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The Northern Pelagic and Blue Whiting Fisheries Working Group

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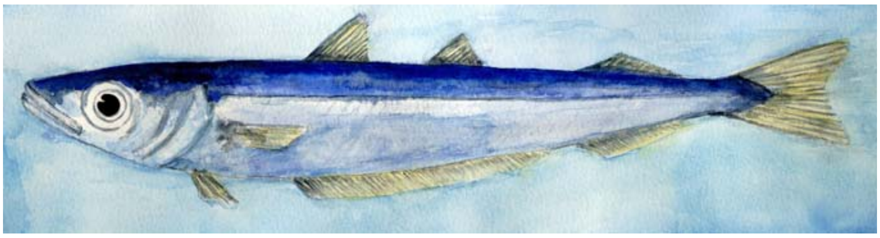

INTERNATIONAL BLUE WHITING SPAWNING STOCK SURVEY SPRING 2004

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Introduction

In spring 2004 the spawning grounds of blue whiting west of the British Isles were surveyed by four vessels from Ireland, the Netherlands, Norway and Russia. The survey was the first 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 (Celtic Explorer: O'Donnell et al. 2004; F. Nansen: Oganin et al. 2004; J. Hjort: Heino et al. 2004; Tridens: Couperus et al. 2004).

This report is based on a workshop held after the international survey in Bergen, 20-22.4.2004, where the data were analysed and the report written. Parts of the document were worked out through correspondence.

Material and methods

Coordination of the survey was initiated in the meeting of the Planning Group on Surveys on Pelagic Fish in the Norwegian Sea in August 2003 (ICES 2003a), and continued by correspondence until the start of the survey. International co-operation allows for wider and more synoptic coverage of the stock and more rational utilisation of resources than uncoordinated national surveys. However, it was recognized that the Norwegian survey is the only tuning time series in blue whiting assessment that has regularly been updated up to now (see ICES 2003b), and that too drastic changes in that survey could jeopardize its utility in tuning the assessment. An important consideration in planning the survey tracks was to keep the coverage of the Norwegian survey as similar to that in earlier years. However, a more regular design of cruise tracks was adopted in order to make coordination of efforts easier. In the end, coverage of the areas from the Porcupine Bank southwards were allocated to the Dutch and Irish vessels, and areas northwards to the Norwegian and Russian vessels. Northern parts of the Porcupine Bank were to be covered by all vessels, who would also meet here for inter-calibration. The Norwegian vessel was selected as the reference vessel.

The participating vessels together with their effective survey periods are listed below:

Vessel	Institute	Effective survey period (dd/mm)
R/V Tridens	Netherlands Fisheries Research Institute, the Netherlands	17/3-27/3
R/V Fridtjof Nansen	PINRO, Murmansk, Russia	23/3-15/4
R/V Johan Hjort	Institute of Marine Research, Bergen, Norway	23/3-17/4
R/V Celtic Explorer	Marine Institute, Ireland	25/3-4/4

The actual cruise tracks differed from the planned ones for various reasons, the most important of which were the problems that F. Nansen had in getting permits for operations in the Irish and Faroese zones. For this reason, the planned inter-calibration between F. Nansen and J. Hjort was conducted later in another area. Other inter-calibrations followed the plans. Frequent contacts were maintained between the vessels during the course of the survey.

Bad weather hampered the survey of Tridens but the conditions got more moderate at the time when the other vessels started their surveys.

The survey was based on scientific echo sounders using 38 kHz frequency. Transducers were calibrated with the standard sphere calibration (Foote et al. 1987) immediately prior (Celtic Explorer, F. Nansen, Tridens) and/or after (Celtic Explorer, Johan Hjort, Tridens) the survey. Salient acoustic settings are summarized in the table on the next page.

Table. Acoustic settings.

	Celtic Explorer	F. Nansen	J. Hjort	Tridens
Echo sounder	Simrad ER 60	Simrad ER 60	Simrad EK 500	Simrad EK 60
Frequency (kHz)	38, 18	38, 120	38, 18	38
Transducer	ES 38B - Serial	ES38B	ES38B - SK	ES 38B
Transducer installation	Drop keel	Hull	Drop keel	Towed body
Transducer depth (m)	8.7	5	10	9
Upper integration limit (m)	15	10	15	15
Absorption coeff. (dB/km)	9.6	10.1	10	9.9
Pulse length (ms)	1.024	1.024	1	1.024
Band width (kHz)	2.425	2.43	3.8	2.425
Transmitter power (W)	2000	2000	2000	2000
Angle sensitivity (dB)	21.9	21.9	21.9	21.9
2-way beam angle (dB)	-20.6	-20.9	-21.0	-20.6
Sv Transducer gain (dB)			27.53	
Ts Transducer gain (dB)	25.22	25.55	27.73	25.5
s_A correction (dB)	-0.53	-0.67		-0.63
3 dB beam width (dg)				
alongship:	7.5	6.99	7.0	7.02
athw. ship:	7.5	6.75	6.7	7.03
Maximum range (m)	750	750	750	750

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 (<200 m depth layer), mesopelagic species, 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 3 scientists. Adjustments for drop-outs were applied where necessary.

On F. Nansen, the FAMAS (Fisheries Acoustic Monitoring & Analysis) software developed by TINRO was used as the primary post-processing tool for acoustic data. Adjustments for drop-outs were applied where necessary using the "PRIDE" program developed by PINRO. This program calculates the dropout coefficient. Data was partitioned into the following categories, blue whiting and other species (including, plankton, mesopelagics and bottom fishes).

On J. Hjort, 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 18 and 38 kHz integration by 3 scientists experienced in viewing echograms. Adjustments for drop-outs were unnecessary.

On Tridens, acoustic data were backed up every 24 hrs and scrutinised later in the laboratory using Sonar data's Echoview (V 3.1) post processing software. Data was partitioned into the following categories plankton (<200 m depth layer), mesopelagic species, 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.

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

	Celtic Explorer	F. Nansen	J. Hjort	Tridens
Circumference (m)	768	716	486	860
Vertical opening (m)	48	50	25-30	30-70
Mesh size in codend (mm)	50	16	22	±30
Typical towing speed (kn)	3.5-4.0	3.3-4.2	3.0-3.5	3.5-4.0

On Johan Hjort, some additional samples were taken with a bottom trawl with 4 x 18 m opening equipped with a Rock-hopper ground gear (3 samples), and a smaller pelagic trawl ("Harstadtrål" capelin trawl) with 10 mm meshes in the codend to target mesopelagic fish (2 samples).

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, Johan Hjort, Tridens) or 100 (F. Nansen) 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 (J. Hjort, occasionally 150), 100 (Celtic Explorer), or 300-400 (F. Nansen) was measured for length and weight.

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.

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. 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 R/V Johan Hjort (103 CTD stations), R/V Fridtjof Nansen (76 CTD stations) and Celtic Explorer (17 CTD stations)(Figure 1). Two sections with higher horizontal resolution were occupied, one east-west sections at the western shelf edge of the Porcupine Bank at latitude 53° 30'N and a section from the Faroes to Shetland (i.e., the Nolsø-Flugga section). Johan Hjort and Celtic Explorer are equipped with SBE911 CTDs and Fridtjof Nansen with a FSI CTD. In addition Johan Hjort registered surface (~4m) temperature, salinity and fluorescence were continuously along the complete track of the cruise using a ship-mounted thermosalinograph (SBE21).

Results

Intercalibration results

Results from the intercalibrations are summarized in the Appendix 1-3. Acoustic intercalibrations showed that the performance of Celtic Explorer was similar to Johan Hjort (which was used as the reference vessel). Fridtjof Nansen tended to record lower values, which was at least partially caused by drop-outs during the exercise. In normal survey operation, the acoustic densities are adjusted for these. Preliminary results from Tridens as well suggest lower recordings than J. Hjort, although for scrutinized data the situation may be the opposite. In the final estimate, the values from Celtic Explorer, F. Nansen and J. Hjort were used as they stand, but those from Tridens were not included.

Catchability of different vessels is difficult to determine because of the large variety of gear employed (see the text table on page 3). In particular, J. Hjort is operating with a trawl that has much smaller vertical opening than the trawls on other vessels. This tended to yield catches that were rather low (usually <100 kg). Tows during the intercalibration exercises nevertheless suggest rather small selectivity differences in absolute terms [difference in mean length: 0.1 cm (Celtic Explorer vs. J. Hjort), 0.3 cm (Tridens vs. J. Hjort), 1.5 cm (F. Nansen vs. J. Hjort)], although the pattern is consistent in J. Hjort always catching on average the smallest fish. This is similar to the results obtained in 2003 between J. Hjort and R/V Smolensk. Because of the small differences, length data from all vessels were treated similarly.

Age readings on J. Hjort and Celtic Explorer are similar both in terms of mean age and length dependence of age. The observed difference in aging between J. Hjort and Tridens was confounded by unrepresentative size distribution in the sub-sample that was aged. There is a marked difference in aging between F. Nansen and J. Hjort, with mean age at length being about one year higher on the former vessel as compared to the latter. Age readings from J. Hjort and Celtic Explorer only were used in the final stock estimate.

Distribution of blue whiting

Blue whiting were recorded in most of the survey area that covered almost 150 thousand square nautical miles (Figure 3). Little or know blue whiting were recorded above the deep waters between the Porcupine Bank-Hebrides and the Rockall Bank, and to the west of the Porcupine Bank. The highest concentrations were recorded in patches along the shelf edge from northwest of Ireland to the Hebrides (see Figure 4). The highest recordings were observed at depths of 450-600 m, sometimes extending to around 300 m depth (or even shallower) 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, or as a ribbon-like layer of dense, isolated shoals. Looser layers of blue whiting in the upper parts of the water column (mostly juveniles) were observed only in the eastern parts of the Faroes sub-area. Blue whiting on shallow waters of the Porcupine Bank and southwards were mostly juveniles.

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 and out of the spawning area. For example, the bulk of fishing activity occurred in the international zone west of the Porcupine Bank and Rockall before the survey, but little or no fish were observed there at the time the area was covered by the survey.

In order to allow comparisons with earlier results, a separate estimate was calculated for the international zone. This gave a biomass estimate of 595 thousand tonnes, which is substantially less than the estimate calculated on basis of Russian data in 2003, 2.9 million tonnes. This difference can, at least to a certain extent, probably be explained by the later coverage of the area in 2004 as compared to 2003.

Stock size

The estimated total abundance of blue whiting for the 2004 international survey was 11.1 million tonnes, representing an abundance of 130×10^9 individuals (Table 1). The spawning stock was estimated at 10.6 million tonnes and 119×10^9 individuals. The geographical distribution of total stock biomass by stratum is shown in Figure 5.

Stock composition

Stock in the survey area is dominated by age classes 4 and 3 years (year classes 2000 and 2001), which make together more than 50% of stock numbers (Table 2, Figure 6). Also blue whiting of ages 2 and 5 years were common. The majority of fish older than one year in age were mature. The spawning stock biomass was dominated by the same ages, with a relatively higher contribution from older fish because of their larger size and absence of immature fish of old age. Fish older than 6 years nevertheless make only 9% of spawning stock biomass.

About half of the spawning stock biomass was recorded in the Hebrides sub-area. Blue whiting of ages 4 and 3 years were most common (Figure 7). Age structure in the northern half of the Porcupine Bank was similar, but the spawning stock biomass was much lower there. About one fifth of the spawning stock resided in the Faroes-Shetland sub-area, where blue whiting of ages 2-4 were almost equally numerous. Age structure in the Rockall sub-area was roughly similar, with age 4 years being the most common. The southern half of the Porcupine Bank hosted little biomass, dominated by blue whiting of age 3 years.

The proportion of mature fish was the highest in the Hebrides (Table 1). The highest proportion of juvenile fish were observed in the southern Porcupine bank (sub-area I), whereas the highest absolute numbers of juveniles were recorded in the Faroes-Shetland sub-area. In the latter sub-area, most of the juveniles were recorded in the Faroes-Shetland channel, whereas relatively few were recorded further west.

Hydrography

The horizontal distribution of temperature and salinity at 10, 200, 400 and 600 meters depths are shown in Figure 8-15. The maps are based on CTD data collected on board Johan Hjort, Fridtjof Nansen and Celtic Explorer (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 difference in temperature between 10m and 400m are less than 1°C and at 1000m depth the temperatures are between 6 and 9°C, with the lowest temperatures at the Porcupine section (Figure 16) and in the north west. In the Faroe-Shetland channel the situation is very different with a strong thermocline around 500m depth separating a layer of warm saline Atlantic water overlying cold (~-0.5°C), deep waters originating in the Norwegian Sea (See Figure 17, 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 8-11). Due to a northward flowing shelf edge current, the warmest and most saline water is found in a narrow band along the shelf edge. The thickness of the mixed layer was 600-800m deep along the continental slope and between the Rockall Bank and the Faroe Banks. In the Rockall Channel the thickness of the mixed layer is more variable. On some station the thickness was only 250-300m whereas on the stations with the deepest mixed layer it was 800-900m deep.

Both in 2003 and this year the temperatures in the southern part of the area were above 11°C. In 2003 the 10°C isotherm extended north to about 60°N and water with temperatures above 9.5°C was observed on the Faroe-Shetland section. 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. In the south, at 400m depth, the horizontal temperature distribution is very similar to last year. Thus, in the northern part of the survey area the temperatures at 10m are lower than last year, whereas in the south the differences between this year and last year are small. At 400m depth the temperature distribution was very similar to last year. Compared to earlier years the temperatures are high in the whole area.

At the Porcupine section (Figure 16) the temperature is quite homogeneous down to about 500m with a gradual change in the thermocline between 500m and 1000m. The most conspicuous feature this year is the very high salinities in the upper few hundred meters with salinities above 35.55. If we go back to 2001 the highest salinities were below 35.50, and in 2002 and 2003 we saw an increased presence of water with salinity above 35.50, but this is the first year we have observed salinities above 35.55. Observations from the Celtic Explorer showed salinities above 35.60 just south of the Porcupine Bank. These high salinities indicate a stronger influence of water of Mediterranean origin.

On the Faroe-Shetland section (Figure 17) 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. The isotherms and isohalines have a characteristic dome shape, with the intermediate (S<34.90) water of Norwegian Sea origin extending up to about 450m in the central part of the section. The 0°C isotherm is found at 500m depth at the western side and it slopes downward to nearly 700m at the eastern side. Last year the 0°C isotherm was found at 700-800m depth. The extent of the Atlantic is smaller and the temperature in the core of the Atlantic water is slightly lower than last year, but still warm compared to previous years. In the upper 200m the temperature is 0.9°C higher than normal, indicating a strong inflow of Atlantic water. The salinities are also high with values above 35.40, and this is consistent with observations from 2003.

The high temperatures and salinities are confirmed by a study of the temperatures and salinities on all blue whiting cruises from 1983 through 2004. 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 compile a time series, the data were grouped in boxes with horizontal dimensions of 2° latitude times 2° longitude, and for each year the mean temperature and salinity from 50 to 600m of all the stations in deep water (bottom depth>600m) in each box were calculated. Some of the boxes had good coverage almost always, 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 18. Years 2002-2004 are the three warmest years observed in this time series. 2002 was a warm year with ~10.7°C, and in 2003 the temperature dropped to the same as in 1998. 2004 is slightly warmer than 2002, making the warmest year in record.

The salinity has also increased over the years, and 2004 was the first year with mean salinity in the box off Porcupine Bank with salinity above 35.50. Also in the boxes further north, where a decrease in temperature from last year was seen, the salinity increased.

In the boxes along the continental shelf in the Rockall Through a similar pattern as described above is seen, but the temperatures did not drop from 2002 to 2003. 2004 was a bit colder than 2003, but still a warm year.

Concluding remarks

Overall, the first international blue whiting spawning stock survey with many participating countries can be deemed a success. With increased forward planning, the survey as a whole can be used to produce even more concise picture on the abundance, structure, distribution and the hydrographic conditions which influence the blue whiting stock.

In terms of hydrography, the years 2002-2004 stand out as three consecutive warm years with high temperatures and salinities in the upper 600m in the Rockall Through, and the Atlantic water in the Faroe-Shetland channel is warmer and more saline than normal.

It is evident that there were differences in operating systems EK 500 and EK 60 in terms of settings. Settings for one system may not be optimal for another, for example when dealing with false bottom echoes. This was most evident during vessel intercalibration periods.

The scrutinizing of echograms is a subjective process and plays a vital role in the accurate partitioning of survey data. Due to expansion of the survey program in 2004 it should be noted that the new participating countries do not always share the years of experience in scrutinizing of blue whiting echograms. Provisions should therefore be made to attempt to alleviate this problem to benefit the survey as a whole.

Differences in opinion arose on various details of acoustic estimation methodology in relation to sampling, stratification, elementary sampling distance units, and weighting of samples.

Data flow both during and after the survey could still be improved. In practice, current solutions do not allow echograms to be exchanged during the survey. More work is still needed for all vessels to be able exchange scrutinized acoustic, hydrographic and biological data in the PGNAPES database format. It is also essential that all data are available well in advance of the meeting where they will be used.

Differences in opinion arose between the age determination of certain fishes. This highlights the need for formulating working methodology that suits all participants.

Temporal coordination of the survey is needed for minimizing the effects of blue whiting migrations on survey results. Vessels surveying the area at different periods might have recorded the same fish moving in and out from the area. It is therefore essential that, as far as possible, the vessels operate during the same time window. The overall timing of survey appears to rather suitable with respect to weather and blue whiting along the shelf edge, but covering the more western and southern stock components would require earlier timing. In early April juvenile fish dominate the southern parts of the Porcupine Bank and further south as the adult fish have dispersed from the spawning area. Similarly, blue whiting aggregations in the international zone are largely dissolved by the early April.

