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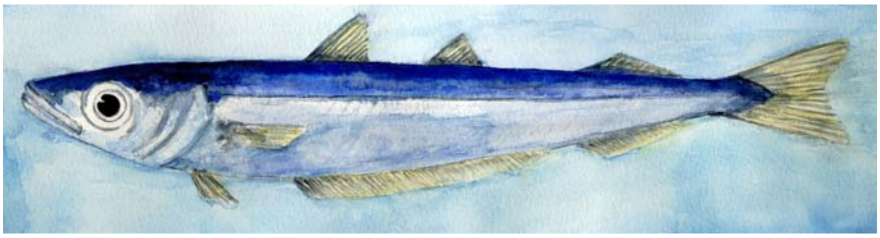

BLUE WHITING SURVEY DURING SPRING 2003

by

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Introduction

During the period March 29–April 27 R/V Johan Hjort surveyed the main spawning areas of blue whiting 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 (or its precessors) have used the data from 1981 for tuning the assessment of stock abundance and structure (e.g., ICES 2002). This survey represents the longest continuous time series (only broken by a couple of years) on abundance and distribution of this stock and is as such also an important contributor on knowledge and information about stock dynamics in general.

In 2003 two other vessels, R/V Atlantniro (AtlantNIRO, Kaliningrad) and R/V Smolensk (PINRO, Murmansk) conducted surveys in the area. The survey of Johan Hjort was not coordinated with the efforts of these vessels because of a large difference in timing of the surveys between Altantniro and J. Hjort and the late stage at which the survey plans of Smolensk become known to us. However, information was exchanged between Johan Hjort and Smolensk, and an inter-calibration was conducted (Appendix 1).

The main purpose of the survey is to assess the abundance of blue whiting in the surveyed area using acoustic assessment methodology. In addition, the survey serves to improve knowledge about the biology and dynamics of this stock, particularly with respect to movements and distribution during and after spawning. This report documents the main results of the survey with the focus on the assessment of stock abundance. Furthermore, methodological issues relating to the quality of the results are discussed.

Material and methods

The cruise tracks of Johan Hjort are shown in Figure 1. Due to the huge area and limited effort available, a pragmatic survey strategy was chosen. This involved a zigzag design along the shelf break in order to have cruise track as perpendicular to the expected gradients of blue whiting abundance as feasible, and a somewhat more systematic coverage in areas where gradients could not be known a priori. The strategy also involved ad hoc cuts of survey track when recordings of blue whiting were absent, and extension of tracks when fish distribution was more extensive than expected. However, in many areas the distribution of blue whiting has no bounds, and areas of zero or very low density could not be reached.

The acoustic survey was conducted with Simrad EK 38 and 18 kHz echo sounders. Both sounders were controlled by a standard sphere calibration (ICES 1987) 1.5 months before the actual survey. The 38 kHz sounder was also calibrated in the end of the survey. The latter calibration showed an error of about +0.2 dB. The earlier calibration was conducted under very cold conditions (water temperature 0.05 ºC). Experience has shown that settings obtained under such conditions result in an upward bias under warmer conditions. With surface temperatures around 10 ºC in the survey area (see Fig. 8), it is probable that the latter calibration is adequate for the current survey. In consequence, the acoustic densities (s_A) recorded were too high by a factor of 1.1039. All data reported here has been corrected by dividing all s_A–values by that factor.

The 38 kHz echo sounder 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 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 2.

For the purpose of identification of the acoustic recordings and for representative biological sampling of the population we used a 486 m circumference pelagic trawl (Åkratrål). Meshes gradually decreasing from 3.2 m in front to 42 mm in the codend. A liner of 22 mm was inserted in the last 5 m of the codend. This is the same pelagic trawl as used in earlier years. Previous surveys have given clear indications of under-sampling of the largest individuals of blue whiting as apparent from catch comparisons with commercial trawlers as well as with Russian research vessels. Therefore we implemented some adjustments in the rigging of the trawl in 2003. Firstly, new and larger doors with more spreading force (Egersund 7.3 m^2) replaced the old Vaco doors. To compensate for the improved spread the weights on the lower wing tips were increase from 340 kg to 750 kg on each side. Under operation we normally had a door spread of 100-110 m and a trawl opening of 30-35 m. This is a substantial improvement from previous years. The better spread and opening produce open meshes and better water flow and hence, we could easily trawl at speeds of 4 knots, which is needed to efficiently catch the larger blue whiting. More details on the trawl and rigging are given in Appendix 3. Occasionally a smaller capelin trawl (Harstadtrål) was used to target mesopelagic fish.

Catch from the trawl hauls was sorted and weighed; Fish were identified to species (when possible) and other taxa to higher taxonomic levels. List of taxa encountered during the survey is given in Appendix 4. Saithe, redfish and black scabbardfish were measured for length. A sample of 50 blue whiting were sexed, aged, and measured for length, weight, and their maturity status, stomach content, parasite load and liver size were estimated using established methods (Fotland et al. 2000). An additional sample of 50 fish (occasionally more) was measured for length and weight. Special morphological measurements were carried out for the first 10 fish in a sample; these data will be analysed at a later stage.

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 parts of the strata were 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. Length frequency distributions from each sample were 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 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 five sub-areas similarly as in previous years (Fig. 5). As in 2002 (Godø et al. 2002), sub-areas I-II were merged due to limited coverage of the sub-area I.

The hydrographical situation in the surveyed area was mapped by a net of 92 CTD stations (Fig. 2), including one east-west section at the western shelf edge of Porcupine Bank at latitude 53° 30'N, a section from Rockall Bank to the shelf edge offshore of the Hebrides 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, but calibration data from the preceding cruises this year has shown that the CTD on Johan Hjort is very stable and only minor corrections (less than 0.005) have been applied. The CTD data will be calibrated and subject to final quality control after the cruise. In addition, surface (~4m) temperature, salinity and fluorescence were recorded continuously along the complete track of the cruise using a ship-mounted thermosalinograph.

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 Bailey (1982).

Results

Methodological issues

We review first some methodological issues that have bearing to interpretation of the results that follow. More details can be found in the appendices.

The new rigging of the large pelagic trawl (see Material and methods and Appendix 3) gave an improved trawl performance when assessed in purely technical terms (maximum towing speed, opening) as well as in terms of quality of samples (Appendix 5): even though small and consistent differences size- and age distribution of catches in comparison to two other vessels (one commercial blue whiting vessel and the Russian research vessel Smolensk) seem to prevail – J. Hjort still fishing slightly smaller fish than the two other vessels – these differences are not likely to bring a major bias in the estimate.

We also investigated variability among and within two trawl hauls taken about one nautical mile apart (Appendix 6). There were small but statistically significant differences in mean length, weight and age between the two hauls. Variability within sub-samples taken from one trawl haul was negligible.

In the area west of St Kilda the spatial structure of blue whiting aggregations along the continental slope was investigated in some detail (Appendix 7). The results highlight that spatial heterogeneity at a scale of few nautical miles results in very large uncertainty at small spatial scales but that the bias is small. With the currently used estimation strata (1º latitude by 2º longitude), this particular source of variability is probably largely evened out in most of the strata.

Measurements of target strength (TS) of blue whiting, initiated in 2002 (Godø et al. 2002), were conducted on seven occasions (Appendix 8). Data analyses carried out on board support the view that current TS is too low and that an upward adjustment to at least the level used for other gadoids in the Northeast Atlantic, i.e., more than 2 dB may be required. However, we are not yet in a position to suggest a new TS relationship for blue whiting. A first rough presentation of the data is available in Appendix 8, but more detailed scrutiny and analyses of these data are needed. The results will be fully reported at a later stage.

Distribution of blue whiting

Blue whiting was recorded along the shelf edge in the whole survey are from southern Ireland to the Faroe/Shetland-area including the northern part of the Rockall Bank (Fig. 3). The highest concentrations were recorded in patches along the shelf edge from northwest of Ireland to the Hebrides, and near Bill Bailey Bank. The highest recordings were observed at 400-600 m depth, sometimes extending to around 300 m depth on the slope areas. Off the shelf break, the recordings often continued towards the ocean as a dense layer of some 50 m in thickness (“the green snake”, see, e.g., Fig. 4 in Godø et al. 2002), or as a ribbon-like layer of dense isolated shoals. In some areas, particularly in the north, there was also another, much less dense layer closer surface that consisted mostly of young blue whiting.

In 2003 the abundance of blue whiting near Porcupine Bank was lower than in 2001-2002 (Monstad et al. 2001, Godø et al. 2002). However, in the Rockall area, particularly in the north, abundance was considerably higher. As in 2002, relatively high abundances of blue whiting were recorded further away from the shelf break than previously, near and along banks between Rockall and the Faroes.

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 of the spawning area. This is bound to influence the results of the survey because the coverage is far from being synoptic. It is possible that some fish were counted repeatedly in different areas, whereas in some areas fish have moved altogether out from the area before it was surveyed. In 2003 the survey took place about a week later than in most previous years. Furthermore, relatively warm conditions have probably promoted earlier spawning. Because of migrations during and after spawning towards north and south, this is expected to result in a displacement of fish away from about 53ºN (Porcupine Bank), as was observed. An intensive commercial fishery operated along the shelf edge off Porcupine Bank in March, but little blue whiting was found in the area when covered by this survey in early April. Similarly, when the survey reached Rockall area, commercial fishing boats were abandoning the area because the fish were migrating out.

Stock size

The estimated total abundance of blue whiting for the 2003 Norwegian survey was 11.4 million tonnes, representing an abundance of $160x10^9$ individuals. This estimate is marginally lower than in 2002 but is substantially higher than in 2001 or before. The geographical distribution of biomass by stratum is shown in Figure 4. The spawning stock was estimated at 10.4 million tonnes. As with total stock, this estimate is marginally higher than estimated in 2002 and substantially higher than in the earlier years. The table below shows the Norwegian acoustic survey estimates of blue whiting in the spawning area since 1990:

Year	Abundance, N x 10^{-9}		Biomass, mill. tonnes		Mean weight, g	Mean length, cm
	total	spawning	total	spawning		
1990	62.9	56.2	6.3	5.7	100.7	27.1
1991	41.5	40.9	5.1	4.8	115.7	27.8
1992	38.4	36.8	4.3	4.2	111.3	27.5
1993	41.5	39.8	5.2	5.0	124.6	28.6
1994	26.8	26.1	4.1	4.1	152.9	31.1
1995	62.0	45.2	6.7	6.1	108.2	26.9
1996	52.2	36.2	5.1	4.5	94.9	25.5
1997	No survey	-	-	-	-	-
1998	79.9	56.6	5.5	4.7	68.3	23.2
1999	120.2	109.6	8.9	8.5	74.4	25.0
2000	102.4	89.8	8.3	7.8	80.7	25.5
2001	96.5	72.1	6.7	5.6	69.0	24.1
2002	175.6	146.8	12.2	10.9	69.3	24.2
2003	160.0	132.0	11.4	10.4	71.6	24.6

The estimate obtained in 2003 is the close to the highest one obtained in the Norwegian surveys, being only about 5% less than in 2002. Although it is possible that the measured decrease represents a genuine decrease in stock abundance, change of the observed magnitude could easily be explained by changes in survey coverage and timing, for example.

Fig. 4 shows that the distribution of biomass in 2003 is different from that observed in 2002. The estimated biomass of blue whiting in the Rockall area in 2003 is about three times as high as in 2003 (Table 1). Also in the Faroes/Shetland area biomass was somewhat higher than in the year before. In both areas the fish were also slightly heavier, on average, than in 2002. On the other hand, lower abundance was measured at Porcupine Bank and in the Hebrides area. Nevertheless, the Hebrides area continues to dominate the stock in the area, and represents more than half of the spawning stock.

Stock composition

The stock was dominated by the year class 2000 (age 3 years) both in terms of biomass and numbers (Table 2, Fig. 5). This was also the dominant year class in 2002. Indeed, the numerical abundance of this year class in the survey area has remained more or less constant, probably because of more and more individuals have reach maturity and recruited to the spawning stock. The second and third in dominance were the year classes from 1999 and 2001. The abundance of year class 1999 was already reduced by about 50%. Earlier year classes (blue whiting of age 5 years and older) make only about 13% of the spawning stock.

There is considerable variability among the four sub-areas (Figure 6). Year class 2000 is dominating by a wide margin both in the Hebrides and in the Rockall area. In contrast, year class 2002 numerically dominates in the Faroes/Shetland area, with a narrow margin to year class 2000; also the length distribution in this area is distinctly bimodal. This is not unexpected, as it is well known that the Faroes/Shetland area is an important nursery area for the stock. Young fish dominate stock numbers also in the Porcupine Bank area. This is probably caused by our late arrival in the area: with large numbers of mature blue whiting already having emigrated, young, more sedentary blue whiting become relatively more dominant.

Mean length and weight of blue whiting in the survey area show a slight increase from 2002 (Tables 1 and 2), largely reflecting the increase in the average age. Nevertheless, average individual size continues to be much smaller than it was in the early 1990's. Length at age in 2003 is very similar to that in 2002, whereas weight at age has slightly increased. Fish of age 1 and 2 are exceptions: in 2003 fish of age 1 year are smaller and those of age 2 years larger than in 2002. Probably reflecting changes in individual size, proportion of mature at age 1 year is lower and at age 2 year higher than in 2002.

Eggs and larvae

Plankton samples were taken from 46 stations. Blue whiting was the most numerous species among fish larvae and mackerel among eggs. All sample distributions were highly skewed with a few samples containing most individuals. Mean numbers of eggs and larvae per sample (with standard deviations) in 2001-2003 were the following:

Year	Blue whiting		Mackerel		Horse mackerel	
	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
2001	6.7 (36.5)	72.9 (207)	23.8 (61.9)	*0.20* (0.78)	*0.46* (1.4)	0.049 (0.31)
2002	*1.7* (4.6)	*21.9* (48.1)	27.8 (98.0)	*0.34* (1.2)	5.3 (29.9)	0.054 (0.30)
2003	16.5 (67)	176 (703)	20.3 (49.6)	7.5 (30.3)	2.7 (7.2)	0.043 (0.21)

In this table, italics are used to mark abundances that are significantly ($p<0.05$) different from the abundance in 2003 as estimated by generalized linear model with logarithmic link and negative binomial error functions.

Abundances of both blue whiting eggs and larvae were the highest ones recorded in this short time series. Significant numbers of eggs at early stages of developmental stages were encountered only in the northernmost part of the survey area (>61ºN, Fig. 7). The abundance of larvae in 2003 is significantly higher than in 2002 but not significantly higher than in 2001 ($p=0.065$). Most of larvae were encountered south of 59ºN, near the continental slope between northwestern Porcupine Bank and the Hebrides. Small larvae of 3-4 mm in length were dominant.

The data suggest that of the three-year period 2001-2003, spawning in 2003 was the most successful. However, interpretation of this observed variability against the variability in recruitment is difficult because of the short time series. It is also obvious that spatial and temporal allocation of sampling effort may have strong influence on the observed variation in abundance.

The abundance of mackerel larvae was significantly higher than in the previous two years. The numbers of mackerel eggs have been rather stable. The abundance of horse mackerel eggs in 2003 was at an intermediate level, whereas the numbers of larvae have been invariably low.

Hydrography

The horizontal distribution of temperature at 10 and 400 metres depths are shown in Figures 8 and 9 respectively. The maps are based on data collected on board Johan Hjort (Fig. 2) and CTD data kindly provided by the scientists on board the Russian ships Smolensk and Atlantniro, 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. Temperatures at 1000 m are typically between 7 and 8 °C, i.e., the vertical temperature decreases by only 2-3°C from the surface to 1000 m depth (see fig. 10), and in the top 600 m the temperatures drop by only about 1 °C. In the Faroe-Shetland channel the situation is different with a strong thermocline around 500 m depth separating a layer of warm saline Atlantic water overlying cold deep waters (~-0.5 °C) 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, and 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 10 m and 400 m depths (Figures 8 and 9). Due to a northward flowing shelf edge current, warm high salinity (S>35.45) water penetrates far north in a narrow band along at the shelf edge, with the 10 °C isotherm at 10 m depth extending north into the Faroes-Shetland channel (Fig. 8). Visual inspection of the sections and horizontal temperature maps indicates that this year's temperatures are up to 0.5 °C and salinities up to 0.05 higher than in 2002. The vertical section plot of temperature and salinity (Fig. 11) shows that the Atlantic water occupies all the area above 500 m and the 0 °C isotherm is depressed down to 700 m. The area occupied by the warm Atlantic water is larger and the maximum temperature is higher than previous years.

