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INTERNATIONAL BLUE WHITING SPAWNING STOCK SURVEY SPRING 2006

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Introduction

In spring 2006, five research vessels representing the Faroe Islands, Ireland, the Netherlands, Norway and Russia surveyed the spawning grounds of blue whiting west of the British Isles. International co-operation allows for wider and more synoptic coverage of the stock and more rational utilisation of resources than uncoordinated national surveys. The survey was the second coordinated international blue whiting spawning stock survey since mid-1990s. The primary purpose of the survey was to obtain estimates of blue whiting stock abundance in the main spawning grounds using acoustic methods as well as to collect hydrographic information. Results of all the surveys are also presented in national reports (Atlantniro: Shnar et al. 2006; Celtic Explorer: Mullins et al. 2006; G. O. Sars: Heino et al. 2006; M. Heinason: Jacobsen et al. 2006; Tridens: Ybema et al. 2006).

This report is based on a workshop held after the international survey in Tórshavn, 20–21/4/2006, where the data were analysed and the report written. Parts of the document were worked out through correspondence during and after the workshop.

Material and methods

Coordination of the 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 2005a), and continued by correspondence until the start of the survey. The participating vessels together with their effective survey periods are listed below:

Vessel	Institute	Survey period
Atlantniro	AtlantNIRO, Kaliningrad, Russia	4/3–29/3
Celtic Explorer	Marine Institute, Ireland	23/3–8/4
G. O. Sars	Institute of Marine Research, Bergen, Norway	18/3–15/4
Magnus Heinason	Faroese Fisheries Laboratory, Faroe Islands	31/3–11/4
Tridens	Institute for Marine Resources & Ecosystem Studies, the Netherlands	15/3–27/3

The cruise lines and trawl stations are shown in Figure 1. Figure 2 shows CTD stations. Survey effort by each vessel is detailed in Table 1. All vessels worked their survey in a northerly direction (Figure 3). Frequent contacts were maintained between the vessels during the course of the survey, primarily through electronic mail.

Frequent periods of bad weather hampered the survey effort for short periods of time, causing either a reduction in vessel speed, or periods where surveying had to be suspended.

The survey was based on scientific echo sounders using 38 kHz frequency. Transducers were calibrated with the standard sphere calibration (Foote et al. 1987) prior to (Celtic Explorer, M. Heinason, Tridens, G. O. Sars) and after (Atlantniro) the survey. Salient acoustic settings are summarized below.

Table: Acoustic instruments and settings for the primary frequency (boldface).

	Atlantniro	Celtic Explorer	G. O. Sars	Magnus Heinason	Tridens
Echo sounder	Simrad EK 500	Simrad EK 60	Simrad EK 60	Simrad EK 500	Simrad EK 60
Frequency (kHz)	**38**, 120	**38**, 18, 120, 200	**38**, 18, 70, 120, 200	**38**	**38**
Primary transducer	ES38B	ES 38B - Serial	ES 38B - SK	ES38B	ES 38B
Transducer installation	Hull	Drop keel	Drop keel	Hull	Towed body
Transducer depth (m)	5	8.7	8	3	7
Upper integration limit (m)	10	15	15	7	12

Absorption coeff. (dB/km)	10	9.6	9.785	10	9.6
Pulse length (ms)	Medium	1.024	1	Medium	1.024
Band width (kHz)	Wide	2.425	2.425	Wide	2.43
Transmitter power (W)	2000	2000	2000	2000	2000
Angle sensitivity (dB)	21.9	21.9	21.9	21.9	21.9
2-way beam angle (dB)	-20.6	-20.6	-20.8	-20.6	-20.6
Sv Transducer gain (dB)	27.30			27.22	
Ts Transducer gain (dB)	27.64	25.23	25.55	27.35	25.87
s_A correction (dB)		-0.73	-0.65		-0.59
3 dB beam width (dg)					
alongship:	6.9	6.99	7.05	7.02	7.02
athw. ship:	6.8	7.03	7.06	6.86	7.16
Maximum range (m)	750	1000	750	750	750
Post processing software	Sonardata Echoview	Sonardata Echoview	BEI	Sonardata Echoview	Sonardata Echoview

Post-processing software and procedures differed among the vessels. On Celtic Explorer, acoustic data were backed up every 24 hrs and scrutinised using Sonar data's Echoview (V 3.1) post processing software for the previous days work. Data was partitioned into the following categories; plankton (<120 m depth layer), mesopelagic species, blue whiting and bottom fish. Partitioning of data into the above categories was carried out by two experienced scientists. Adjustments for drop-outs were applied where necessary. In addition, as an experiment, the data were also scrutinised using the Norwegian BEI system by a different scientist.

On G. O. Sars, the acoustic recordings were scrutinized using the Bergen Echo Integrator (BEI, Foote et al. 1991) once or twice per day. Blue whiting were separated from other recordings using catch information, characteristics of the recordings, and frequency response between integration on 38 kHz and on other frequencies by a scientist experienced in viewing echograms. Adjustments for drop-outs were unnecessary although noise of unknown origin plagued data when swell was against the cruise track. Bubble correction of 10-20% was applied when it was apparent that bubbles associated with heavy seas were dampening registrations; the actual value used was somewhat arbitrary.

On Magnus Heinason, acoustic data were scrutinised every 24 hrs on board using Sonar data's Echoview (V 3.50) post processing software. Data were partitioned into the following categories: plankton (<200 m depth layer), mesopelagic species, blue whiting and krill. Partitioning of data into the above categories was based on trawl samples.

On Tridens, acoustic data were scrutinized every 24 hrs using Sonar data's Echoview (V 3.25) post processing software. Data was partitioned into the following categories plankton (all layers), blue whiting and bottom fish (including argentines, mackerel and horse mackerel). Partitioning of data into the above categories was largely subjective and was viewed by 1 scientist.

On Atlantniro, the Sonar data's Echoview (V 3.20) post processing software was used as the primary post-processing tool for acoustic data. Data was partitioned into the following categories, blue whiting, Eutrigla gurnardus, plankton, mesopelagic species and other species. The acoustic recordings were scrutinized once per day.

All vessels used a large or medium-sized pelagic trawl as the main tool for biological sampling. The salient properties of the trawls are as follows:

	Atlantniro	Celtic Explorer	G. O. Sars	Magnus Heinason	Tridens
Circumference (m)	716	768	586	640	1120
Vertical opening (m)	50	48	25-35	38-48	30-70
Mesh size in codend (mm)	16	50	22	40	±20
Typical towing speed (kn)	3.3-4.0	3.5-4.0	3.0-4.0	3.0-4.0	3.5-4.0

On G. O. Sars, some additional samples were taken with a bottom trawl with 4 x 18 m opening equipped with a Rock-hopper ground gear was used on some shallower areas.

Catch from the trawl hauls was sorted and weighed; fish were identified to species (when possible) and other taxa to higher taxonomic levels. Normally a sub-sample of 50 (Celtic Explorer, G. O. Sars, Tridens) or 50-100 (M. Heinason) blue whiting were sexed, aged, and measured for length and weight, and their maturity status were estimated using established methods. An additional sample of 50 fish (M. Heinason, G. O. Sars), 200 (Celtic Explorer), 250 (Tridens, only length) was measured for length and weight. On Atlantniro 50 fish were measured for length, weight and sex and an additional 250 were measured for length.

The acoustic data as well as the data from trawl hauls were analysed with a SAS based routine called “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 representatively covered 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.

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 representing 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. No weighting of individual trawl samples was used because of differences in trawls and numbers of fish sampled and measurements. 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 separately for each sub-area. 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.

The hydrographical situation in the surveyed area was mapped by all vessels (Figure 2, Table 1). G. O. Sars, Celtic Explorer, Atlantniro and Tridens are equipped with SBE911 CTDs. In addition, on G. O. Sars surface (~4m) temperature, salinity and fluorescence were continuously registered along the complete track of the cruise using a ship-mounted thermosalinograph (SBE21).

Results

Inter-calibration results

Results from the inter-calibration between R/V G. O. Sars and R/V Magnus Heinason are summarized in Appendix 1. Acoustic inter-calibrations showed that the performance of Magnus Heinason was very similar to G. O. Sars (which was used as the reference vessel). Bad weather prevented the planned inter-calibration between Celtic Explorer and Tridens, while Atlantniro was too far ahead of G.O. Sars to be within reach for at inter-calibration.

Catchability can vary among the vessels due to the large variety of gear employed (see the text table on page 3). However, the difference during the inter-calibration exercise between G. O. Sars and Magnus Heinason nevertheless suggested rather small differences in size selectivity in mean length relative to G. O. Sars; the mean length from M. Heinason was 0.8 cm lower.

The age readings from the different vessels were comparable with some small inconsistencies, i.e., some fish being aged too old for their size. The age-length key was edited manually before it was used in the assessment, i.e., some missing entries were added manually in those few cases where length measurements were available without corresponding age entries.

Distribution of blue whiting

Blue whiting were recorded in most of the survey area that covered about 170 thousand square nautical miles (Figures 4–6). The highest concentrations were recorded in the area between the Hebrides, Rockall and the banks southwest of the Faroes. In comparison to 2005, the biomass was more evenly and more southerly distributed, with more fish close to the traditional hot spot close to the Hebrides shelf brake.

As most strata were surveyed by more than one vessel, there is some inevitable variability in vessel-specific acoustic observations. This is illustrated by displaying vessel-specific estimates of mean acoustic density in each survey stratum (Figure 5). These are often in good agreement, but also big discrepancies occur, which can be attributed to spatial and temporal heterogeneity in abundance of blue whiting.

Stock size

The estimated total abundance of blue whiting for the 2006 international survey was 10.4 million tonnes, representing an abundance of 108×10^9 individuals (Table 2). The spawning stock was estimated at 10.3 million tonnes and 105×10^9 individuals. The geographical distribution of total stock biomass by stratum is shown in Figure 7.

In comparison to the results in 2004–2005, the increase in stock numbers and biomass are substantial:

		2004	2005	2006	Change from 2005 (%)
Biomass (mill. t)	Total	11.4	8.0	10.4	+30
	Mature	10.9	7.6	10.3	+36
Numbers (10^9)	Total	137	90	108	+20
	Mature	128	83	105	+27
Survey area (nm^2)		149 000	172 000	170 000	–1

There was heterogeneity in the temporal trend between the sub-areas, however. There was no change in the southern Porcupine Bank, whereas biomass significantly decreased in the Faroes/Shetland sub-area and increased elsewhere, in particular in the Rockall sub-area:

	Sub-area	Biomass (million tonnes) 2005		2006		Change (%)
			% of total		% of total	
I	S. Porcupine Bank	0.21	3	0.20	2	–5
II	N. Porcupine Bank	0.47	6	0.74	7	+57
III	Hebrides	4.3	54	5.2	50	+22
IV	Faroes/Shetland	1.4	18	0.94	9	–33
V	Rockall	1.6	20	3.3	32	+105

Stock composition

Stock in the survey area is dominated by age classes 4 and 3 years (year classes 2002 and 2003), which make together about 60% of spawning stock biomass (Table 3, Figure 7). This represents a shift to the dominance of young fish from the survey in 2005. The year classes that were dominant in 2005, now at age 5-6 years, make 29% of the remaining spawning stock biomass.

Half of the spawning stock biomass was recorded in the Hebrides sub-area. The age structure of stock in this area resembled that of the total survey area (Figure 8). In the southern and northern areas, younger blue whiting were relatively more abundant. However, in Rockall, significant numbers of large, old blue whiting were measured, and the age distribution was more spread than elsewhere.

Almost all fish older than one year in age were mature. The proportion of juvenile fish was highest in the Faroes/Shetland sub-area (Table 2), whereas almost all fish were mature in the northern Porcupine and Hebrides sub-areas. In the Porcupine Bank, no sampling on the slopes of the bank (where juvenile usually occur) was conducted, contributing to the relative of paucity of young fish in the stock estimate.

Hydrography

The horizontal distribution of temperature and salinity at 10, 200, 400 and 600 meters depths are shown in Figures 9–16. The maps are based on CTD data collected on board G. O. Sars, Atlantniro, Celtic Explorer and Tridens (Figure 2). The cooperation has given a good 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 temperature between 10m and 400m are less than 1°C and at 1000m depth the temperatures are between 6 and 8°C. At the Porcupine section (Figure 17) the temperature is quite homogeneous (11-11.5°C) down to about 500m with a gradual change in the thermocline between 500m and 1000m. Weak stratification is typical for the area, and in the northern part of the Rockall Channel the mixed layer was 600–700m deep. 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 18, Faroe-Shetland section). This gives rise to the strongest horizontal gradients in the area too, particularly in deep water.

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 52°N to 60°N at 10m, 200m, 400m and 600m depths (Figures 9-12). Due to a northward flowing shelf edge current, the warmest and most saline water is found in a narrow band along the shelf edge.