Acoustic abundance estimates critically depend on the applied target strength. The target strength currently used for blue whiting is based on cod and is considered to be too low, possibly as much as by 40% (see Godø et al. 2002, Heino et al. 2003). This would imply an overestimation of stock biomass by a similar factor. New target strength measurements should therefore have high priority in the future research agenda.

Coordination of the blue whiting spawning stock survey lies currently on the Planning Group for North-east Atlantic Pelagic Ecosystem Surveys (PGNAPES). The survey in 2004 has highlighted that there is also a need for solving practical questions at a smaller scale (see above). This could be tackled in a workshop arranged in advance of the 2005 survey.

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Table 1. Assessment factors of blue whiting, spring 2004.

Subarea	n.mile²	Numbers (millions) Mature	Total	%mature	Biomass (1000 tonnes) Mature	Total	%mature	Mean weight g	Mean length cm	Density t/n.mile²
I S. Porcupine Bank	14 217	2 292	3 029	75.7	190	209	90.1	69.1	24.1	15
II N. Porcupine Bank	28 924	12 960	13 370	96.9	1 062	1 074	98.9	80.3	26.1	37
III Hebrides	35 693	64 290	65 890	97.6	5 726	5 787	99.0	87.8	27.0	162
IV Faroes/Shetland	23 003	23 700	30 720	77.2	2 289	2 701	84.7	87.9	25.8	117
V Rockall	47 838	15 540	16 850	92.2	1 295	1 333	99.0	79.1	25.9	28
Tot.	149 674	118 800	129 900	91.5	10 590	11 100	95.4	85.5	26.4	74

Table 2. Stock estimate of blue whiting, spring 2004.

Length (cm)	Age in years (year class) 1 2003	2 2002	3 2001	4 2000	5 1999	6 1998	7 1997	8 1996	9 1995	10 1994	Numbers (10^6)	Biomass (10^6 kg)	Mean weight (g)	Prop. mature (%)
14.0 - 15.0	117	0	0	0	0	0	0	0	0	0	117	2	12.6	0
15.0 - 16.0	475	0	0	0	0	0	0	0	0	0	475	8	17.2	0
16.0 - 17.0	792	0	0	0	0	0	0	0	0	0	792	16	20.6	0
17.0 - 18.0	1006	0	0	0	0	0	0	0	0	0	1006	25	24.7	0
18.0 - 19.0	1181	0	0	0	0	0	0	0	0	0	1181	34	29.1	0
19.0 - 20.0	756	549	0	0	0	0	0	0	0	0	1305	44	33.9	28
20.0 - 21.0	339	1408	0	0	0	0	0	0	0	0	1746	70	40.2	48
21.0 - 22.0	90	1839	42	3	0	0	0	0	0	0	1974	94	47.5	57
22.0 - 23.0	18	2429	1100	272	7	0	0	0	0	0	3826	215	56.3	67
23.0 - 24.0	102	4851	2697	1150	18	0	0	0	0	0	8817	545	61.8	83
24.0 - 25.0	11	3667	7002	5717	634	103	0	0	0	0	17134	1167	68.1	93
25.0 - 26.0	0	1538	9795	9150	1190	35	43	0	0	0	21751	1616	74.3	97
26.0 - 27.0	0	837	6311	9981	2601	80	0	80	0	0	19891	1611	81.0	99
27.0 - 28.0	0	141	3696	8956	2410	842	49	101	53	0	16249	1459	89.8	99
28.0 - 29.0	0	225	2266	4382	3319	520	222	579	94	0	11608	1187	102	100
29.0 - 30.0	0	58	514	2852	2400	982	553	133	58	0	7551	833	110	100
30.0 - 31.0	0	59	383	1207	1672	943	677	195	0	0	5136	631	123	100
31.0 - 32.0	0	0	125	448	1381	787	544	180	0	0	3465	476	137	100
32.0 - 33.0	0	0	6	278	473	437	456	238	0	0	1888	291	154	100
33.0 - 34.0	0	0	97	0	254	89	243	146	537	0	1367	226	166	100
34.0 - 35.0	0	0	315	0	52	52	153	153	0	0	725	122	168	100
35.0 - 36.0	0	0	0	0	36	518	23	22	114	0	714	146	205	100
36.0 - 37.0	0	0	0	0	157	94	16	94	9	0	370	85	229	100
37.0 - 38.0	0	0	0	0	0	0	87	0	132	87	307	80	262	100
38.0 - 39.0	0	0	0	0	170	13	13	13	13	13	233	53	229	100
39.0 - 40.0	0	0	0	0	0	13	17	13	107	13	163	44	272	100
40.0 - -41.0	0	0	0	0	0	7	7	7	7	7	35	12	333	100
41.0 – 42.0	0	0	0	0	0	3	3	4	4	4	18	5	299	100
TSN (10^6)	4886	17603	34350	44397	16775	5521	3111	1962	1131	127	129900			
TSB (10^6 kg)	138	1092	2697	3762	1775	713	427	262	205	34	11100			
Mean length (cm)	18.1	23.5	25.9	26.7	28.7	30.5	31.4	30.9	34.0	38.2	26.4			
Mean weight (g)	28.3	62.0	78.5	84.7	106	129	137	133	181	263	85.5			
Condition	4.8	4.8	4.5	4.4	4.5	4.6	4.4	4.5	4.6	4.7	4.6			
% mature	3	76	96	99	100	100	100	100	100	100	91.5			
% of SSB	+	8	25	36	17	7	4	3	2	+				

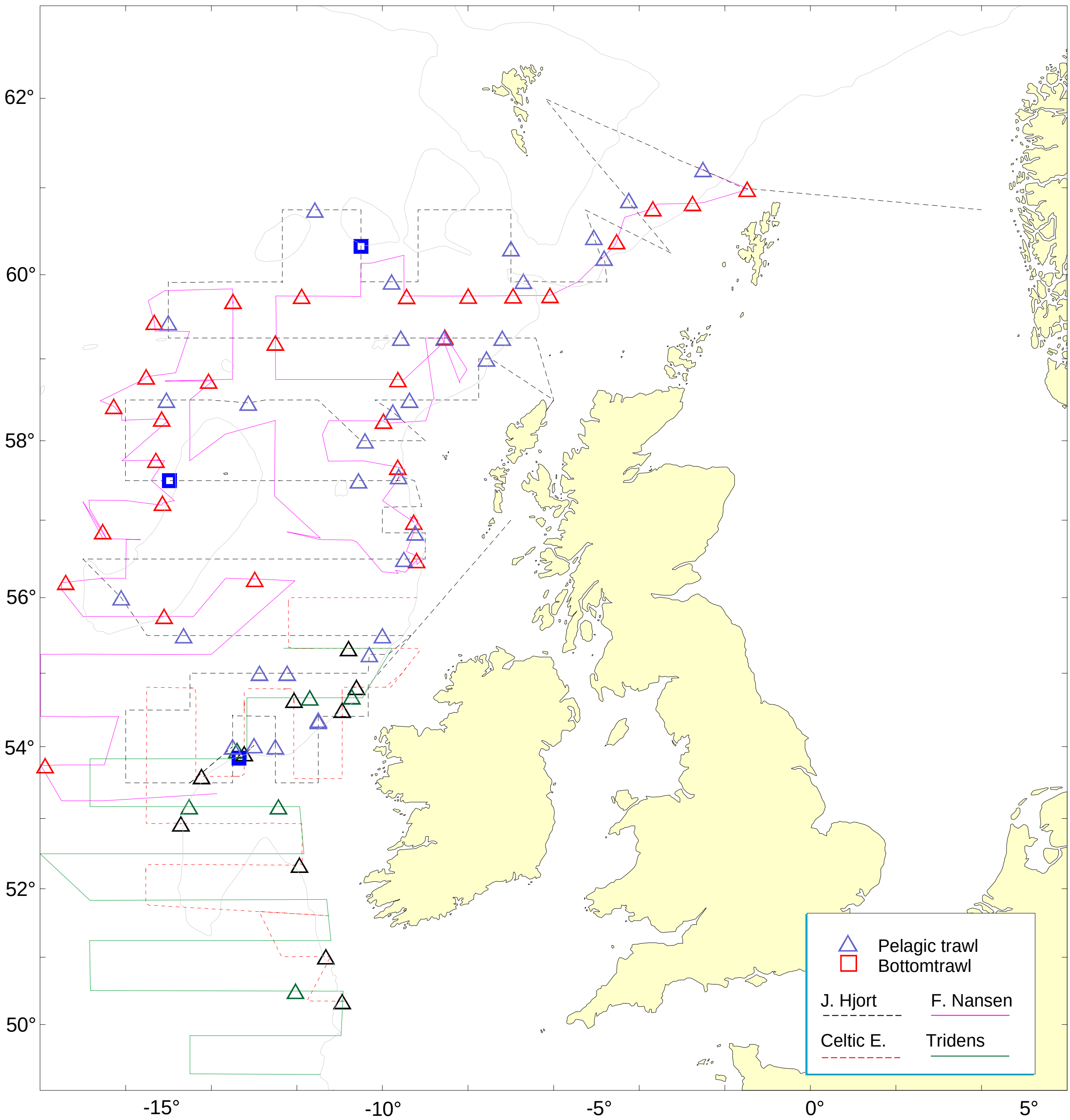

Figure 1. Cruise tracks with trawl stations.

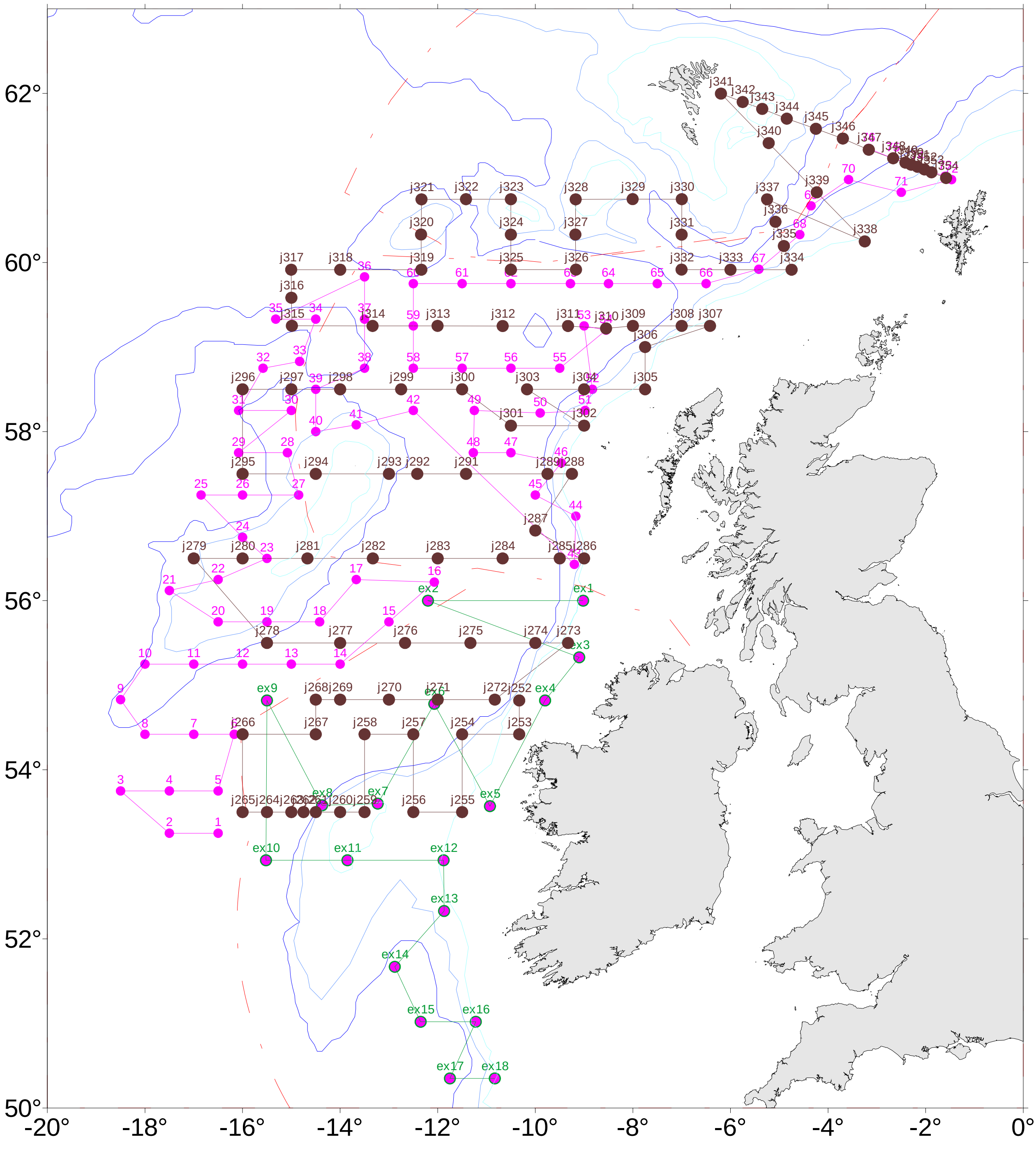

Figure 2. CTD stations for R/V Johan Hjort (brown), R/V Fridtjof Nansen (magenta) and Celtic Explorer (green), in March-April 2004.

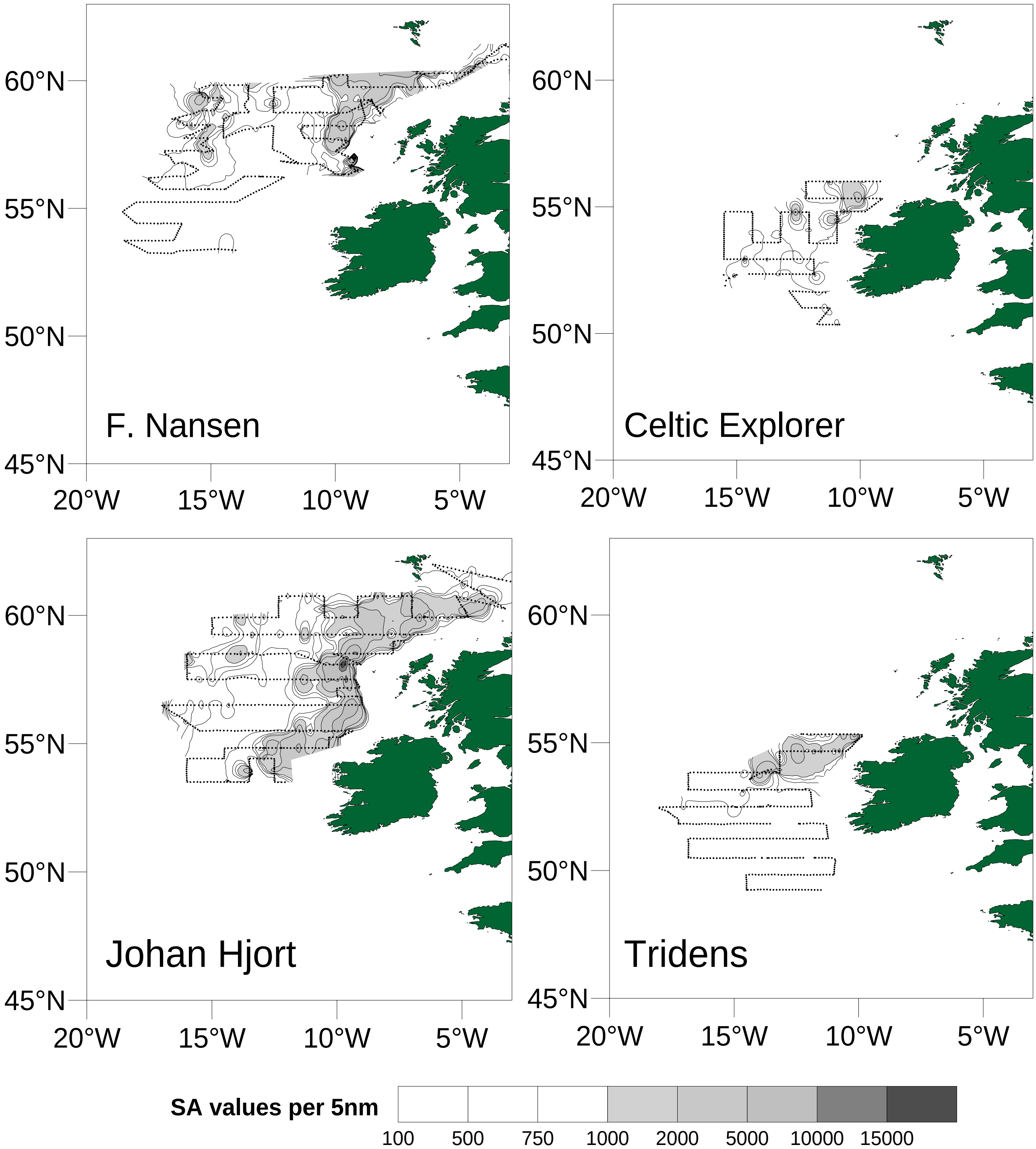

Figure 3. Density of blue whiting in terms s_A-values (m^2/nm^2) based on 5 nm values reported by each of the four research vessels.

