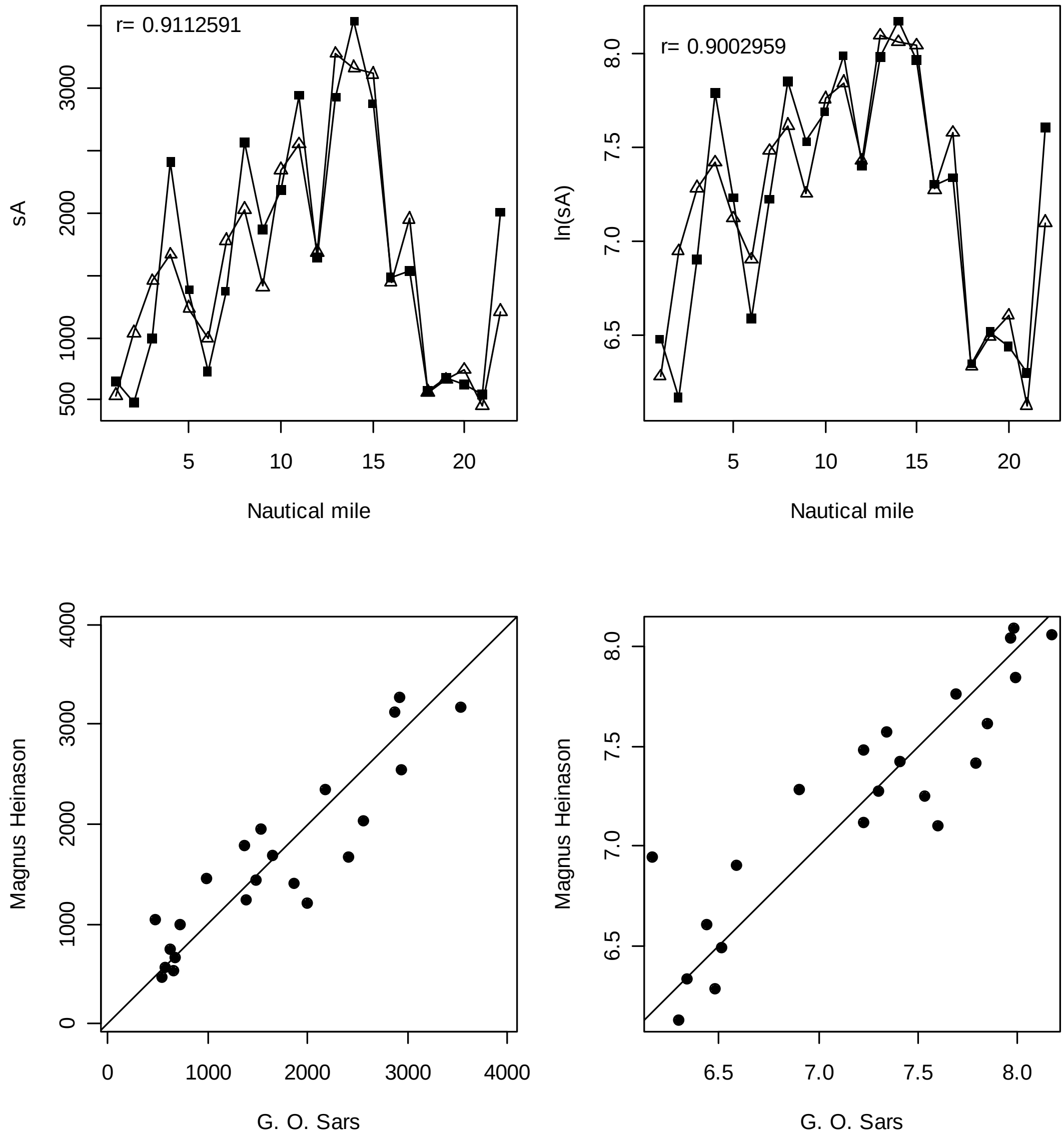
In the data analysis we focused on acoustic densities (s_A, m^2/nm^2) allocated to blue whiting. On both vessels the routine procedures were followed for scrutinizing the data. Figure 1 shows acoustic densities recorded by the two vessels and allocated to blue whiting. These are in good quantitative agreement. Regression model suggests that intercept is not significantly different from zero. Regression forced through the origin has a slope that is not significantly smaller than one and rather high coefficient of determination (R^2). Given the relatively low overall level of variation in acoustic density of blue whiting along the cruise track (less than one order of magnitude), the results are very encouraging and suggest that combining the acoustic data from these two vessels is unproblematic, at least under decent weather conditions.