In the last couple of years and this year the temperatures in the southern part of the area were above 11°C. Both last year and this year the 10°C isotherm extended north to about 58°N and the warmest water in the Faroe-Shetland channel was just above 9°C. The temperature is lower this year than last year.

On the Faroe-Shetland section (Figure 18) there is a characteristic wedge shaped core of Atlantic water on the eastern slope and Atlantic water in the upper hundred meters across the whole channel. Below the Atlantic water, cold and low salinity intermediate water of Norwegian Sea origin extending up to about 500m. The 0°C isotherm is found at 600m depth at the western side, 500m central in the channel and it slopes downward to nearly 700m at the eastern side. This is about the same depth as last year, but shallower than in 2003. The temperature and salinity in the core of the Atlantic water are about the same as last year, but colder and less saline than seen in the record warm and saline water in 2003.

Based on the hydrographic observations obtained during the blue whiting surveys, the mean temperature and salinity from 50 to 600m of all the stations in deep water (bottom depth>600m) in 2° latitude times 2° longitude boxes has been calculated for each survey. The box with limits 52° to 54°N and 16° to 14°W had few gaps, and the time series of mean temperature and salinity for this box is shown in figure 19. 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, i.e. 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

Main results

- The effort by five participating vessels gave a very broad spatial coverage. In addition, through overlapping coverage in core areas, information on the spatial and temporal dynamics of blue whiting is gained, giving a better idea of accuracy of the results.
- The third international blue whiting spawning stock survey shows a clear increase in stock numbers and biomass (~20–36%), in comparison to the survey in 2005. The estimates are still lower than in 2004. The area surveyed was the same as in 2005, but 15% larger than during the 2004 survey.
- Considering total stock biomass in those survey strata that were covered in both 2005 and 2006, and adjusting for changes in the proportional coverage within each stratum, suggests an increase of about 22%, that is, somewhat lower than the estimates from the total survey areas.
- Most of the increase in the stock estimate comes from the Rockall sub-area, in particular from its western part. This area was covered earlier in season this year than in 2005; also the surveyed area was greater. Hebrides and northern Porcupine sub-areas, which had similar coverage in 2005 and 2006, showed more moderate increases.
- The stock in the survey area is dominated by age classes 4 and 3 years (year classes 2002 and 2003), which make together about 60% of spawning stock biomass. This represents a shift to the dominance of younger fish from the survey in 2005. The year classes that were dominant in 2005, now at age 5-6 years, make 29% of the remaining spawning stock biomass.
- Dealfish (*Trachipterus arcticus*) occurred in unprecedented frequency in the trawl catches. Also some commercial vessels reported very high proportions of dealfish in their catch.

Interpretation of the results

- Abundance estimates from acoustic surveys should generally be interpreted as relative indices rather than absolute measures. In particular, acoustic abundance estimates critically depend on the applied target strength. The target strength currently used for blue whiting is based on cod and considered to be too low, possibly as much as by 40% (see Godø et al. 2002, Heino et al. 2003, 2005, Pedersen et al. 2006). This would imply an overestimation of stock biomass by a similar factor. This bias is, however, roughly constant from year to year, and does not affect conclusions about relative change in abundance of stock.

- The overall timing of survey appears to be rather suitable with respect to covering the traditional core distribution area of blue whiting. The possibility of covering western (west of Rockall) and southern (off Porcupine Bank) areas earlier in the season, at the time of the peak fishery in those areas, should be considered.
- The lower biomass in the northern region indicates that the northern migration of post-spawning blue whiting was delayed in 2006 compared to last year. There seem to be a delay of about two weeks in the northern migration into the Faroese EEZ. This was clear from the low abundance in the Faroese area (northern part of Sub-area IV), as well as from the fact that the Faroese commercial vessels were waiting in the Faroese area by 12 April, because their quota was finished in EU waters. In 2005 the fishery in the Faroese area started around 1 April.

Practical experiences and lessons for the future surveys

- Data exchange during and after the survey was relatively smooth due to improved adherence to the PGNAPES data format. Further improvements to the data exchange and database format were discussed. It was agreed that proposed changes of data formats will be sent in before the start of the survey in order for all vessels to use the most up to date format for data exchange. An important change in the database format was to switch from common PGNAPES species naming to the use of the standard three-letter species code used by ICES. All 2006 data will be imported into the database shortly and made available for the survey participants on the web.
- Fish sampling procedures were discussed and it was suggested that Tridens would use a similar procedure as Celtic Explorer and G.O. Sars: take up to 50 samples for biological measurements and up to another 200 for length measurements. Furthermore Tridens should consider using 7 maturity stages, following the standards for this survey.
- Cruise tracks were planned and executed more consistent than in 2005; transect directions were now parallel and shallow waters (less than 200m) were generally not included in the acoustic data that were used in the stock estimate.
- Tridens is still not able to do trawling samples at night. Because blue whiting often occur patchily, good trawl sample coverage can only be achieved if all vessels could fish at any time of the day.
- The age reading workshop in Hirtshals in 2005 revealed no surprising disagreements between Norwegian and Dutch age readers. Thus, so far, no cause could be found for discrepancies in age readings during the 2005 intercalibration between G.O. Sars and Tridens.
- We recommend sharing expertise (e.g., in scrutinizing echograms) through exchange of scientific personnel. Exchange calls should be made as soon as possible, preferably not later than during the PGNAPES meeting in August 2006.
- It is suggested that all vessels should be capable to do CTD downcasts up to 1000m.
- It was agreed that during the survey participants may send observations of the acoustic survey in the form of aggregated distribution maps to their contacts in the national fleets to increase cooperation.
- The survey area south of Porcupine Bank was covered after the majority of the international fishing fleet had left this area while the most northern survey area was covered before the fleet arrived.

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Table 1. Survey effort by vessel.

Vessel	Effective survey period (dd/mm)	Length of cruise track (nm) *	Trawl stations	CTD stations	Aged fish	Length-measured fish
Atlantniro	3/3–29/3	2512	30	46	371	371*
Celtic Explorer	23/3–8/4	2175	17	28	730	2961
G. O. Sars	18/3–15/4	3087	24	76	865	2368
Magnus Heinason	31/3–11/4	1254	14	21	365	1111
Tridens	15/3–27/3	1365	10	30	400	400*

* Used in the stock estimate. The actual number was higher but combining all data was not straightforward.

Table 2. Assessment factors of blue whiting, spring 2006.

Sub-area		Numbers (10^9)			Biomass (10^6 tonnes)			Mean weight	Mean length	Density
	n.mile^2	Mature	Total	%mature	Mature	Total	%mature	g	cm	ton/n.mile^2
I S. Porcupine Bank	13268	2.18	2.18	100	0.20	0.20	100	93.4	26.9	15
II N. Porcupine Bank	24841	8.51	8.51	100	0.74	0.74	100	87.3	26.7	30
III Hebrides	34916	55.1	57.1	96.4	519	5.24	99.1	91.7	26.9	150
IV Faroes/Shetland	32439	9.82	10.3	95.5	0.92	0.94	98.3	91.0	26.3	29
V Rockall	64355	29.5	29.9	98.7	3.27	3.28	99.7	109.5	27.2	51
Tot.	169819	105	108	97.3	10.3	10.4	99.3	96.3	26.9	61

Table 3. Stock estimate of blue whiting, spring 2006.

Length (cm)	Age in years (year class) 1 2005	2 2004	3 2003	4 2002	5 2001	6 2000	7 1999	8 1998	9 1997	10+ 1996	Numbers (10^6)	Biomass (10^6 kg)	Mean weight (g)	Prop. mature* (%)
15.0 – 16.0	132	0	0	0	0	0	0	0	0	0	132	2	16.8	0
16.0 – 17.0	795	0	0	0	0	0	0	0	0	0	795	15	19.4	0
17.0 – 18.0	971	0	0	0	0	0	0	0	0	0	971	23	23.4	1
18.0 – 19.0	444	28	0	0	0	0	0	0	0	0	472	14	29.5	17
19.0 – 20.0	364	296	0	0	0	0	0	0	0	0	660	24	36.4	48
20.0 – 21.0	288	833	0	0	0	0	0	0	0	0	1121	48	42.9	80
21.0 – 22.0	106	867	106	0	0	0	0	0	0	0	1079	55	50.9	93
22.0 – 23.0	61	558	711	161	0	0	0	0	0	0	1491	85	57.2	100
23.0 – 24.0	0	1164	1964	766	0	0	0	0	0	0	3894	247	63.5	100
24.0 – 25.0	0	806	5184	2275	102	154	0	0	0	0	8520	597	70.1	100
25.0 – 26.0	0	746	10441	8070	1369	210	0	0	0	0	20838	1605	77.0	100
26.0 – 27.0	0	238	7620	7965	2345	957	0	16	0	0	19141	1624	84.9	100
27.0 – 28.0	0	3	4317	8932	3015	658	0	0	0	0	16925	1598	94.4	100
28.0 – 29.0	0	0	1094	6901	2798	1088	49	0	0	0	11931	1279	107	100
29.0 – 30.0	0	0	649	2631	2861	1229	272	0	53	0	7694	923	120	100
30.0 – 31.0	0	0	25	847	1766	913	391	89	0	0	4032	554	137	100
31.0 – 32.0	0	0	86	305	805	995	468	80	0	0	2738	429	157	100
32.0 – 33.0	0	0	0	20	908	516	181	60	0	0	1685	288	171	100
33.0 – 34.0	0	0	0	60	350	322	251	8	0	0	990	206	208	100
34.0 – 35.0	0	0	3	8	274	472	139	8	48	0	952	221	233	100
35.0 – 36.0	0	0	0	0	16	225	331	232	94	0	897	237	264	100
36.0 – 37.0	0	0	0	0	0	221	192	39	43	0	495	140	282	100
37.0 – 38.0	0	0	0	0	0	12	112	113	21	0	259	79	305	100
38.0 – 39.0	0	0	0	0	0	0	54	54	0	0	108	40	373	100
39.0 – 40.0	0	0	0	0	0	0	14	14	0	0	27	8	307	100
40.0 – 41.0	0	0	0	0	0	0	1	61	25	0	88	37	420	100
41.0 – 42.0	0	0	0	0	0	0	0	10	4	0	14	5	356	100
42.0 – 43.0	0	0	0	0	0	0	5	6	5	7	24	8	353	100
TSN (10^6)	3162	5540	32201	38942	16608	7972	2459	791	293	7	107975			
TSB (10^6 kg)	87	329	2598	3603	1896	1104	495	206	73	3	10393			
Mean length (cm)	18.0	22.9	25.8	27.0	28.7	30.0	32.9	35.2	35.2	42.5	26.9			
Mean weight (g)	27.6	59.5	80.7	92.5	114	139	201	260	249	337	96.3			
Condition (g/dm^3)	4.7	5.0	4.7	4.7	4.8	5.1	5.6	6.0	5.7	4.4	4.9			
% mature*	13	97	100	100	100	100	100	100	100	100	97.3			
% of SSB	0	3	25	35	18	11	5	2	1	0				