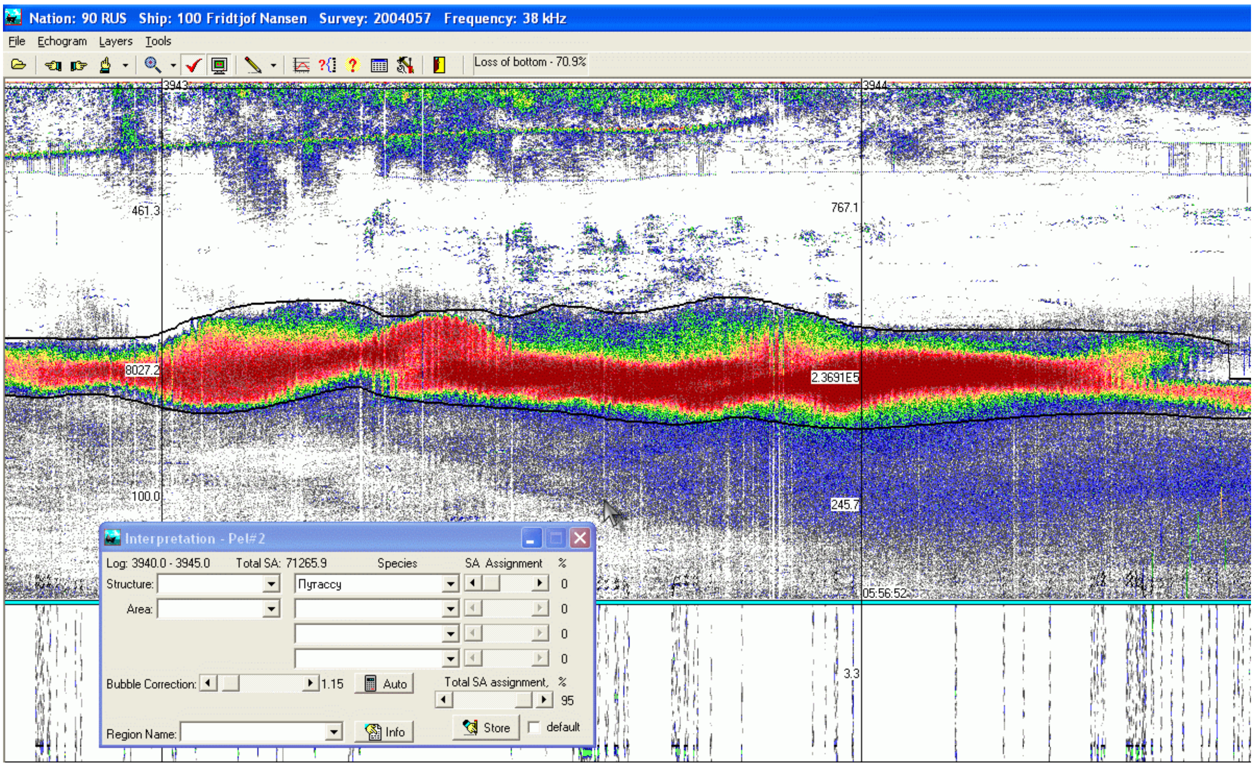

Figure 4. Blue whiting aggregation recorded by Fridtjof Nansen off the Hebrides, April 2004, with an acoustic density of 236910 m^2/nm^2. This may be the highest density ever recorded for blue whiting.

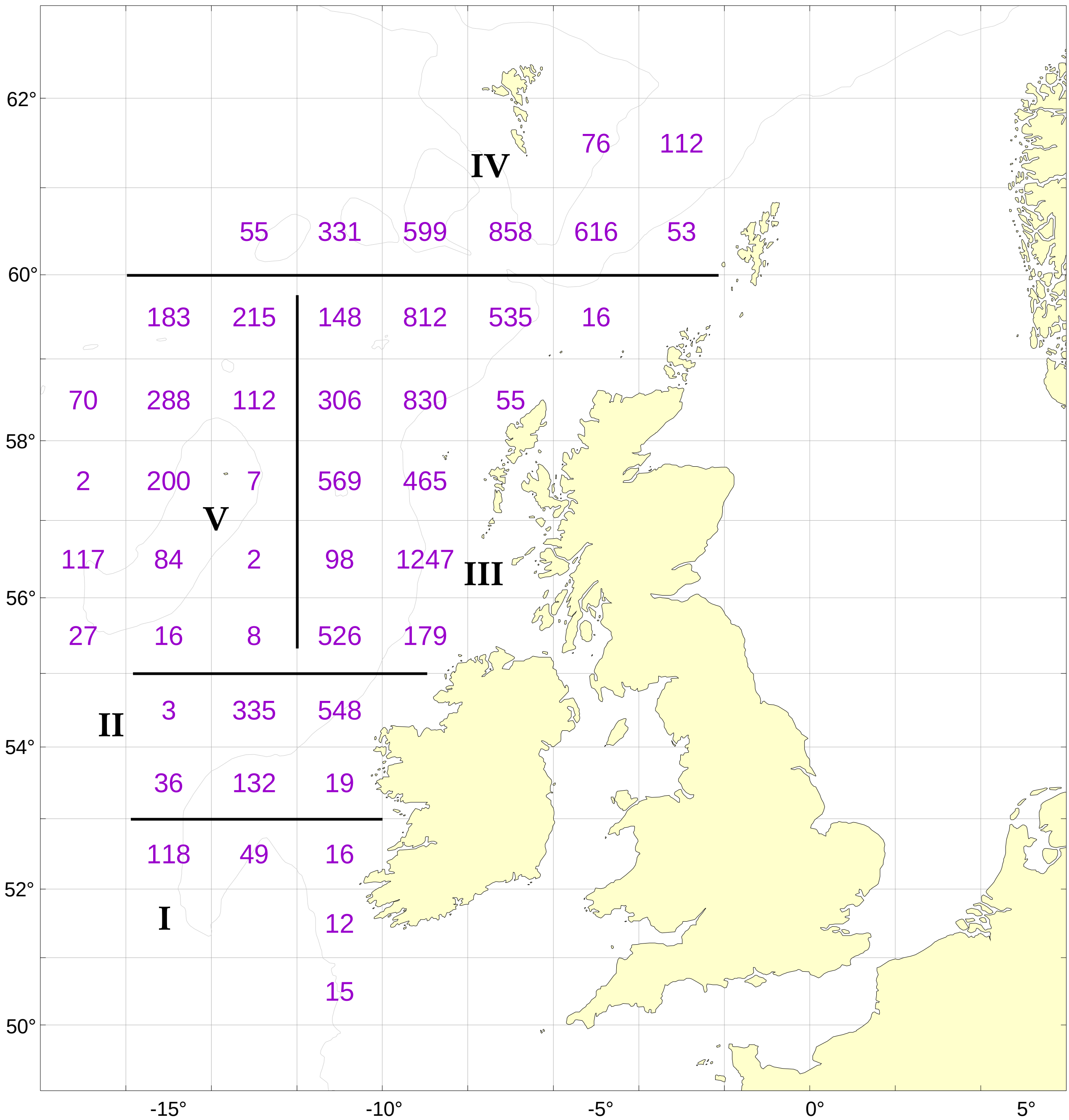

Figure 5. Blue whiting biomass in 1000 tonnes, spring 2004. Marking of sub-areas I-V used in the assessment.

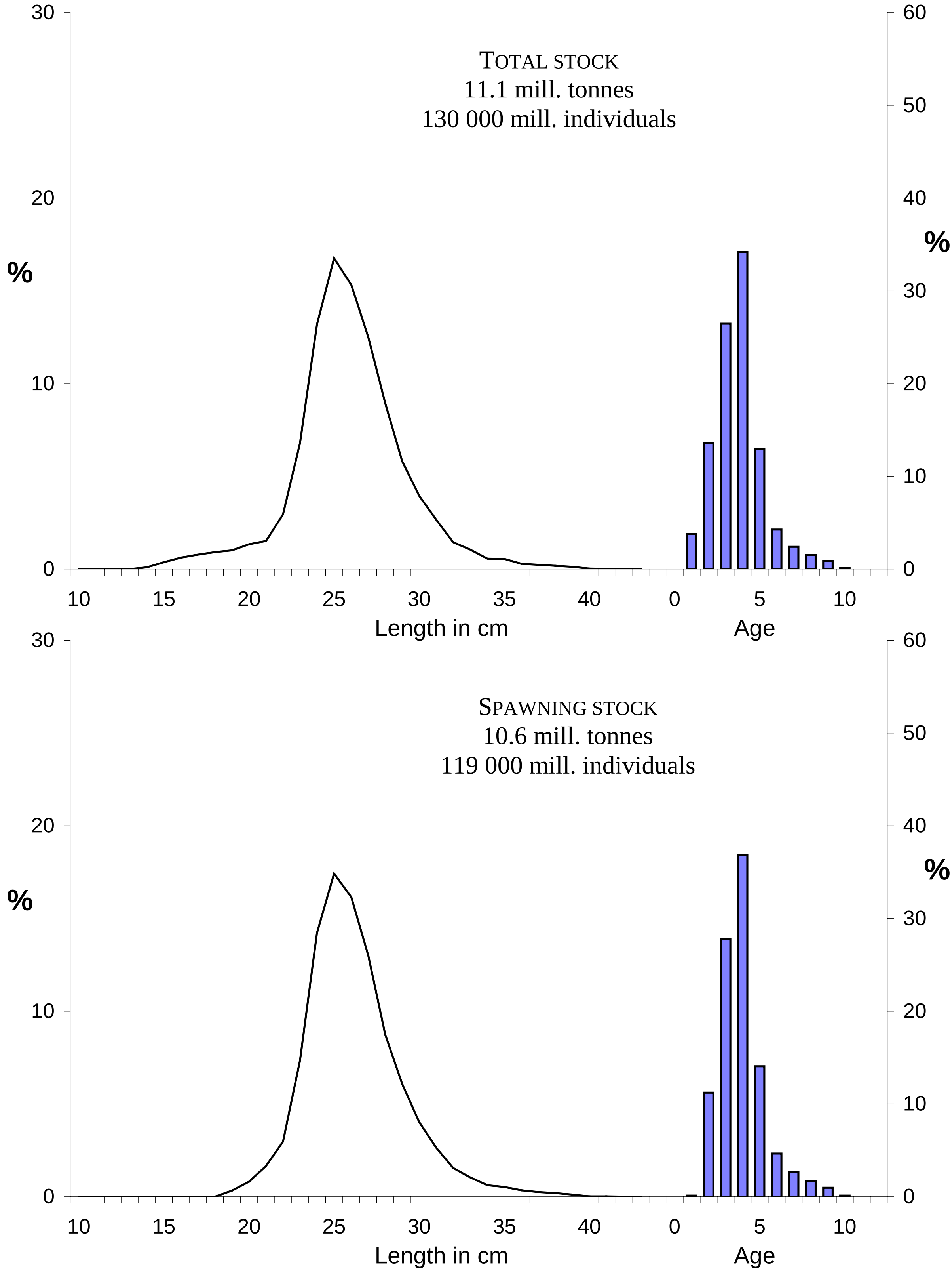

Figure 6. Length and age distribution in the total and spawning stock of blue whiting in the area to the west of the British Isles, spring 2004.

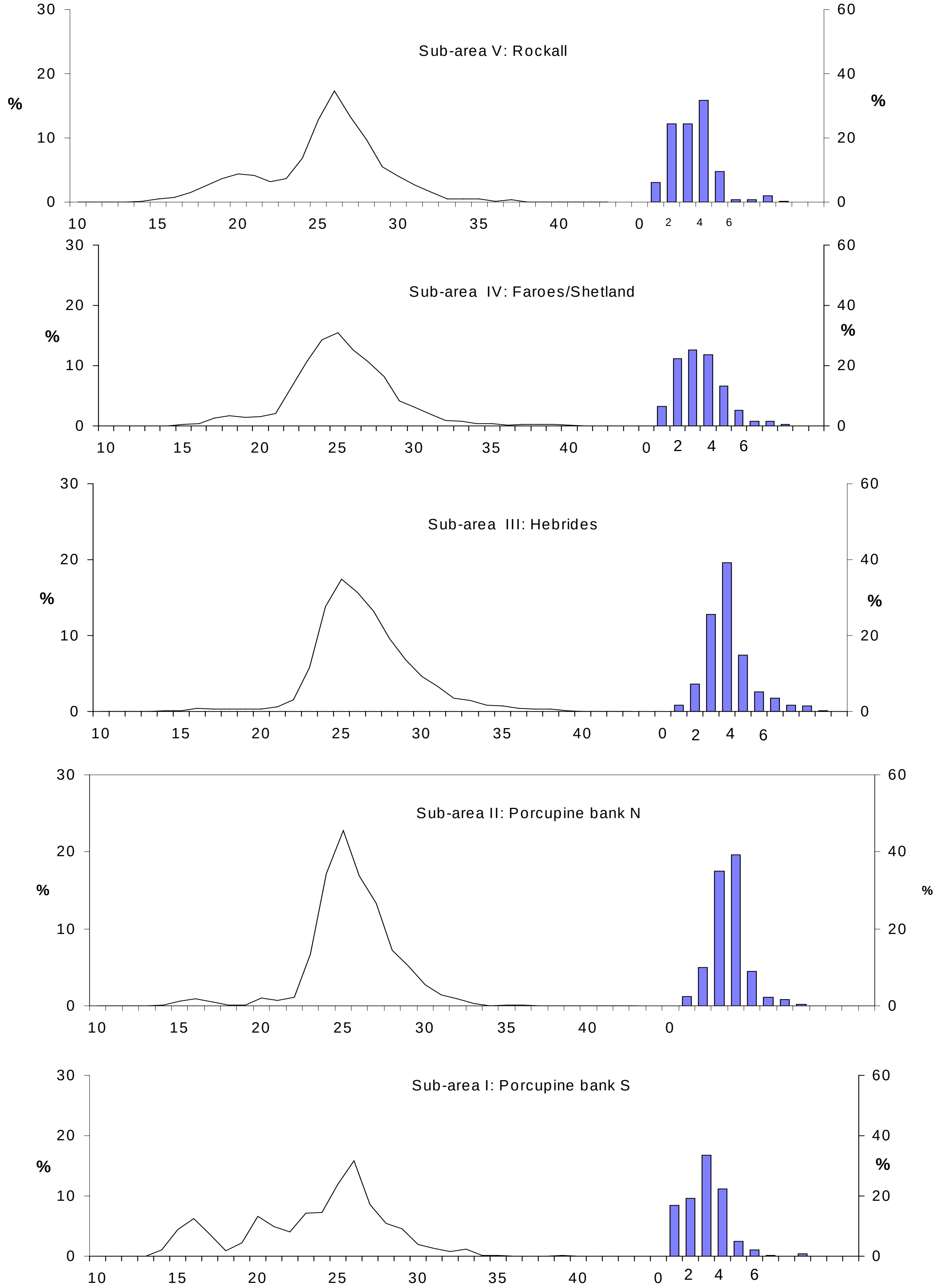

Figure 7. Length and age distribution of blue whiting by sub-areas (I-V), spring 2004.