The high temperatures and salinities are confirmed by a study of the temperatures and salinities on all blue whiting cruises from 1983 through 2003. Since the hydrographic surveys have been dependent on the fishery surveys, the CTD stations have been distributed along the shelf edge and have in general not been in the same positions from year to year. In order to make time series, the data were grouped in boxes with horizontal dimensions of 2° latitude times 2° longitude. For each year the mean temperature and salinity from 50 to 600 m of all the stations in deep water (depth >600 m) in each box was calculated. Some of the boxes had good coverage nearly every year, while others had many years missing. However, in general the same variation from year to year was seen in the boxes along the shelf edge south of the Wyville-Thompson ridge. The box with limits 52° to 54°N and 16° to 14°W had few gaps; 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 reaches a local maximum (~10.5 °C) with the three following years a few tenths of a degree colder. 2002 is the warmest with ~10.7 °C and in 2003 the temperature was about the same as in 1998. A closer inspection shows that the decrease in temperature is caused by a lower temperature in the deep part of the layer, whereas in the upper part it is the same as last year. The vertical gradient within this layer was very small last year with a change in temperature of only about 0.7 °C from 50 m to 600 m, but this year it dropped by 1.3 °C.

In the boxes along the continental shelf in the Rockall Through a similar pattern as described above is seen in the time series, but the temperatures did not peak in 2002 and the temperatures in 2003 are higher or at least as high as in 2002. Thus in the Rockall Through the temperatures in 2003 from 50 m to 600 m are the highest on record. In the northern part of the Rockall Through the temperatures in the 50-600 m layer are typically about 0.5 °C and salinity 0.05 higher than in 2002. In the shallow layer 50-150 m, the temperatures are the highest on record for the whole area, and in the northern part the temperature is more than 0.5 °C higher than last year.

The temperatures in the whole area are high in 2003, and except for the area to the west of Porcupine Bank, 2003 stands out as the warmest year in the observation period from 1983 to 2003. There is no clear linear trend, but the last five years are clearly warmer than the average of the whole period (1983-2003), and about 0.5°C above the first years in the period. Even though the increase is not as evident in the salinity curve, the high temperatures are typically associated with high salinities (Fig. 12).

Concluding remarks

Estimates of total and spawning stock biomass of blue whiting in the survey area west of the British Isles in 2003 show no significant change from 2002. However, there is a significant change in the age structure of the spawning stock. The year class 2000, probably one of the strongest year classes in record, continues to dominate the spawning stock. The abundance of the cohort in the survey area in 2003 was similar to that observed in the year before, but because of an increase in individual size, the contribution of that cohort on spawning biomass has increased by about 25%. This year class alone is responsible for 50% of spawning stock biomass. In addition, year class 1999 has a share of 25%. In 2004, these year classes, now representing 75% of spawning stock biomass, will be much reduced in numbers. At the same time, it seems that the new year class recruiting to the spawning stock, year class 2001, is of moderate strength, at best. Thus, we can expect a significant reduction spawning stock biomass in 2004, unless year class 2002 proves to be strong and recruits to the spawning stock at an early age.

It is important to emphasize that the acoustic estimates of blue whiting stock, although traditionally expressed in numbers and biomass, should be understood as relative rather than absolute measures of stock abundance. The estimates are based on a target strength relationship that is known to be too low, resulting in a large upward bias in the estimates. On the other hand, it is clear that the coverage of the spawning stock by the survey is not complete.

Despite record high exploitation level in the recent years, abundance of blue whiting appears remarkably stable. This is most likely due to exceptionally good recruitment during the period 1995-2000. With year class 2001 probably being only moderate in abundance, one can not expect that the current catch levels can be maintained from year to year without reducing the abundance of the spawning stock.

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Table 1. Assessment factors of blue whiting, spring 2003.

Subarea			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
I+II	Porcupine Bank	24 763	7 863	12 160	64.7 %	504	719	77.2 %	53.8	22.2	26
III	Hebrides	29 654	76 469	84 728	90.3 %	6 075	6 351	95.7 %	75.0	25.3	214
IV	Faroes/Shetland	16 960	33 328	45 107	73.9 %	2 591	3 041	85.2 %	67.4	23.5	179
V	Rockall	12 224	15 709	17 939	87.6 %	1 354	1 399	96.7 %	78.0	25.4	114
Total		83 601	133 368	159 934	83.4 %	10 524	11 445	92.0 %	71.6	24.6	137

Table 2. Stock estimate of blue whiting, spring 2003.

Length	Age in years									Numbers	Biomass	Mean	Proportion
	1	2	3	4	5	6	7	8	9				
(cm)	2002	2001	2000	1999	1998	1997	1996	1995	1994	(10^6)	(10^6 kg)	weigth, (g)	mature
14.0 - 15.0	167									167	2.8	16.8	2.9
15.0 - 16.0	1015									1015	19.4	19.1	4.1
16.0 - 17.0	3105									3105	68.1	21.9	5.7
17.0 - 18.0	3939									3939	108.1	27.4	7.9
18.0 - 19.0	7135	18								7153	236.5	33.1	11.0
19.0 - 20.0	6853	45								6898	262.7	38.1	15.0
20.0 - 21.0	3159	812								3971	174.4	43.9	31.5
21.0 - 22.0	1042	1983	325							3349	163.0	48.7	65.1
22.0 - 23.0	106	4995	2084							7185	399.5	55.6	86.9
23.0 - 24.0		6600	7823	45						14468	897.4	62.0	92.0
24.0 - 25.0		7175	17435	1395						26004	1758.6	67.6	95.4
25.0 - 26.0		1834	22266	5018	105					29223	2184.4	74.7	97.9
26.0 - 27.0		530	13601	6551	366	172				21220	1758.5	82.9	99.1
27.0 - 28.0			4548	7756	1699	101	203			14307	1314.0	91.8	99.8
28.0 - 29.0			1755	3557	1050	953				7316	751.6	102.7	99.9
29.0 - 30.0			466	3321	865	301	956	233		6143	694.2	113.0	100
30.0 - 31.0				802	1025	70			150	2048	266.5	130.1	100
31.0 - 32.0				311	605	160				1076	149.1	138.5	100
32.0 - 33.0						364	351			715	113.3	158.5	100
33.0 - 34.0						223	121			344	67.7	196.9	100
34.0 - 35.0					20	85	51			156	26.8	172.5	100
35.0 - 36.0													
36.0 - 37.0							27	27	79	133	28.1	212.1	100
TSN (10^6)	26520	23992	70303	28756	5735	2430	1708	260	229	159935			
TSB (10^6 kg)	895	1487	5220	2637	616	303	218	32	37	11445			
Mean length (cm)	18.6	23.5	25.3	27.3	28.9	30.0	30.4	30.2	32.6	24.6			
Mean weight (g)	33.7	62.0	74.3	91.7	107.5	124.5	127.6	121	161.8	71.6			
Condition	5.2	4.8	4.6	4.5	4.5	4.6	4.5	4.4	4.7	4.8			
% mature	10.1	77.4	99.1	100	100	100	100	100	100	92.0			
% of SSB	0.9	11.2	50.4	25.7	6.0	3.0	2.1	0.3	0.3				

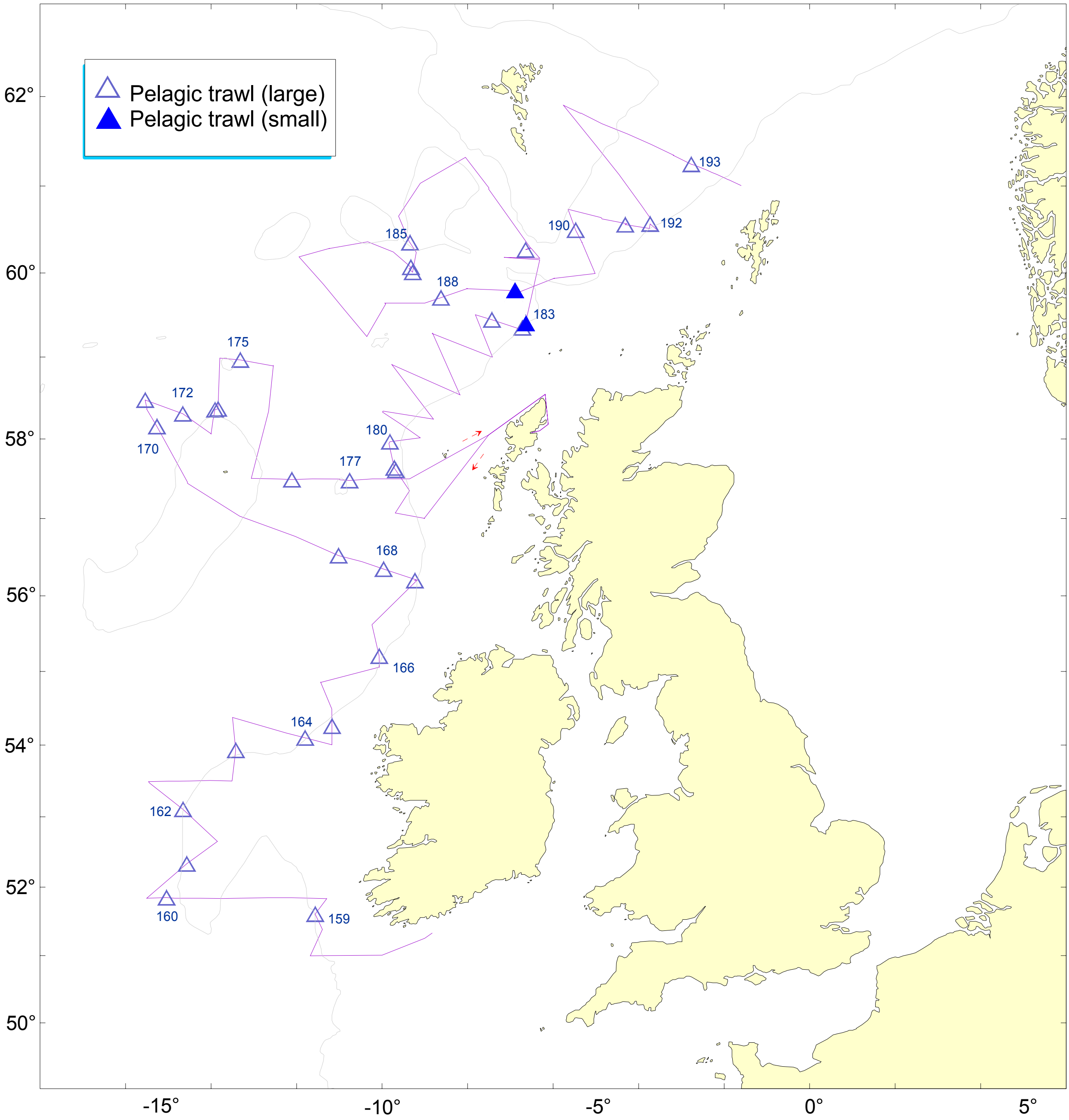


Figure 1. Cruise tracks with trawl stations, R.V. “Johan Hjort” 29 March–27 April 2003.

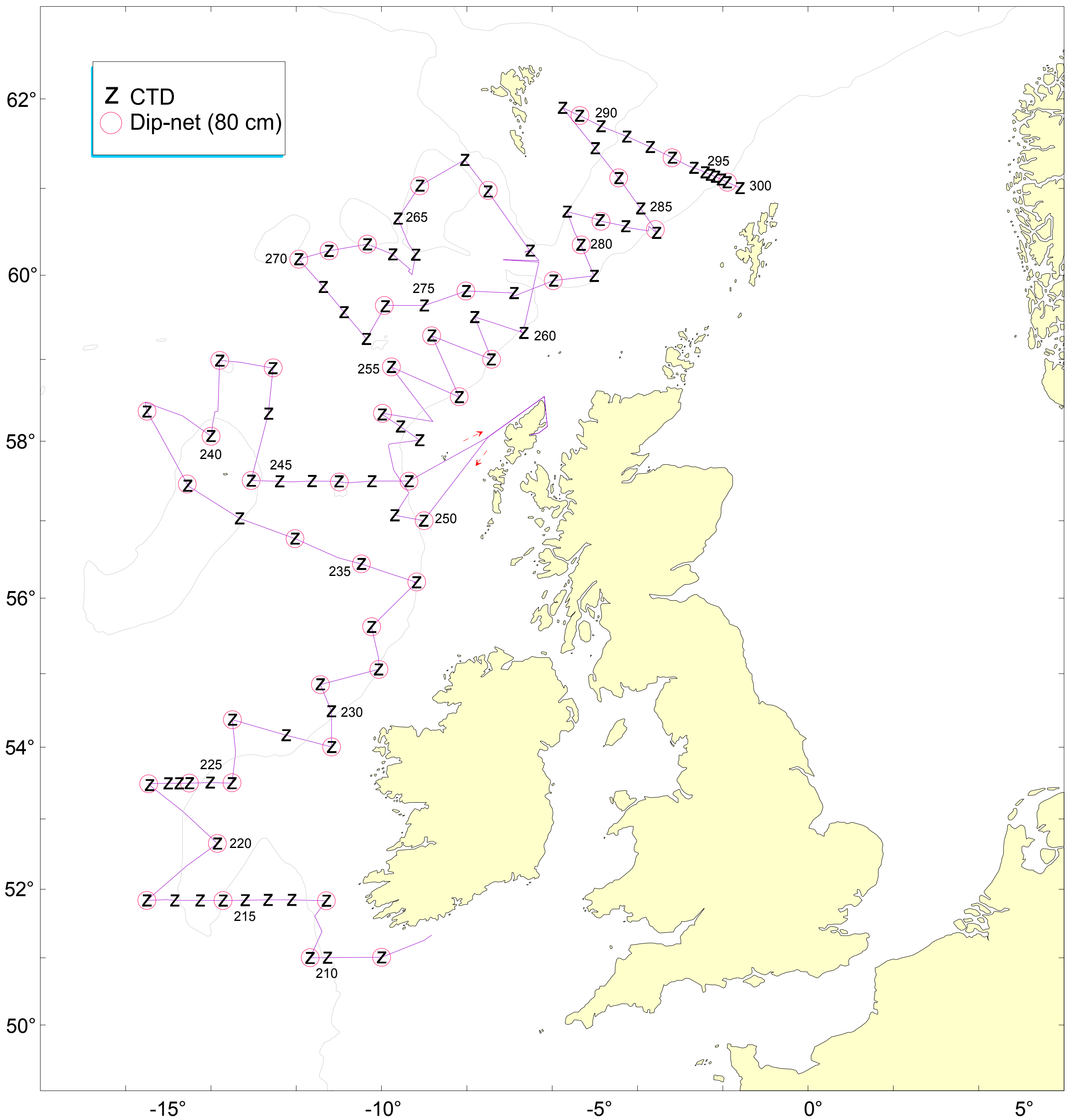


Figure 2. Cruise tracks with CTD and plankton stations, R.V. "Johan Hjort" 29 March–27 April 2003.