* Percentage of mature individuals per age or length class

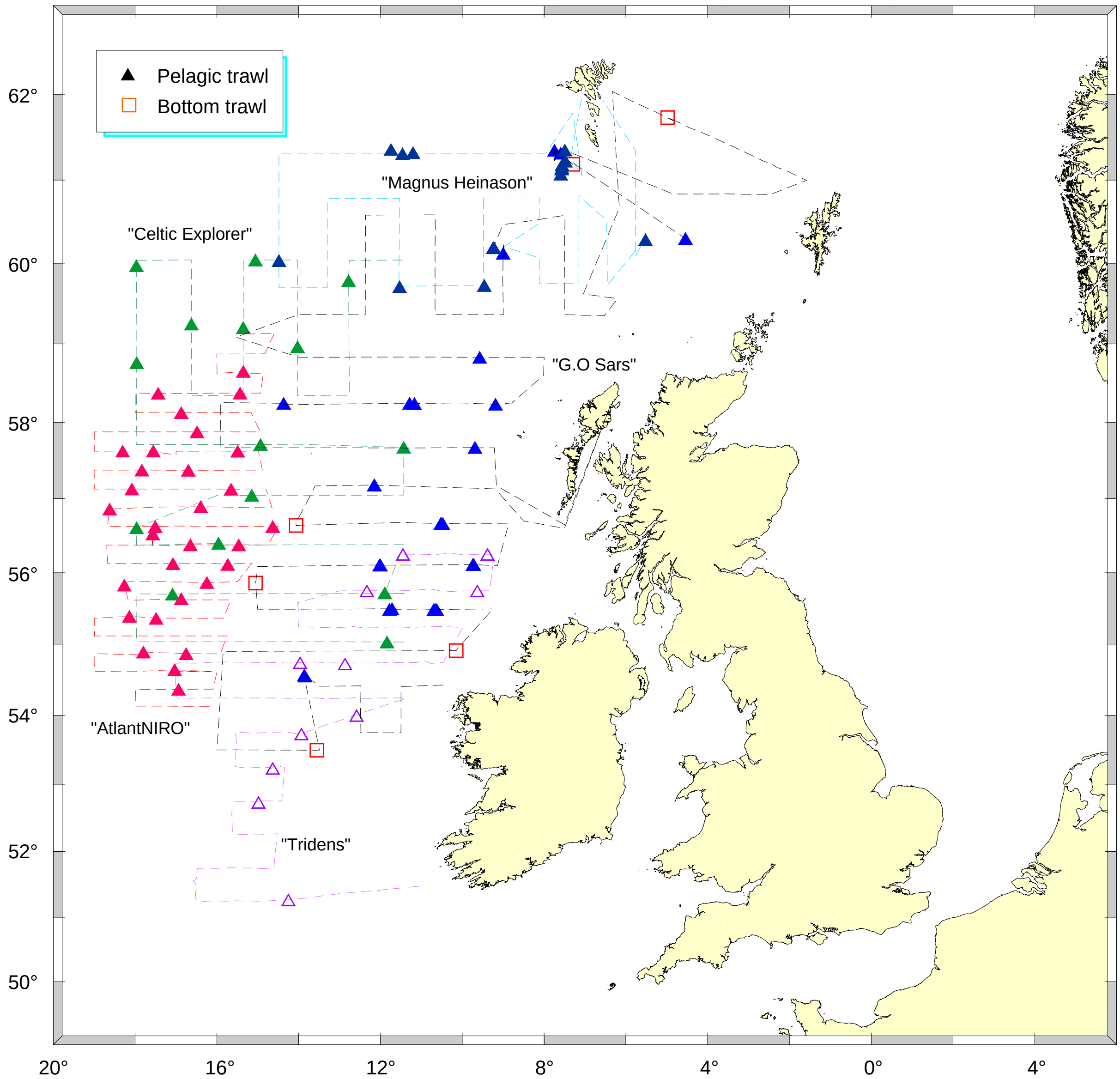

Figure 1. Cruise tracks and trawl stations during the International Blue Whiting Spawning Stock Survey in spring 2006. The figure shows all survey activity; in Figure 4, only the cruise tracks from which acoustic data were used in the stock estimate are shown.

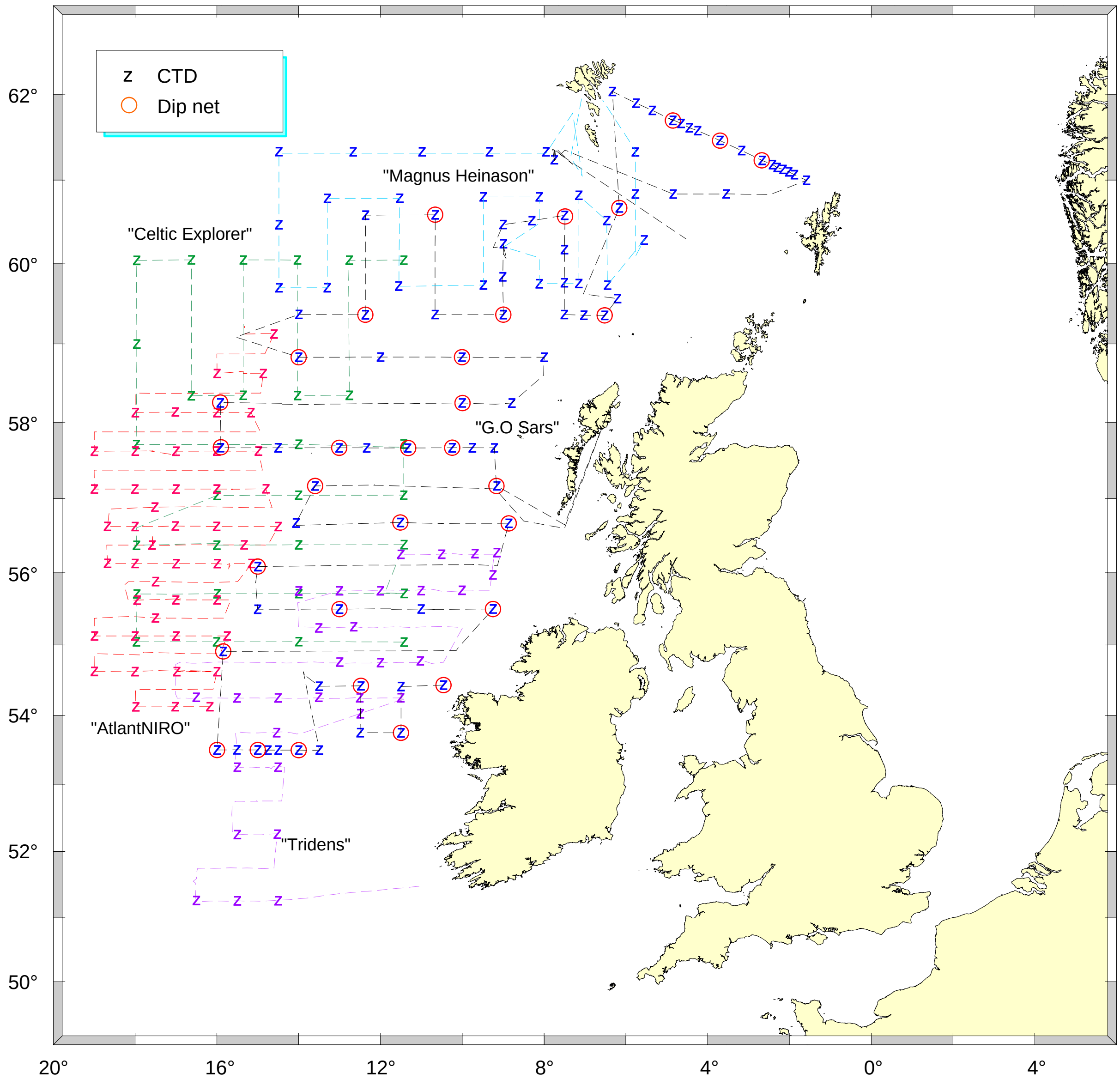

Figure 2. CTD stations for R/V Atlantniro, R/V Celtic Explorer, R/V G. O. Sars, and R/V Tridens in March-April 2006.

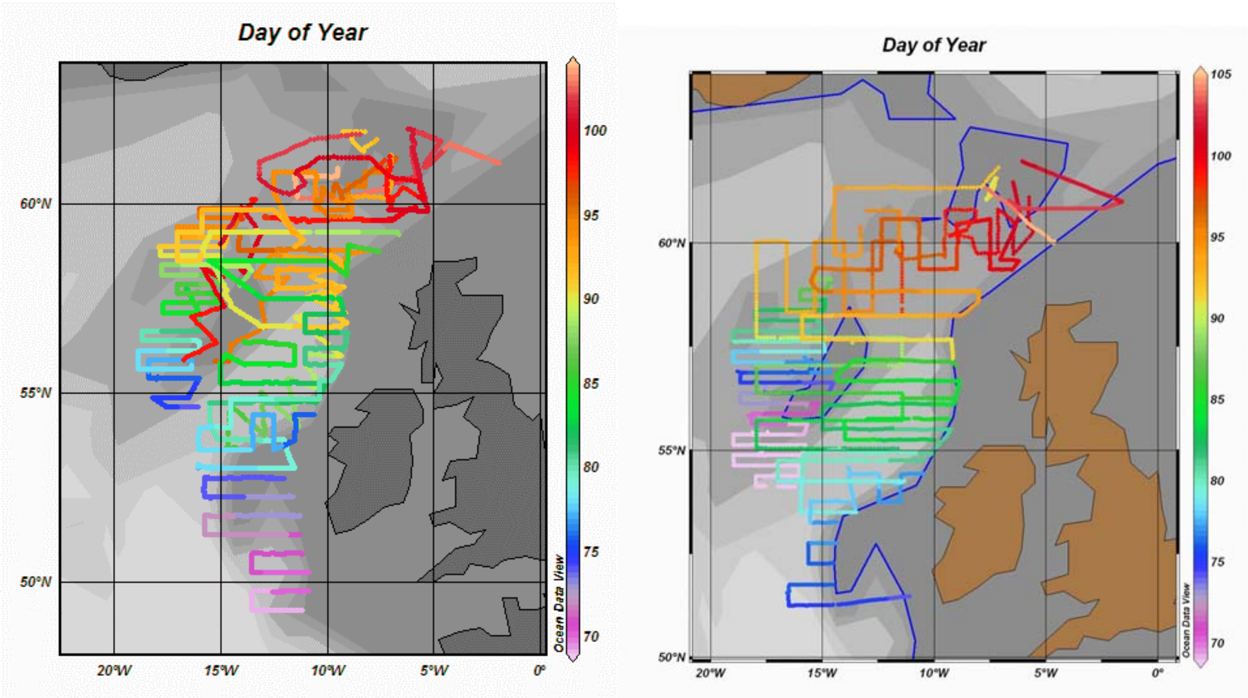

Figure 3. Temporal progression of the survey, 10 March–14 April 2005 (left) and 3 March–15 April 2006.

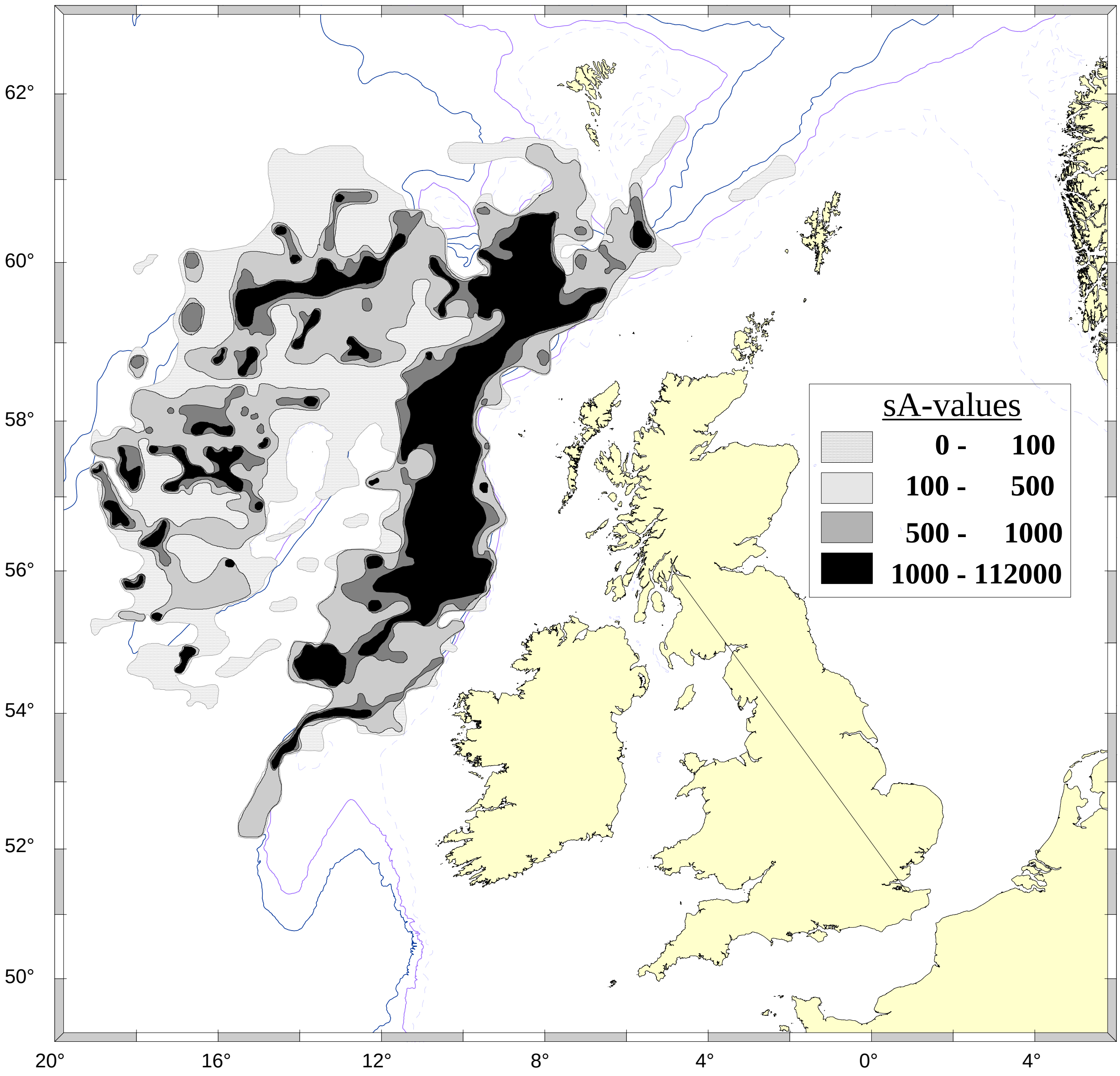

Figure 4. Schematic map of blue whiting acoustic density (s_A, m^2/nm^2) in spring 2006.