After the acoustic inter-calibration, pelagic trawls of the two vessels were compared. Both vessels towed to the same direction at a distance of about 0.5-1 nm apart. Magnus Heinason towed at depth of 550 m for 60 minutes and caught 23 kg of blue whiting. G. O. Sars towed for 63 minutes at depths of 500-550 metres and caught 29 kg of blue whiting.

As seen in Fig. 2, blue whiting in the pooled catch of G. O. Sars were somewhat larger in mean length (mean±sd length: 27.4±2.2 cm) compared to the blue whiting in the catch of Magnus Heinason (26.5±2.4cm). The difference in means was statistically significant (p=0.0002). In 2005, a similar difference was observed. Although spatial heterogeneity (Appendix 5) may contribute to the difference, the results suggest that G.O. Sars is slightly more efficient in capturing large blue whiting.

Table 1. Regression models for the full data. Intercept is estimated in the first regression, whereas regression through the origin is assumed in the latter one. The null hypothesis for t-tests on slope is that the slope is not different from one. Acoustic densities from G. O. Sars are taken as the independent variable and those from Magnus Heinason as the dependent variable.

Model	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
Intercept estimated	Intercept	237	159	1.49	0.151	82.2
	Slope	0.836	0.084	1.94	0.066	
Intercept=0	Slope	0.946	0.042	1.27	0.219	95.8



Fiure 1. Comparison of blue whiting acoustic densities recorded by Magnus Heinason (triangles) and G. O. Sars (squares). The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

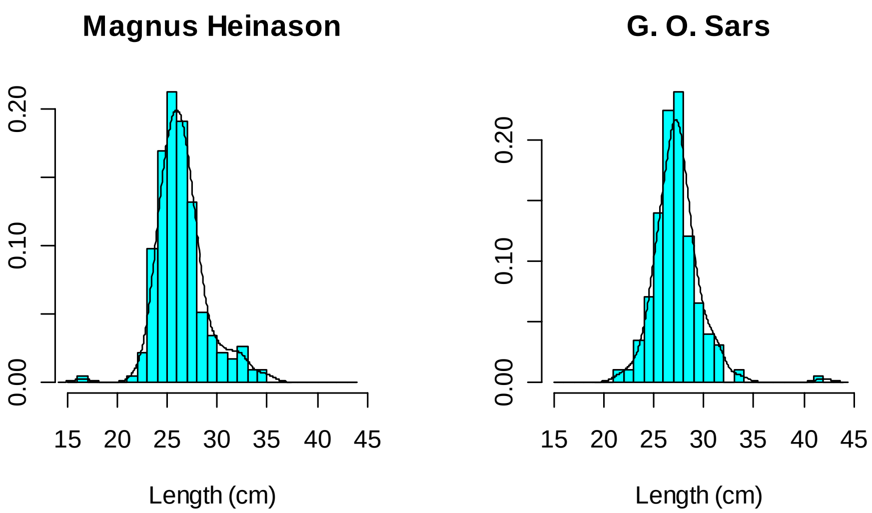


Figure 2. Length distributions from the trawls hauls by Magnus Heinason and G. O. Sars. Smoothing is obtained by normal kernel density estimates. G. O. Sars: n=200; Magnus Heinason: n=235.

Appendix 7. *In situ* target strength measurements of blue whiting

Geir Pedersen, Ronald Pedersen and Terje Torkelsen

Introduction

Acoustic abundance estimates of blue whiting have been considerably higher than analytic estimates stock assesment. 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 close to layers of blue whiting (Godø *et al.* 2002; Heino *et al.* 2003). Target strength data was also obtained in the 2005 cruise using a towed body as well as an "acoustic lander" (Heino *et al.* 2005). In addition, measurements were performed during a methodology cruise in the Norwegian Sea in 2005 using an "acoustic lander". The preliminary results from these experiments confirm the view that the current TS equation results in overestimation of fish, but the 2002-2003 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. The 2005 data provided supporting data of good quality, but it was felt that a set of measurements in 2006 was needed to come to a satisfactory conclusion regarding the target strength of blue whiting. In the 2006 cruise two different instrument platforms were used to measure the target strength of blue whiting; a target strength probe (TS-probe) and a "acoustic lander".

