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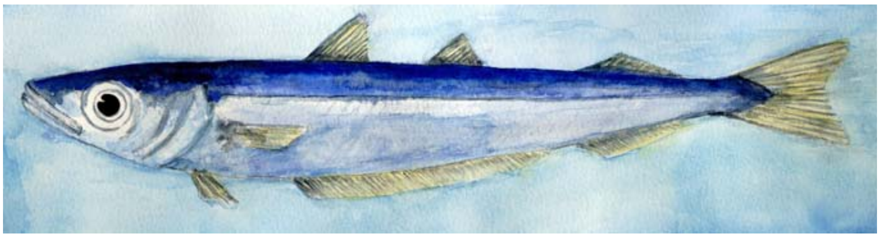

INTERNATIONAL BLUE WHITING SPAWNING STOCK SURVEY SPRING 2007

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Introduction

In spring 2007, 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 fourth 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. 2007; Eros: Godø et al. 2007; M. Heinason: Jacobsen et al. 2007; Tridens: Ybema 2007).

This report is based on a workshop held after the international survey in IJmuiden, 18–19/4/2007 where the data were analysed and the report written. Parts of the document were worked out through correspondence during the workshop and during a protracted period 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 2006 (ICES 2006a), 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
Atlantida	AtlantNIRO, Kaliningrad, Russia	17/3–24/3
Celtic Explorer	Marine Institute, Ireland	28/3–12/4
Eros	Institute of Marine Research, Bergen, Norway	20/3–27/3
Magnus Heinason	Faroese Fisheries Laboratory, Faroe Islands	30/3–10/4
Tridens	Institute for Marine Resources & Ecosystem Studies, the Netherlands	9/3–20/3

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). Contacts were maintained between the vessels during the course of the survey, primarily through electronic mail.

Bad weather hampered the survey effort for much of March, causing either a reduction in vessel speed, or periods where surveying had to be suspended. Engine problem forced Atlantida to prematurely abandon the survey.

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 the survey (Celtic Explorer, M. Heinason, Tridens, Eros). Salient acoustic settings are summarized below.

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

	Atlantida	Celtic Explorer	Eros	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**, 120	**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	9	3	7
Upper integration limit (m)	10	15	15	7	12
Absorption coeff. (dB/km)		9.9	9.785	10	9.7
Pulse length (ms)	Medium	1.024	1.024	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)	-21.1	-20.6	-20.8	-20.9	-20.6
Sv Transducer gain (dB)	27.57			27.22	25.11
Ts Transducer gain (dB)	27.73	25.55	25.55	27.35	
s_A correction (dB)		-0.65	-0.65		-0.67
3 dB beam width (dg)					
alongship:	6.81	6.39	7.05	7.02	6.99
athw. ship:	6.67	6.67	7.06	6.86	6.96
Maximum range (m)	750	1000	900	750	750
Post processing software	Sonardata Echoview	Sonardata Echoview	LSSS	Sonardata Echoview	Sonardata Echoview

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

On Celtic Explorer, acoustic data were backed up every 24 hrs and scrutinised using Sonar data's Echoview (V 3.4) 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 (very seldom). In addition, as an experiment, parts of the data were also scrutinised using the Norwegian LSSS system by a different scientist.

On Eros, the acoustic recordings were scrutinized using the Large Scale Survey System (LSSS) 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.

On Magnus Heinason, acoustic data were scrutinised every 24 hrs on board using Sonar data's Echoview (V 4.10) 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 4.10) post processing software. Data were partitioned into only blue whiting using a new developed detection algorithm. Plankton will be partitioned in a later stage. All echograms had been scrutinized by two experienced scientists. To monitor transceiver output, a monitoring algorithm was created in Echoview. Both algorithms will contribute to a general Echoview template used in this survey.

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:

	Atlantida	Celtic Explorer	Eros	Magnus Heinason	Tridens
Circumference (m)	716	768	586	640	1120
Vertical opening (m)	50	50	30-40	42-48	30-70
Mesh size in codend (mm)	16	20	22	40	±20

Typical towing speed (kn)	4.0	3.5-4.0	3.5	3.0-4.0	3.5-4.0

On Eros, some additional samples were taken after the main survey with a commercial blue whiting trawl with 2400 m circumference.

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 30 (Eros), 50 (Celtic Explorer, Tridens) or 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 70 (Eros), 100 (M. Heinason, Celtic Explorer), 200 (Tridens, only length) was measured for length and weight. On Atlantida 30 or more fish were aged, weight and sex and an additional 42 or more 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)[1]. 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

[1] The above-cited TS relationship actually implies $\langle\sigma\rangle = 6.59 \cdot 10^{-7} L^{2.18}$. It is not known where this difference originates from.

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). Atlantida, Celtic Explorer, and Tridens are equipped with SBE911 CTDs. Magnus Heinason was equipped with SBE911 only for the last days of survey, covering the Nolsø–Flugga section. Eros is equipped with SAIV CTD. All vessels were able to take CTD stations to the depth of 2000 meter or more, except Tridens who only took CTD stations to 650 meters.