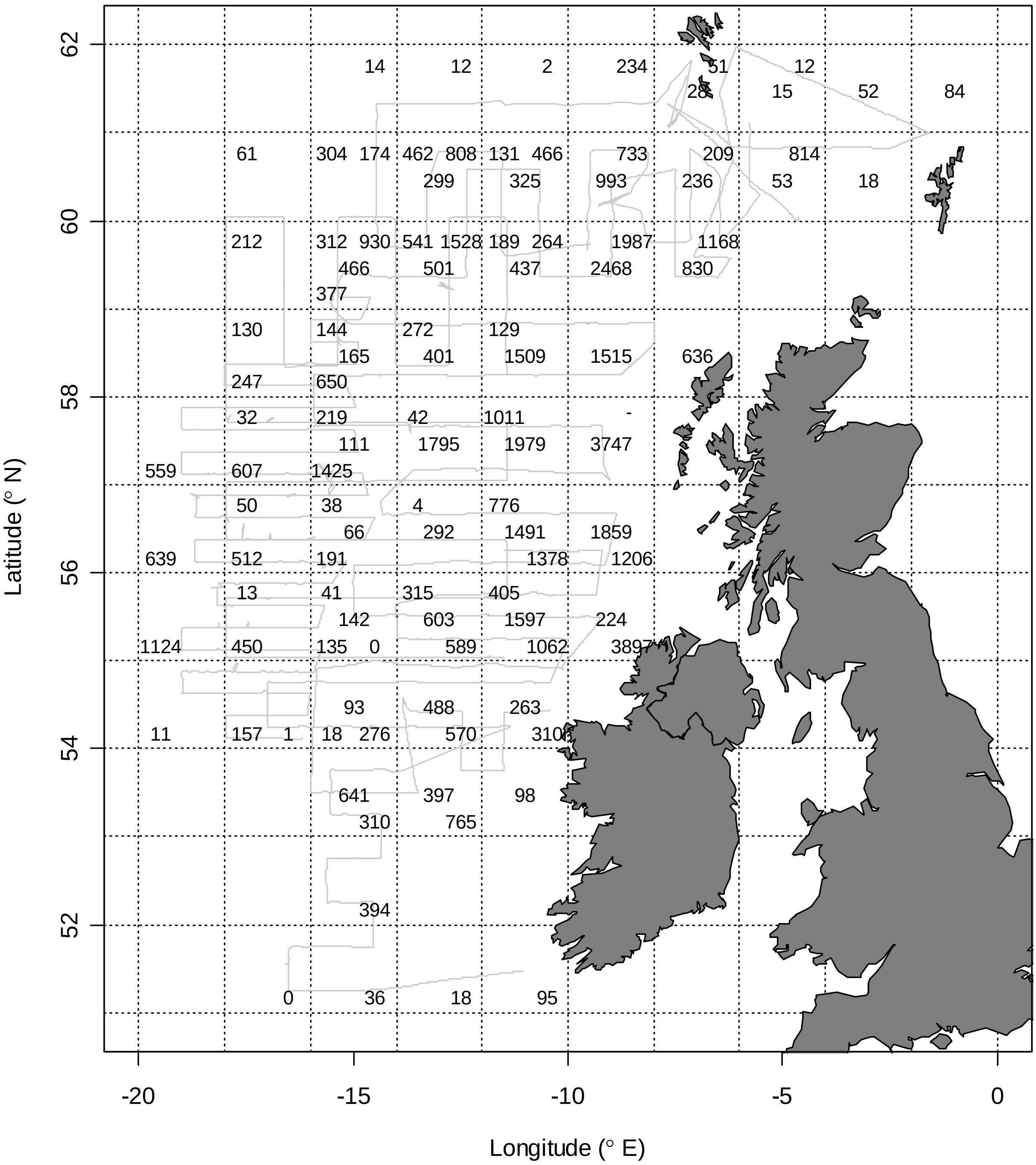

Figure 5. Mean blue whiting acoustic density (s_A, m^2/nm^2) for each vessel. top left: Celtic Explorer; top right: Magnus Heinason; bottom right: Tridens; bottom left: Atlantniro; centre: G.O. Sars.

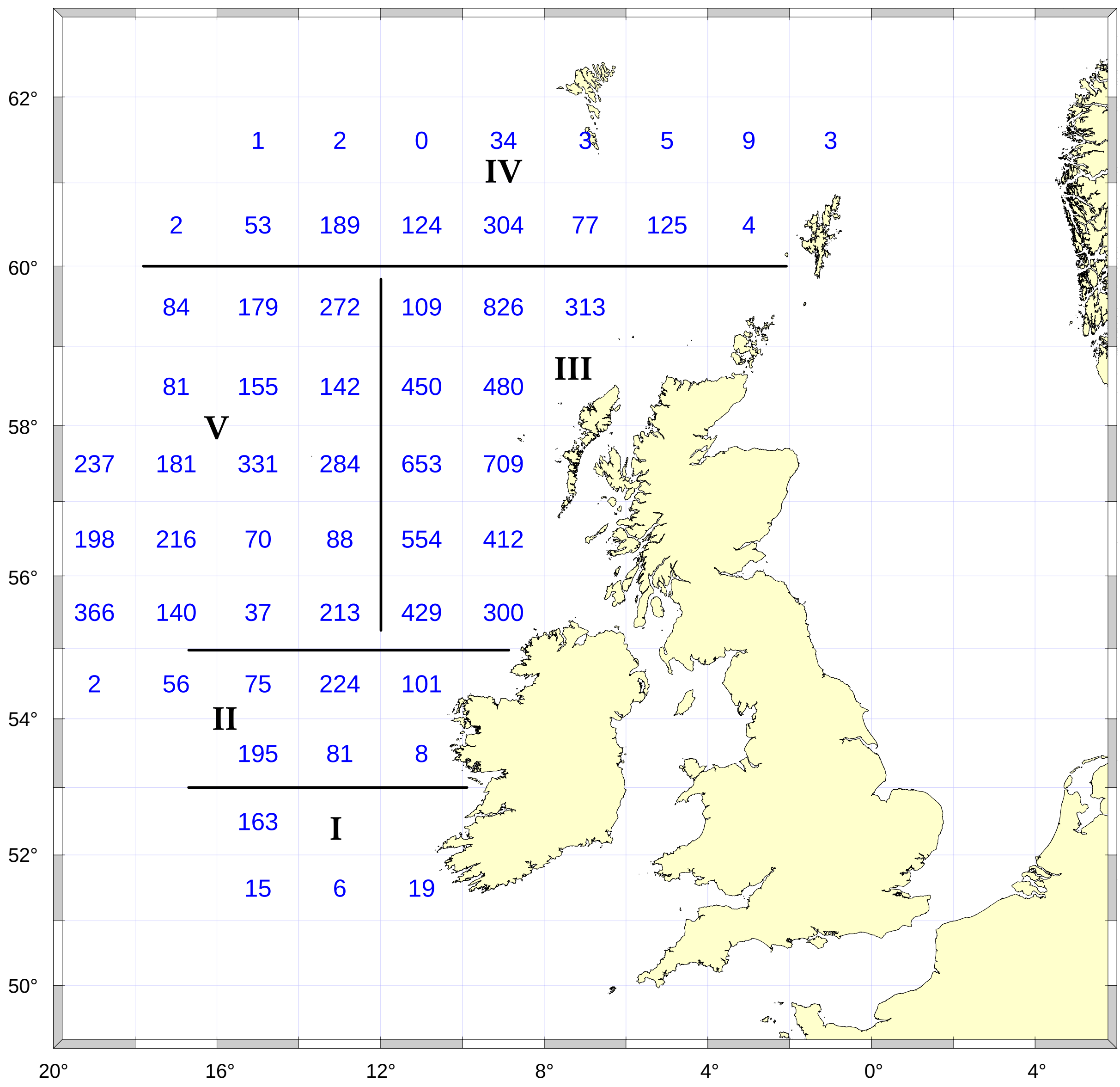

Figure 6. Blue whiting biomass in 1000 tonnes, spring 2006. Marking of sub-areas I-V used in the assessment.

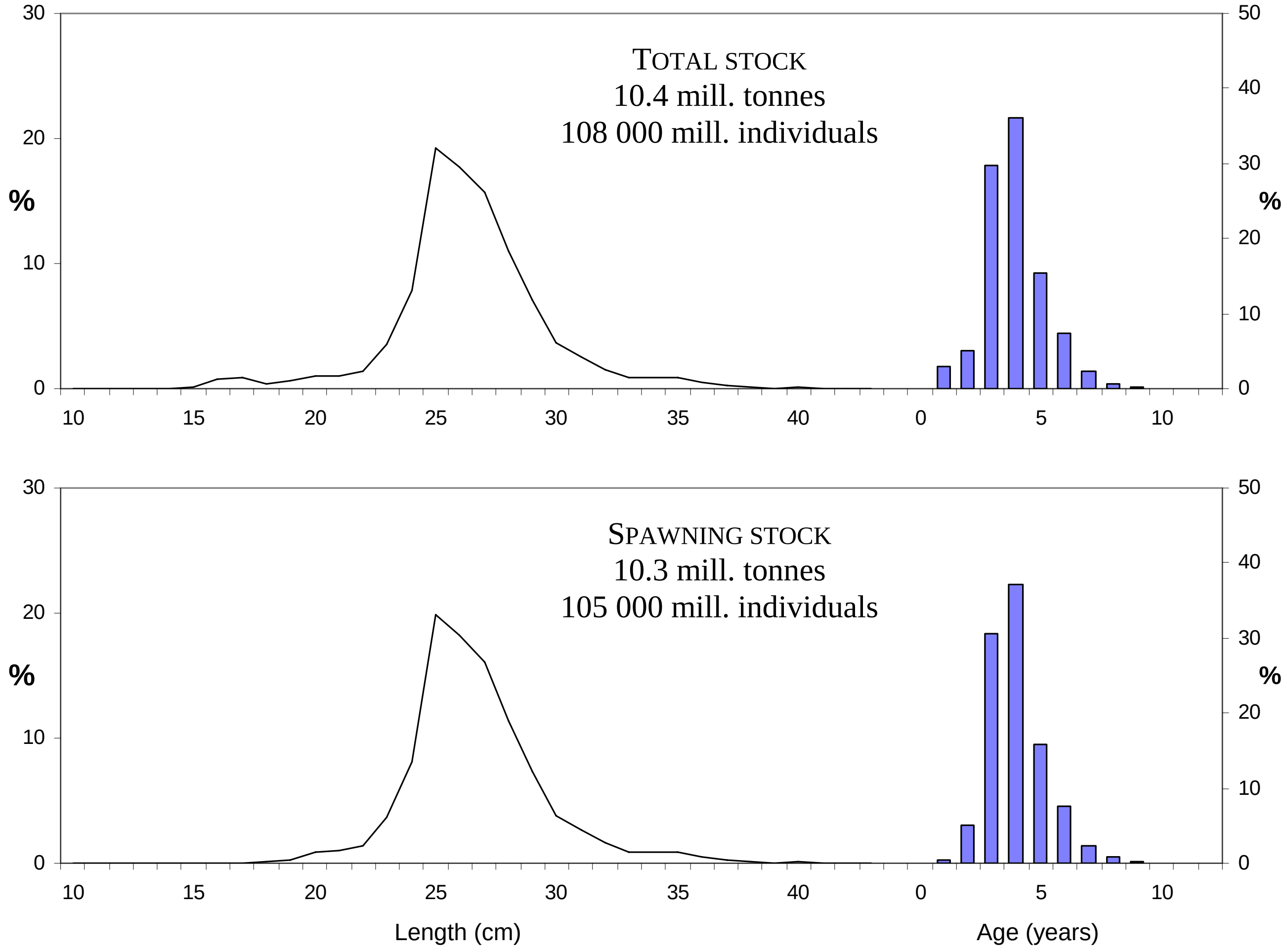

Figure 7. Length and age distribution in the total and spawning stock of blue whiting in the area to the west of the British Isles, spring 2006.