Material and methods

Biological data

Trawl hauls were performed in connection with each of the TS station (as described in the main part of this cruise report) in order to confirm the species and length composition.

TS-probe

The TS-probe contains a computer with ER60 software, 38 kHz split-beam GPT and a ES38DD transducer (and in some experiments also a 120 kHz split-beam GPT and ES120 transducer). In addition, the probe is equipped with roll, pitch, temperature sensors and compass in addition to a stabilization unit. The pulse length was set to 1.024 ms on all occasions. The probe was lowered close to the layers of blue whiting, thus enabling single echo detection. A calibration sphere was positioned below the transducer in most of the experiments in order to monitor the transducers operation during the measurements. A total of 12 measurements were performed using this equipment, measuring blue whiting with a mean length ranging from 17.3 to 28.4 cm (Table 1).

Acoustic lander

The lander was set up with standard instrumentation: Computer with EK60 software, 38 kHz split beam GPT and ES38DD transducer. A sensor unit within a separate pressure container consisting of compass, inclinometer and depth sensor is installed. The instruments are installed in a glass sphere, and eight 7 A/h batteries are installed in a glass sphere. Settings of the instruments in the Mini Landers prior to deployment are selected for the actual area and measure situation. Range, ping rate, and transmit power of the echosounder are selected from an external computer by using Ethernet and Net-Up remote control program.

The lander was deployed twice at N60° 12,35' and W008° 59,52' on the 9th of April, and again at N61° 22,7' and W007° 47,5' on the 14th of April (Table 1). On both occasions the lander was deployed in the morning and retrieved in early evening. The pulse duration was set to 1.024 ms and the pulse repetition rate was set to maximum. On the first deployment a calibration sphere (CU60) was suspended beneath the transducer to monitor the performance of the transducer with depth.

More details on the instruments used can be found in the instrument report.

Calibrations

The echosounders were calibrated prior to the cruise in accordance with recommended procedures (Foote *et al*. 1987). The 38 kHz was calibrated with a copper sphere of diameter 60 mm (CU60), while the 120 kHz was calibrated using a tungsten carbide sphere with diameter 38.1 cm (WC38.1). Additional depth calibrations were performed in Byfjorden and Ofotfjorden prior to the cruise by positioning the sphere near the acoustic axis below the transducers. The transducer/sphere was then lowered from the surface to approximately 500 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 (Table) as well as after filtering using a target tracking approach (Handegard *et al.* 2003).

Preliminary results

Accurate results and final conclusions are not yet available. Nevertheless, preliminary analyses indicate matching results from previous cruises (Godø *et al.* 2002; Heino *et al.* 2003; Heino *et al.* 2005).

Table display the estimated mean TS for each of the experiments. These results are preliminary, and a more thorough analysis must be performed in order to eliminate any potential errors. However, the results are similar to the ones obtained in the previous experiments (Figure 1). The data from all experiments including the 2006 cruise is now being analyzed, and a full paper on these experiments will be submitted for publication later this year.

Table 1. Summary of TS experiments.

Target Strength Sonde

Date	Time	Bottom Depth	Measure Depth	Reference Target	GPT-1 Freq.	GPT-2 Freq.	GPT-3 Freq.	Trawl Station	Comments
19.03.06	14:30	2500	480	Cu60	38	-	-	196	Medium size blue whiting
22.03.06	17:30		470	Cu60	38	-	-	199	
25.03.06	16:20		485	Cu60	38	-	-	204	
26.03.06	11:21	300	275	Cu60	38	-	-	205	Small size blue whiting, redfish
03.04.06	01:44	520	420	Wc38.1	38	120	-	208	Small size blue whiting near bottom
09.04.06	07:24	1500	460	-	38	-	-	213	
12.04.06	04:01	233	190	-	38	120	-	215	
12.04.06	04:16		170	-	38		-		
14.04.06	07:00	684	410	-	38	120	-	216	
14.04.06	07:15		430				-		
14.04.06	16:02	712	430	WC38.1	38	120	-	218	
15.04.06	10:02	644	400	-	38	120	-	219	