Results

Inter-calibration results

Results from the inter-calibration between R/V Celtic Explorer and R/V Magnus Heinason are summarized in Appendix 1. Acoustic inter-calibrations showed that the performance of Magnus Heinason appeared to be somewhat different from Celtic Explorer (which was used as the reference vessel). Closer scrutiny of results suggests that some of the difference arose from spatial heterogeneity in blue whiting density. However, the possibility of different behavioural responses of schools should not be overlooked.

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 Celtic Explorer and Magnus Heinason nevertheless suggested rather small differences in size selectivity in mean length relative to Celtic Explorer; the mean length from M. Heinason was 0.8 cm lower. This is a similar difference to that observed between G.O. Sars and M. Heinason in 2006.

Other inter-calibrations were not practical because of large distances in time and/or space.

The age readings from the different vessels showed differences in mean age at a given length (Appendix 2). While these differences may well reflect variability between individuals in different areas, inconsistencies in age readings should also be considered.

Distribution of blue whiting

Blue whiting were recorded in most of the survey area that covered about 135 thousand square nautical miles (Figures 4–6). The highest concentrations were recorded in the area between the Hebrides, Rockall and Faroes Banks. For example, a record dense school was recorded in the northern flanks of the Porcupine Bank (Figure 7).

In comparison to 2006, the biomass was comparatively distributed, although a moderate decrease in biomass was recorded in the Rockall sub area. In the transboundary region between North and South Porcupine and Rockall sub-areas a notable increase of biomass was recorded in 2007. With the exception of the southern and western extremes of the survey confines remaining 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 2007 international survey was 11.2 million tonnes, representing an abundance of 104×10^9 individuals (Table 2). The spawning stock was estimated at 11.1 million tonnes and 102×10^9 individuals. The geographical distribution of total stock biomass by stratum is shown in Figure 8.

In comparison to the results in 2006, there is a modest increase in stock biomass and a modest decrease in stock numbers:

		2004	2005	2006	2007	Change from 2006 (%)
Biomass (mill. t)	Total	11.4	8.0	10.4	11.2	+8
	Mature	10.9	7.6	10.3	11.1	+8
Numbers (10^9)	Total	137	90	108	104	–4
	Mature	128	83	105	102	–3
Survey area (nm^2)		149 000	172 000	170 000	135 000	–20

Survey area is significantly reduced from 2006. This reduction occurred mostly in the peripheral areas which have had low densities in earlier years. Also two rectangles south of Rockall were excluded this year.

There was substantial heterogeneity in the temporal trend between the sub-areas. There was very large relative increase in the southern (Porcupine Bank) sub-areas, whereas biomass was unchanged in the Hebrides, slightly increased in the Faroes/Shetland sub-area and decreased the Rockall sub-area:

Sub-area		Biomass (million tonnes) 2006		2007		Change (%)
			% of total		% of total	
I	S. Porcupine Bank	0.20	2	0.75	7	275
II	N. Porcupine Bank	0.74	7	1.8	16	141
III	Hebrides	5.2	50	5.3	47	1
IV	Faroes/Shetland	0.94	9	1.1	10	17
V	Rockall	3.3	32	2.3	20	–31

Stock composition

Stock in the survey area is dominated by age classes 4 and 5 years (year classes 2003 and 2002), which make together about 55% of spawning stock biomass (Table 3, Figure 8). These are the same year classes that dominated the stock in 2006, although their ranking is now swapped. The numbers of the 2003 year class remain unchanged (suggesting that it was not yet fully recruited to the spawning stock in 2006), whereas the numbers of age class 2002 are reduced by 36 %.

Half of the spawning stock biomass was recorded in the Hebrides sub-area, as was the case also in 2006. The age structure of stock in this area resembled that of the total survey area (Figure 9). In the northern areas, younger blue whiting were relatively more abundant, while in the Rockall, there were particularly few young blue whiting. This is similar spatial structuring as observed earlier.

Virtually 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 virtually all fish were mature in the Hebrides sub-area and all fish were mature in the other areas. In particular, in the Porcupine Bank no juveniles were encountered, despite two hauls on the slopes of the bank where juvenile often occur.

Concluding remarks

Main results

- The fourth international blue whiting spawning stock survey shows a modest increase in stock biomass (~8%) and a modest decrease in stock numbers (~3–4%) in comparison to the survey in 2006. The biomass estimates are almost as high as in 2004 when the largest stock was measured, whereas stock numbers are markedly lower than in 2004.