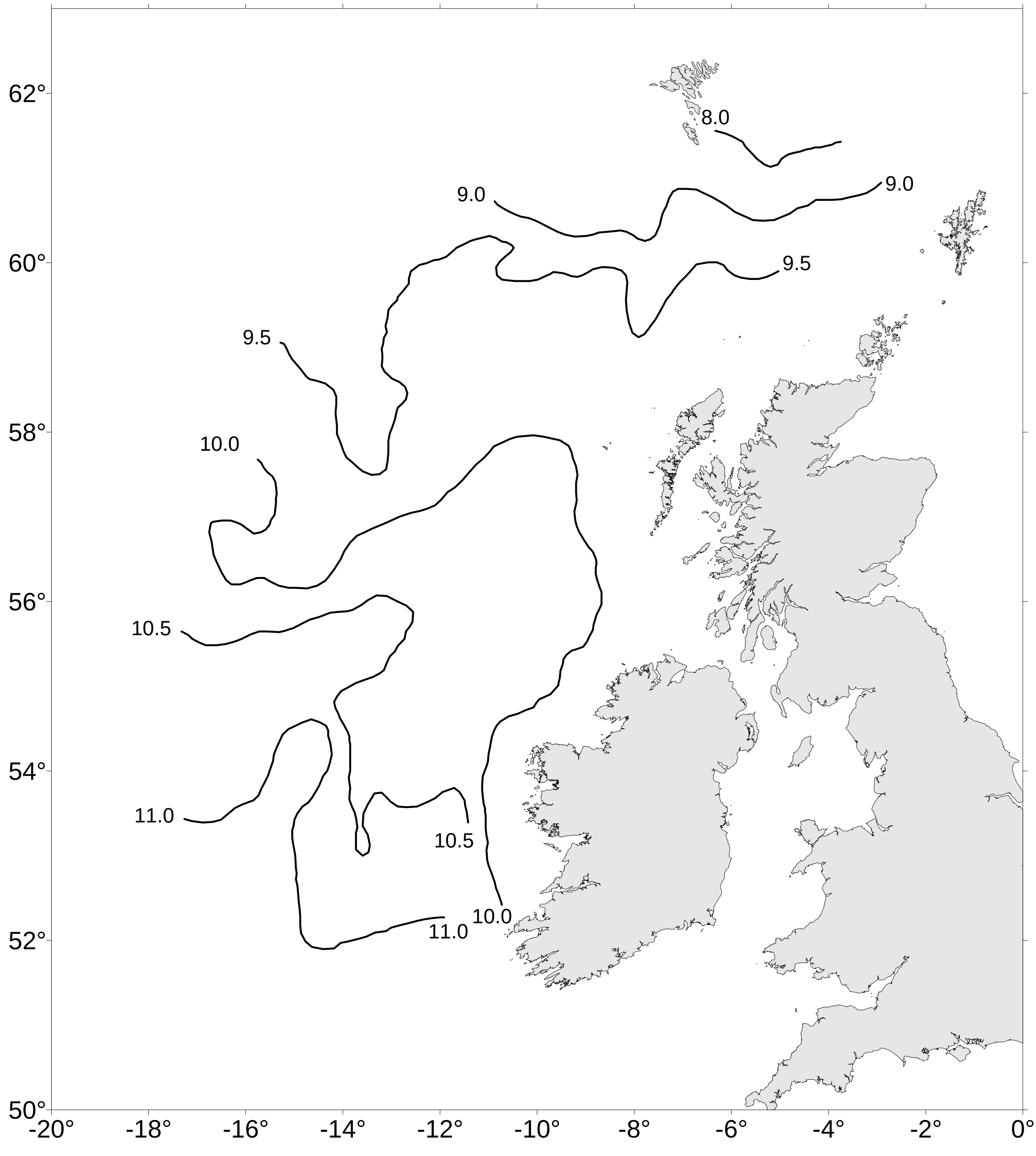

Figure 8. Horizontal temperature distribution, °C, in March-April 2004 at 10m depth

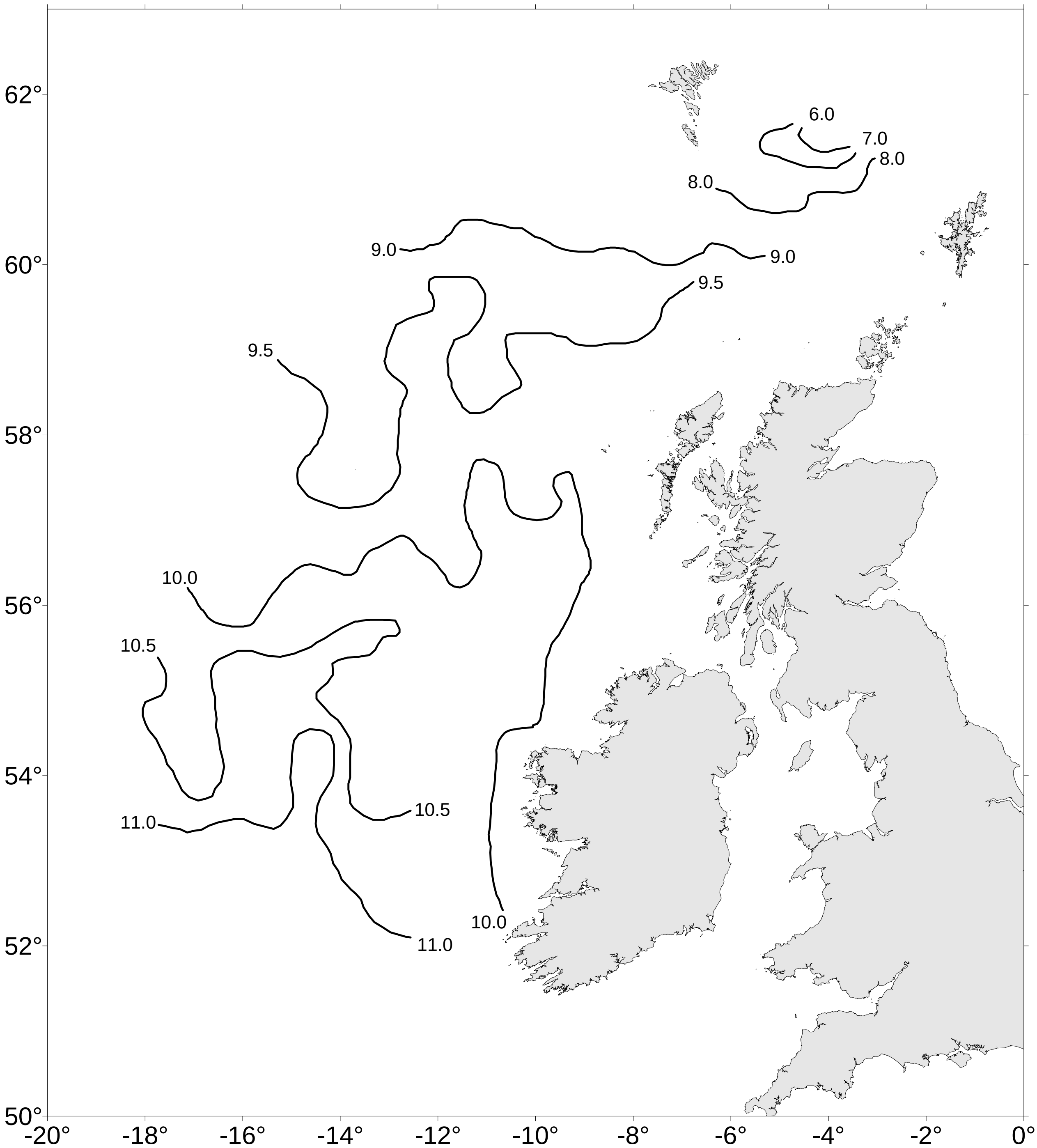

Figure 9. Horizontal temperature distribution, °C, in March-April 2004 at 200m depth

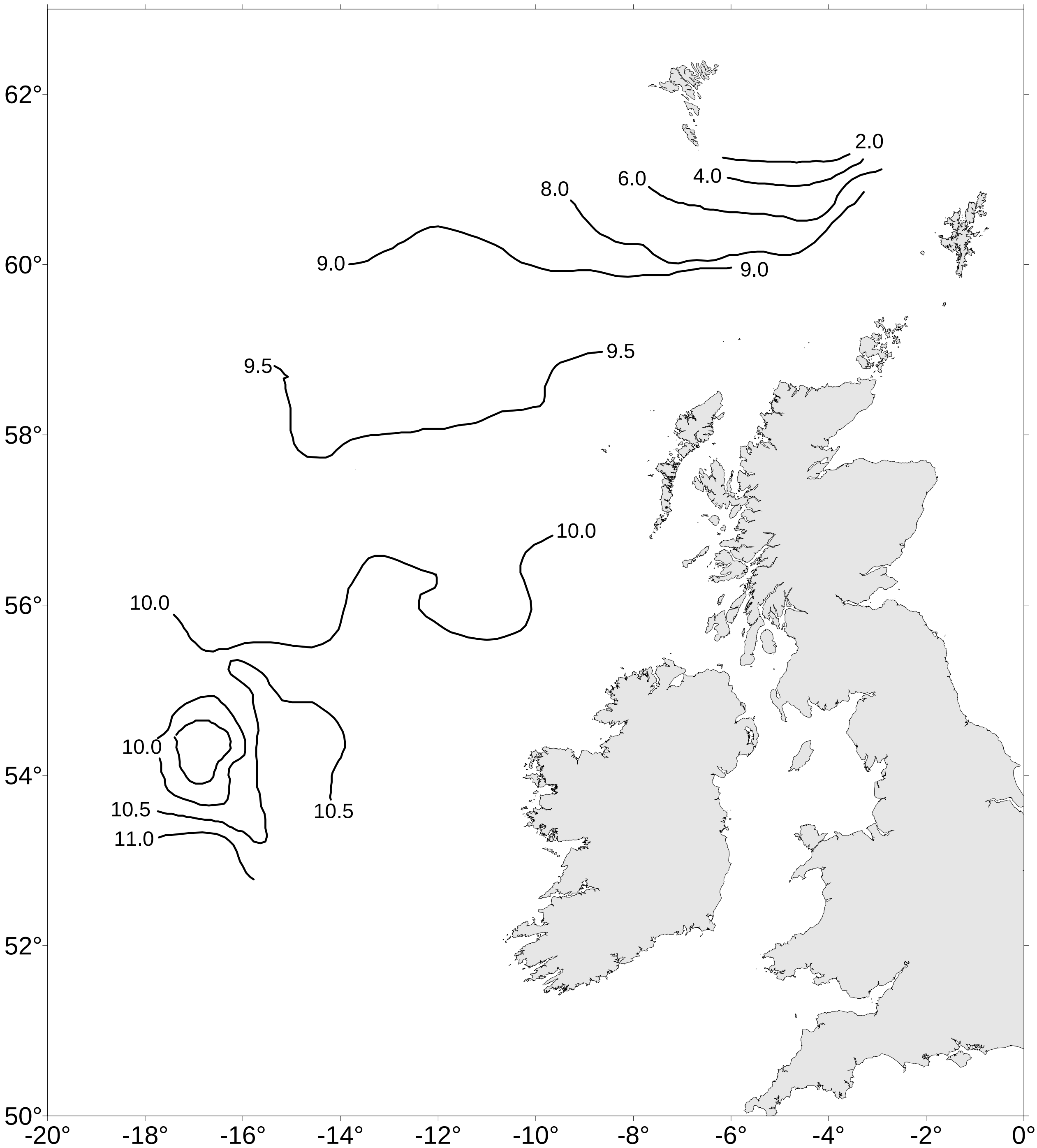

Figure 10. Horizontal temperature distribution, °C, in March-April 2004 at 400m depth

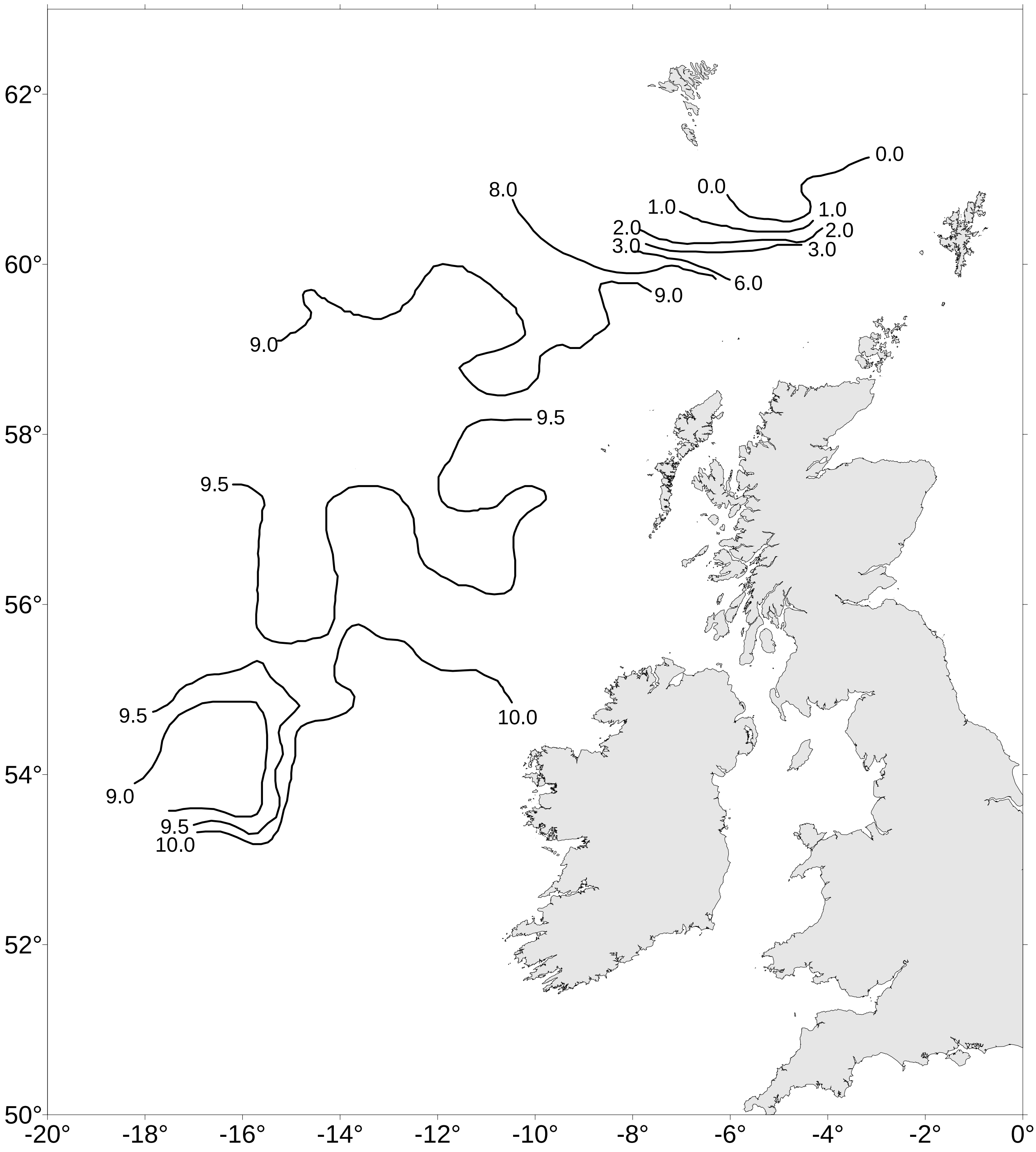

Figure 11. Horizontal temperature distribution, °C, in March-April 2004 at 600m depth

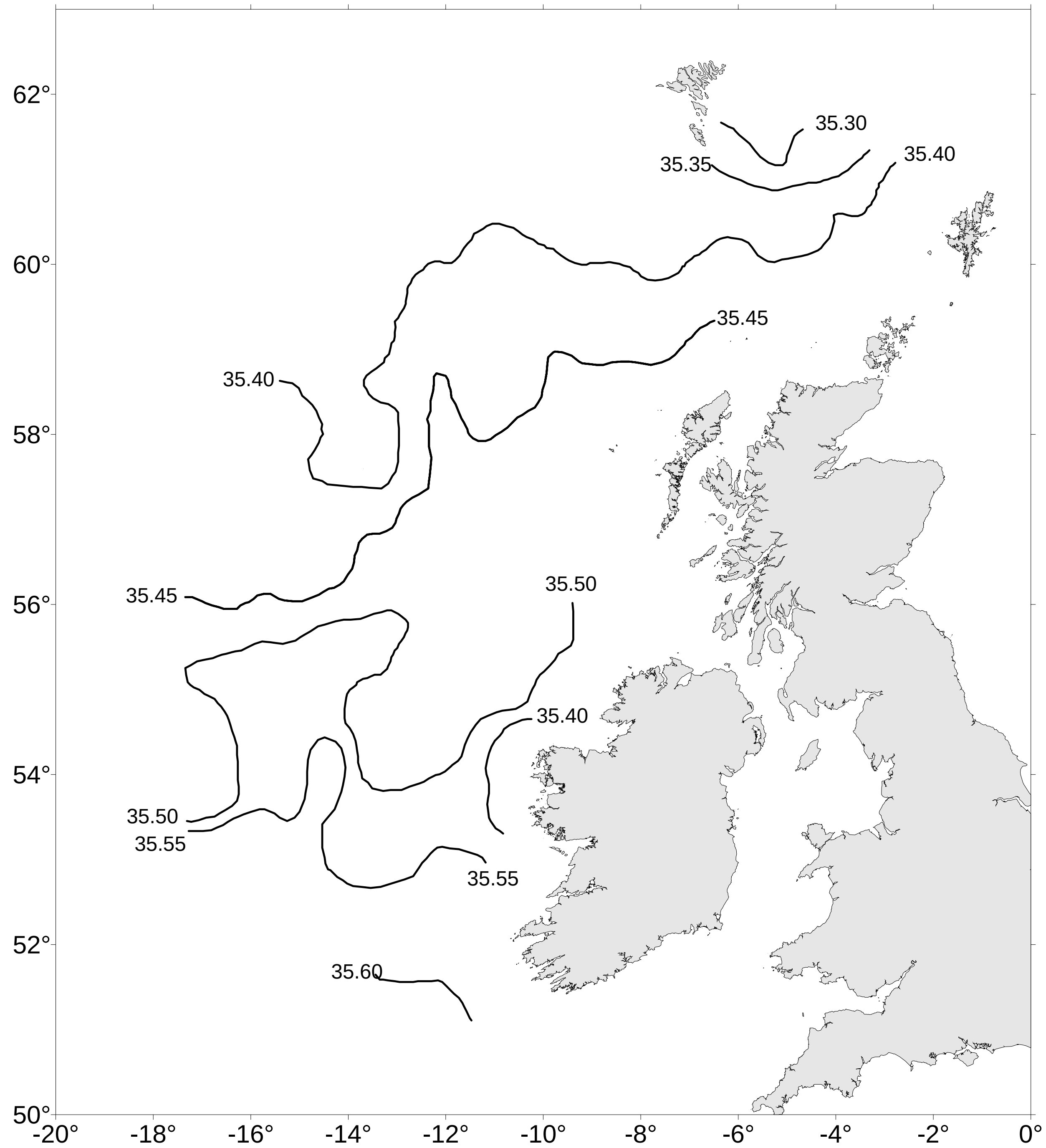

Figure 12. Horizontal salinity distribution, °C, in March-April 2004 at 10m depth