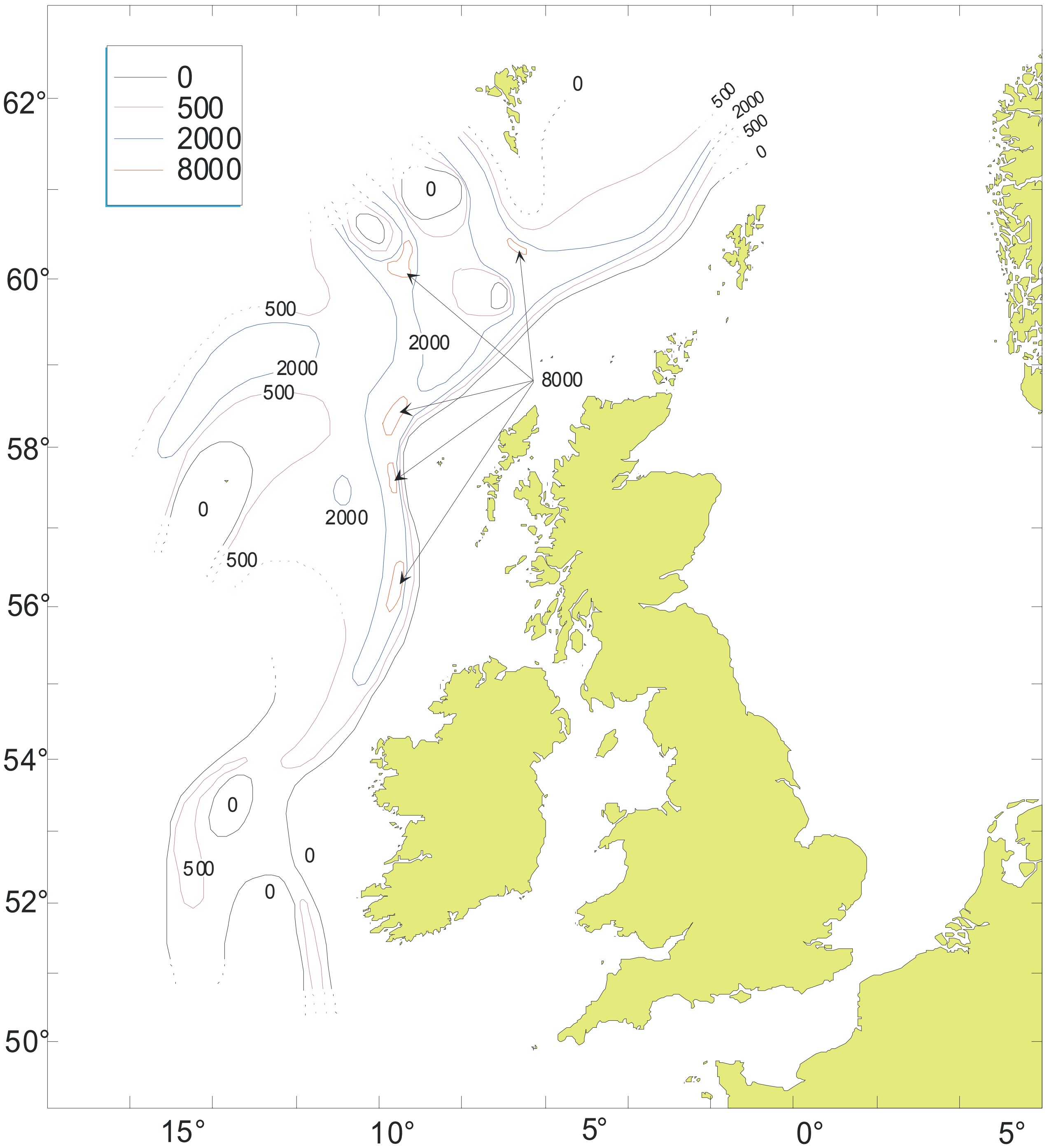


Figure 3. Distribution of blue whiting in spring 2003 in terms of echo intensity (s_A-values, $m^2/n.mile^2$). The map is based on observed echo intensities along the cruise track (Fig. 1) and on knowledge on bottom topography and its influence on distribution of blue whiting.

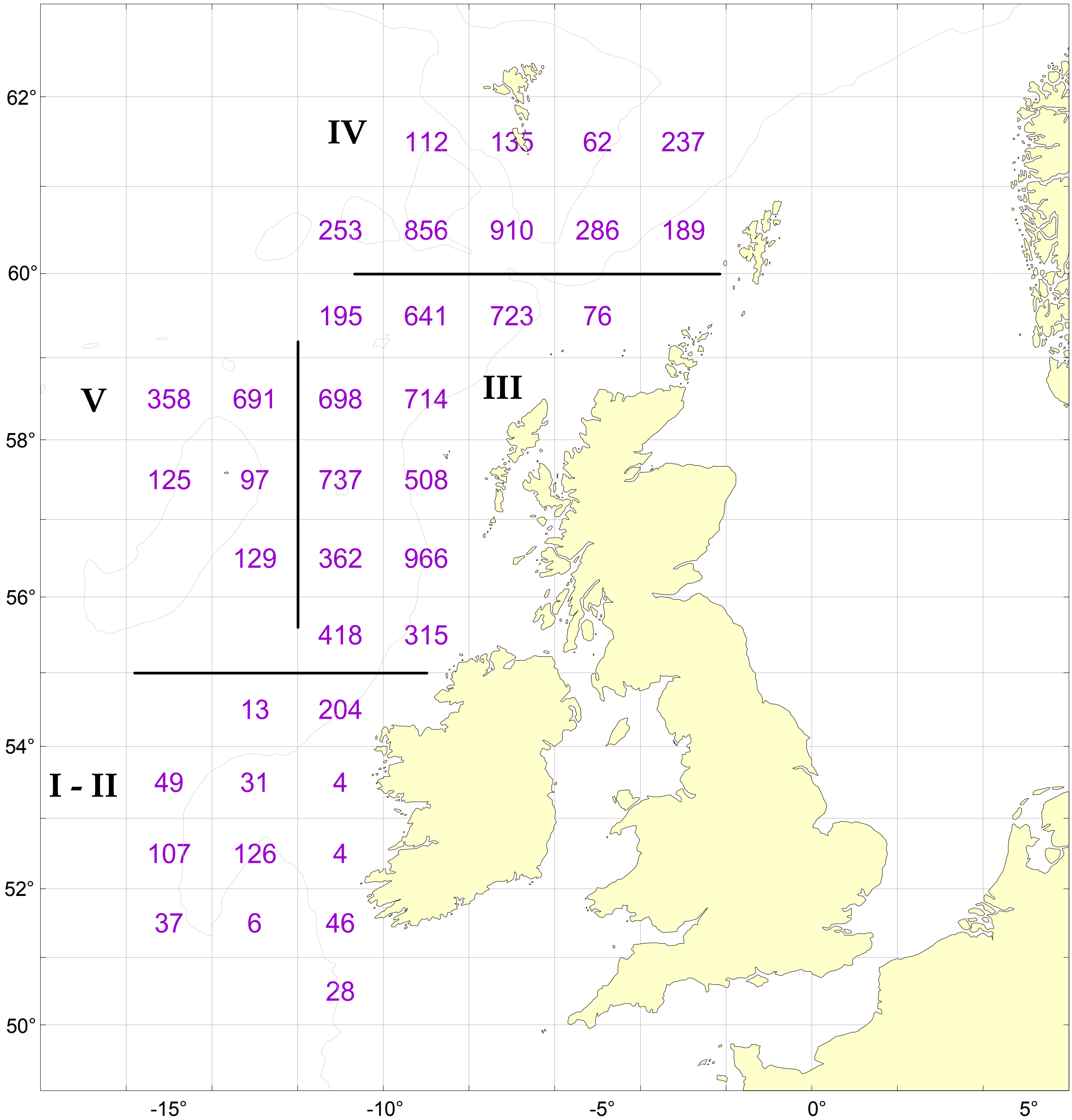


Figure 4. Blue whiting biomass in 1000 tonnes, spring 2003. Marking of sub-areas I-V used in assessment.

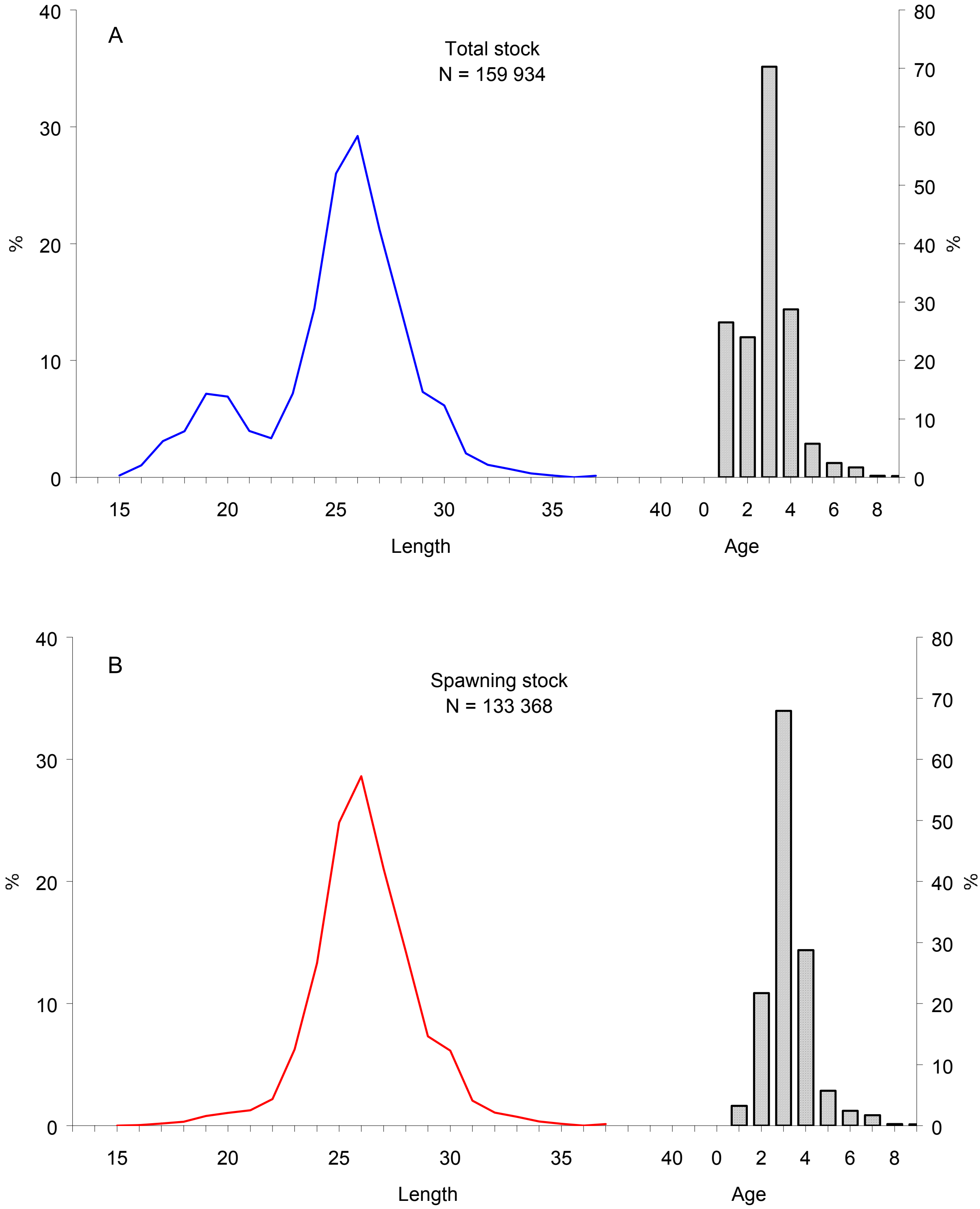


Figure 5. Length and age distribution in the total (A) and spawning (B) stock of blue whiting in the area to the west of the British Isles, spring 2003. N*10^{-6}.

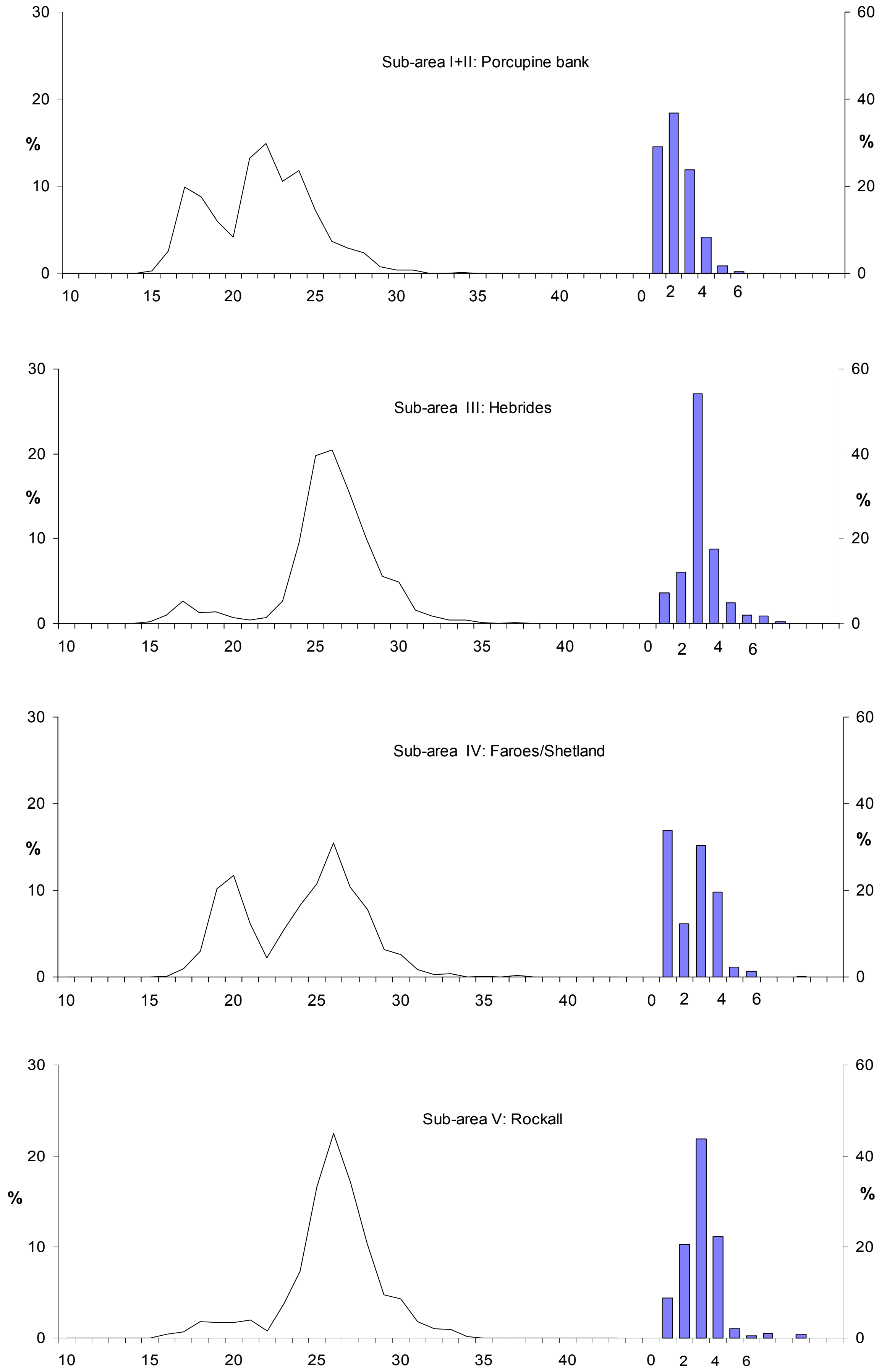


Figure 6. Length and age distribution of blue whiting by sub-areas (I-V), spring 2003.