- The survey area was reduced by about 20 % from 2006. Most of the reduction came from areas with low density in 2006. Nevertheless, the estimates would have been expected to be higher if the same coverage were achieved.
- Most of the increase in the stock estimate comes from the southern sub-areas (the Porcupine Bank). This area was covered earlier in season this year than in 2006. With later coverage, the biomass would probably have moved to the Hebrides sub-area. In the Hebrides and the Faroes sub-areas biomass was essentially unchanged, whereas biomass decreased in the Rockall sub-area where coverage was also significantly reduced.
- The stock in the survey area is dominated by age classes 4 and 5 years (year classes 2003 and 2002), which make together about 55% of spawning stock biomass. These are the same year classes that dominated the stock in 2006, although their ranking is now swapped.
- Mean age (4.6 years), length (27.7 cm) and weight (108 g) are the highest on record in the international survey time series (2004–2007). Numbers of “old” blue whiting, ages 6 to 8 years, are the highest on record. On the other hand, numbers of young blue whiting, ages 1 to 3 years, are record low. Recruitment to the spawning stock appears to be rather low.
- The spawning stock biomass appears to be maintained to a large degree by growth of individuals in the spawning stock while recruitment makes a moderate contribution.
- Dealfish (*Trachipterus arcticus*) continued to be present at most of the trawl catches. Also catch numbers were often high, and dealfish was often among the species that made up bulk of the sample biomass. 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.
- Distribution of blue whiting in the spawning area is highly dynamic. The survey currently stretches over a five to six week period. Longer survey time periods are considered to increase the likelihood of double counting of migrating schools. It is therefore proposed that a more concerted effort will be made during the 2008 survey to conduct the survey over a four week window.
- Rough assessment of uncertainty in the acoustic data suggests that 95% confidence intervals for total stock biomass estimate are 20%...+22%, and 50% confidence limits are –7.7%...+7.2% (Appendix 3). This high uncertainty is caused by very high proportion of total acoustic backscattering having been observed over very short parts of survey track. In 2004–2006, the uncertainty was lower, roughly ±10…13%. Because of high uncertainty in 2007 in particular, the change in stock biomass is within what could be caused by chance factors, and we cannot reject the null hypothesis that stock biomass is unchanged.

Recommendations

- Coordinated survey timing- the issue of coordinated timing was raised. At present all members agree that the temporal progression of the survey is too long, taking up to 6 weeks to complete the entire survey program. Peak spawning time is between the last 2 weeks of March and the first 2 weeks in April (± 1–2 weeks). The group recommends a more concerted effort to survey the entire area between these times over a 3–4 week time frame.

- Review southern extension of survey coverage with the aim of refocusing survey effort to the area north of 52°N
- Dealfish: Data review underway. The group recommends biological data should be collected from individuals encountered during the 2008 survey.
- Pre-agreed preliminary survey tracks to be formulated at the PGNAPES 2007 meeting for surveys carried out in 2008.
- Dedicated sub group should be maintained within PGNAPES meeting to address issues arising from the survey program in 2007
- Data backlog in PGNAPES database from start of coordinated survey time series (2004 onwards): Leon to update the group at PGNAPES August meeting in 2007.
- Update on PGHERS acoustic manual to be provided at the August meeting.
- Data exchange- the group discussed the issue of at sea data exchange. It was suggested that once a vessel has completed an E–W band of ICES rectangles then all transect data (biological, logbook, hydrographic and acoustic) should be made available to the group. This will be restricted to vessels with broadband systems.
- Continue established at sea communications with data summaries, fleet activity and survey findings.
- Location of 2008 post cruise meeting will be arranged in Kaliningrad.
- Maintain survey methodologies as agreed in the PGNAPES acoustic manual for all survey operations (including CTD depth coverage, parallel transect design and spacing and log sheet entries).
- Group recommends the formation of a single species ID guide for the future surveys combining existing knowledge and onboard guides currently in use.
- Echoview Template. Leon Smith has updated Template (V8) with common species codes. Sytse Ybema has also been working on a template that includes a school detection algorithm and transmission detection window. For the 2008 survey these templates should be combined.
- Intercalibration methods to be reviewed and the manual updated.
- Continuation of knowledge and personnel exchange between participant countries and vessels.
- Discussions are to take place at the PGNAPES meeting on how to use the Oracle database to streamline data extraction into the final survey report format.
- Ways to ensure that hydrographic data are analysed at the same time frame as biological data.

Achievements

- Good coverage of core distribution areas
- Improved coordination of survey effort
- Personnel and skill exchange between vessels
- Improvements in semi-automated school detection in currently used post-processing software packages
- First time use of Online Oracle PGNAPES database for historic data extraction

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Table 1. Survey effort by vessel.

Vessel	Effective survey period	Length of cruise track (nm) *	Trawl stations	CTD stations	Aged fish	Length-measured fish
Atlantida	17/3–24/3	919	3	13	205	377
Celtic Explorer	28/3–12/4	1890	18	27	850	2700
Eros	20/3–27/3	1347	10**	20	171	527
Magnus Heinason	30/3–10/4	1402	13	14	549	1363
Tridens	9/3–20/3	897	8	18	262	400

* Used in the stock estimate. Steaming in, e.g., shallow areas excluded.
** Seven more samples were taken after the main survey for commercial and scientific purposes. These include 203 aged and 1000 length-measured fish.