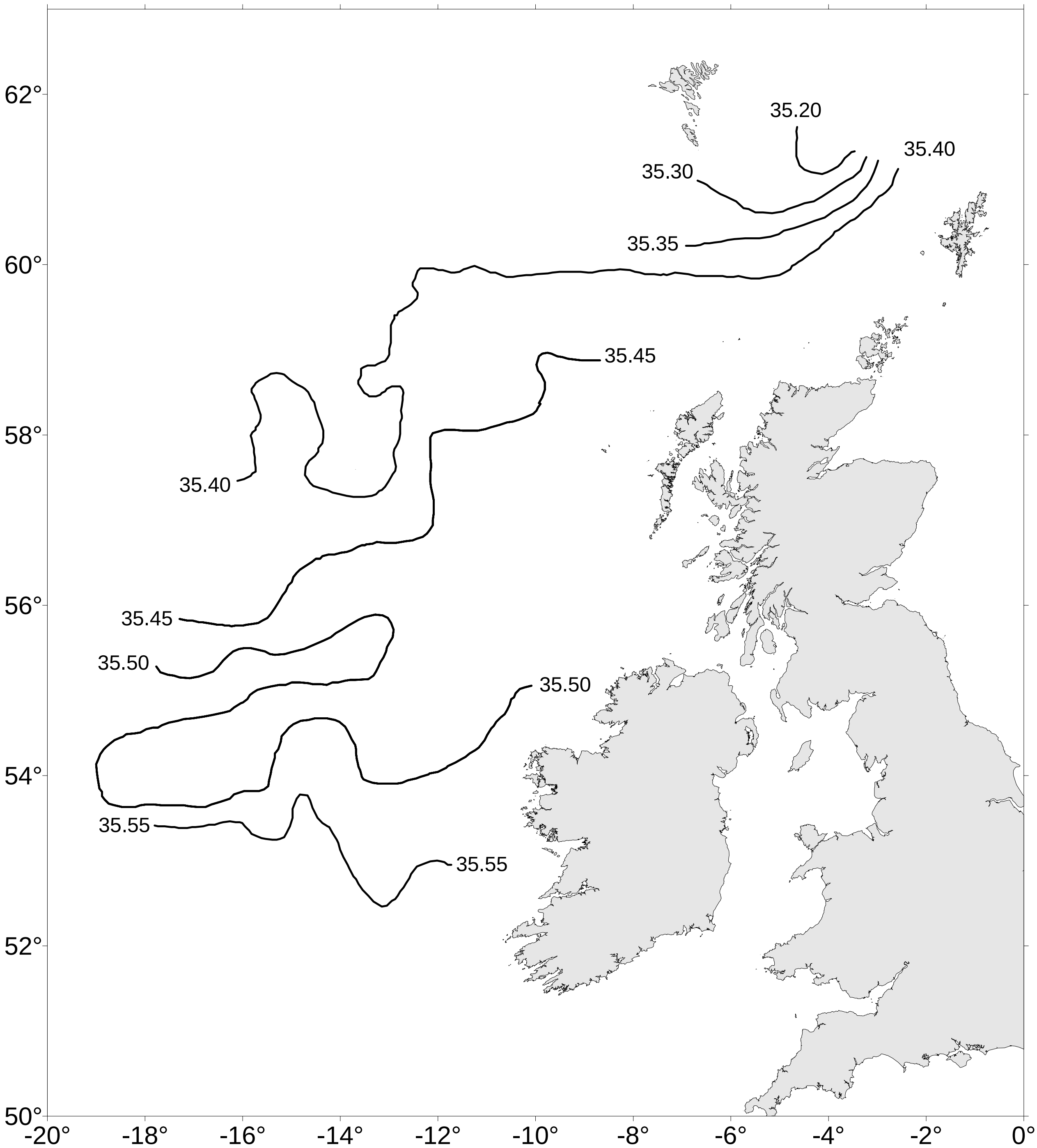

Figure 13. Horizontal salinity distribution, °C, in March-April 2004 at 200m depth

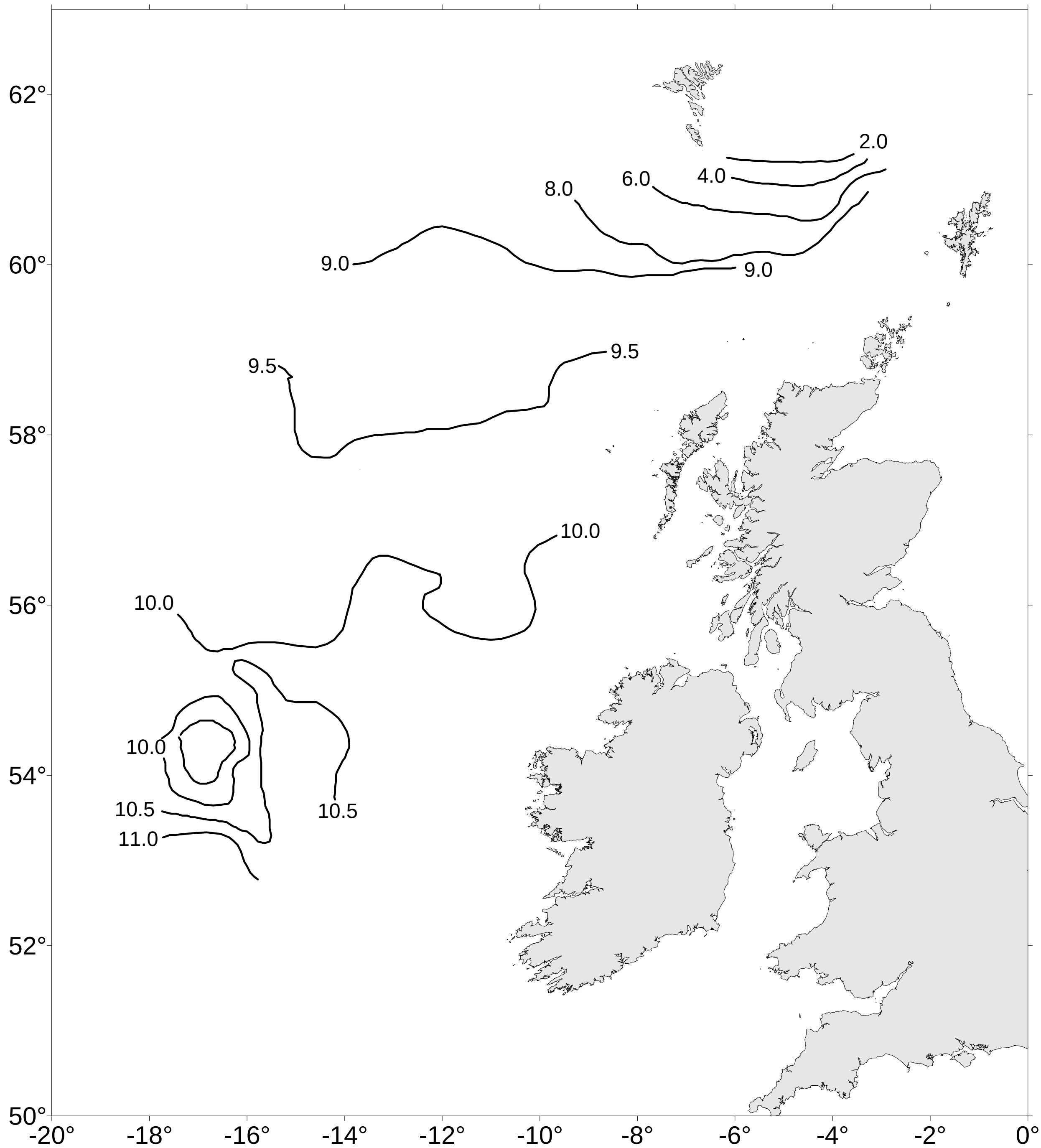

Figure 14. Horizontal salinity distribution, °C, in March-April 2004 at 400m depth

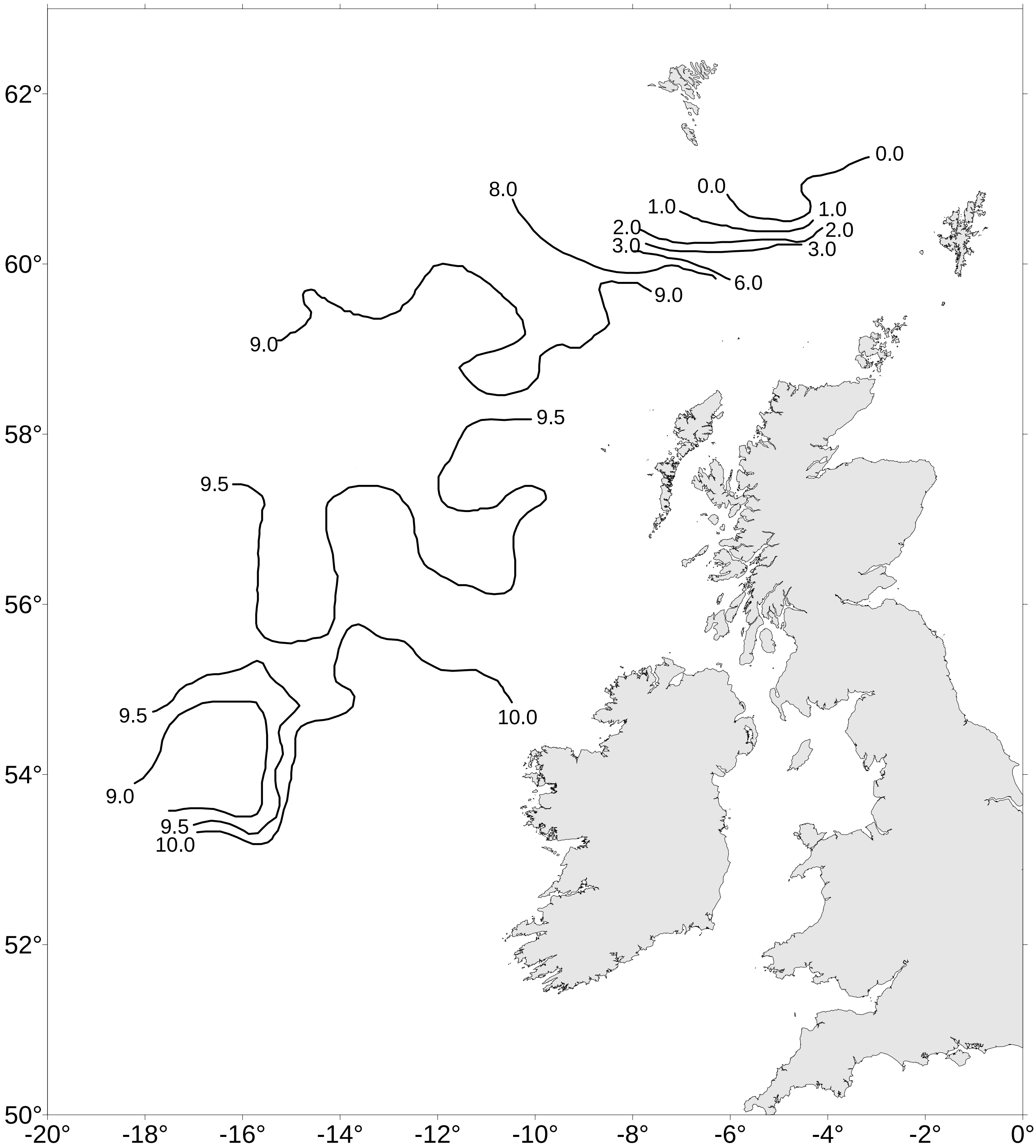

Figure 15. Horizontal salinity distribution, °C, in March-April 2004 at 600m depth

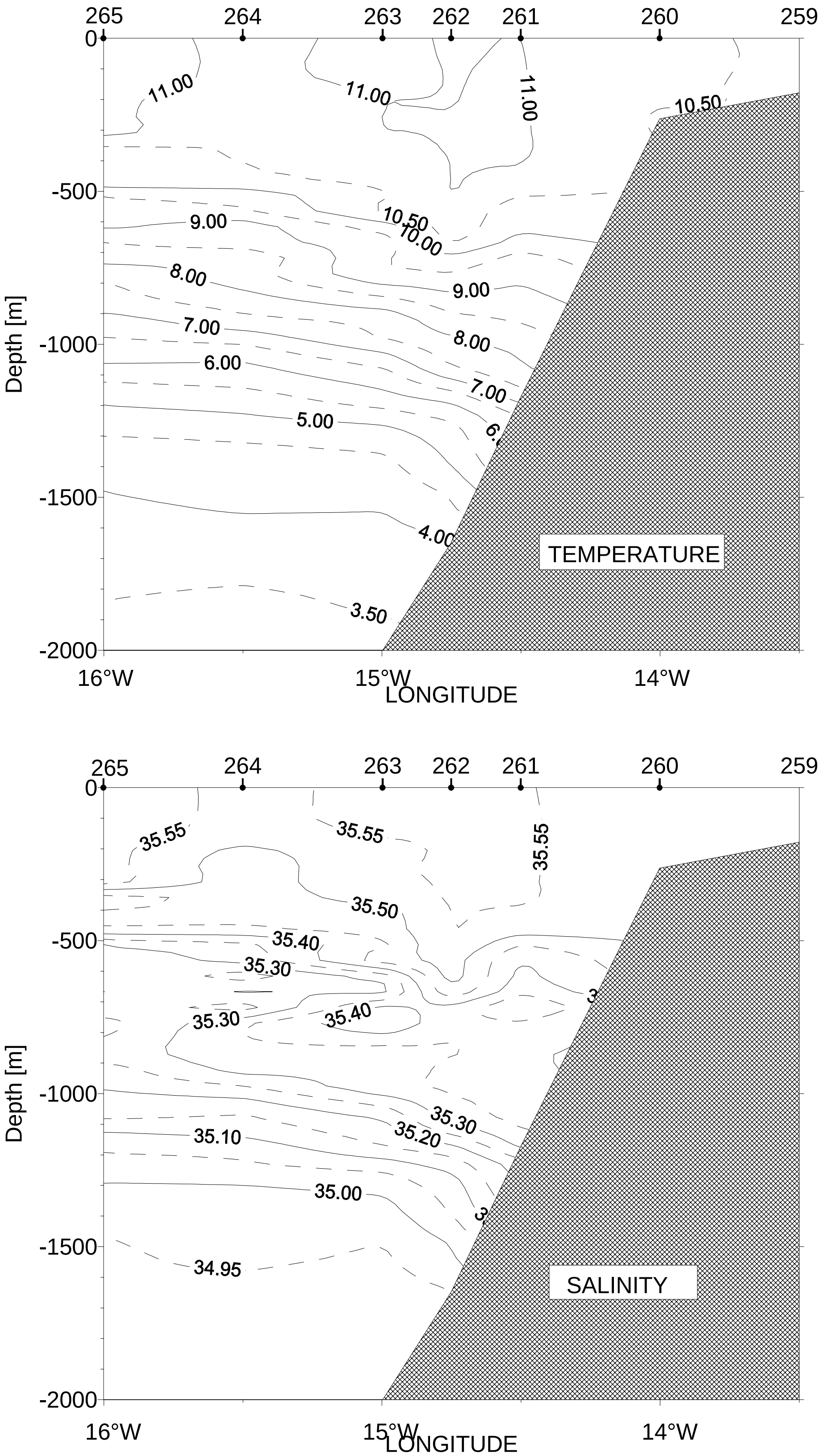

Figure 16. Vertical distribution of temperature (°C) and salinity in a section at the shelf edge at the Porcupine Bank at 53° 30'N. Station numbers at the top of the panels

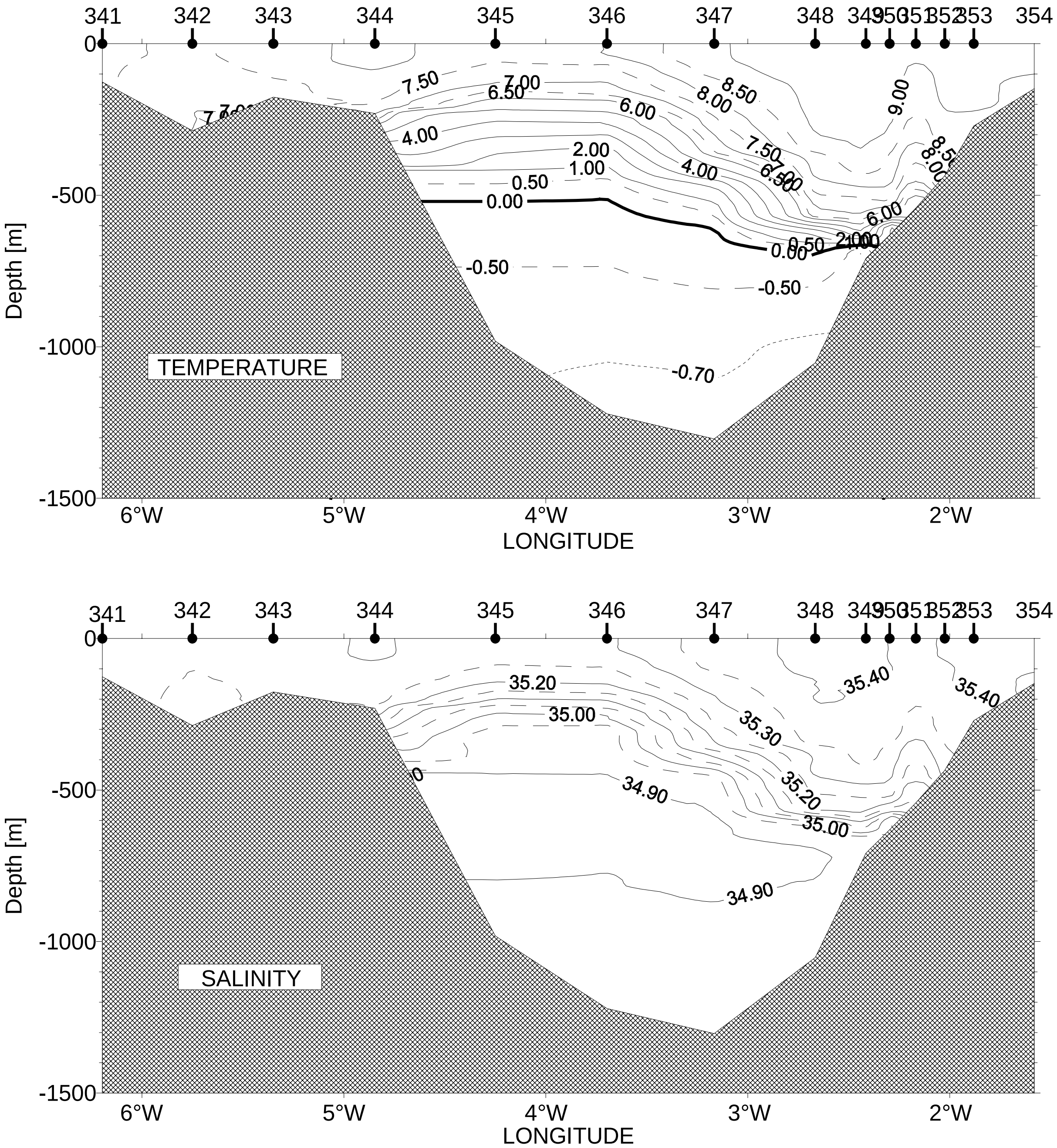

Figure 17. Vertical distribution of temperature (°C) and salinity in a section from the Faroes to Shetland (Nolsø-Flugga). Station numbers at the top of the panels.