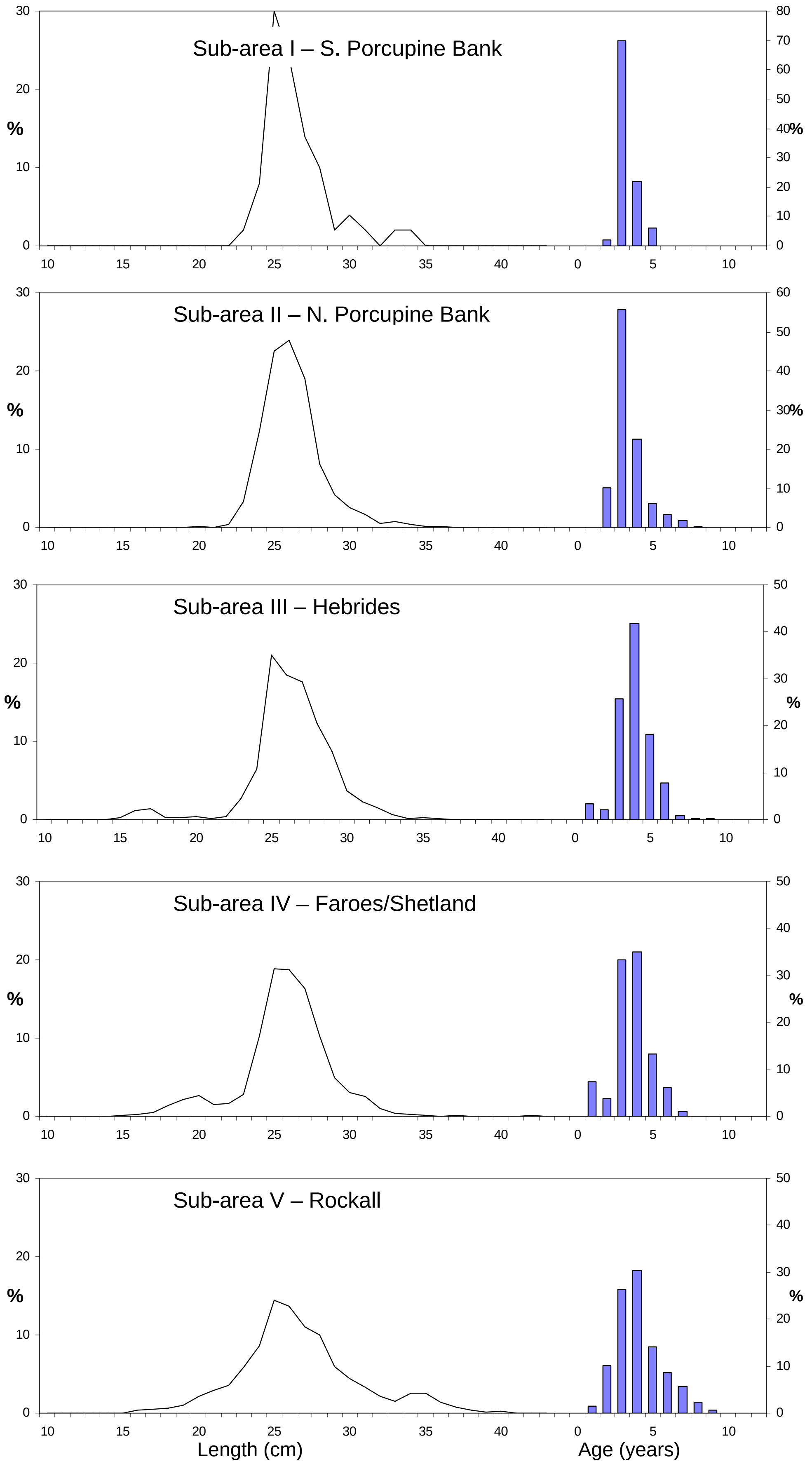

Figure 8. Length and age distribution of blue whiting by sub-areas (I–V), spring 2006.

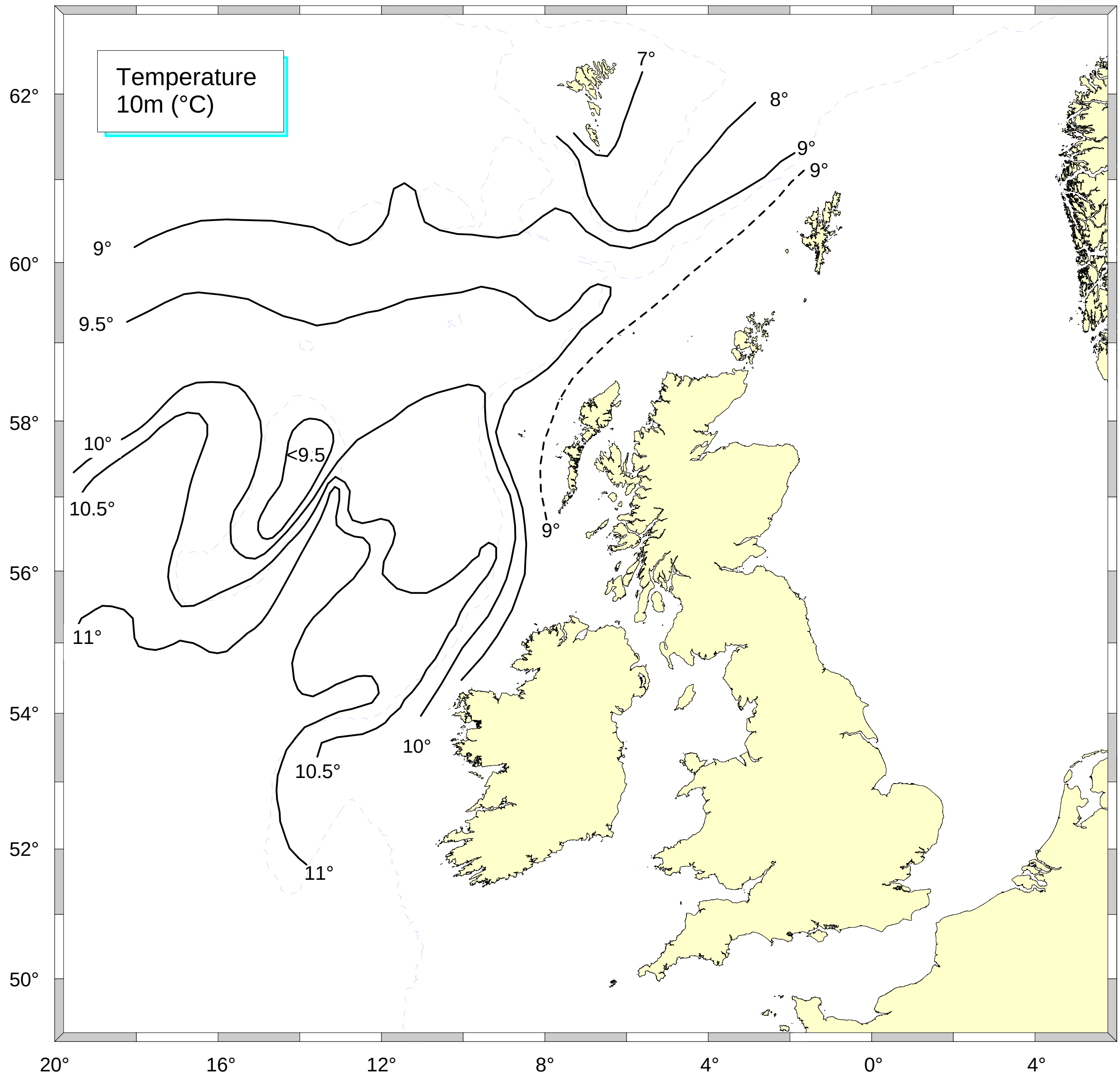

Figure 9. Horizontal temperature distribution, °C, in March-April 2006 at 10m depth.

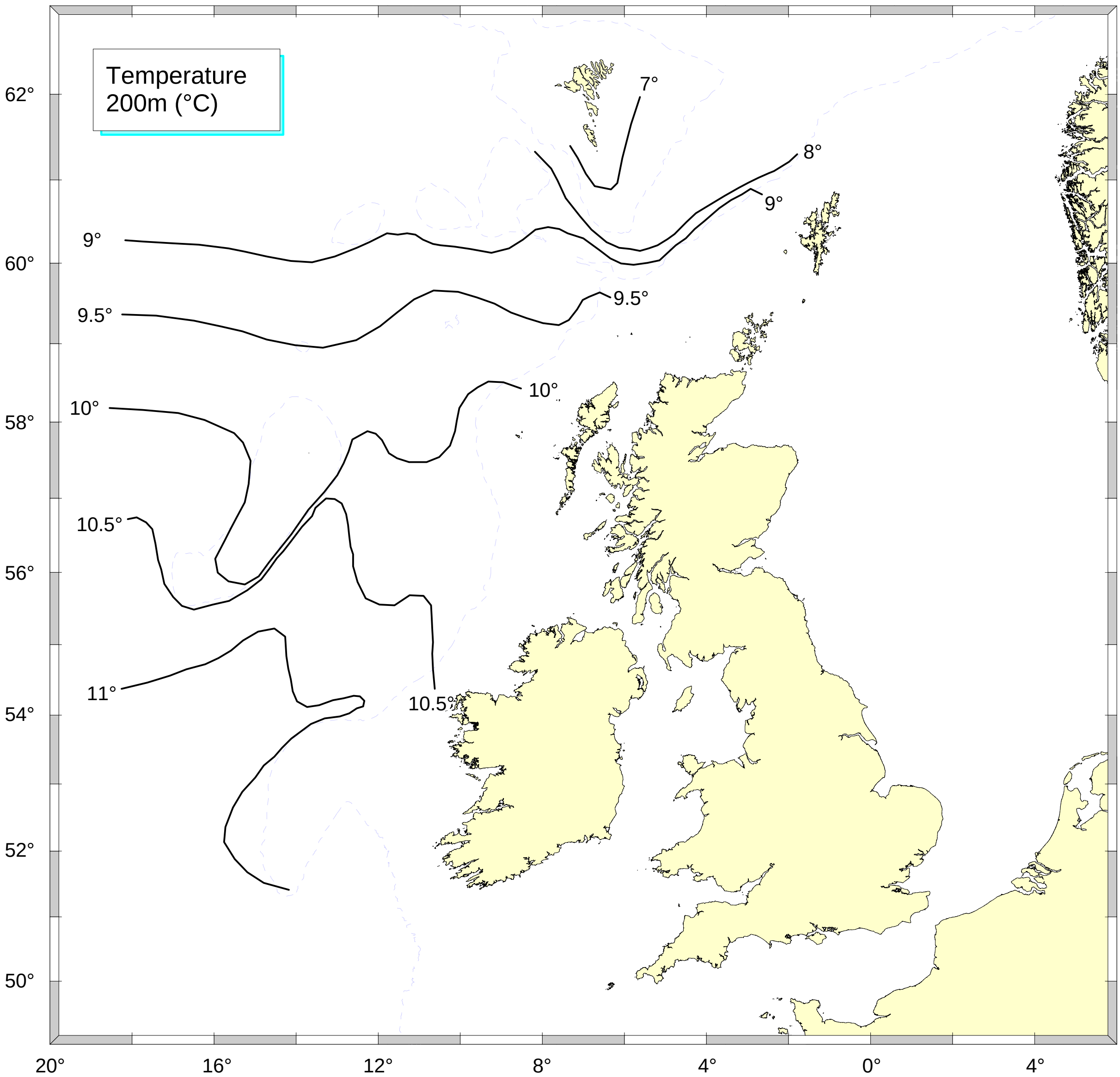

Figure 10. Horizontal temperature distribution, °C, in March-April 2006 at 200m depth.