Table 2. Assessment factors of blue whiting, spring 2007.

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	16095	6.9	6.9	100	0.75	0.75	100	108	28.1	47
II	N. Porcupine Bank	16496	17.0	17.0	100	1.8	1.8	100	105	28.0	108
III	Hebrides	34936	51.0	51.7	98.6	5.2	5.3	99.4	102	27.5	151
IV	Faroes/Shetland	16191	8.7	9.7	89.6	1.1	1.1	96.6	114	26.3	68
V	Rockall	51462	18.5	18.5	100	2.3	2.3	100	124	28.4	44
Tot.		135181	102	104	98.3	11.1	11.2	99.4	108	27.7	83

Table 3. Stock estimate of blue whiting, spring 2007.

	Age in years (year class)										Num-	Bio-	Mean	Prop.
Length	1	2	3	4	5	6	7	8	9	10+	bers	mass	weight	mature*
(cm)	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	(10^6)	(10^6 kg)	(g)	(%)
16.0 – 17.0	57	0	0	0	0	0	0	0	0	0	57	1	25	0
17.0 – 18.0	225	0	0	0	0	0	0	0	0	0	225	7	31	0
18.0 – 19.0	450	9	0	0	0	0	0	0	0	0	459	16	34	2
19.0 – 20.0	465	0	0	0	0	0	0	0	0	0	465	19	41	0
20.0 – 21.0	376	57	0	0	0	0	0	0	0	0	433	20	46	13
21.0 – 22.0	150	387	40	128	0	0	0	0	0	0	705	35	50	79
22.0 – 23.0	0	501	763	88	0	0	0	0	0	0	1352	79	59	100
23.0 – 24.0	0	551	1147	154	16	0	0	0	0	0	1868	126	68	100
24.0 – 25.0	0	753	2631	1080	229	108	0	0	0	0	4801	367	77	100
25.0 – 26.0	0	370	4697	4502	1633	188	22	0	0	0	11413	962	84	100
26.0 – 27.0	0	26	4121	8143	4140	1617	551	0	0	0	18597	1702	92	100
27.0 – 28.0	0	0	2107	9497	5418	2734	1184	0	0	0	20941	2088	100	100
28.0 – 29.0	0	0	713	6125	4645	2740	1415	361	174	0	16173	1771	110	100
29.0 – 30.0	0	0	87	1856	4685	2671	904	510	53	0	10766	1327	123	100
30.0 – 31.0	0	0	36	763	2302	1321	1121	530	154	0	6226	894	144	100
31.0 – 32.0	0	0	0	164	997	767	663	526	118	46	3280	531	162	100
32.0 – 33.0	0	0	0	112	505	810	809	129	114	257	2735	496	181	100
33.0 – 34.0	0	0	0	210	107	484	135	181	211	17	1344	266	198	100
34.0 – 35.0	0	0	0	30	79	179	323	115	12	0	739	172	233	100
35.0 – 36.0	0	0	0	0	31	279	141	93	6	184	735	189	258	100
36.0 – 37.0	0	0	0	0	0	0	15	0	110	86	210	63	299	100
37.0 – 38.0	0	0	0	0	0	35	0	48	0	1	84	23	275	100
38.0 – 39.0	0	0	0	0	8	0	0	17	0	23	47	15	325	100
39.0 – 40.0	0	0	0	0	0	17	0	0	0	42	59	24	405	100
TSN (10^6)	1723	2654	16343	32851	24794	13952	7282	2509	951	655	103714			
TSB (10^6 kg)	67.6	181	1415	3285	2793	1732	1006	393	167	153	11193			
Mean length (cm)	19.3	23.5	25.7	27.3	28.3	29.2	29.8	31.1	31.9	34.5	27.7			
Mean weight (g)	39.3	68.3	86.6	100	113	124	138	157	176	234	108			
Condition (g/dm^3)	5.5	5.3	5.1	4.9	5.0	5.0	5.2	5.2	5.4	5.7	5.1			
% mature*	0	100	100	100	100	100	100	100	100	100	98.3			
% of SSB	0	2	13	30	25	16	9	4	2	1				