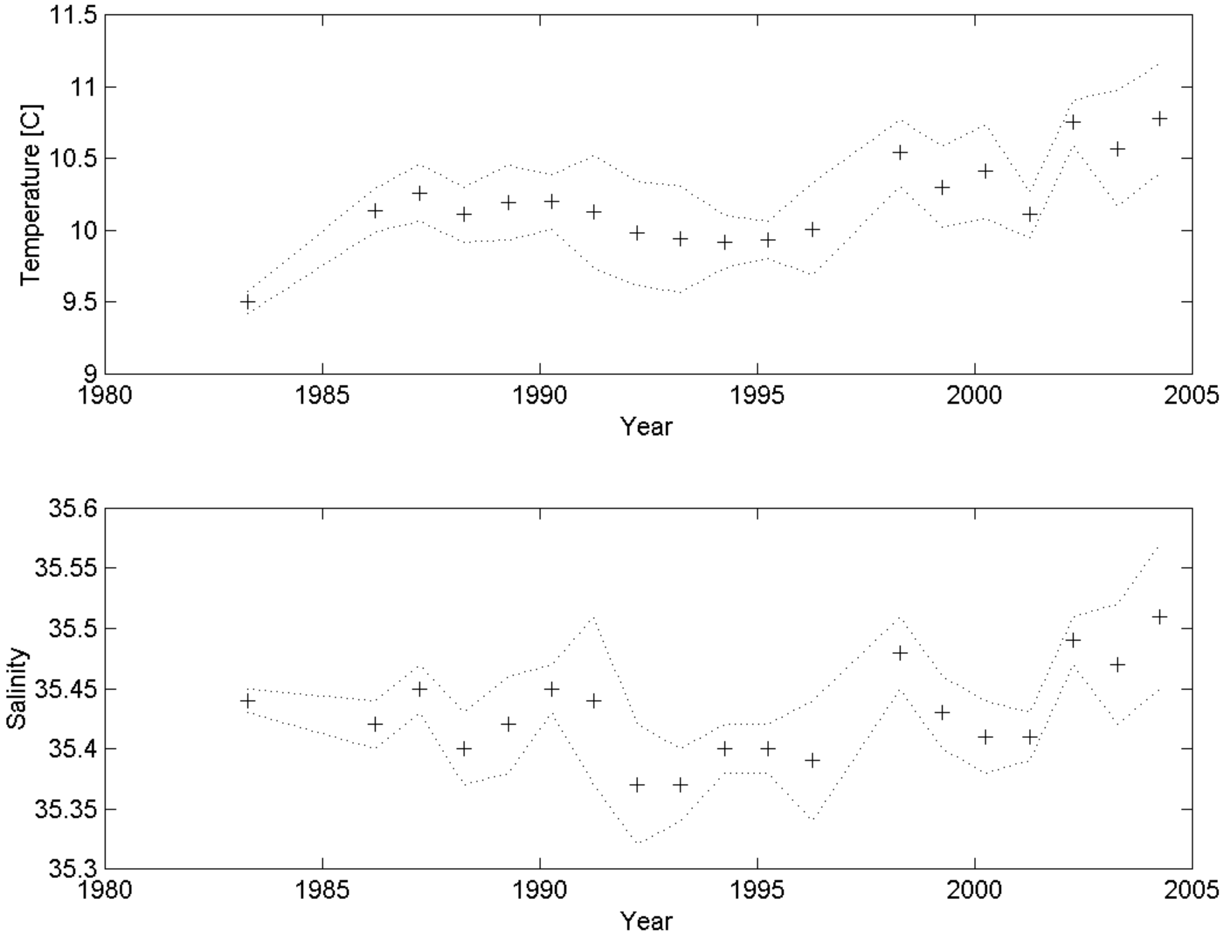

Figure 18. Yearly mean temperature and salinity from 50-600m (crosses) of all stations in a box with bottom depth>600m, west of the Porcupine bank bounded by 52° to 54°N and 16° to 14°W. Dotted lines are drawn at plus-minus one standard deviation of all observations in each box, each year.

Appendix 1. Inter-calibration between R/V Celtic Explorer and R/V Johan Hjort

Acoustic inter-calibration between R/V Johan Hjort and R/V Celtic Explorer was conducted on 24 March 2004 on the northern slopes of the Porcupine Bank (N 54^{o} 00’ and W 13^{o} 00’) under good weather conditions. The main acoustic features in the area were a layer in depths of 100-300 m, probably consisting of mesopelagic fish, and a layer of blue whiting in depths around 400-600 metres. The blue whiting layer got gradually sparser further away from the shelf edge. The inter-calibration was run over 37 nautical miles between 10:30-15:35 GMT. For the first 20 nm, both vessels were cruising towards north, with Celtic Explorer following J. Hjort at a distance of 0.5 nm and 5-10º (about 1-1.5 cables) to the starboard side. The roles were then reversed, and the vessels cruised southwards for 20 nm. In the beginning the logs were synchronized. After the turn, the synchronization was not very good.

The data were stored by 100 m depth layers. However, as the main acoustic features spanned more than one such layer, we focus on combined layers from depths of 100-300 m and from 400-600 m. In addition, the data were scrutinized, and the acoustic densities allocated to blue whiting were compared.

Figure 1 shows total acoustic densities recorded by the two vessels for the first 20 nm. These display similar overall patterns but considerable differences between individual observations. Much higher values on miles 6-10 in 100-300 m layer for Celtic Explorer in comparison to J. Hjort are caused by noise involving interference and false bottom echoes. Observations for the lower depth layer (400-600 m) were little contaminated by noise, but the value from Celtic Explorer for the first mile probably includes some bottom echoes. Regression models fitted on logarithmic scale show a rather poor fit (low R^2, a large intercept and slope much less than one) for the upper depth layer, but a reasonably good fit (moderately high R^2, a non-significant intercept and slope only little less than one) for the lower depth layer (Table 1).

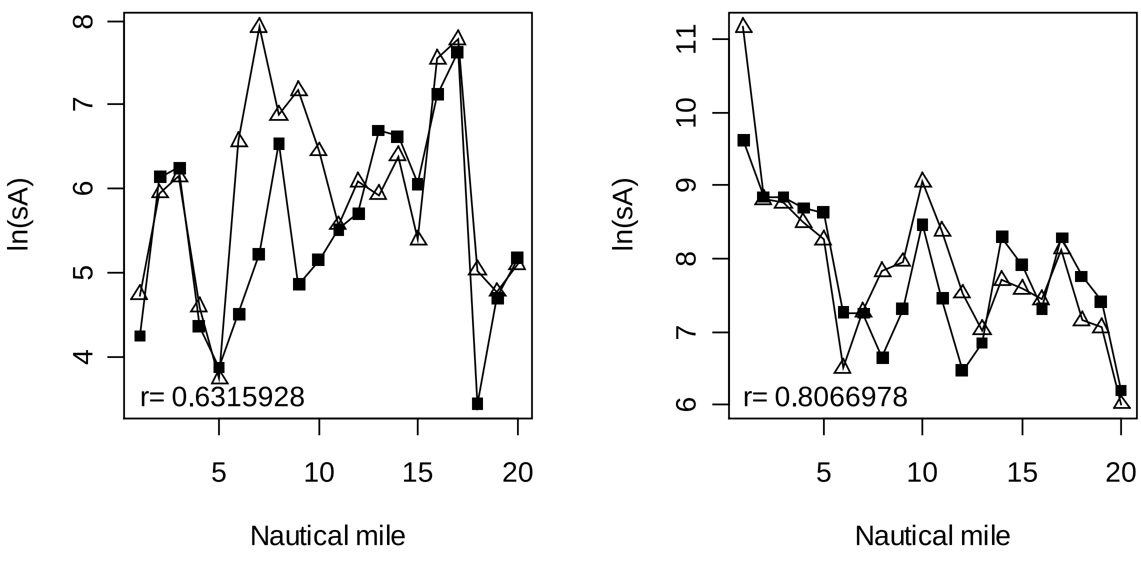

Figure 1. Acoustic densities recorded at the depth layers 100-300m (left) and 400-600 m (right) by Celtic Explorer (triangles) and J. Hjort (squares). Correlation coefficients between the time series are inserted.

Table 1. Regression models for the first 20 nm (n=20) fitted on logarithmic scale. The null hypothesis for t-tests on slope is that the slope is not different from one. Acoustic densities from Johan Hjort are taken as the independent variable and those from Celtic Explorer as the dependent variable.

Depth layer	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
100-300 m	Intercept	3.855	1.030	3.74	0.001	32.2
	Slope	0.509	0.174	-2.82	0.012	
400-600 m	Intercept	0.383	1.308	0.29	0.773	65.1
	Slope	0.967	0.167	-0.198	0.386	

Scrutinized data show much better correspondence than raw data (Figure 2), probably because they are less influenced by noise and bottom echoes. The largest discrepancy occurs on miles 31-32, and is probably caused by noise that cannot be separated from blue whiting echoes in the data from Celtic Explorer. The large difference in the last mile is caused asynchrony in logs, such that the last mile of Celtic Explorer covers more of a dense shelf edge spawning aggregation than the last mile of J. Hjort.

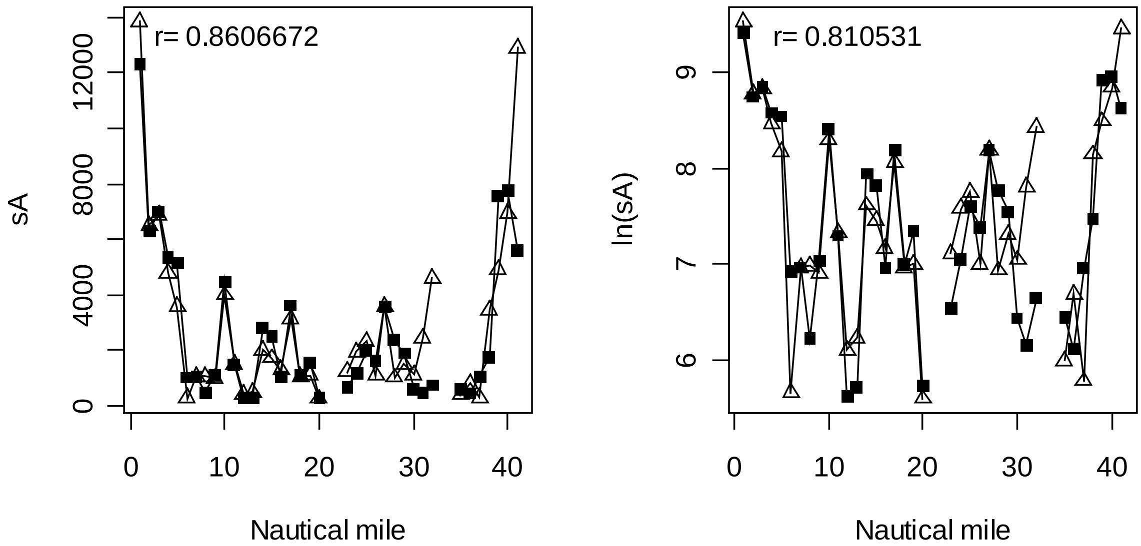

Figure 2. Comparison of blue whiting acoustic densities recorded by Celtic Explorer (triangles) and J. Hjort (squares). Miles 21-22 and 33-34 are not included because of respectively turning and steering problems of Celtic Explorer.

We established regression models to compare the acoustic observations by the two vessels (Table 2). Simple regression models fitted data well, with slope parameters being well estimated (low standard errors) and a high proportion of variability in data being explained by the models. Depending on the subset of data, estimated slope varied in the range 0.95-1.05, but was never significantly different from one. Furthermore, none of the intercepts was significantly different from zero. Regressions forced through the origin were thus considered. These had slopes between 0.95 and 1.03; again, no slope was estimated to be significantly different from one. The results thus show that the acoustic densities for blue whiting made on both vessels are very similar. We therefore conclude that, because the estimated slope varied on both sides of one (depending on the subset of data) but none of the estimates was significantly different from one, the acoustic data from Celtic Explorer and J. Hjort can be used interchangeably without any correction factors.

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 half nautical mile apart. Celtic Explorer towed at depth of 500 m for 55 minutes and caught 11.2 kg of blue whiting. J. Hjort towed for 70 minutes at depths of 480-500 metres and caught 16 kg of blue whiting. The length distributions in the catches were similar. Blue whiting in the catch of Johan Hjort were almost identical in average length (mean±sd: 26.1±1.9cm) with the blue whiting in the catch of Celtic Explorer (26.2±2.0cm). The difference was statistically insignificant (p=0.528). The performance of the pelagic trawls of the two vessels thus appears to be similar, at least under conditions encountered during this comparison.

Age readings on both vessels were similar, with mean age of 3.8±1.0 years on Celtic Explorer and 3.6±1.1 years on J. Hjort. This difference in not statistically significant (p=0.393). Neither did linear models using length to explain ages indicate significant differences between the two vessels.

Table 2. Regression models on scrutinized data for the first 20 nm (n=20), all data (n=37), miles 31-32 excluded (n=35) and miles 31-32 and 41excluded (n=34). Intercept is estimated in the first three regressions, whereas regression through the origin is assumed for the last three. The null hypothesis for t-tests on slope is that the slope is not different from one. No logarithmic transformation was applied here in order to make the models more robust for possible predictions outside the observed ranges. Acoustic densities from Johan Hjort are taken as the independent variable and those from Celtic Explorer as the dependent variable.

Data	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
First 20 nm	Intercept	-304.6	200.1	-1.522	0.145	96.4
	Slope	1.051	0.0477	1.064	0.221	
All	Intercept	228.6	377.9	0.605	0.549	74.1
	Slope	0.9912	0.0991	-0.089	0.395	
All\31-32nm	Intercept	-46.30	366.7	-0.126	0.900	78.7
	Slope	1.035	0.0936	0.370	0.369	
All\31,32,41nm	Intercept	-36.67	198.4	-0.185	0.855	91.5
	Slope	0.9537	0.0514	-0.900	0.262	
First 20 nm	Slope	0.9995	0.0349	-0.015	0.394	97.7
All	Slope	1.0334	0.0698	0.479	0.352	85.9
All\31-32nm	Slope	1.0262	0.0645	0.407	0.364	88.2
All\31,32,41nm	Slope	0.9470	0.0360	-1.474	0.134	95.5

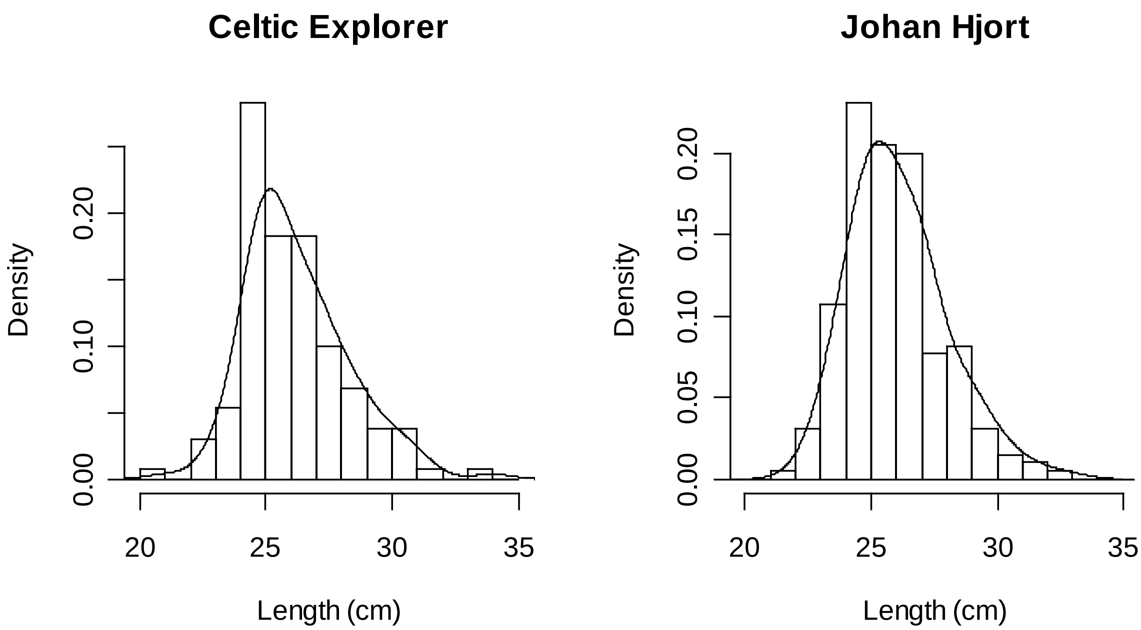

Figure 3. Length distributions from the trawls hauls of Celtic Explorer and J. Hjort. Smoothing is obtained by normal kernel density estimates. J. Hjort: n=195; Celtic Explorer: n=131.