Acoustic Lander

Date	Time	Bottom Depth	Measure Depth	Reference Target	GPT-1 Freq.	GPT-2 Freq.	GPT-3 Freq.	Trawl Station	Comments
09.04.06	11:33	549	430	CU60	38			214	
14.04.06	09:24	655	403	-	38			218	

Table 2. Summary of analysed experiments showing instrument platform, mean fish length (cm) and mean target strength (dB re $1m^2$).

Experiment	Type	<L>	<TS>
STA-196	TS-Probe	26.5	-37.1
STA-199	TS-Probe	29.0	-35.6
STA-204	TS-Probe	27.3	-35.7
STA-205	TS-Probe	22.5	-38.9

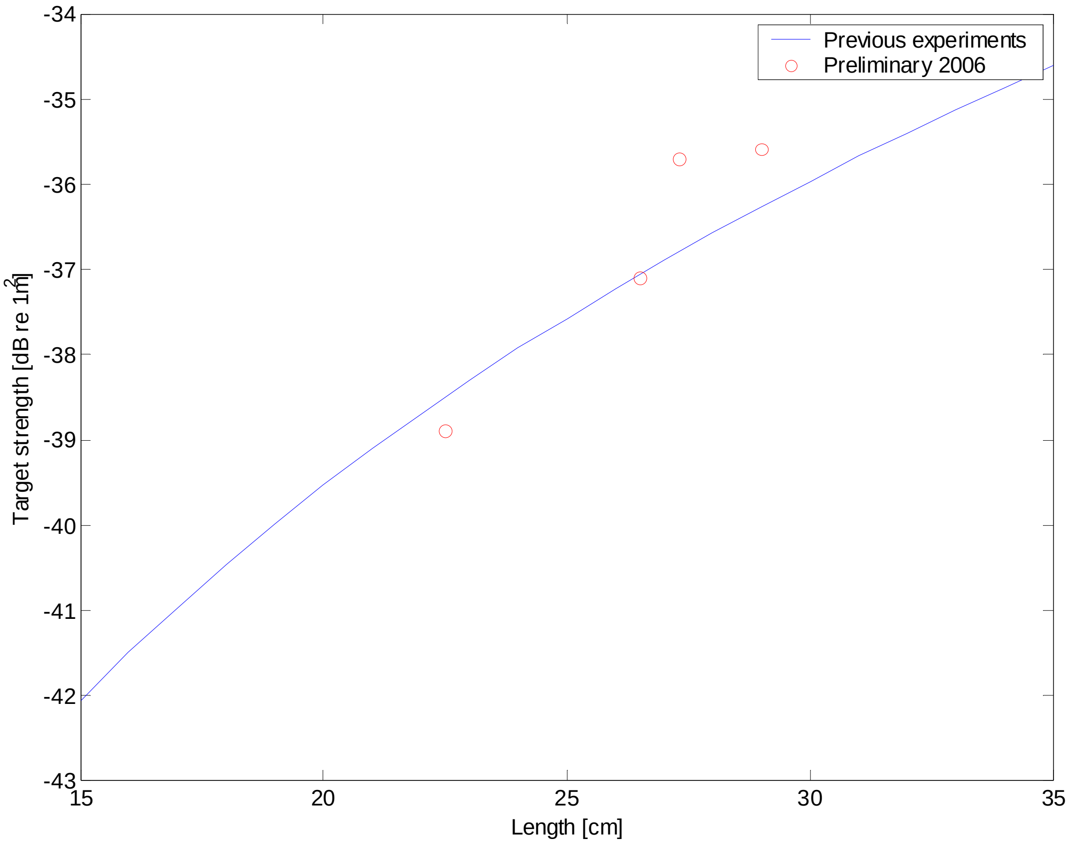


Figure 1. Preliminary results from the 2006 cruise and curve based on the analysed data from earlier experiments.

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