* Percentage of mature individuals per age or length class

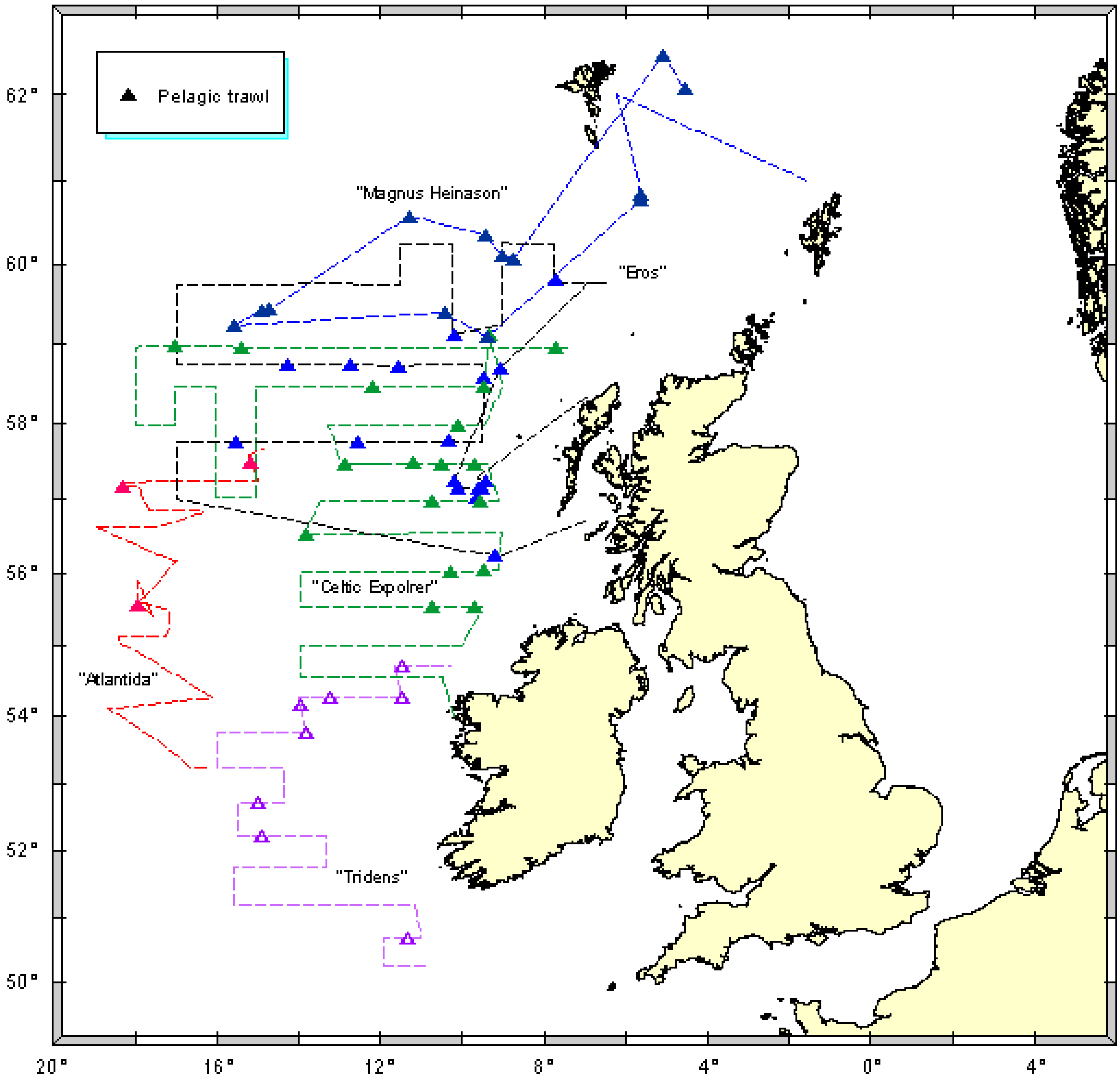


Figure 1. Cruise tracks and trawl stations during the International Blue Whiting Spawning Stock Survey in spring 2007. The figure shows all survey activity; in Figure 4, only the cruise tracks from which acoustic data were used in the stock estimate are shown.