Appendix 2. Inter-calibration between R/V Tridens and R/V Johan Hjort

Acoustic inter-calibration between R/V Johan Hjort and R/V Tridens was conducted on 25 March 2004 on the northern slopes of the Porcupine Bank (N 53^{o} 45' and W 14^{o} 00') under good weather conditions. The main acoustic feature in the area was a loose layer of blue whiting in depths around 400-600 metres. The inter-calibration was run over nautical miles between 07:50-12:20 GMT. For the first 30 nm, both vessels were cruising along 700 m depth contour towards north-east, with J. Hjort following Tridens at a distance of 0.5 nm and 5-10º (about 1-1.5 cables) to the starboard side. The vessels then continued for some miles towards deeper water, followed by a course to east and then south to the shelf edge. In the beginning the logs were synchronized, but later scrutiny suggested a shift of one nautical mile. Attempts to exchange echograms failed, but inspection of data suggests that this gives a reasonable synchronization of data.

We focused on combined layers from depths of 15-400 m (registrations of plankton and mesopelagic fish) and from 400-600 m (mostly blue whiting). Three miles with strong false bottom registrations on J. Hjort were excluded from the analyses. In addition, the data were scrutinized, and the acoustic densities allocated to blue whiting were compared.

Figure 1 shows acoustic densities recorded by the two vessels for the depth layers corresponding to the main layers. These display similar overall patterns but considerable differences between individual observations. Regression models fitted on both natural and logarithmic scales show reasonable fits (moderately high R^2) with positive intercepts and slope parameters less than one (Table 1); the deviations from one-to-one relationship are mostly statistically significant. The general pattern suggested by these regressions is that Tridens tends to record lower acoustic densities than Johan Hjort.

Scrutinized data from the two vessel show rather noisy relationship (Figure 2). There seems to be a tendency for larger allocation to blue whiting at low densities on Tridens than on J. Hjort, the difference being less at higher densities. We established regression models to compare the scrutinized data (Table 2). Model where the intercept is estimated shows a large positive intercept and a small slope parameter. When the regression is forced through the origin, the slope parameter is estimated to be less than one but not significantly so.

No firm conclusions can be drawn from this inter-calibration in absence of echograms that could facilitate interpreting the results. There seems to be a tendency for Tridens to record lower acoustic densities than J. Hjort. In the scrutinized data this relationship may be reversed, although the regression model forced through the origin fails to detect a significant deviation from one-to-one relationship.

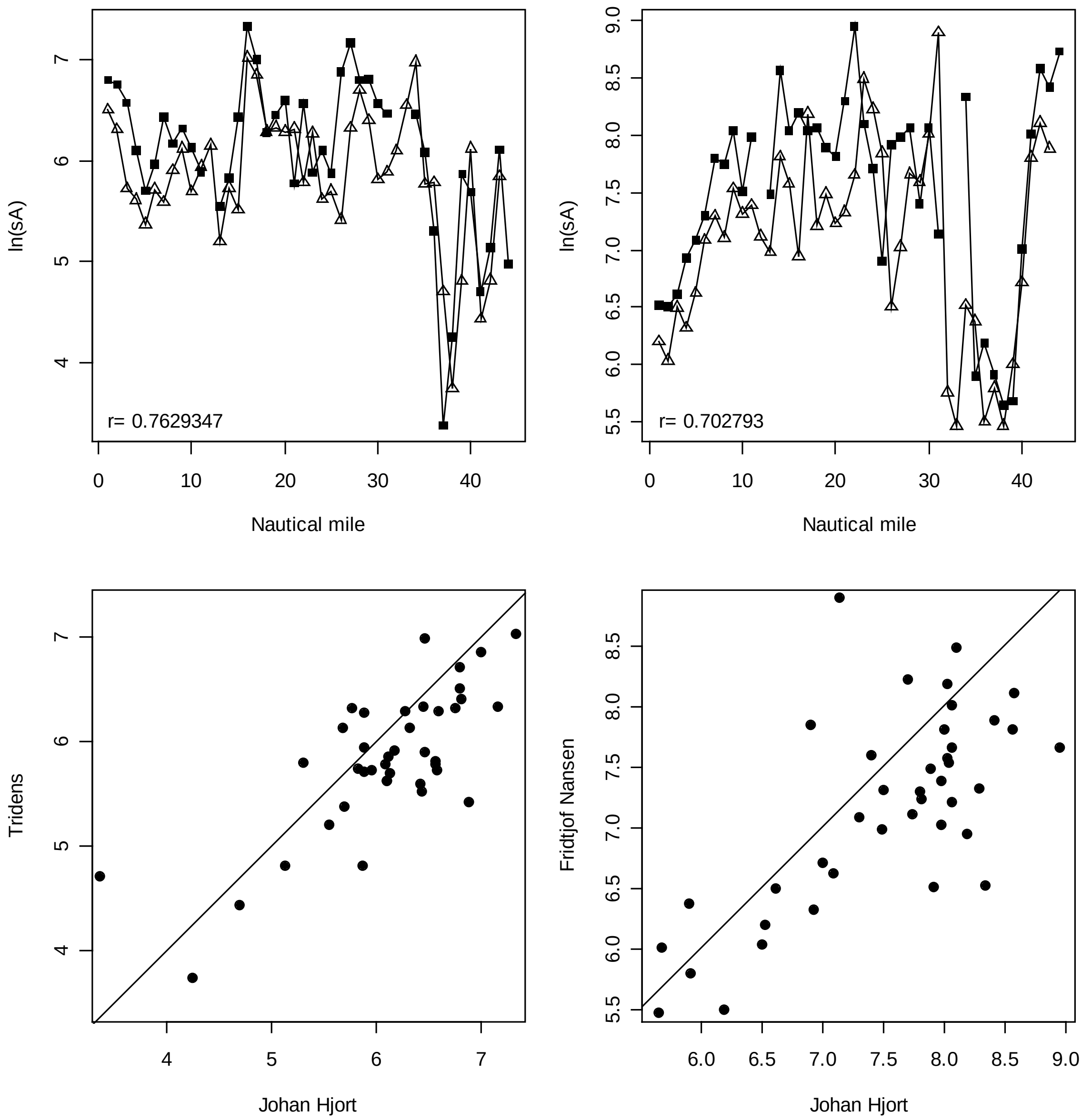

Figure 1. Acoustic densities recorded at the depth layers 15-400m (left) and 400-600 m (right) by Tridens (triangles) and J. Hjort (squares). Correlation coefficients between the time series are inserted. The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

Table 1. Regression models with three miles with false bottom echoes removed (leaving n=40). The null hypothesis for t-tests on slope is the slope being not different from one. Values from J. Hjort are taken as the independent variable and those from Tridens as the dependent variable. The last four models are forced through the origin.

Depth layer	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
15-400 m	Intercept	108.9	57.0	1.91	0.064	49.7
	Slope	0.542	0.088	-5.17	<0.001	
400-600 m	Intercept	1018	384	2.65	0.012	11.4
	Slope	0.294	0.133	-5.31	<0.001	
15-400 m,	Intercept	1.718	0.569	3.02	0.005	58.2
log-trans.	Slope	0.672	0.092	-3.54	0.003	
400-600 m,	Intercept	2.100	0.835	2.51	0.016	49.4
log-trans.	Slope	0.674	0.111	-2.95	0.007	
15-400 m	Slope	0.689	0.0458	-6.80	<0.001	85.3
400-600 m	Slope	0.588	0.0786	-5.24	<0.001	58.9
15-400 m, log	Slope	0.950	0.0126	-4.02	<0.001	99.3
400-600m, log	Slope	0.950	0.0131	-3.84	0.001	99.3

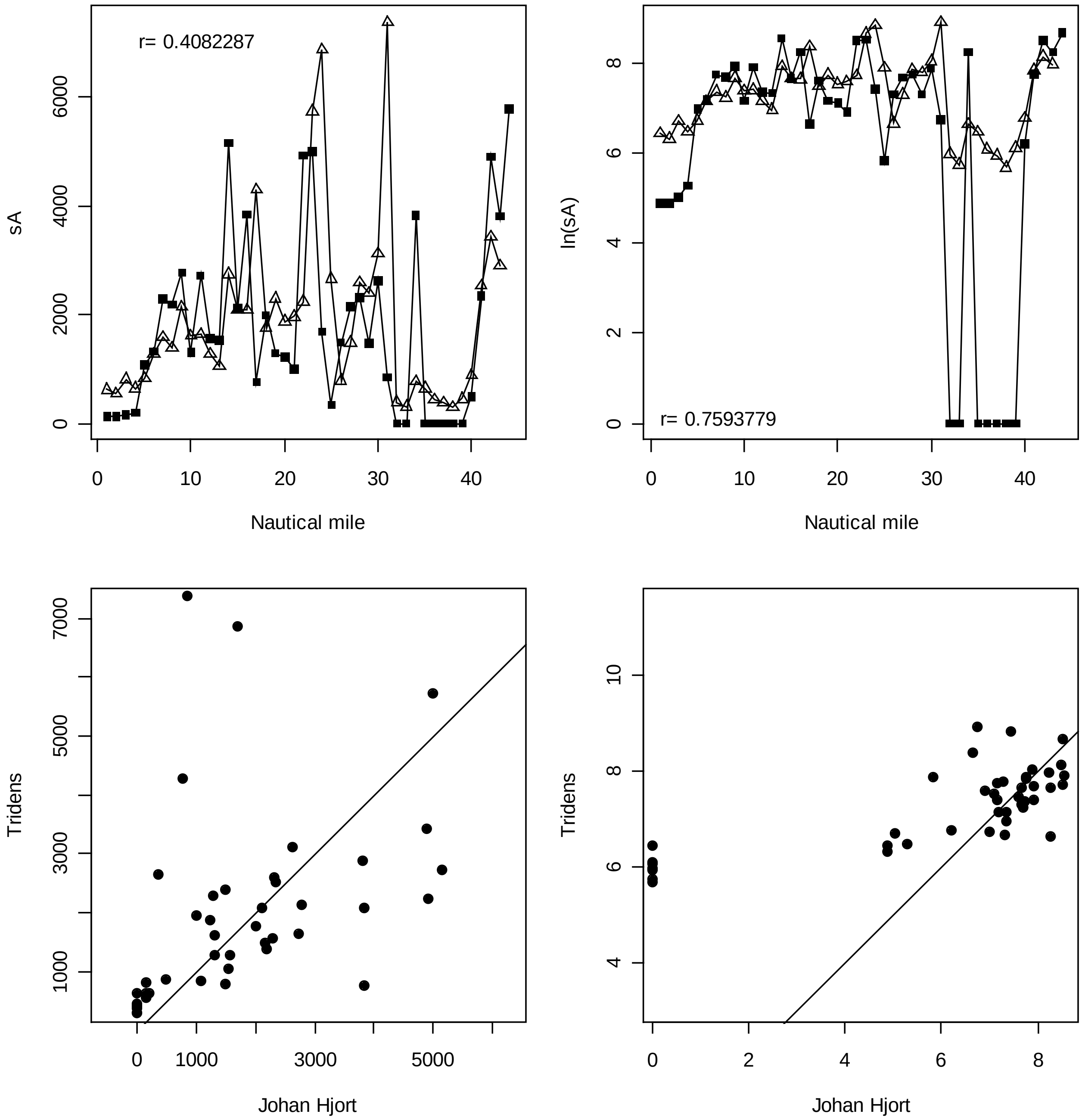

Figure 2. Comparison of blue whiting acoustic densities recorded by Tridens (triangles) and J. Hjort (squares). Acoustic densities equal to zero have been replaced with s_A=1 in the top right panel. The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

Table 2. Regression models for the scrutinized data (n=43). 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. In order to make the models more robust for possible predictions outside the observed ranges no logarithmic transformation was applied. Acoustic densities from Johan Hjort are taken as the independent variable and those from Tridens as the dependent variable.

Data	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
All	Intercept	1197	345	3.48	0.001	16.7
	Slope	0.435	0.152	-3.72	0.001	
All	Slope	0.828	0.114	-1.51	0.127	55.9

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 half nautical mile apart. J. Hjort towed for 14 minutes at depths of 500-550 metres and caught 25.3 kg of blue whiting. Tridens towed at similar depth and duration and caught 2000 kg of blue whiting. The length distributions in the catches were similar (Fig. 3). Blue whiting in the catch of Johan Hjort were comparable in average length (mean±sd: 25.7±2.0 cm) with the blue whiting in the catch of Tridens (26.0±2.0cm). The difference was statistically insignificant (p=0.068). Despite the striking difference in catch weight, the two trawls appear to have rather similar size selectivity.

Mean age for the sample taken by J. Hjort is 3.5±0.9 years (mean±sd), whereas that for Tridens is 2.8±0.9 years, a highly significant difference (p<0.001). The lengths for aged fish are also different, 26.0±2.3cm for J. Hjort and 24.2±2.8cm for Tridens. The lower mean length appears largely to explain the observed difference in mean age. In linear model AGE~VESSEL+LENGTH (assuming equal length dependence) the vessel factor is small (-0.22 years) and not statistically significant (p=0.102). However, linear model AGE~VESSEL*LENGTH (allowing for different length dependencies) shows that aging on Tridens show stronger dependence on length that aging on J. Hjort (Tridens: 0.31 yr/cm; J. Hjort: 0.21 yr/cm, p=0.031).

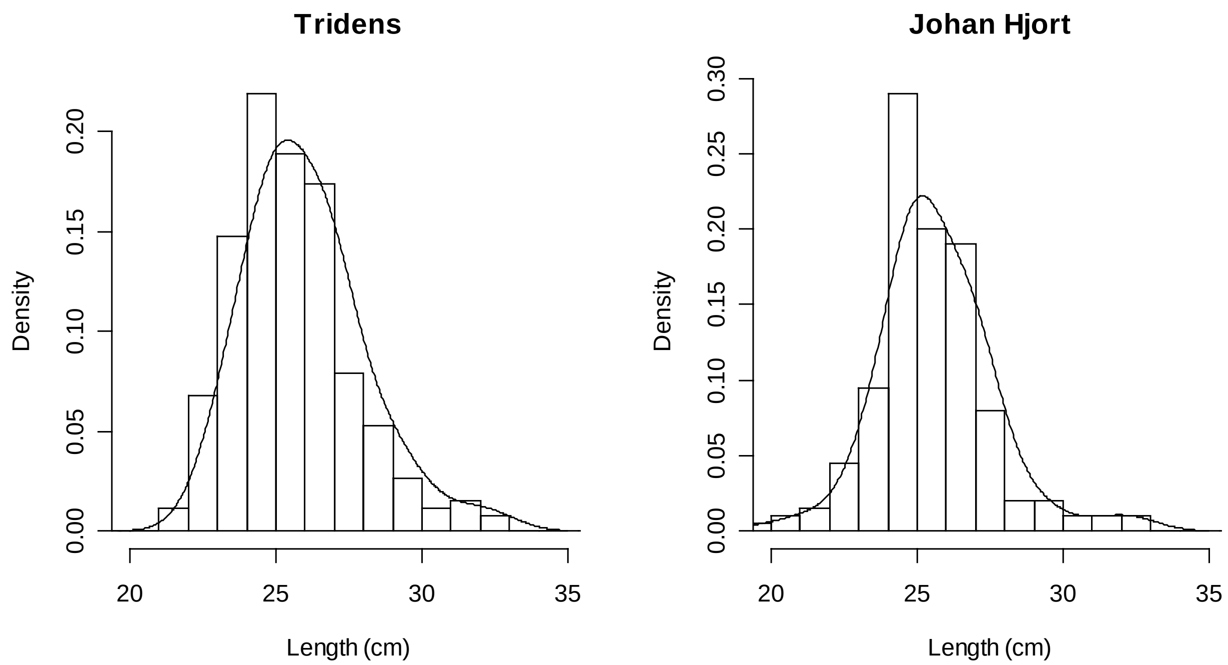

Figure 3. Length distributions from the trawls hauls of Tridens and J. Hjort. Smoothing is obtained by normal kernel density estimates. J. Hjort: n=200; Tridens: n=265.

Appendix 3. Inter-calibration between R/V Fridtjof Nansen and R/V Johan Hjort

Acoustic inter-calibration between R/V Johan Hjort and R/V Fridtjof Nansen was conducted on 9 April 2004 off the shelf edge north of the Outer Hebrides (N 59^o 00' and W 08^o 20') under reasonably good weather conditions. The inter-calibration was run over 39 nautical miles between 06:35-12:35 GMT. For the first 30 nm, both vessels were cruising towards the shelf at course 160º, with F. Nansen following J. Hjort at a distance of about 0.2 nm to the starboard side at speed of 7-8 knots. At the shelf edge the vessel turned to the opposite direction, but problems with bubbles forced a turn to new course at 30º. The inter-calibration was then continued for further 9 nm. In the beginning the logs were synchronized. Synchronization remained satisfactory all through the calibration.