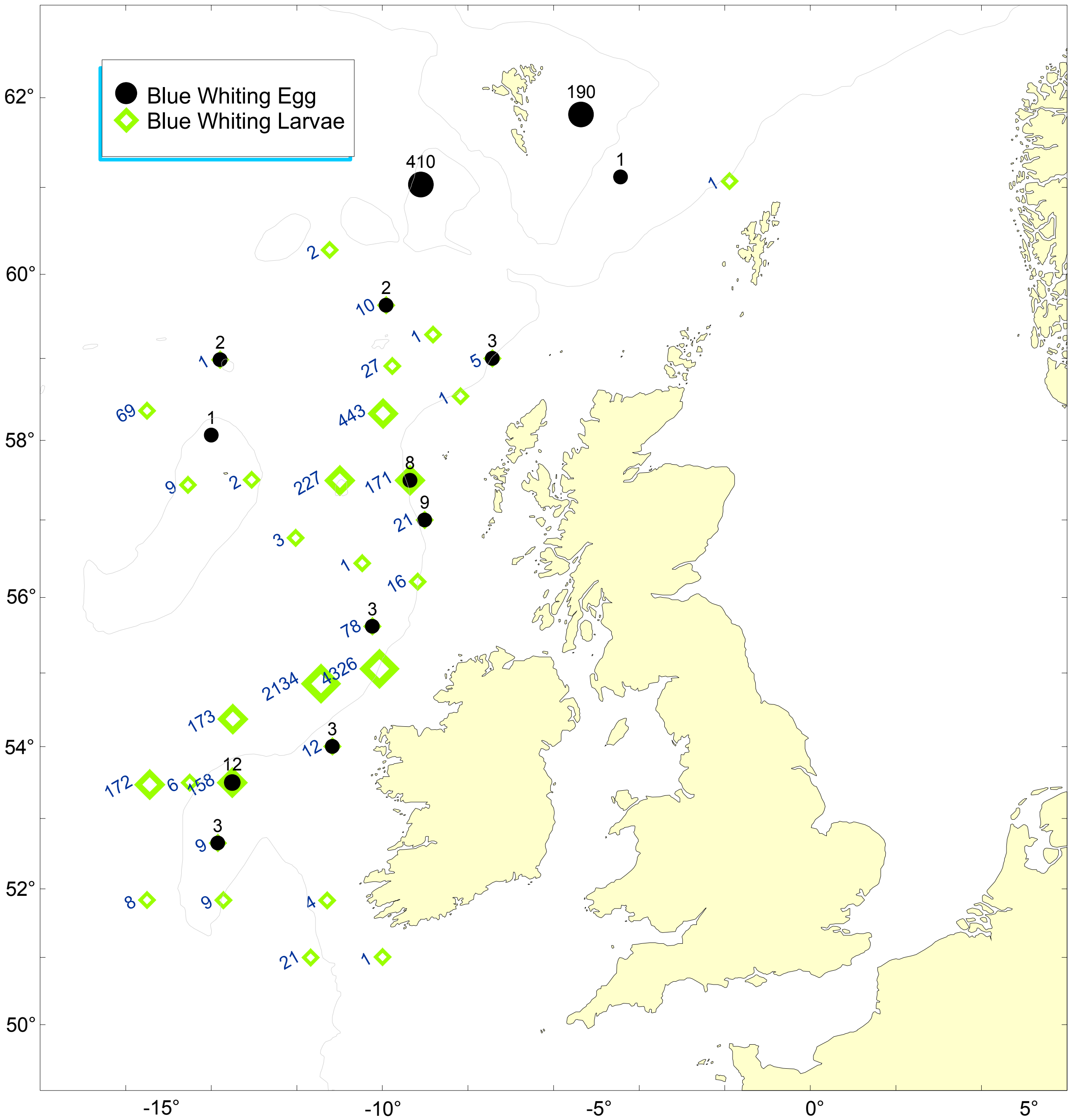


Figure 7. Distribution of blue whiting eggs and larvae in spring 2003. Number of individuals is also inserted.

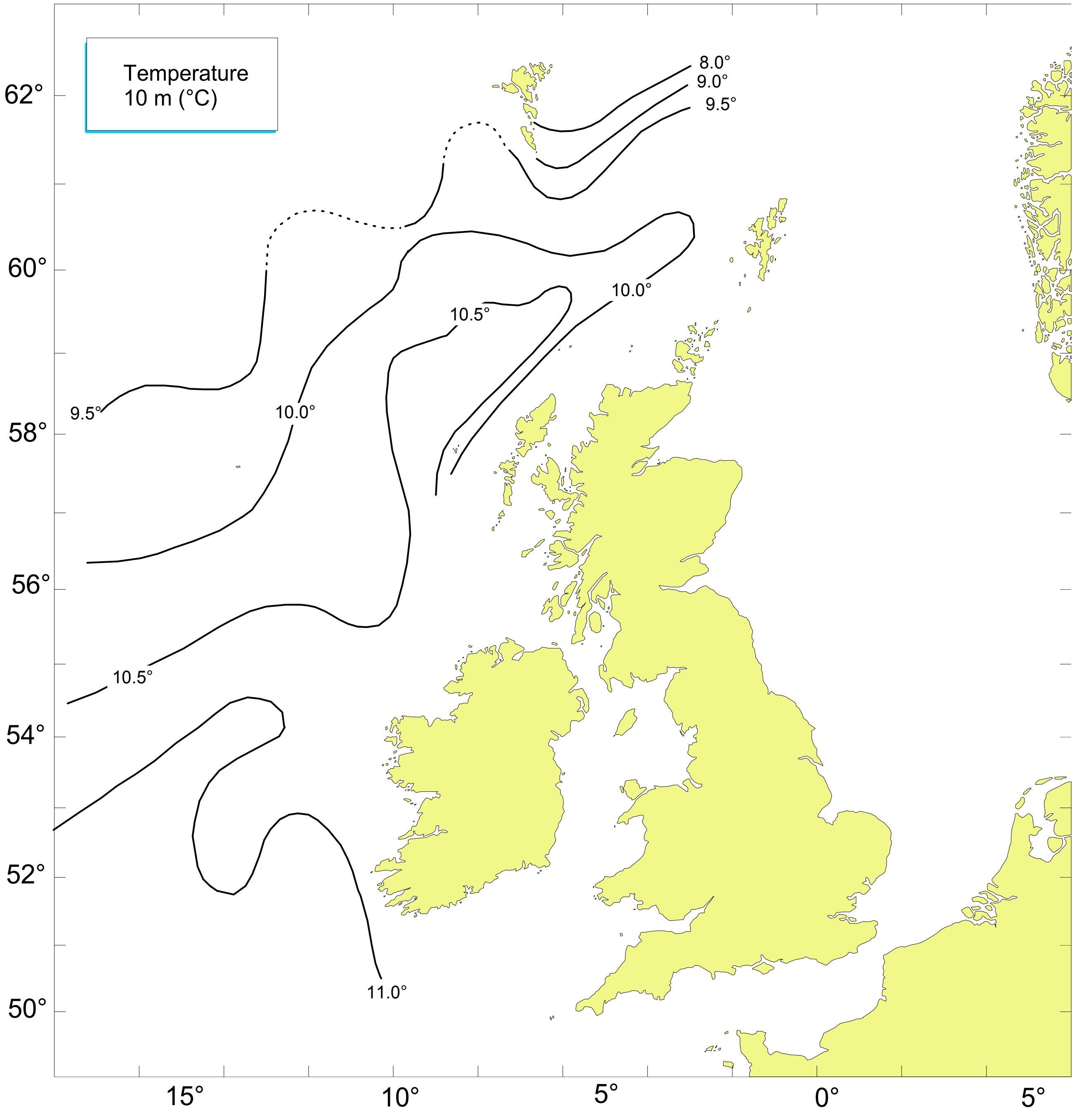


Figure 8. Horizontal temperature distribution, °C, at 10m depth

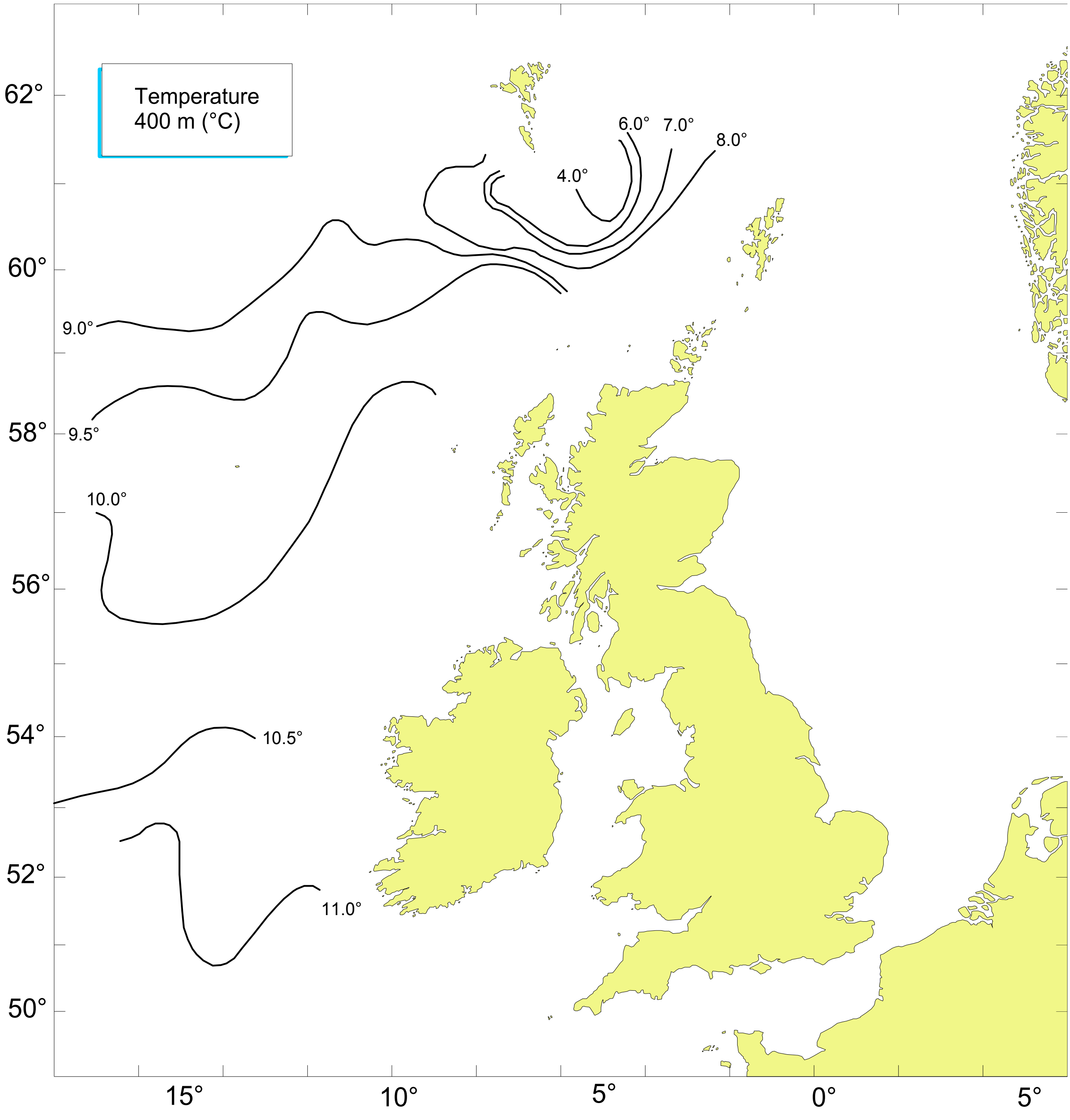


Figure 9. Horizontal temperature distribution, °C, at 400m depth

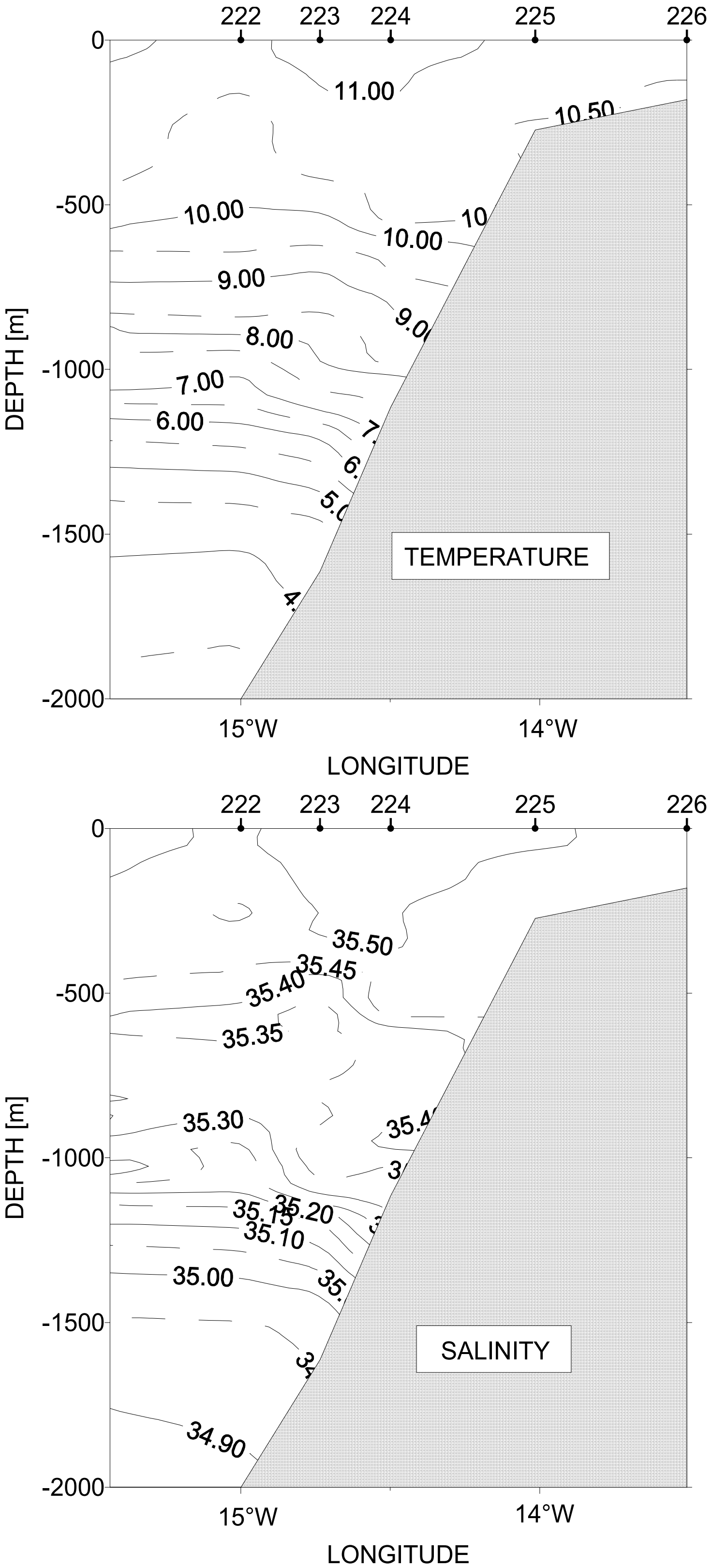


Figure 10 Vertical distribution of temperature (°C) and salinity in a section at the shelf edge at the Porcupine Bank at 53° 30'N. Station numbers at the top of the panels