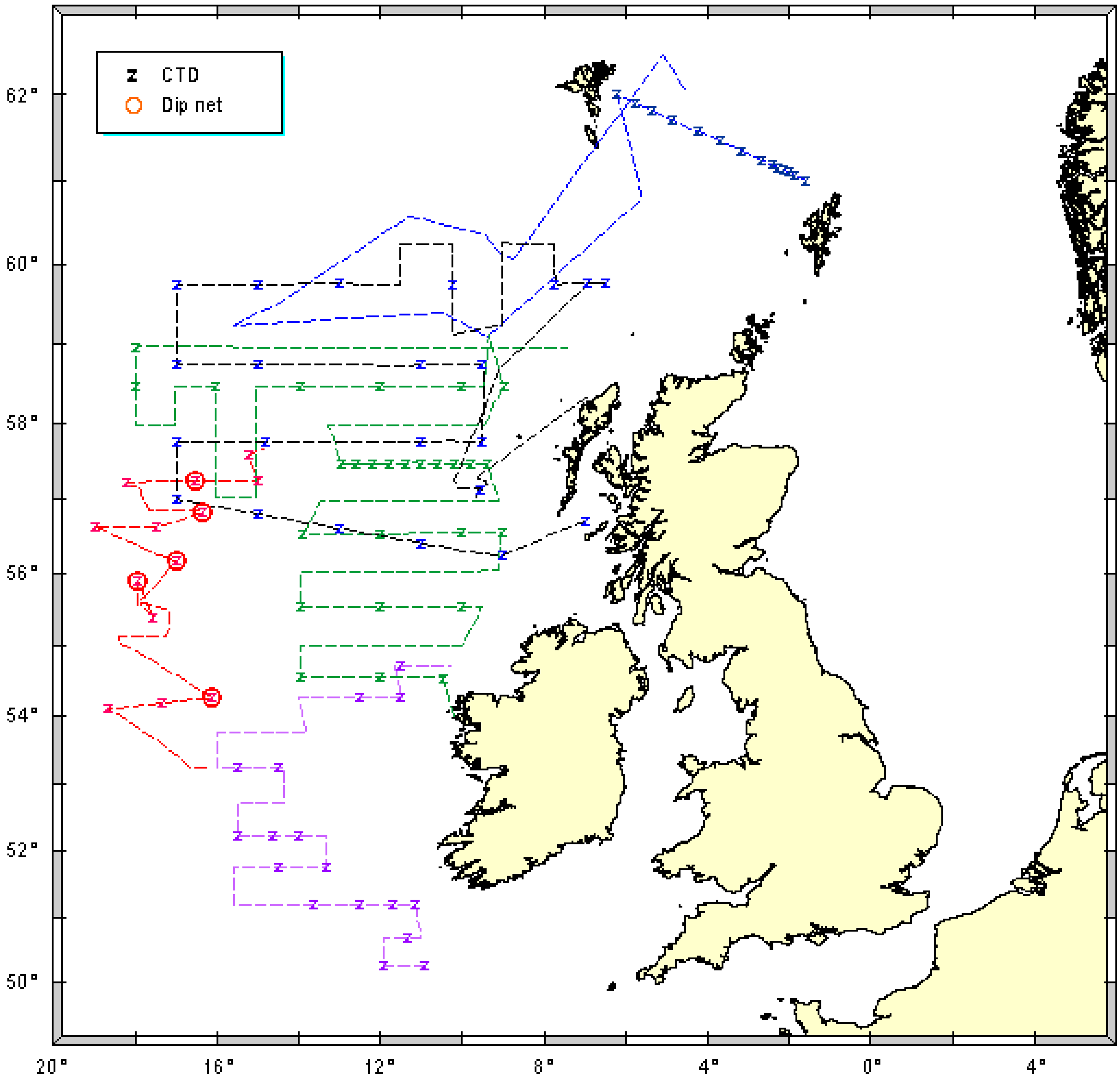


Figure 2. CTD stations for R/V Atlantida, R/V Celtic Explorer, F/V Eros, R/V Magnus Heinason and R/V Tridens in March-April 2007.