The main acoustic features in the area were a layer in depths of 50-200 m, probably consisting of mesopelagic fish, and a layer of blue whiting in depths around 400-600 metres. The blue whiting layer was well-defined in the beginning but got gradually sparser and vertically more dispersed closer to the shelf edge. The range of acoustic densities encountered was, however, relatively low.

The data were stored by 100 m depth layers. Contamination from false bottom echoes was dealt with during the post-processing of the data. As the main acoustic features spanned more than one such 100 m depth layer, we focus on combined layers from depths of 15-200 m and from 400-600 m. In addition, the data were scrutinized, and the acoustic densities allocated to blue whiting were compared. However, towards the end of the inter-calibration blue whiting were increasingly mixed with other acoustic targets, making scrutinizing more difficult than during normal survey conditions.

Figure 1 shows acoustic densities recorded by the two vessels for the depth layers corresponding to the main layers. These display similar overall patterns but considerable differences between individual observations. Regression models fitted on both natural and logarithmic scales show reasonable fits (moderately high R^2) with positive intercepts and slope parameters less than one (Table 1); the deviations from one-to-one relationship are mostly statistically significant. The general pattern suggested by these regressions is that Fridtjof Nansen tends to record lower acoustic densities than Johan Hjort on all but lowest densities where the situation is reversed.

Scrutinized data from the two vessel show similar correspondence as raw data (Figure 2). For the first 30 nautical miles, the data are noisy but there is no clear, consistent difference between the vessels. For the last 9 nm values by F. Nansen are consistently lower than those from J. Hjort, indicating that the difference arises from different scrutinizing of data rather than spatial heterogeneity.

We established regression models to compare the acoustic observations by the two vessels (Table 2). These display a pattern similar to the one in raw data: positive intercepts and slope parameters less than one; however, the intercepts are not significantly different from zero. For regressions forced through the origin the slope parameter is either 0.630 or 0.655, depending on whether the last nine miles are included. However, it is obvious that because of rather noisy data, it is not possible to estimate the slope robustly: bootstrapping the data gives 95% confidence limits (0.453, 0.880) for the whole data, and (0.474, 0.922) for the first 30 nm.

The regression models suggest that Fridtjof Nansen tends to record by about 35 % lower acoustic densities than Johan Hjort. As this factor is larger for scrutinized data than for raw data, it is probable that part of the difference comes from scrutinizing. Another reason probably is the difference between hull-mounted (as in F. Nansen) and drop-keel mounted (as in J. Hjort) transducers:

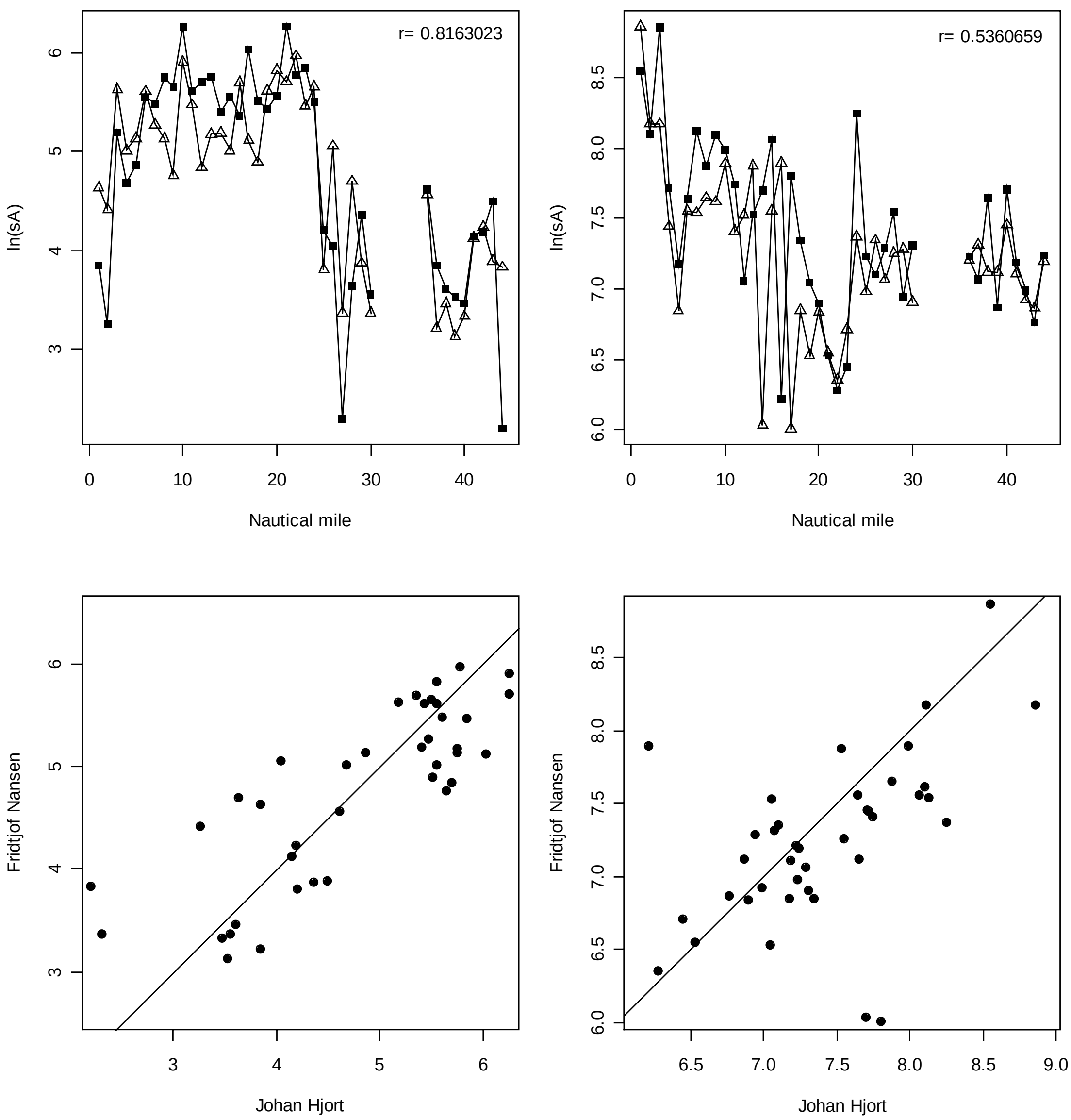

Figure 1. Acoustic densities recorded at the depth layers 15-200m (top left) and 400-600 m (top right) by Fridtjof Nansen (triangles) and J. Hjort (squares). Correlation coefficients between the time series are inserted. The break in curves is due to course adjustments by the shelf edge. The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

Table 1. Regression models for the miles 1-30 and 36-44 (n=39). The null hypothesis for t-tests on slope is that the slope is not different from one. Acoustic densities from Johan Hjort are taken as the independent variable and those from Fridtjof Nansen as the dependent variable. The last four models are forced through the origin.

Depth layer	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
15-200 m	Intercept	51.1	18.2	2.81	0.008	58.4
	Slope	0.575	0.080	-5.32	<0.001	
400-600 m	Intercept	479	256	1.87	0.069	44.9
	Slope	0.592	0.108	-3.78	<0.001	
15-200 m,	Intercept	1.628	0.371	4.38	< 0.001	66.6
log-trans.	Slope	0.654	0.076	-4.55	< 0.001	
400-600 m,	Intercept	3.447	0.985	3.50	0.001	28.7
log-trans.	Slope	0.512	0.133	-3.69	0.001	
15-200 m	Slope	0.753	0.053	-4.67	< 0.001	84.1
400-600 m	Slope	0.761	0.061	-3.91	0.001	80.4
15-200 m, log	Slope	0.979	0.020	-1.05	0.227	98.5
400-600m, log	Slope	0.974	0.012	-2.18	0.040	99.4

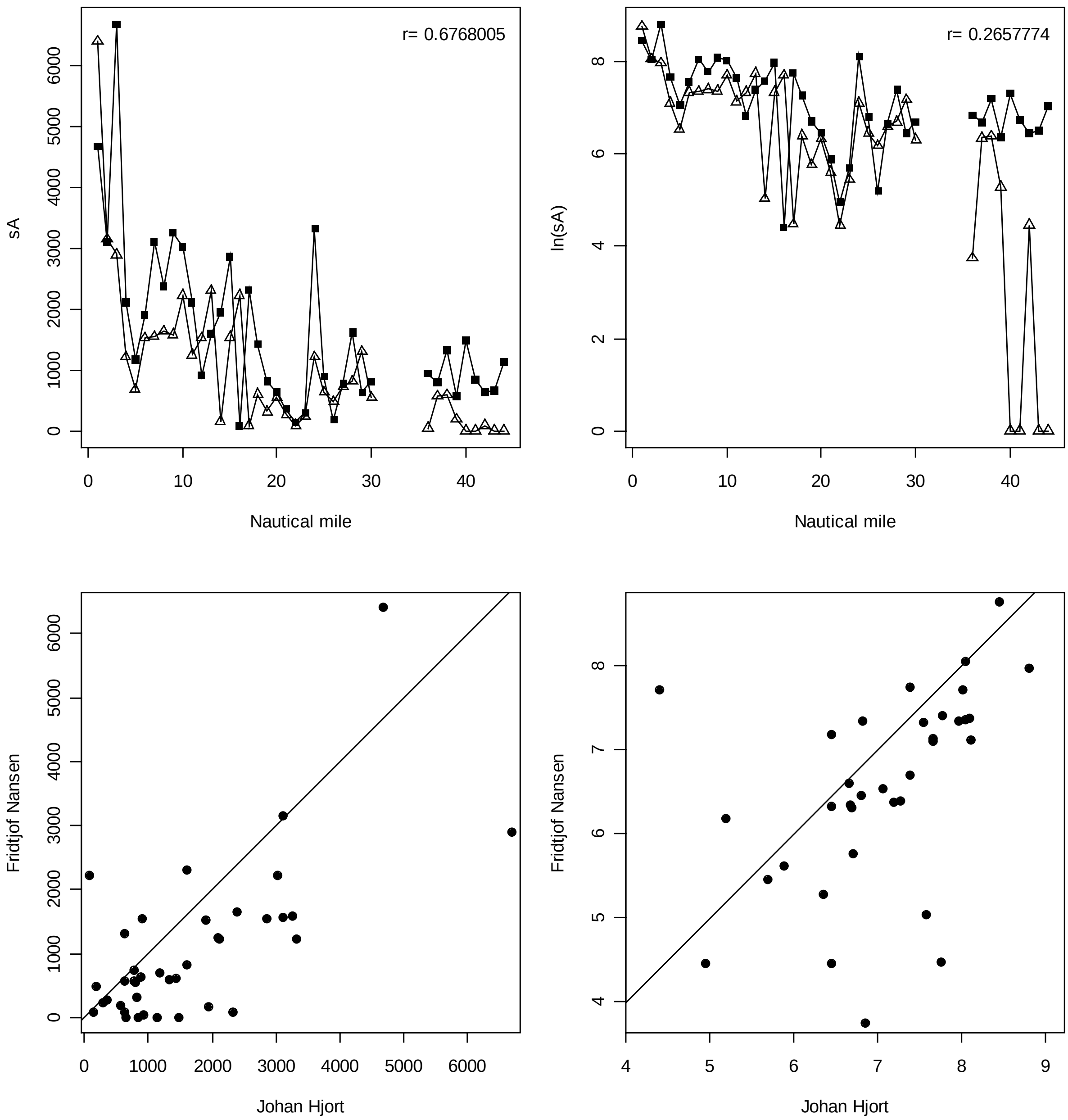

Figure 2. Comparison of blue whiting acoustic densities recorded by Fridtjof Nansen (triangles) and J. Hjort (squares). Acoustic densities equal to zero have been replaced with s_A=1 in the top right panel. The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

Table 2. Regression models for the whole scrutinized data (n=39), and for the first 30miles. Intercept is estimated in the first two regressions, whereas regression through the origin is assumed for the last two. The null hypothesis for t-tests on slope is that the slope is not different from one. In order to make the models more robust for possible predictions outside the observed ranges no logarithmic transformation was applied. Acoustic densities from Johan Hjort are taken as the independent variable and those from Fridtjof Nansen as the dependent variable.

Data	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
All	Intercept	74.76	227.9	0.328	0.745	45.8
	Slope	0.603	0.107	-3.68	0.001	
First 30nm	Intercept	314.5	287.5	1.09	0.283	41.9
	Slope	0.550	0.122	-3.68	0.001	
All	Slope	0.630	0.068	-5.45	< 0.001	69.4
First 30nm	Slope	0.655	0.0764	-4.52	< 0.001	71.7

the former is much more susceptible to additional absorption and drop-outs caused by bubbles that lead to lower recorded acoustic densities.

The actual correction factor (or more generally, function) to convert acoustic observations by F. Nansen to the scale of J. Hjort cannot be estimated very reliably from the data. There are two independent reasons for this. First, the data are rather noisy. Second, the data cover only a limited range of acoustic densities. This is particularly important as values higher than the highest one observed in this exercise (6686 m^2/nm^2) make up almost one half of the cumulative acoustic density (despite accounting for only about 3% of data at the time of writing). Discrepancies arising from scrutinizing are likely to be relatively smaller for dense aggregations of blue whiting, such that data set including high densities would probably suggest higher slope. It would therefore be prudent to apply not one but several correction factors while combining data from the two vessels in order to check robustness of the results to this choice.

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 half nautical mile apart. Fridtjof Nansen towed at depth of 500 m for 46 minutes and caught 293 kg of blue whiting. J. Hjort towed for 50 minutes at depths of 495-515 metres and caught 60 kg of blue whiting. The length distributions in the catches display some dissimilarities (Figure 3). Median lengths are rather similar (F. Nansen: 27.1 cm, J Hjort: 26 cm), but the catch of F: Nansen is more skewed, containing much more large and somewhat fewer small blue whiting. Blue whiting caught by Johan Hjort were significantly smaller (mean±sd: 26.2±2.1 cm) than the blue whiting in the catch of F. Nansen (27.7±3.0cm). The difference was statistically significant ($p<0.001$) and similar in magnitude to what has been observed in 2003 when comparing Norwegian and Russian pelagic research trawls (Heino et al. 2003). There is also a significant difference in mean age: 4.7 ±1.7 years (±sd) for J. Hjort and 5.9 ±1.7 years for F. Nansen. This difference, however, seems to a large extent be due to differences in age readings: linear model AGE~VESSEL+LENGTH suggests that age readings on F. Nansen for a fish of given length are on average about one years higher that those on J. Hjort.

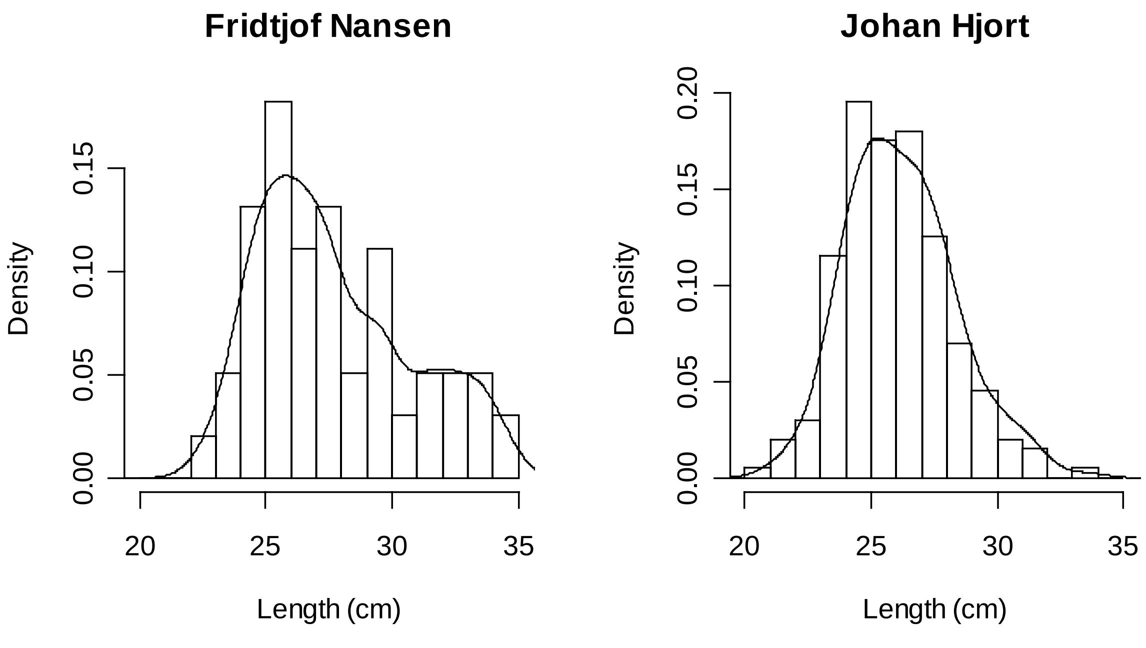

Figure 3. Length distributions from the trawls hauls of Fridtjof Nansen and J. Hjort. Smoothing is obtained by normal kernel density estimates. J. Hjort: n=200; Fridtjof Nansen: n=100.