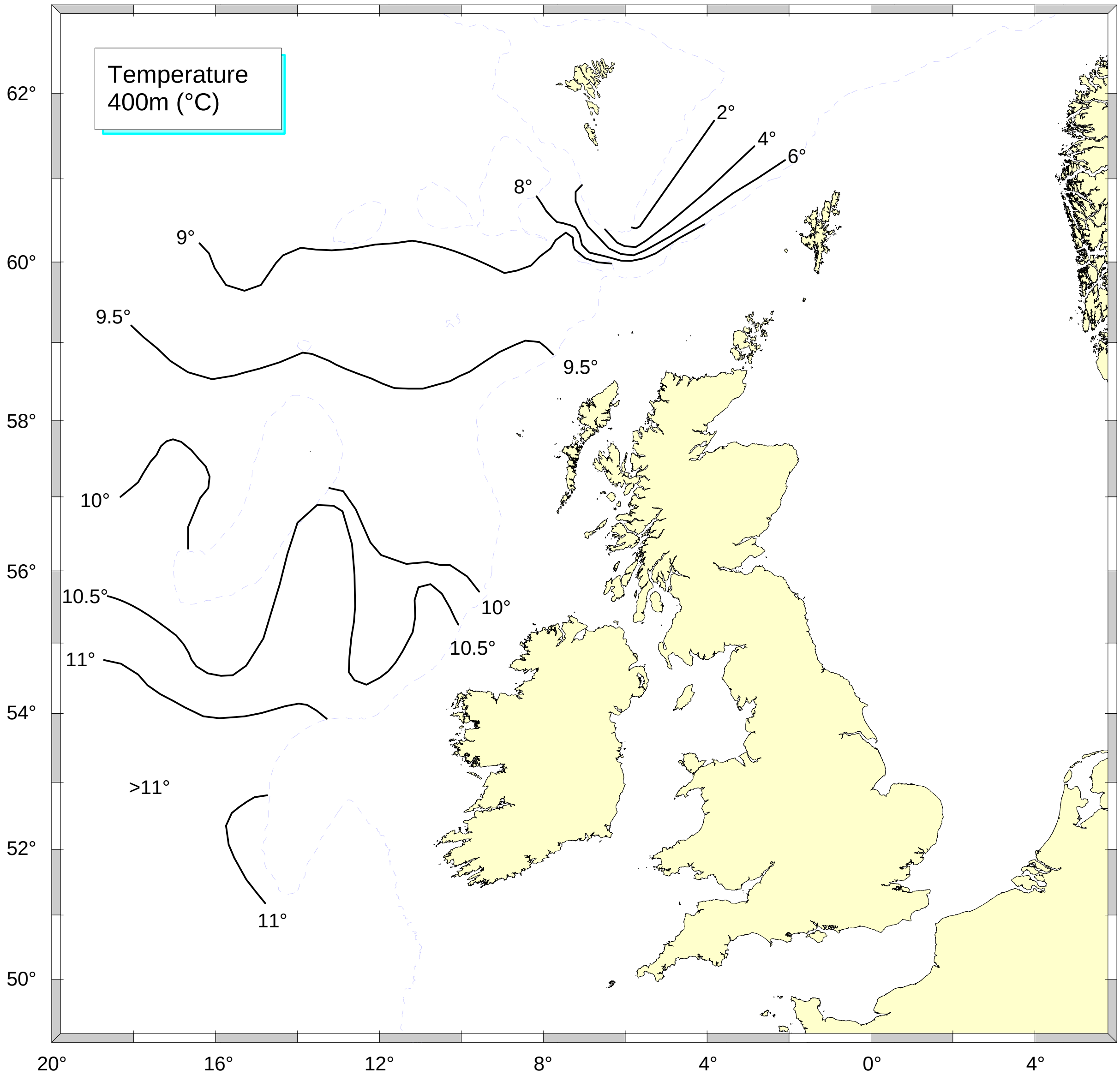

Figure 11. Horizontal temperature distribution, °C, in March-April 2006 at 400m depth.

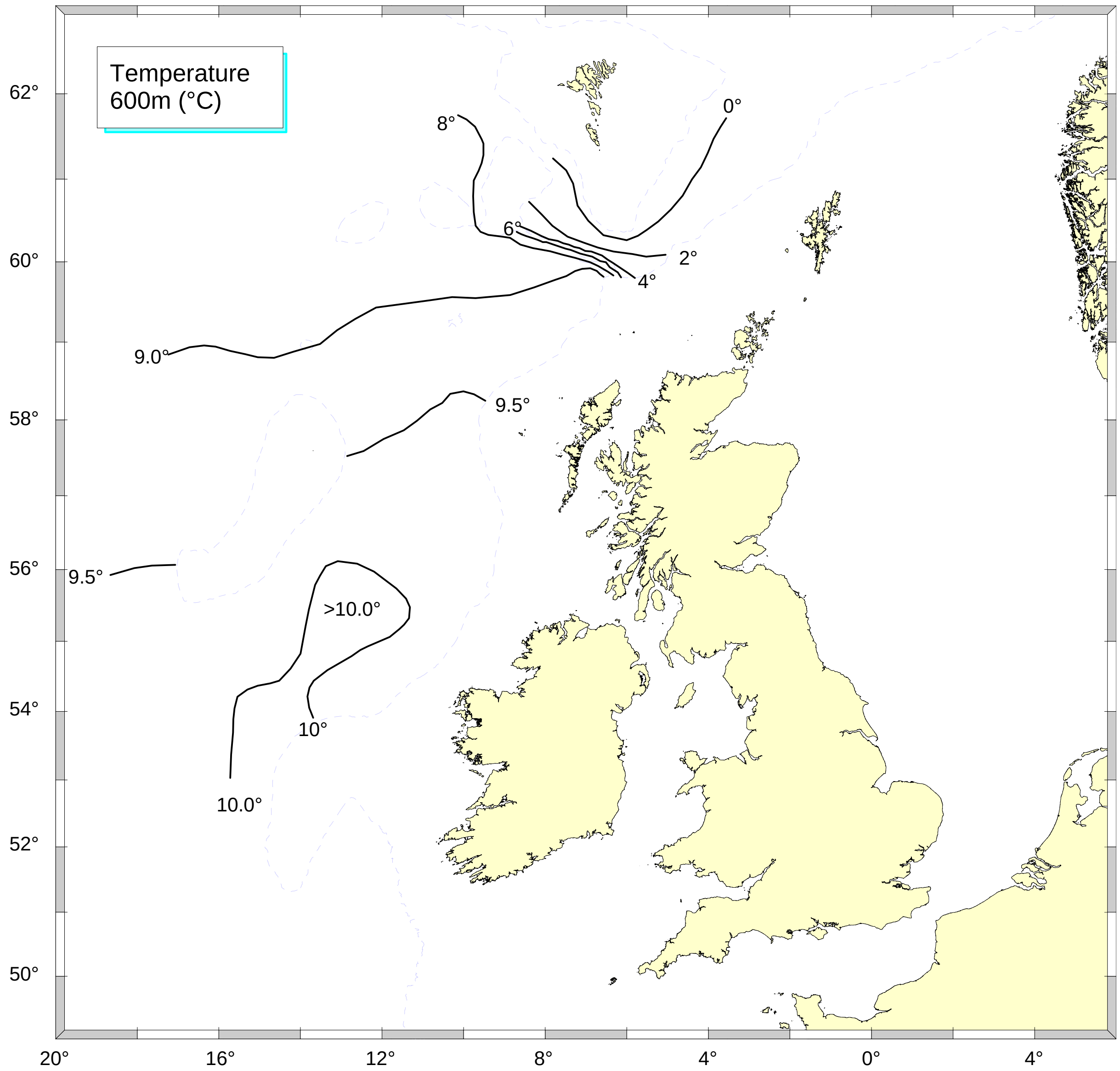

Figure 12. Horizontal temperature distribution, °C, in March-April 2006 at 600m depth.

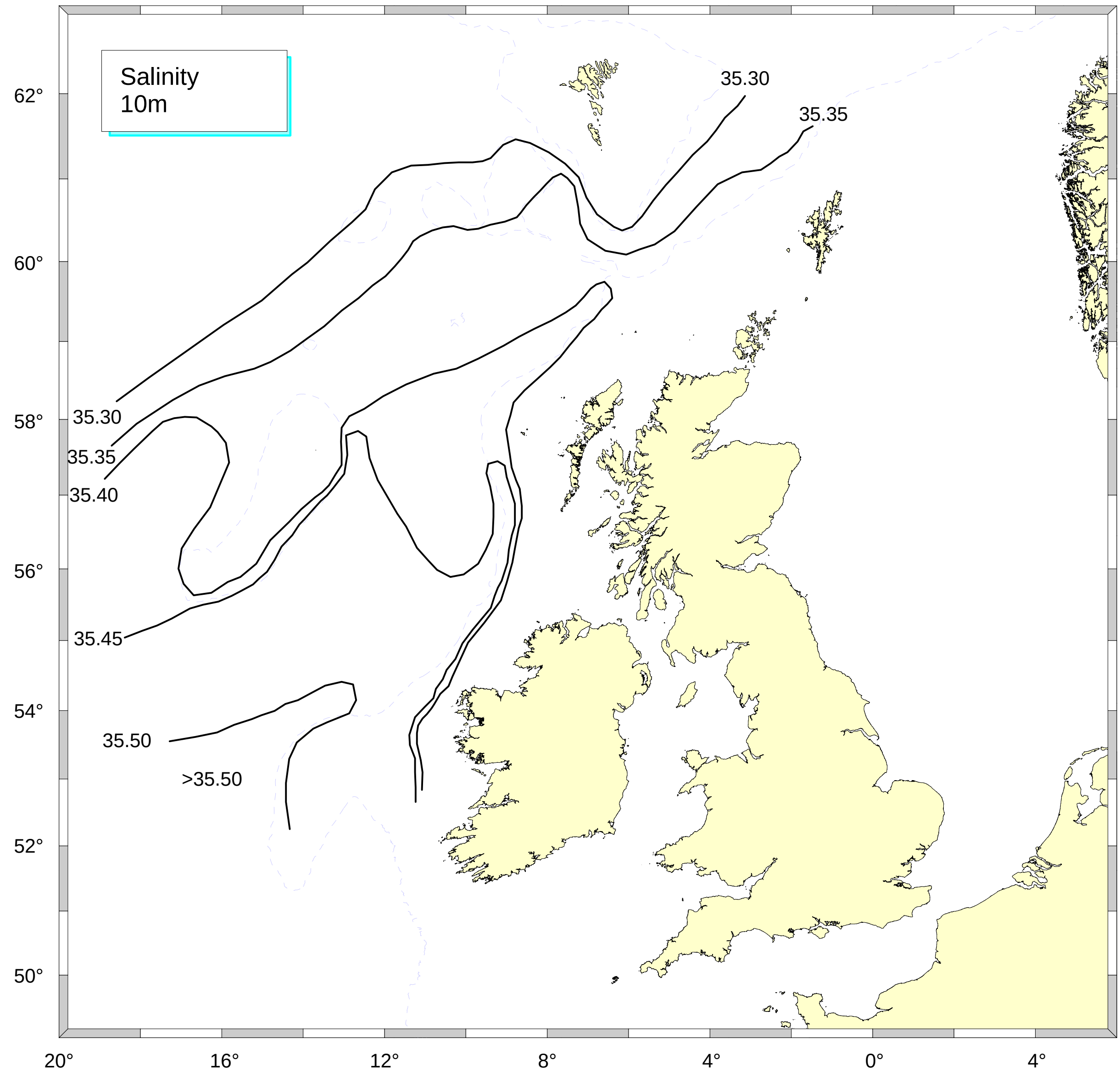

Figure 13. Horizontal salinity distribution, °C, in March-April 2006 at 10m depth.

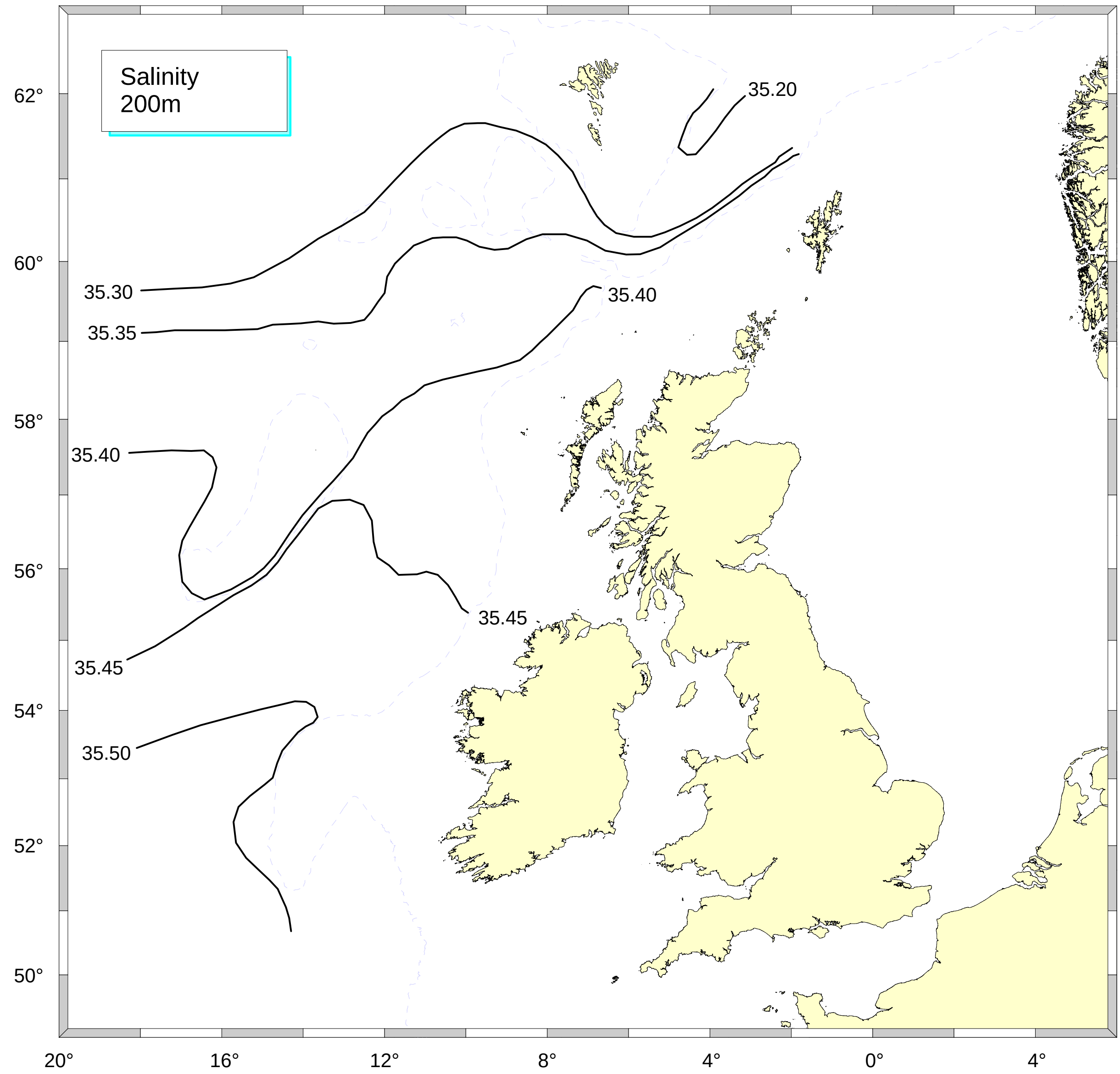

Figure 14. Horizontal salinity distribution, °C, in March-April 2006 at 200m depth.