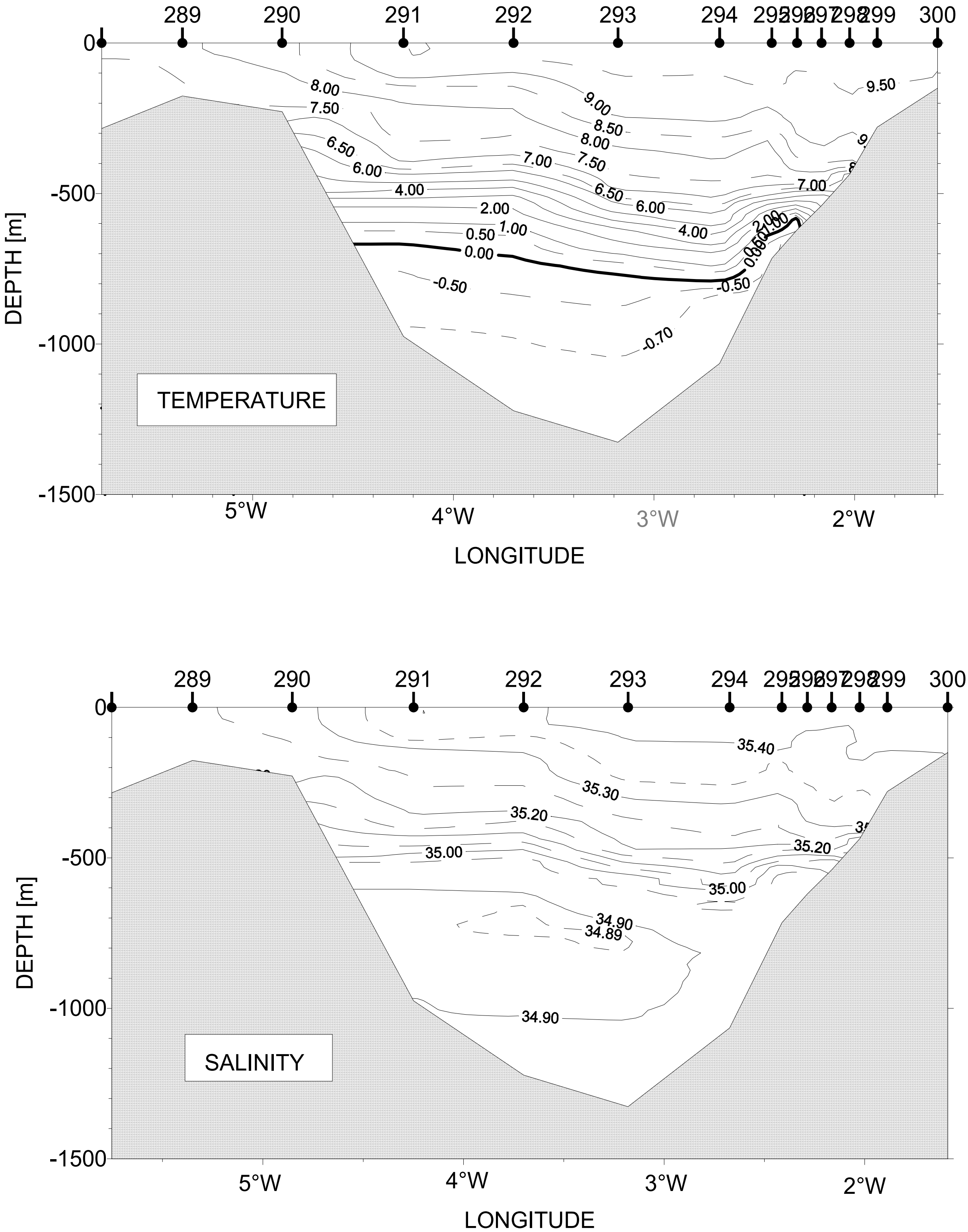


Figure 11. Vertical distribution of temperature (°C) and salinity in a section from the Faroes to Shetland (Nolsø-Flugga). Station numbers at the top of the panels.

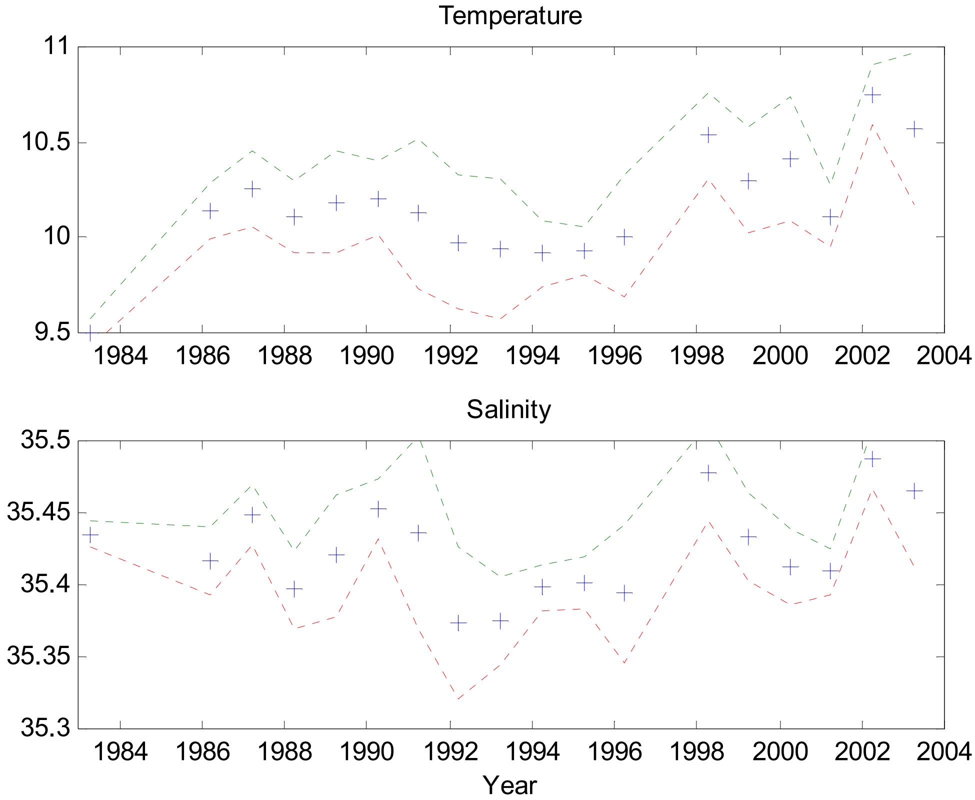


Figure 12. Yearly mean temperature and salinity from 50-600 m (crosses) of all stations in a box with bottom depth >600 m, west of the Porcupine bank bounded by 52° to 54°N and 16 to 14°W. Dotted lines are drawn at plus-minus one standard deviation of all observations in each box, each year.

Appendix 1. Inter-calibration between R/V Smolensk and R/V J. Hjort

Mikko Heino, R/V Johan Hjort (IMR, Bergen)
Sergey Ratushnyy, R/V Smolensk (PINRO, Murmansk)

Inter-calibration between R/V Johan Hjort and R/V Smolensk was conducted on 20 April 2003. The inter-calibration took place during 7 hours at position N 60° 16' and W 6° 38' under good weather conditions. The main acoustic feature in the area was a layer of blue whiting in depths around 400-500 metres. Standard instrument settings were kept during the experiment to simulate a realistic survey situation. A comparison showed that the vital settings of the EK500 of the two vessels are identical during survey situation. During the experiment the echogram annotation was printed every nautical mile and the EK500 integrator output was transferred between vessels every 5 nm. The inter-calibration was run over 35 nautical miles. For the first 15 nm, both vessels were cruising towards west, with J. Hjort following Smolensk at the distance of 1 nm and 10º (about 1.5 cables) to the barboard side. The roles were then reversed, and the vessels cruised eastwards for 20 nm. Thus, two transects totalling 33 nm were covered by both vessels. The logs were matched such that the vessels would cover "same" miles.

The acoustic densities recorded by the vessels displayed similar overall variations (Figure 1), and the correlations between the measurements were reasonably strong in all depths layers (Table 1). The regression models explain a large proportion of variability in the data. For example, the regression for the combined layer 200-600 m explains about 75% of variance in the data. However, there is a tendency for the acoustic instruments of Smolensk to give lower s_A-values than those of J. Hjort. These results are comparable to those obtained in inter-calibrations between J. Hjort and R/V Atlantniro and R/V Fridtjof Nansen in 2002 (Godø et al. 2002). One possible explanation for the difference can be the drop keel of J. Hjort that reduces the influence of bubbles on acoustic recordings (Godø et al. 2002).

By means of the established regression models (Table 1), acoustic data from one vessel can be converted to a scale where the data from one vessel are comparable to the data of the other vessel (Figure 2). However, such exercise should be carried out only with great caution because there is no guarantee that the established relations (Table 1) hold for acoustic densities above (or below) to what was recorded during the inter-calibration. Maximum acoustic densities observed during the inter-calibration were well below those that may be observed in dense aggregations along the edge of continental shelf.

After the acoustic inter-calibration, pelagic trawls of the two vessels were compared. Smolensk towed at depth of 400 m for 30 minutes and caught 3000 kg of blue whiting. J. Hjort towed for 15 minutes at depths of 410-450 metres and caught 500 kg of blue whiting. Both vessels towed to the same direction at a distance of about one nautical mile apart. The length distributions in the catches were very similar, both being distinctly bimodal (Figure 3). The first peak at 18-19 cm of length represents age 1 yr fish, and the other at 24-25 cm fish of age 2 yr and older. There was a small but statistically significant (linear model: $p<0.001$) difference between the length distributions: mean length in the haul from J. Hjort was 23.0 cm (standard deviation 3.5 cm), and mean length in the haul from Smolensk was 24.6 cm (standard deviation 3.8 cm), the difference thus being about 1.5 cm.

On the basis of single comparison, it is not possible to conclude whether the observed difference represent differences in selectivity or, e.g., local variations in distribution of fish of different sizes.

In any case, the difference was small, and for most practical purposes the selectivity properties can be consider as similar.

Reference

Godø, O. R., Heino, M., Oganin, I., Ratushnyy, S., Sentyabov, E., Gerber, E. and Timoshenko, N. 2002. Report and preliminary evaluation of Norwegian and Russian blue whiting surveys in 2002. Working Document to The Northern Pelagic and Blue Whiting Fisheries Working Group, Vigo, Spain, 29 April-8 May 2002. 26 pp. ICES CM 2002/ACFM19.

Table 1. Comparison of acoustic esimates between R/V "Johan Hjort" and R/V "Smolensk". All calculations are based on s_A-values transformed to their natural logarithms. Logarithms of zeros have been replaced with a small number (-1, corresponding to s_A=0.37), influencing the results for depths 100-400m.

Depth interval (m)	15-100		100-200		200-300		300-400	
Nautical miles	33		33		33		33	
Vessel	J. Hjort	Smolensk	J. Hjort	Smolensk	J. Hjort	Smolensk	J. Hjort	Smolensk
Descriptive statistics								
Average	3.71	2.93	0.63	-0.10	1.99	1.56	2.47	2.60
Standard deviation	1.02	1.20	1.61	1.54	2.73	2.20	2.69	2.35
Minimum	1.66	1.16	-1	-2.3	-1	-1	-1	-1
Maximum	6.30	5.86	4.89	5.26	6.32	5.77	7.00	6.93
Comparative statistics								
Absolute difference		-0.774		-0.801		-0.430		0.132
Relative difference		-20.9%		-114%		-21.6%		5.33%
Correlation (r)		0.734		0.786		0.762		0.820
Significance [P(r=0)]		<0.001		<0.001		<0.001		<0.001
Regression (Smolensk=y, Johan Hjort=x)								
Intercept (a)		-0.269		-0.575		0.340		0.833
Standard error of a		0.551		0.181		0.313		0.325
Slope (b)		0.864		0.752		0.614		0.716
Standard error of b		0.144		0.106		0.094		0.090
% variance explained		53.8%		61.8%		58.1%		67.3%

Depth interval (m)	400-500		500-600		600-700		200-600	
Nautical miles	33		33		23		33	
Vessel	J. Hjort	Smolensk	J. Hjort	Smolensk	J. Hjort	Smolensk	J. Hjort	Smolensk
Descriptive statistics								
Average	7.69	7.38	5.75	5.45	3.66	3.30	8.01	7.68
Standard deviation	0.67	0.69	1.14	1.10	1.33	2.05	0.56	0.61
Minimum	6.20	6.21	2.94	2.56	0.97	-1.61	7.16	6.72
Maximum	8.95	8.74	8.30	7.92	5.36	5.83	9.00	8.83
Comparative statistics								
Absolute difference		-0.308		-0.302		-0.362		-0.330
Relative difference		-4.00%		-5.25%		-9.87%		-4.12%
Correlation (r)		0.854		0.924		0.923		0.862
Significance [P(r=0)]		<0.001		<0.001		<0.001		<0.001
Regression (Smolensk=y, Johan Hjort=x)								
Intercept (a)		0.623		0.318		-1.90		0.218
Standard error of a		0.741		0.390		0.501		0.791
Slope (b)		0.879		0.892		1.42		0.932
Standard error of b		0.096		0.067		0.129		0.010
% variance explained		73.0%		85.3%		85.3%		74.3%

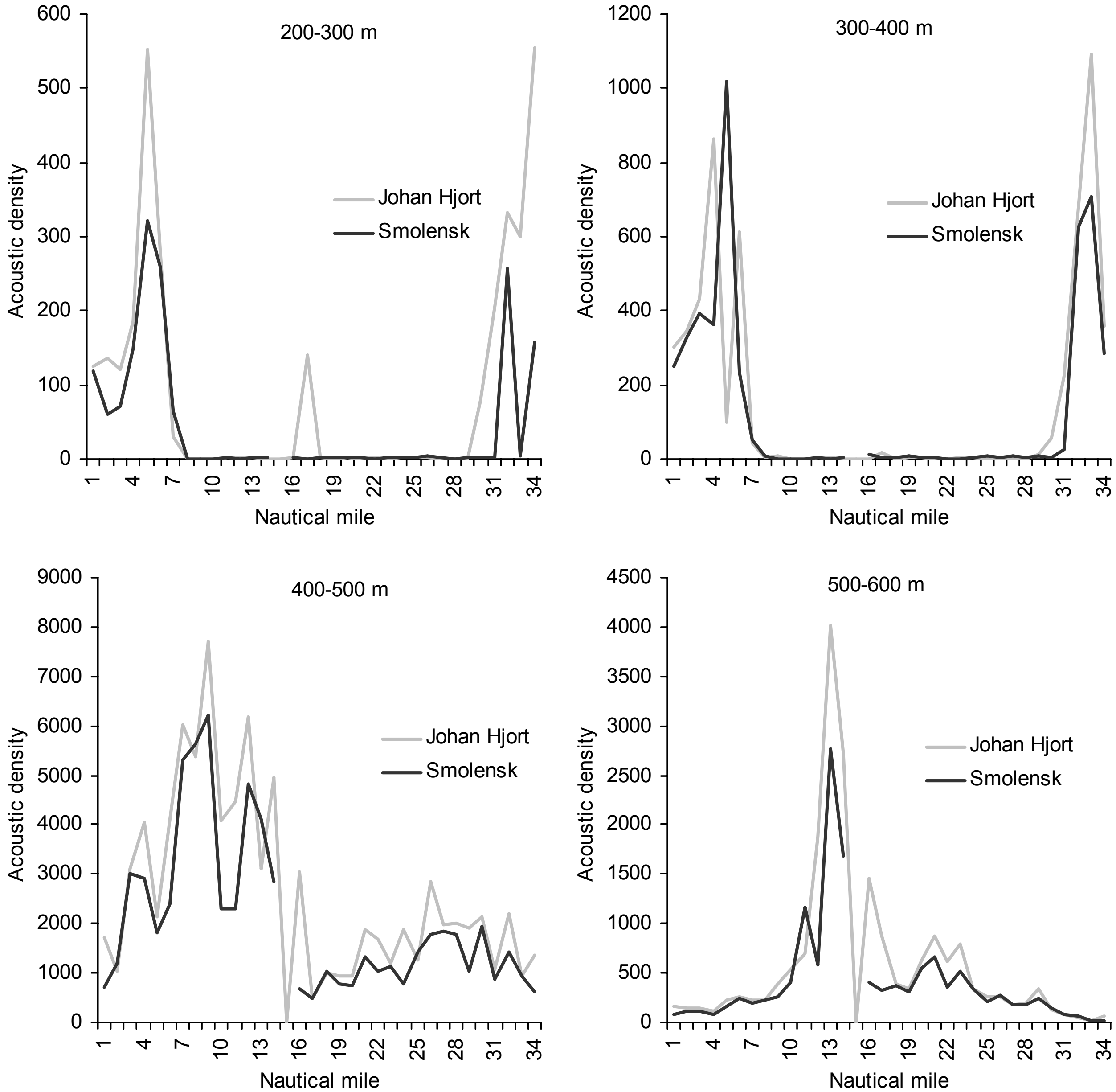


Figure 1. Acoustic densities (sA) measured by Smolensk and Johan Hjort during the inter-calibration.