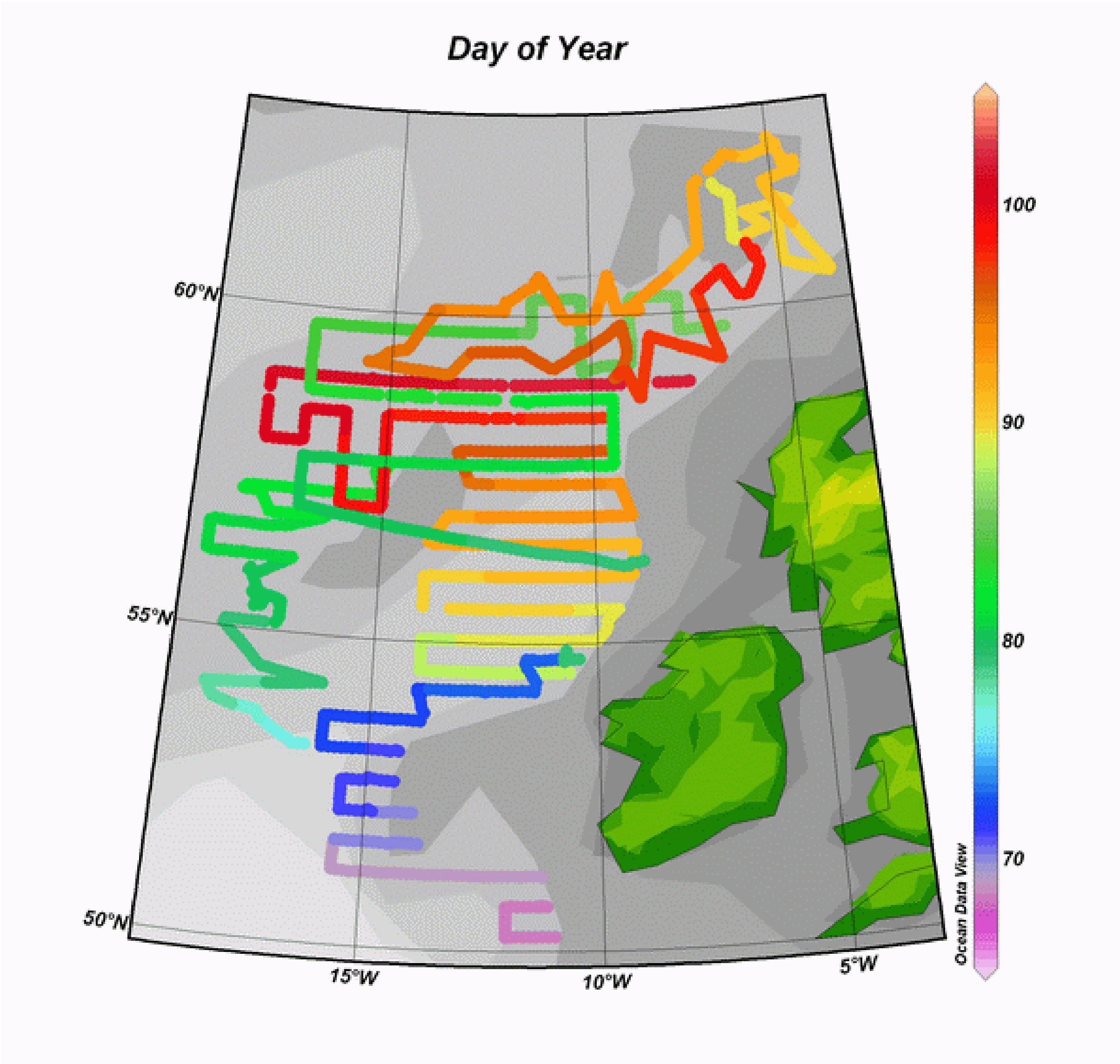


Figure 3. Temporal progression of the survey, 9 March–12 April 2007.

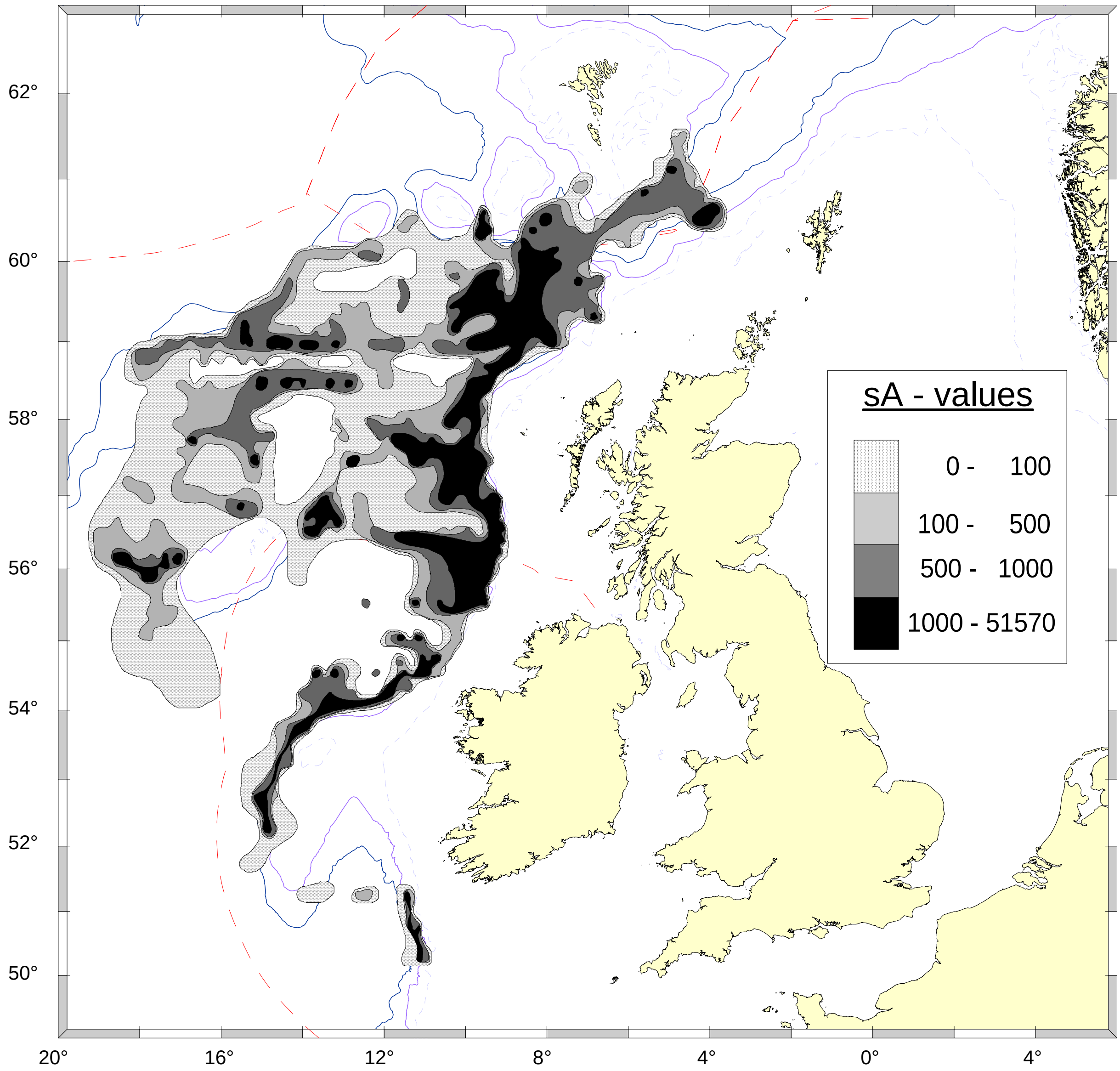


Figure 4. Schematic map of blue whiting acoustic density (s_A, m^2/nm^2) in spring 2007.