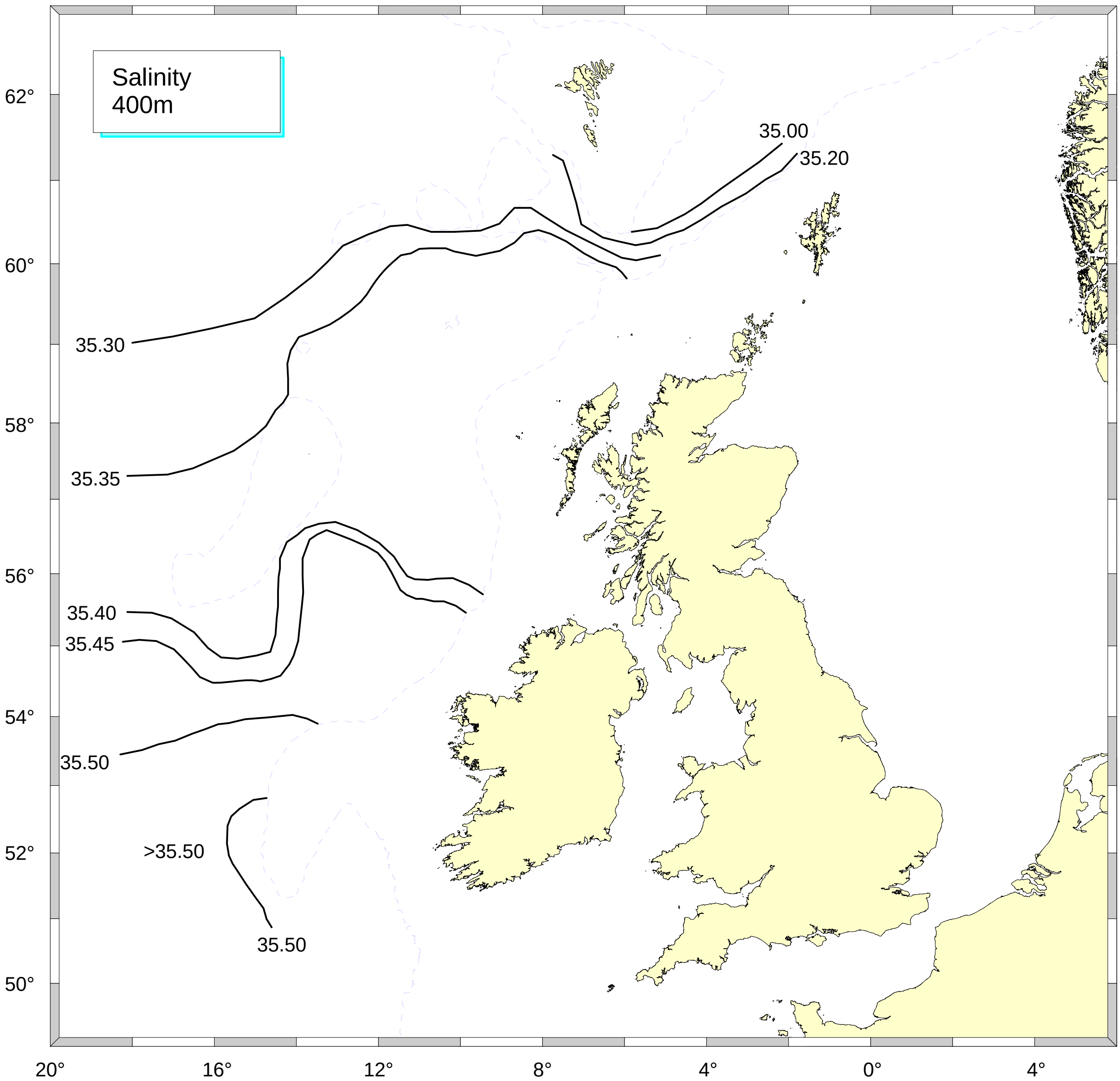

Figure 15. Horizontal salinity distribution, °C, in March-April 2006 at 400m depth.

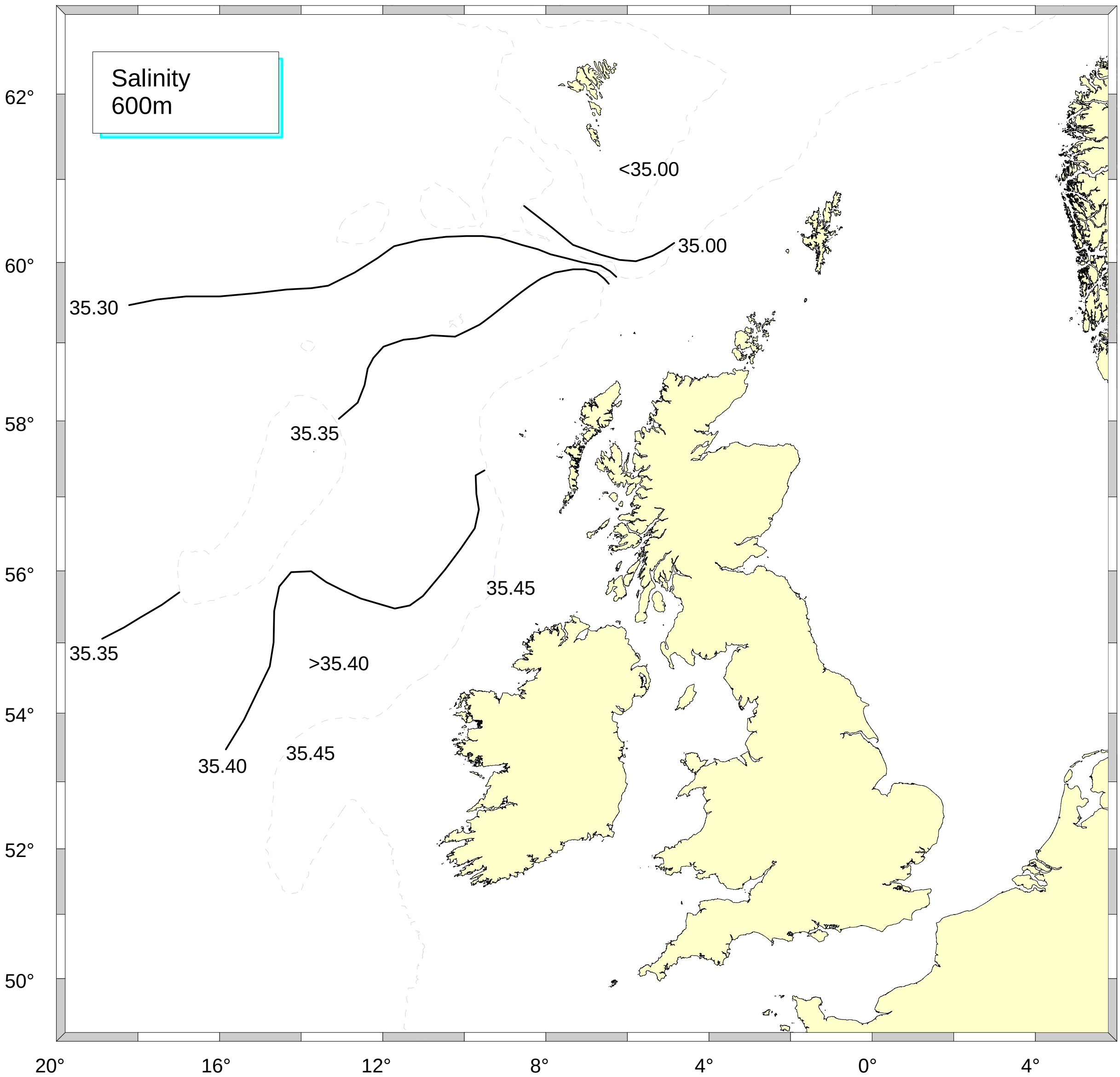

Figure 16. Horizontal salinity distribution, °C, in March-April 2006 at 600m depth.

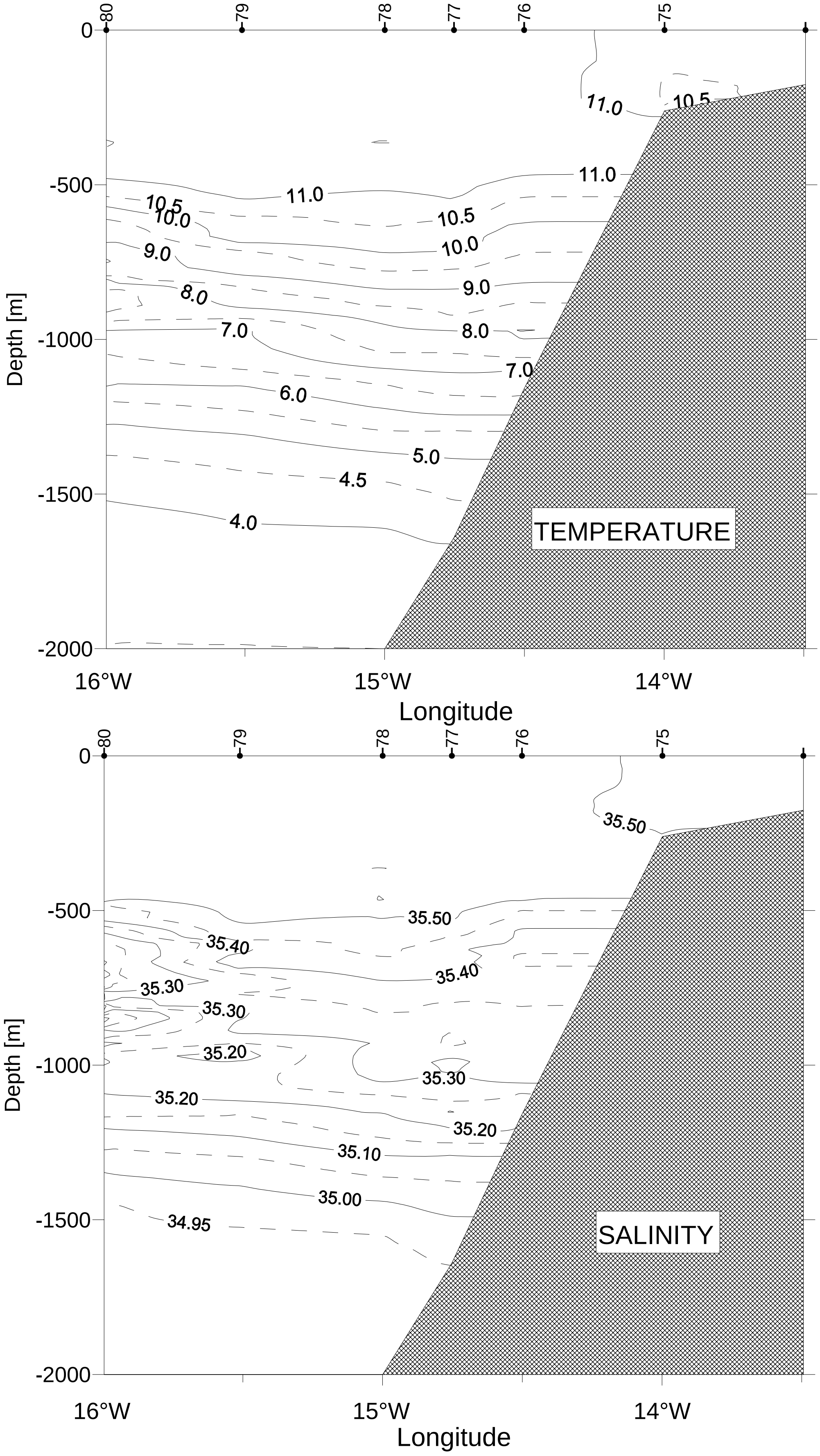

Figure 17. Vertical distribution of temperature (°C) and salinity in a section at the shelf edge at the Porcupine Bank at 53° 30'N. Station numbers at the top of the panels.