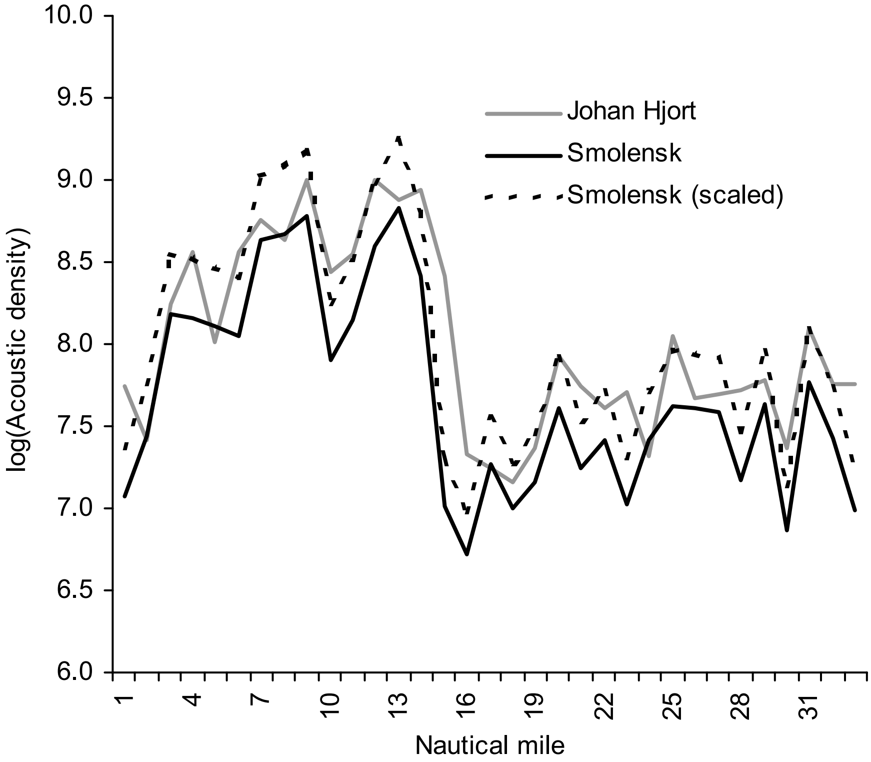


Figure 2. Acoustic density in depths of 200-600m along the survey track. The dotted line represents recordings of Smolensk scaled with the regression in Table A1.

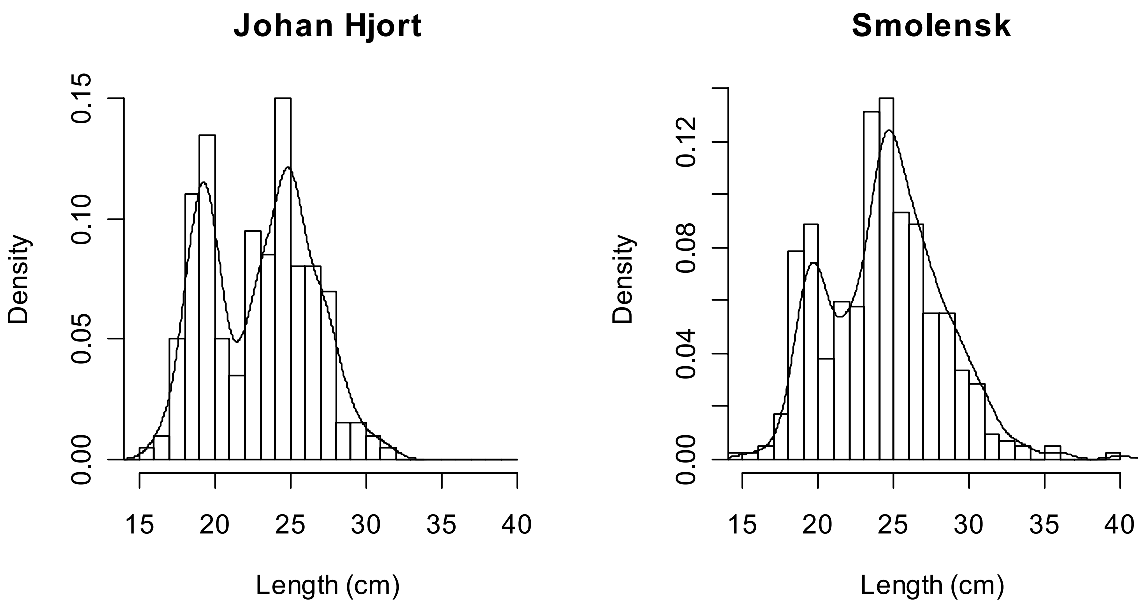


Figure 3. Length distributions from the trawls hauls of J. Hjort and Smolensk. Smoothing is obtained by normal kernel density estimates. J. Hjort: n=100; Smolensk: n=418.

Appendix 2. Acoustic equipment and setting of the instruments

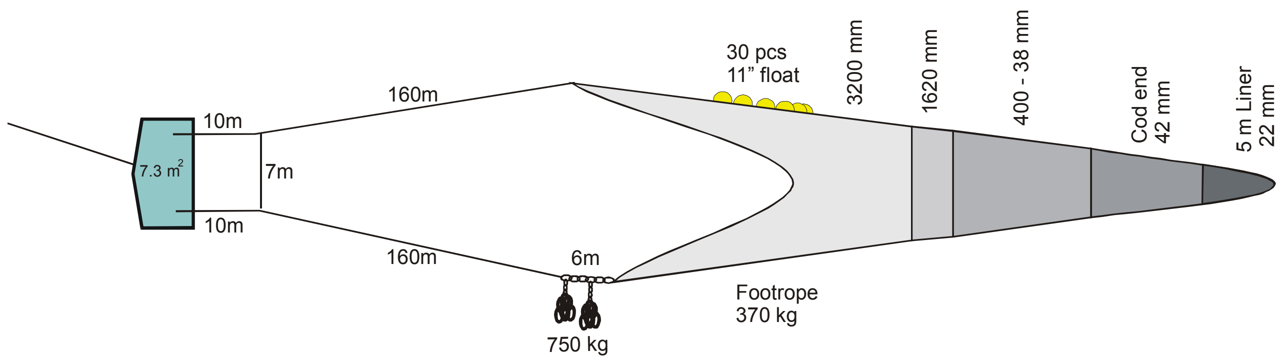
Acoustic equipment and setting of the instruments on the R/V "Johan Hjort", 29 March - 27 April 2003.

Echo sounder:	Simrad EK - 500
Frequency:	38 kHz
Transducer:	ES38B - SK
Absorption coeff.:	10 dB/km
Pulse length:	Medium (1ms)
Band width:	Wide (3.8 kHz)
Transmitter power:	2000 W
Angle sensitivity:	21.9 dB
2-way beam angle:	-21.0 dB
Sv Transducer gain:	27.37 dB [1]
Ts Transducer gain:	27.57 dB [2]
3 dB Beamwidth	
alongship:	7.0 dg
athw. ship:	6.8 dg
Range:	1000 m

[1] Changed to 27.57 dB after the calibration in the end of the survey.
[2] Changed to 27.75 dB after the calibration in the end of the survey.

Appendix 3. Configuration of the large 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 2003.



Appendix 4. Taxa encountered during the blue whiting survey in spring 2003.

Scientific name	Common name	Number of stations[1]
Micromesistius poutassou	Blue whiting	31
Myctophidae	Lanternfishes	25
Hydrozoa/Scyphozoa	Jellyfish	21
Maurolicus muelleri	Pearlside	19
Sternoptychidae	Hatchetfishes	16
Syngnathidae	Pipefishes and seahorses	15
Pandalidae	Deep water shrimp	15
Euphausiacea	Krill	12
Cephalopoda	Squids, octopusses	9
Chauliodus sloani	Sloane's viperfish	9
Notolepis rissoi	Small barracudina	8
Nansenia groenlandica	Greenland argentine	7
Nemichthyidae	Snipe-eels	7
Gonostoma elongatum		4
Coleoidea	Squids, octopusses	4
Paralepidae	Barracudinas	4
Stomia ferox	Scaly dragonfish	3
Argyropelecus hemigymnus	Spotted hatchetfish	3
Pollachius virens	Saithe	3
Xenodermichtys copei	Bluesnout smooth-head	2
Searsia koefoedi	Koefoed's searsid	2
Gadiculus argenteus	Silvery pout	2
Aphanopus carbo	Black scabbardfish	1
Gonatus fabricus	Squid	1
Holtbyrnia macrops	Bigeye serasid	1
Howella sherborni		1
Tunicata	Tunicates	1
Malacosteus niger		1
Melanostomias sp.	Scaleless dragonfish	1
Polymetme corythaeola		1
Cyclopterus lumpus	Lumpsucker	1
Sagamichtys schnakenbecki	Schnakenbeck's searsid	1
Scopelosaurus lepidus		1
Sebastes mentella	Deep sea redfish	1
Argyropelecus olfersi	Large hatchetfish	1
Argentina silus	Greater silversmelt	1

[1]Total number of trawl stations was 35.

Appendix 5. Comparison of trawl hauls of R/V Johan Hjort and other vessels.

In order to compare the performance of the large pelagic trawl of Johan Hjort with a (very) large commercial pelagic trawl, two samples (representing two trawl hauls) were obtained from one Norwegian vessel that was trawling in the area 60º00’ N, 9º16’ W. Johan Hjort took two trawl hauls from the same area. Both vessels towed at similar speeds (above 3 knots, with J. Hjort having slightly higher speed). Length distributions in these samples are presented in Fig. 1. The samples are summarized in the table below:

Vessel	Station	Sample size	Length		Weight		Condition		Age[1]	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV
Johan Hjort	187	128	25.7	0.091	84.2	0.297	4.88	0.090	3.62	0.352
	188	100	26.1	0.074	87.1	0.249	4.82	0.079	3.40	0.188
	both	228	25.9	0.084	84.5	0.276	4.86	0.086	3.51	0.288
Fishing vessel	510	72	27.7	0.107	108.5	0.383	4.92	0.106	4.26	0.303
	511	100	26.6	0.082	87.7	0.272	4.56	0.087	4.02	0.268
	both	172	27.1	0.095	96.4	0.352	4.71	0.103	4.14	0.287

[1]Sample size: 50 fish.

The two trawl hauls of Johan Hjort were not significantly different from each other (linear model: p=0.118 or larger for all variables). In contrast, the samples from the commercial vessel differed from each other with respect to mean length (p=0.006), weight (p<0.001) and condition (p<0.001) but not with respect to age (p=0.315).

Catches of Johan Hjort consisted of blue whiting that were significantly shorter (p<0.001), lighter (p<0.001) and younger (p<0.001) but relatively more obese (p=0.001) than the those from the catches of the commercial vessel. Taking the second haul of J. Hjort as a reference sample (the second haul provided a larger catch), it is seen that only the first haul of the commercial vessel significantly (p=0.05 or less) differs from this reference sample with respect to length and weight, and that only the second commercial haul had significantly different mean condition. However, both commercial samples had significantly different mean ages.

Trawling during the inter-calibration with R/V Smolensk (Appendix 1) provides another comparison. A difference of 1.6 cm in mean length (little less than half standard deviation) was observed, with Smolensk catching larger fish than J. Hjort (see Appendix 1, Fig. 3).

These results show that the large pelagic trawl of Johan Hjort continues to fish slightly smaller fish than a (very) large pelagic trawl operated by commercial vessel or a large pelagic trawl operated by a Russian research vessel. However, the differences are much less striking than before (in 2002, difference in mean length of a commercial sample and our own sample from the same area was more than four centimetres). It is also important to realize that hauls of commercial vessels last for hours and thereby catch fish from a very large area. It is impossible to ascertain that the sampled catch actually originates from an area adjacent to the one from which our own sample was taken. Furthermore, large opening of a commercial pelagic trawl enables catching fish from a larger vertical range than is in practice possible in scientific hauls.

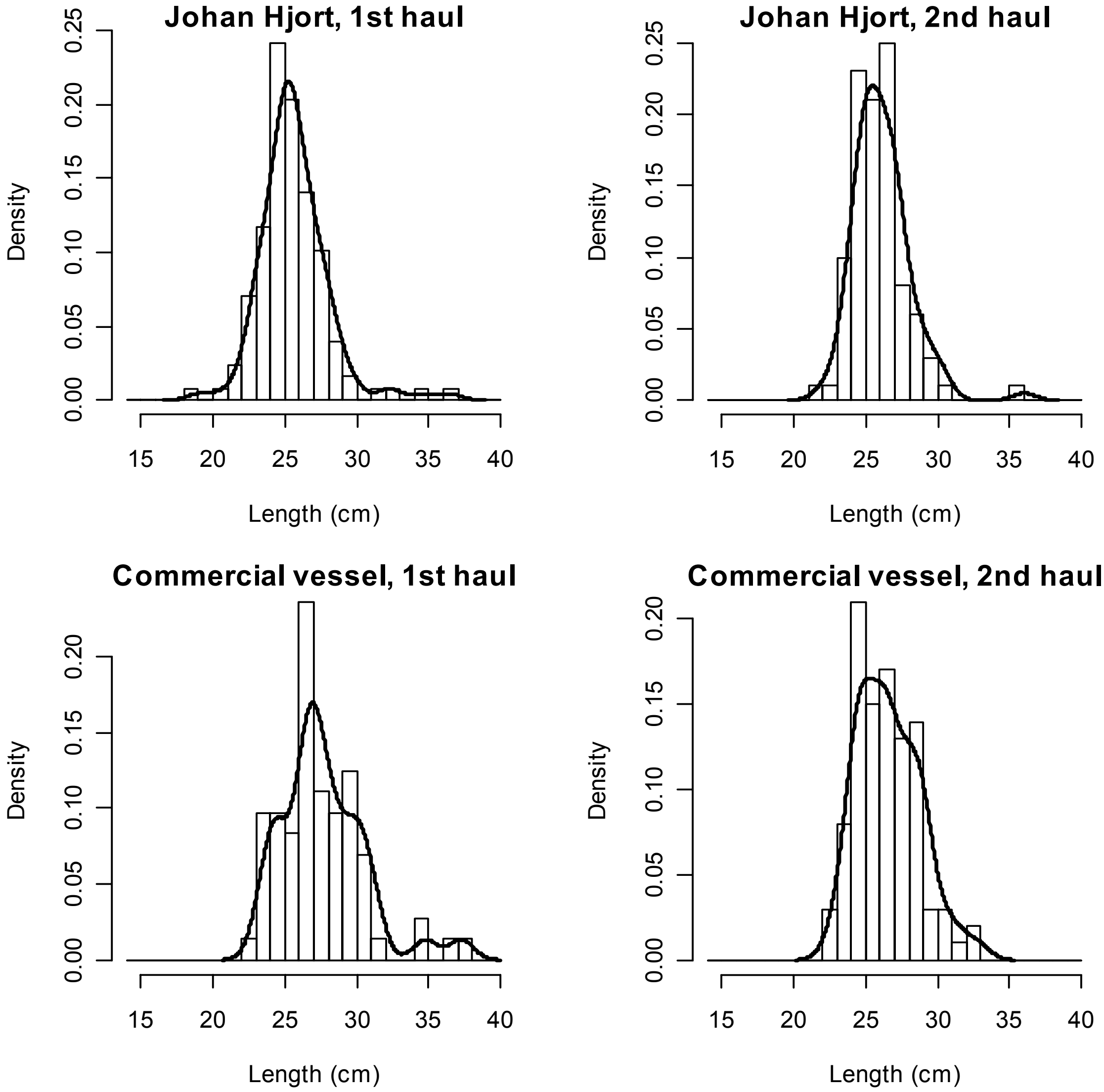


Figure 1. Length distributions from the trawls hauls of J. Hjort and a commercial vessel. The hauls are from the same area and time but the commercial vessel had much longer hauls. Smoothing is obtained by normal kernel density estimates.