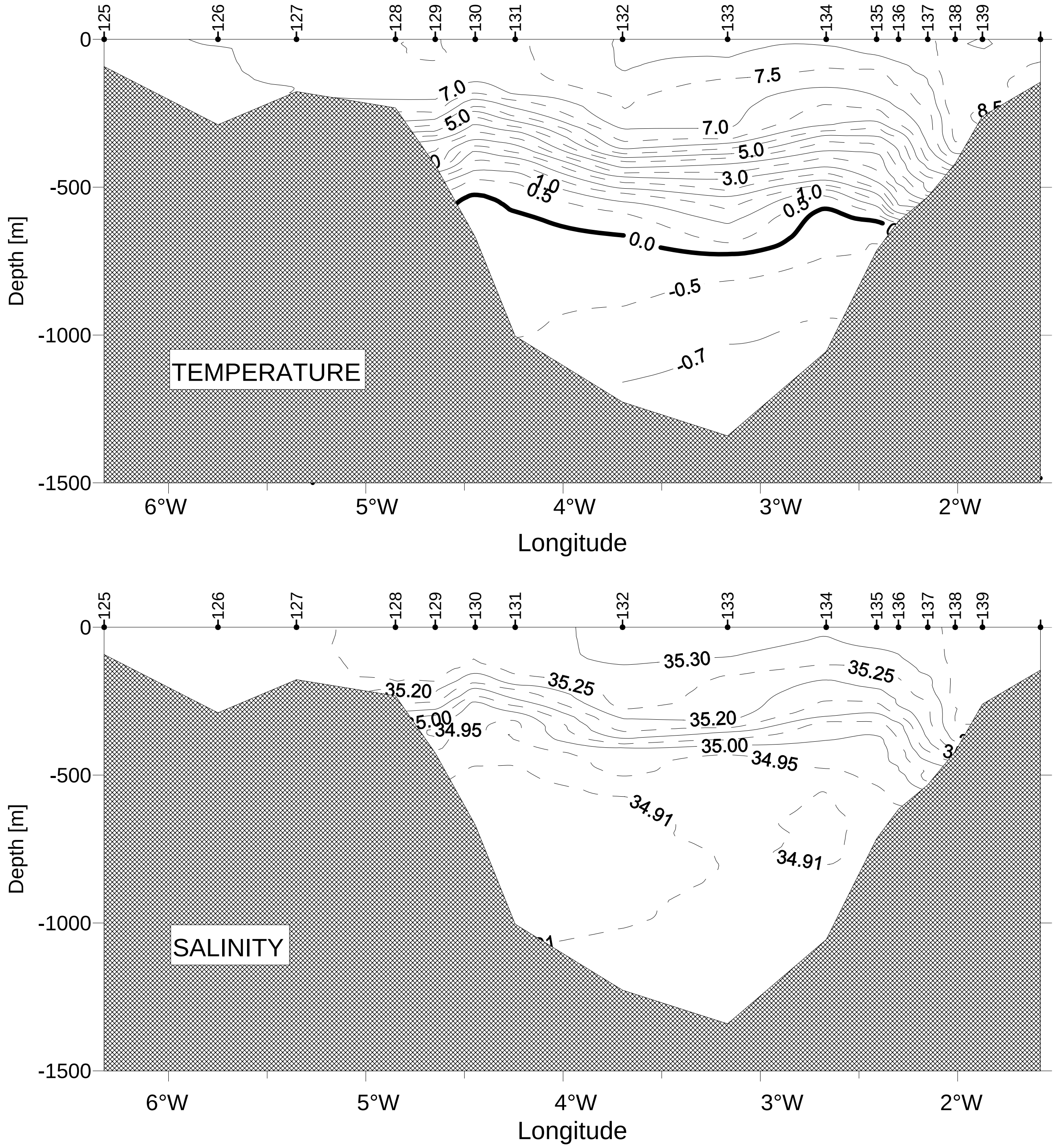

Figure 18. Vertical distribution of temperature (°C) and salinity in a section from the Faroes to Shetland (Nolsø-Flugga). Station numbers at the top of the panels.

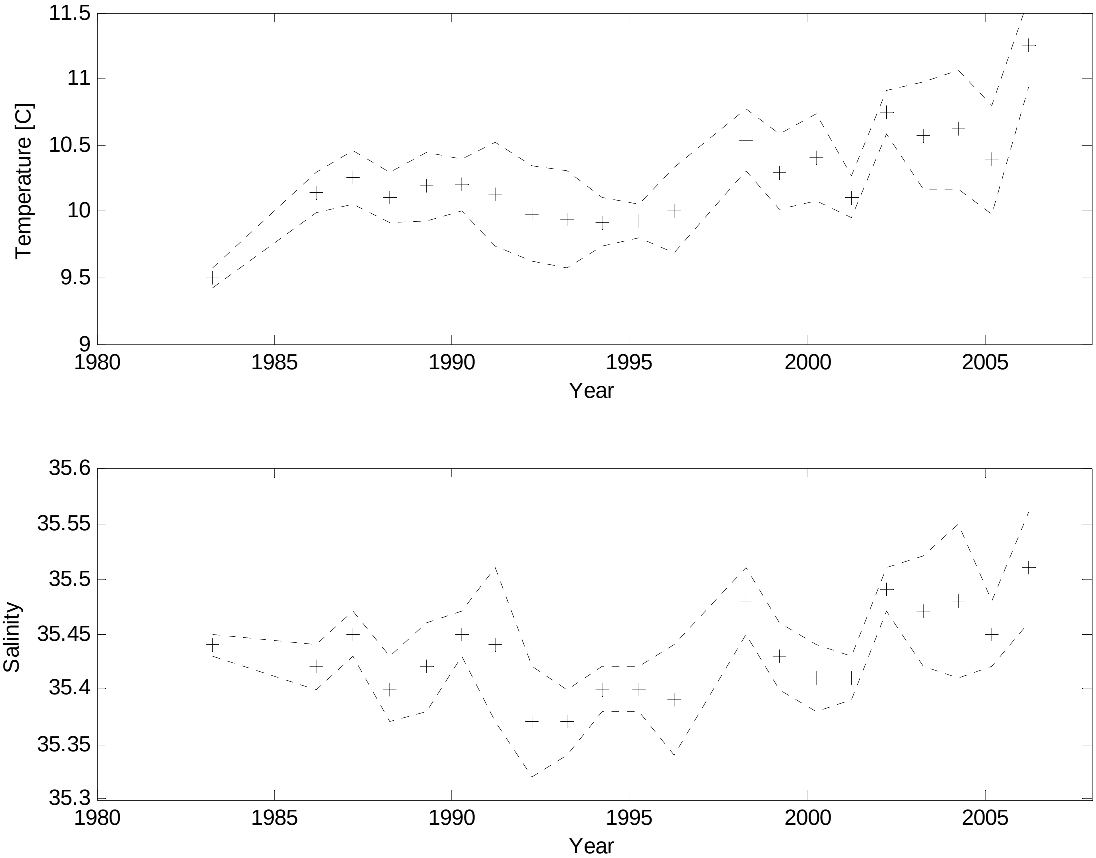

Figure 19. Yearly mean temperature and salinity from 50-600m (crosses) of all stations in a box with bottom depth>600m, west of the Porcupine bank bounded by 52° to 54°N and 16° to 14°W. Dotted lines are drawn at plus-minus one standard deviation of all observations in each box, each year.

Appendix 1. Inter-calibration between R/V 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 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

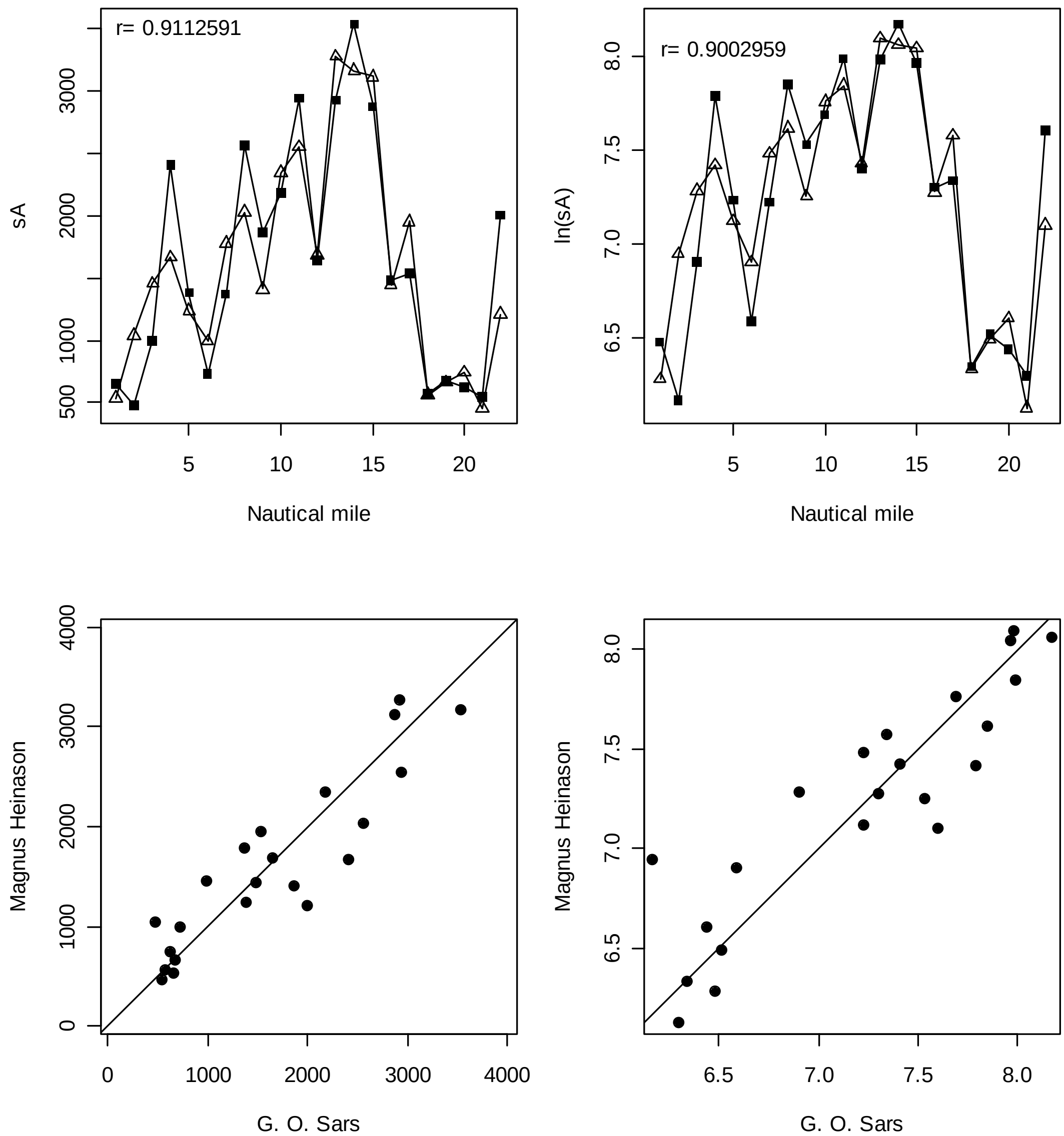

Figure 1. Comparison of blue whiting acoustic densities recorded by Magnus Heinason (triangles) and G. O. Sars (squares). The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

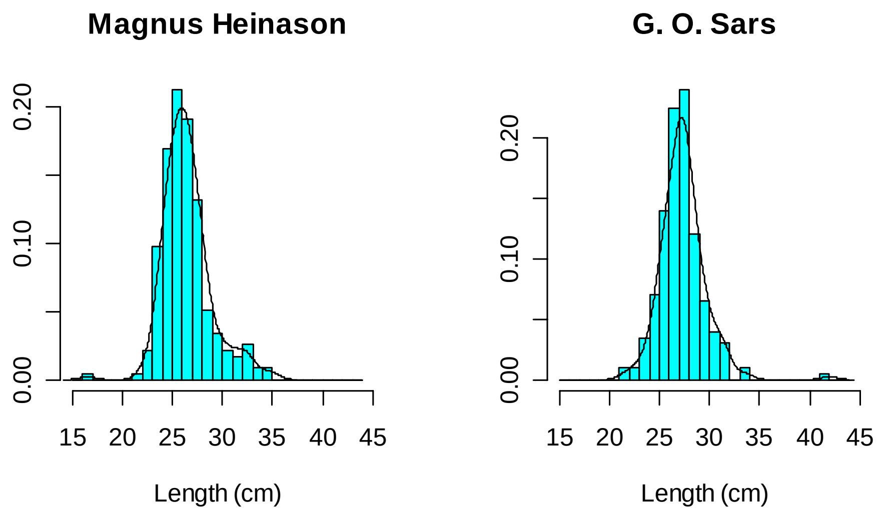

Figure 2. Length distributions from the trawls hauls by Magnus Heinason and G. O. Sars. Smoothing is obtained by normal kernel density estimates. G. O. Sars: n=200; Magnus Heinason: n=235.