Appendix 6. An analysis of variability among sub-samples and two adjacent trawl hauls

In order to investigate the possibility that size distribution of fish depends on the part of trawl catch from which they were collected, we analysed two trawl hauls in more detail. These hauls were taken on April 17 from close-by areas and are summarized by the table below:

Station	Time (GMT)	Latitude	Longitude	Distance	Depth	Catch
178	12:07	57º37'N	9º41'W	3.9 nm	430-463 m	108 kg
179	15:31	57º38'N	9º43'W	2.4 nm	360-420 m	70 kg

The catch from the first haul was emptied into four baskets and from the second one to three baskets. From each basket 50 fish were taken and measured for length and weight; only the fish from the first basket were aged. The results by station and basket are summarized as follows:

Station	Basket	Length		Weight		Condition		Age	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
178	1	24.10	0.118	64.86	0.274	4.53	0.077	2.84	0.088
178	2	24.67	0.077	68.68	0.210	4.54	0.083		
178	3	24.41	0.093	66.24	0.229	4.50	0.101		
178	4	24.73	0.080	70.28	0.219	4.59	0.092		
178	all	24.48	0.093	67.52	0.233	4.54	0.088	2.84	0.088
179	5	25.34	0.076	73.72	0.239	4.47	0.093	3.20	0.082
179	6	25.02	0.103	73.04	0.291	4.57	0.078		
179	7	24.91	0.091	70.60	0.230	4.49	0.074		
179	all	25.09	0.090	72.45	0.254	4.51	0.082	3.20	0.082

The first haul contained fish that were on average 0.6 cm shorter, 5 g lighter and 0.4 years younger than fish in the second haul. Although the differences were small and the variable station explains only about of 2-4% of variance in the data, these differences are statistically significant ($p=0.013$, $p=0.007$ and $p=0.039$ for length, weight and age, respectively). The data thus suggest that spatial heterogeneity in the scale considered here is not a large source of error in estimating the structure of the stock. The situation is, however, clearly different in areas where young blue whiting occur in upper parts of the water column.

There were some, albeit small, differences in length and weight estimated from different basket from a single trawl haul. An analysis of variance shows that these effects are statistically not significant ($p=0.645$ and $p=0.549$ for length and weight, respectively) – in other words, the observed differences can be explained by sampling noise alone. The same conclusion holds for other catches treated similarly (station 180, 4 sub-samples of 50 fish each: $p=0.669$ and $p=0.848$ for length and weight, respectively).

Appendix 7. An analysis of uncertainty in estimated acoustic density (s_A)

To gain better understanding on spatial structure of the dense aggregations of blue whiting – and consequences of this structure on the estimated acoustic density – an area west of St Kilda was covered using a densely spaced cruise track (Fig. 1). The track was 157 nm long and was covered at one go during a period of 16 hours.

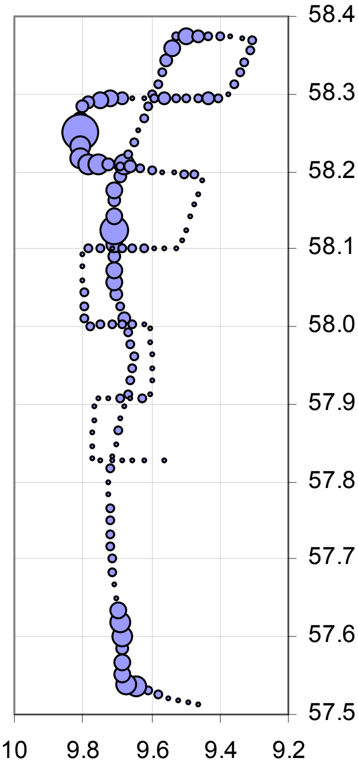
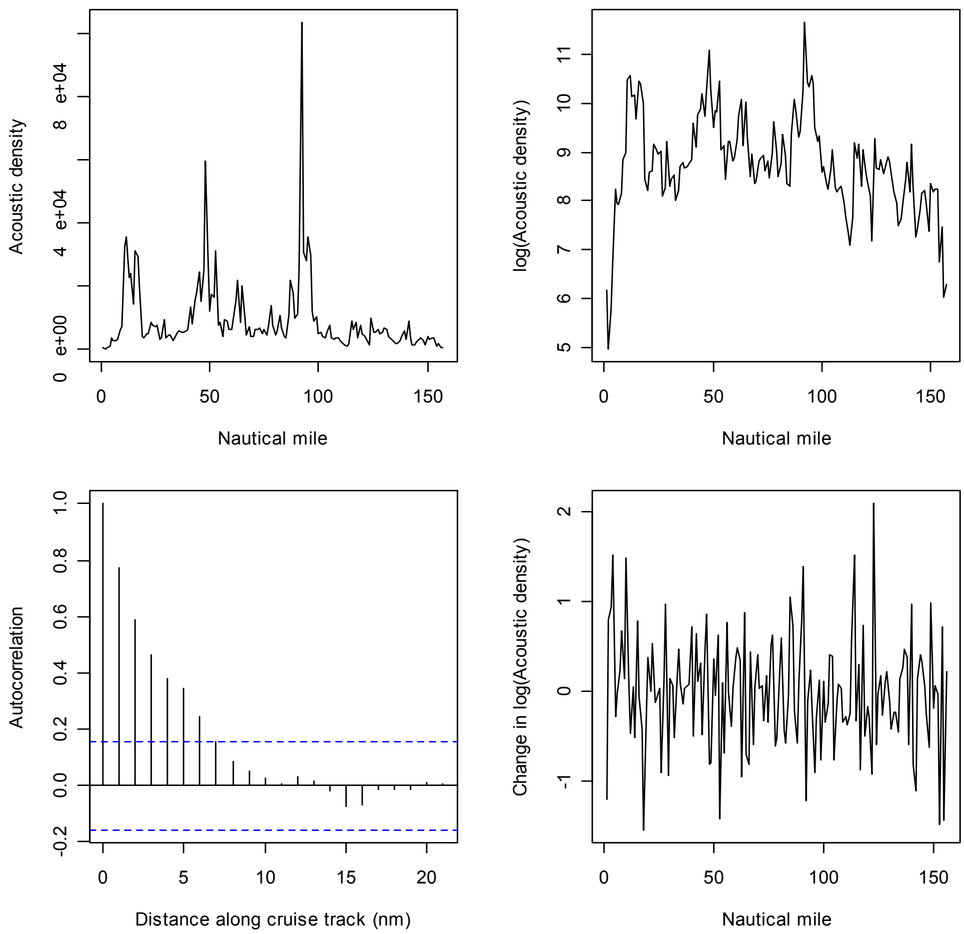


Figure 1. Cruise track. The widths of circles are proportional to square root of s_A.

Mean acoustic density on the cruise tack was 9363 m^2nm^{-2}. However, individual nautical miles show variations of over three orders of magnitude. The variation of acoustic density along the cruise track is shown below (Fig. 2). After logarithmic transformation, the data is approximately normally distributed and seem to have rather uniform structure (with exception of few miles in the beginning and in the end when the vessel was departing/entering the shallow area with low s_A-values). There is a strong spatial autocorrelation along the cruise track over distances of 1-3 nm, but this autocorrelation decays fairly rapidly and becomes negligible beyond 6 nm. Differences in $\log(s_A)$ between consecutive miles confirm the assertion that the structure of variations along the cruise track are homogeneous: these difference behave quite like white noise. The structure of the data also seems to be independent of direction of the cruise line, as suggested by the linear model $\mathrm{diff}(\log(s_A))$ ~

Figure 2. Variation of acoustic density along the cruise track (top row). An autocorrelation function based on the log-transformed data (bottom left). Diagram showing differences between consecutive miles along the cruise track (bottom right).



diff(latitude)*diff(longitude) which explains only 2.4% of changes along the cruise track.

During a typical blue whiting survey, the area in Fig. 1 has usually been covered with a zigzag cruise track crossing the area from west to east and back once or twice. One such crossing represents roughly 15 nm of cruise track. To assess the variability in mean s_A expected in such crossing, we calculated the mean s_A in all possible 15 nm sections of the whole cruise track, connecting the two ends of the track together. Thus, the autocorrelation observed along the cruise track is maintained. These samples show strong variability, with 95% of samples spanning the range 1903-22486 m^2nm^{-2} (Table 1). The distribution is skewed such that most samples slightly underestimate the mean acoustic density, while some samples result in gross overestimation. If two independent 15 nm samples are collected the variability is somewhat reduced and, remarkably, median estimate is moved close to the observed mean. For comparison, we also considered random sampling of 15 individual nautical miles, thus ignoring the spatial correlation structure.

These results are based on limited data and from one are only. Nevertheless, they indicate that large variability can be expected when estimating density of blue whiting in dense post-spawning aggregations along the shelf edge. The good news is that the result can expected to be unbiased. This means that in larger areas covered by several cruise tracks errors can be expected even out, but that estimating of density of blue whiting at smaller scale is subject to considerable error.

Table 1. Descriptive statistics of distribution of mean s_A values in all 15 nm sections along the cruise track (157 in total), and from 2000 random pairs of such 15 nm samples. For comparison, 2000 replicates of 15 randomly sampled miles are also considered.

	Mean s_A	2.5% quantile	Median s_A	97.5% quantile
Whole cruise track	9363			
One 15 nm sample	9363	1903	7500	22486
Two 15 nm samples	9285	3133	8922	18834
15 random 1 nm samples	9356	5027	8868	16466

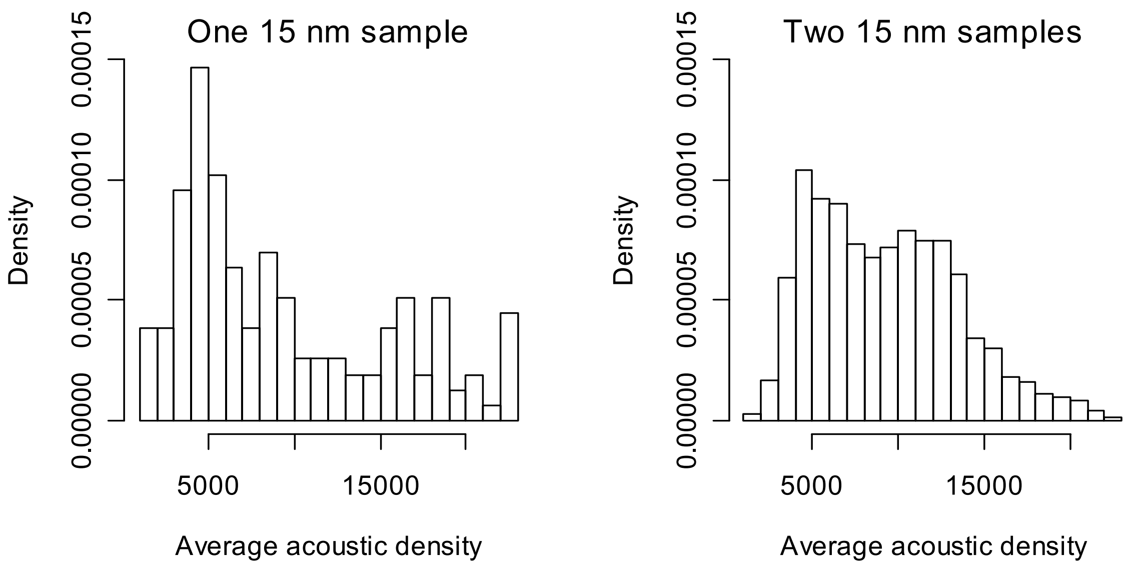


Figure 3. Distribution of mean s_A values in all 15 nm sections along the cruise track (157 in total , panel left). Distribution of mean s_A values in 2000 pairs of observations from the distribution in the left-hand-side panel (right).

Appendix 8. Acoustic target strength of blue whiting

Introduction

Acoustic surveys on the spawning stock of blue whiting has been carried out since the end of the 1970s, first by Norwegian vessel only, and in later years periodically by Russian vessel effort. Appraisal of acoustic backscattering to total biomass of the spawning stock has been based on a conversion factor obtained from early observations of cod and has never been validated (see e.g. Monstad 1986 and Godø *et al.* 2002 for more information about the survey). Further, there has been a substantial discrepancy between the survey based measurement of stock biomass and the smaller biomass from the analytical assessment performed by the ICES (ICES 2002). The evaluation of the state of the stock has become more difficult in later years due to the increased exploitation, lower mean age in the catch, and consequently, larger uncertainty in the analytical assessment.

Due to the above, there is a strong need for precise *in situ* target strength (TS) measurements of blue whiting. An accurate and reliable acoustic assessment would furnish a better analytical assessment as well as establish a standalone platform for evaluation of the development of the spawning stock.

In 2002 some initial trials with measurements of blue whiting TS strength were done (Godø *et al.* 2002). In this paper we describe results from *in situ* TS measurements done during the 2003 survey for spawning blue whiting west of the British Isles in April 2003.

Material and methods

The data were collected on board R/V Johan Hjort on 7 locations (Figure 1). The two first experiments (301-302) are not used in the present analysis as later calibration showed substantial deviation from the target level of performance.

The measurements were done with a pressure resistant transducer (Simrad 38-DD) connected to a Simrad EK 60 echosounder. The transducer was lowered to the fish concentrations so as to obtain single fish resolution. The experiments were all done with the transducer at 300-400 m depth.

The system was calibrated with a standard copper sphere (Foote *et al.* 1987). The sphere was attached to the transducer frame with three thin nylon strings. The length of these could be adjusted from the vessel to secure a full coverage of the transducer beam during the calibration. Performance was adjusted to the correct -33.6 dB target strength of the sphere. Similarly, we attached the sphere to the transducer during one of the experiments to evaluate potential depth dependency of the transducer.

Methodology for TS measurements is thoroughly described by Ona (1999). The TS data presented here are all screened through target tracking procedures for separating echoes of single fish (see Ona and Hansen (1996) and Handegard et al. (2003)). This reduced the amount of data but improved proper discard of double echoes and other noise. All echograms were carefully studied to avoid noisy data with poor resolution. Only measurements from single individuals with 10 pings or more and with vertical distance to nearest neighbour of 0.5 m or more were accepted. TS of fish meeting these requirements make the basis of the presented TS estimates.

To confirm the species and size compositions of the fish one or two trawl hauls were taken on each of the TS stations.

Results

Calibration
Absolute calibration was done in surface layers. Even though the transducer is designed for high pressures, limited changes in performance may take place with depth. A test with the standard sphere attached to the transducer showed that some change took place with depth (Figure 3). The performance at first decreased and had a minimum at 100 m and thereafter increased and approached the surface level at 400 m. As our TS measurement were done close to 400 m the following analyses are done without any adjustments in TS for the depth dependent performance.

Conditions for measurements
Quality TS measurements have to be done at well-resolved fish distributions. This is achieved by lowering the transducer to the fish concentrations with the potential danger of affecting the natural behaviour of the fish. We experienced that it is very difficult to approach the blue whiting with out setting up an avoidance reaction. Therefore we had to do the measurements at longer distance than the optimal. The problem was worsened by the heave and roll of the vessel, which is reflected in the undulation of the single fish recordings. The problem was periodically much worse than apparent in the example of blue whiting registration in Figure 4. When such measurements are carried out in the open sea a heave compensated winch is needed.

Measurements
The measurements are based on several hours of recordings. During the process of target tracking most of the echoes are excluded because they do not meet the requirements. The TS from the 5 valid stations gave TS between –37.2 and -38.6 dB except for station 304 from which TS was 4 dB lower (Figure 5). The same graph shows that the fish root mean square length varied from about 22 – 26 cm. In most cases the TS distributions of blue whiting have to peaks; one around –37 dB and another between –48 and - 55 dB (Figure 6). This may be caused by the acoustic properties of the fish as well as the fact that the length distribution often had two peaks. Possible contamination of the recordings by small mesopelagic fish or other small life forms cannot be excluded as all trawl catches had a small numbers of various species. Particularly, we expect that this might have happened in station 304, which showed very low TS compared to the others. Station 307 had a substantial contribution of saithe. These fish are included in the mean length of the trawl catch and the associated TS in Figure 5 to demonstrate consistency of the results, but the station is not considered suitable for TS determination of blue whiting.

It is apparent that there are several problems associated with TS measurements of blue whiting, both generally and in this particular case. The analysis so far confirms the impression from the first tests in 2002 that the TS strength of blue whiting is substantially higher than the one presently used in the survey. As indicated in Figure 5 the TS might be even higher than the one used for cod and haddock in the Barents Sea, which is about 5 . The available data will be further studied and given a more thorough analysis. This not only for the production of the most reliable results but also for planning of a better sampling program including both improved technology and data analysis.

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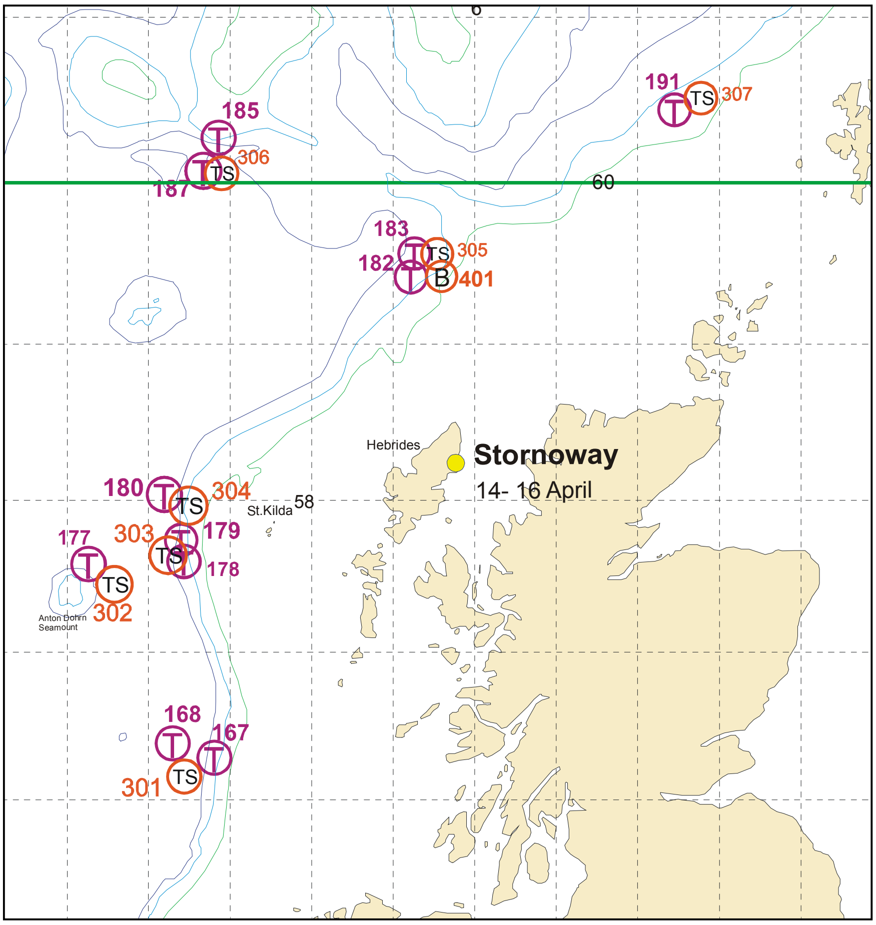

Figure 1. Map with TS stations

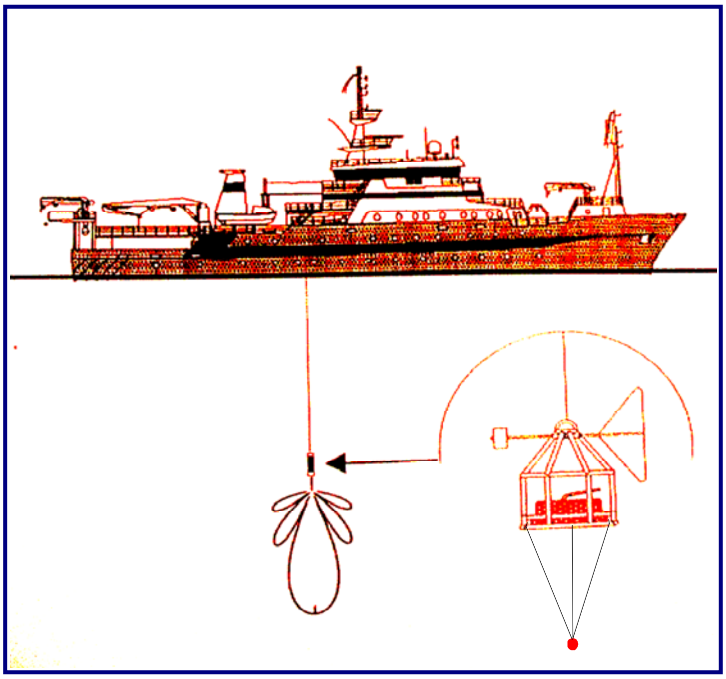

Figure 2. Experimental setup. Enlarged is the transducer with attached standard calibration sphere.

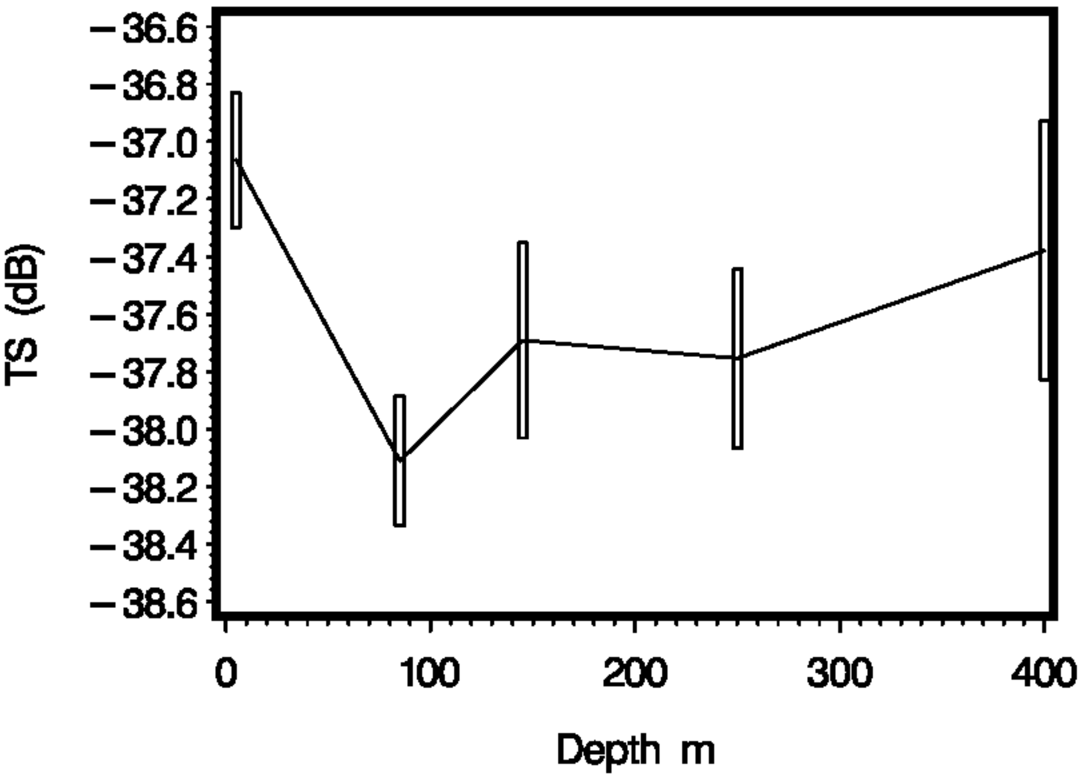

Figure 3. Change in TS of the standard sphere with depth.

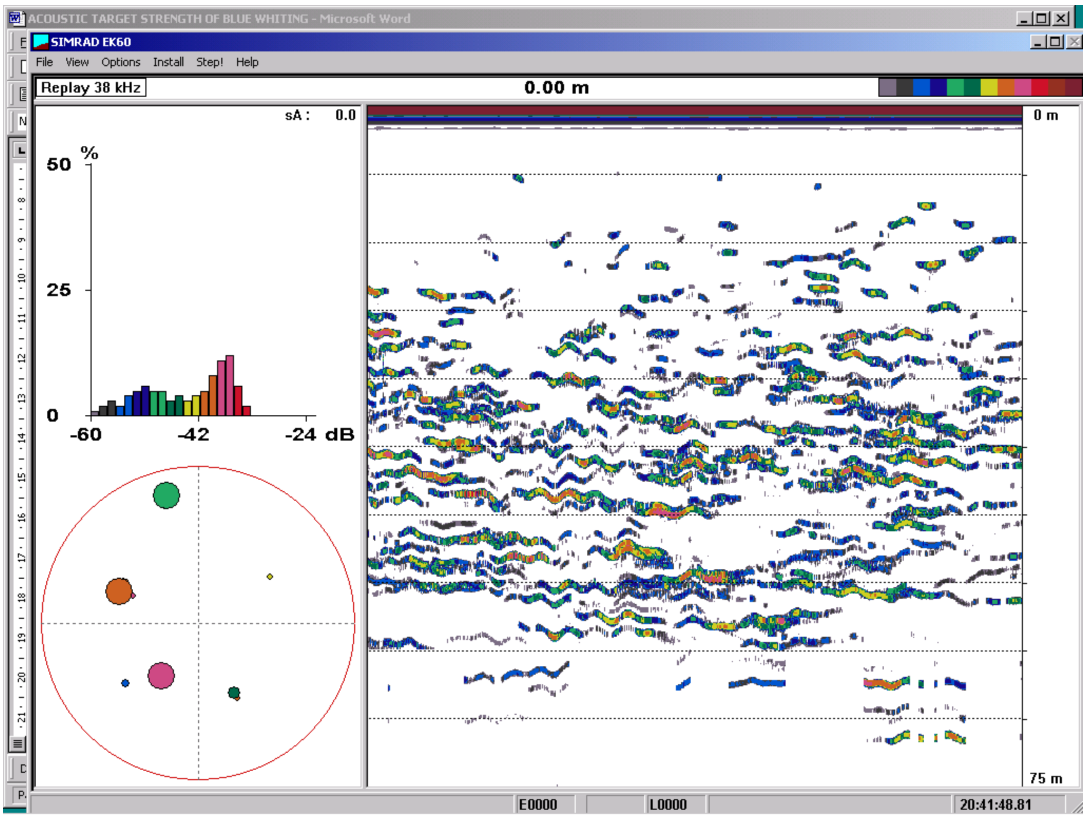

Figure 4. Blue whiting recordings during TS measurements from station 306.

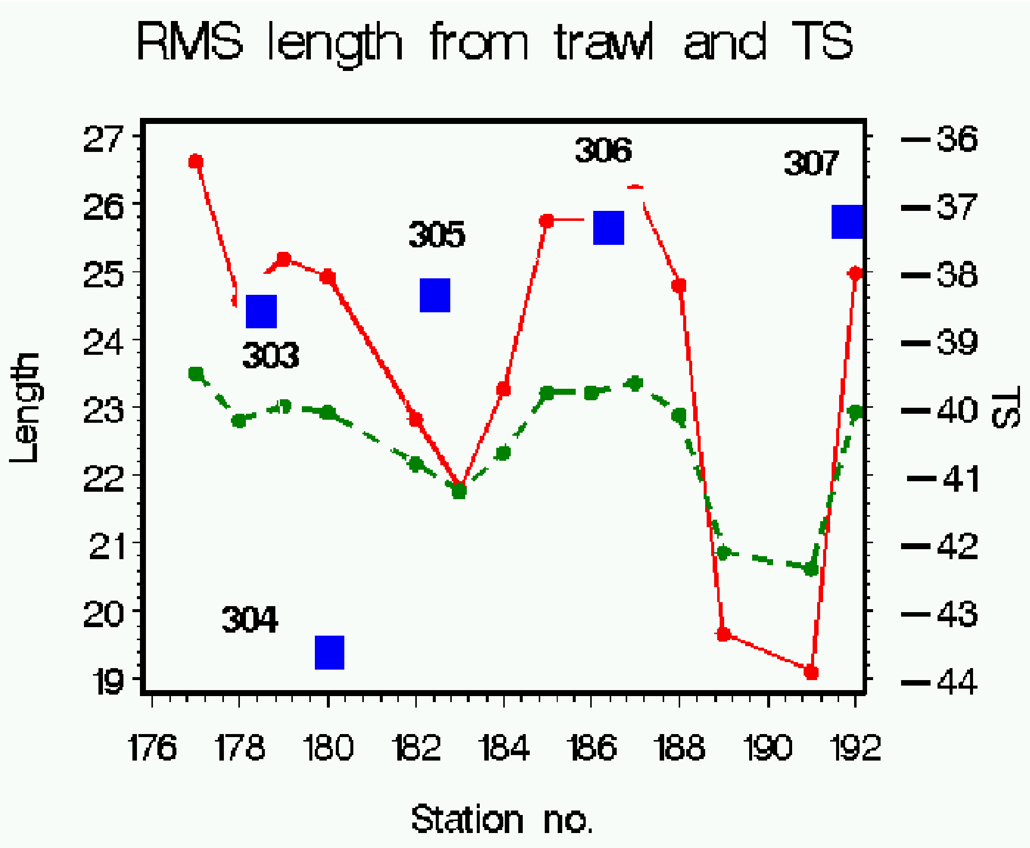

Figure 5. Root mean square length from all trawl catches and the associated TS when using the relationship TS=20log(L)–68 (the same as for cod and haddock in the Barents Sea).

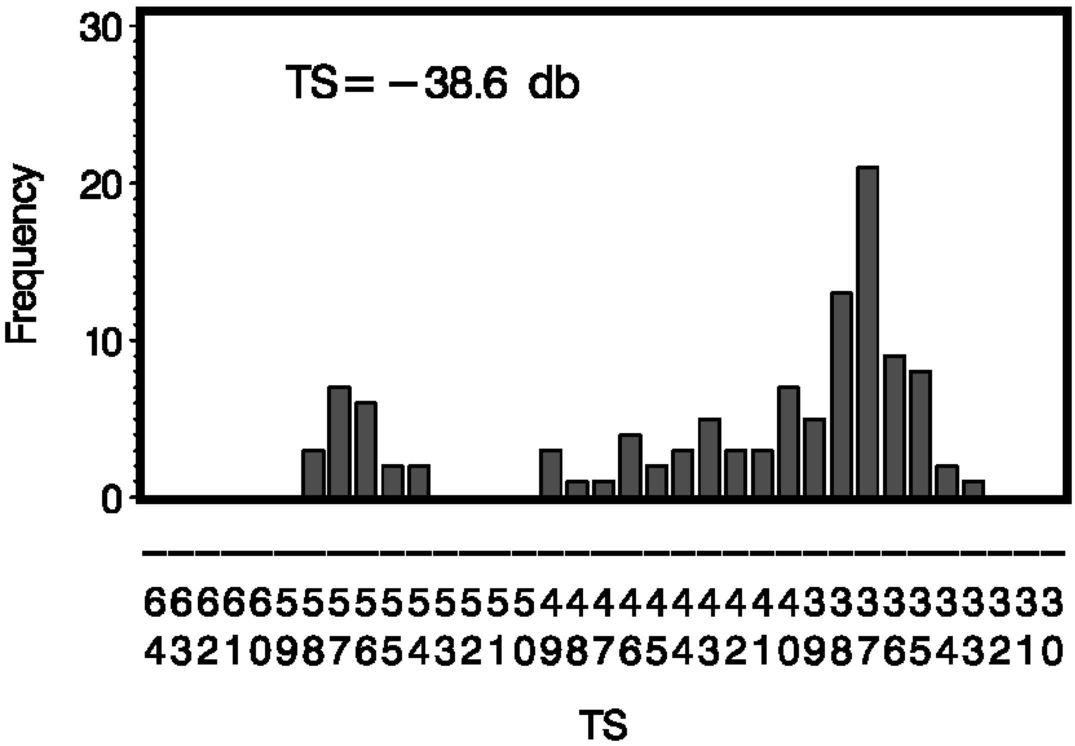

Figure 6. TS distribution from TS station 303.