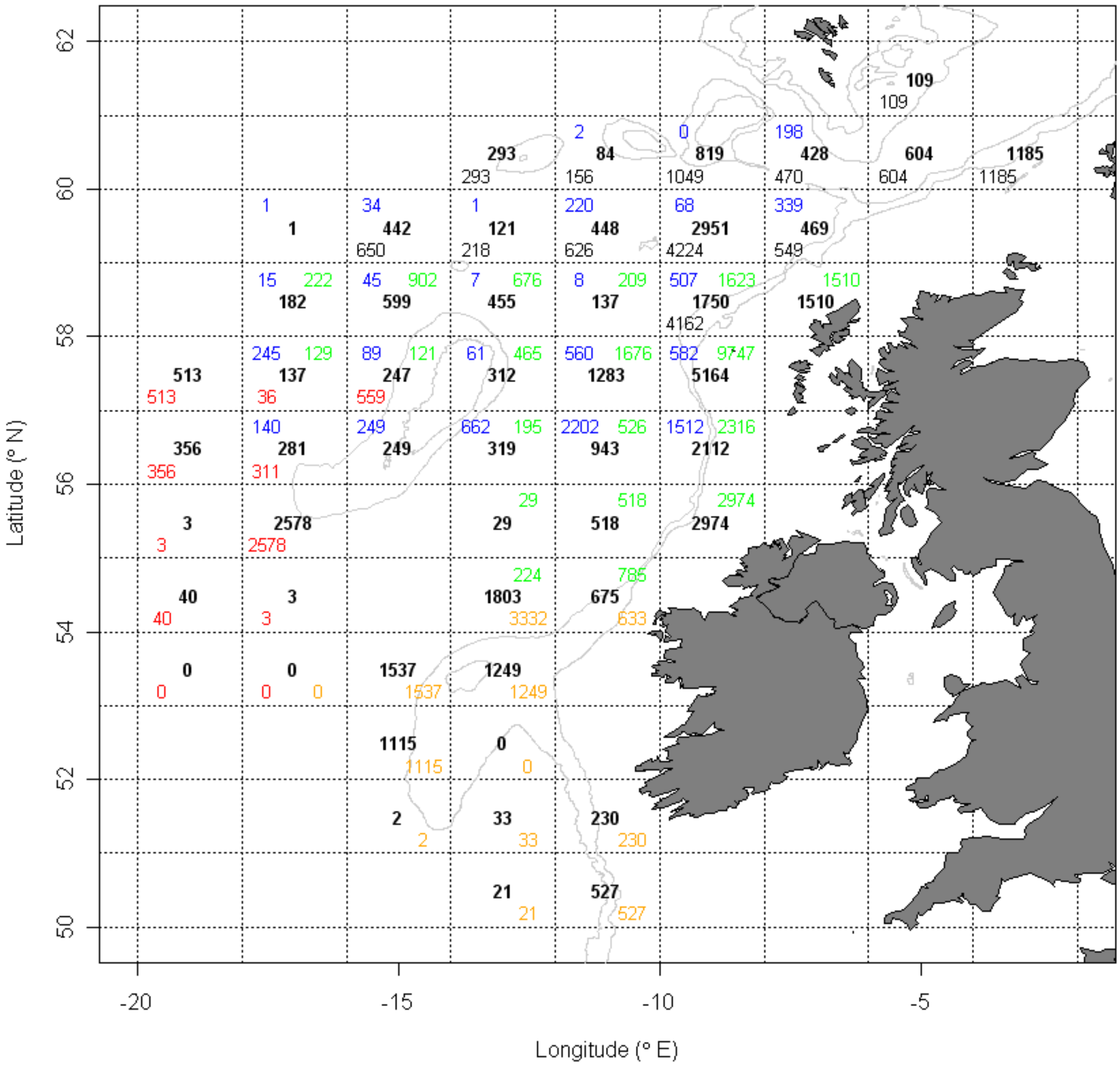


Figure 5. Mean blue whiting acoustic density (s_A, m^2/nm^2) for all vessels combined and for each vessel: Celtic Explorer (top right, green); Magnus Heinason (bottom left, black); Tridens (bottom right, orange); Atlantida (bottom left, red); Eros (top left, blue)

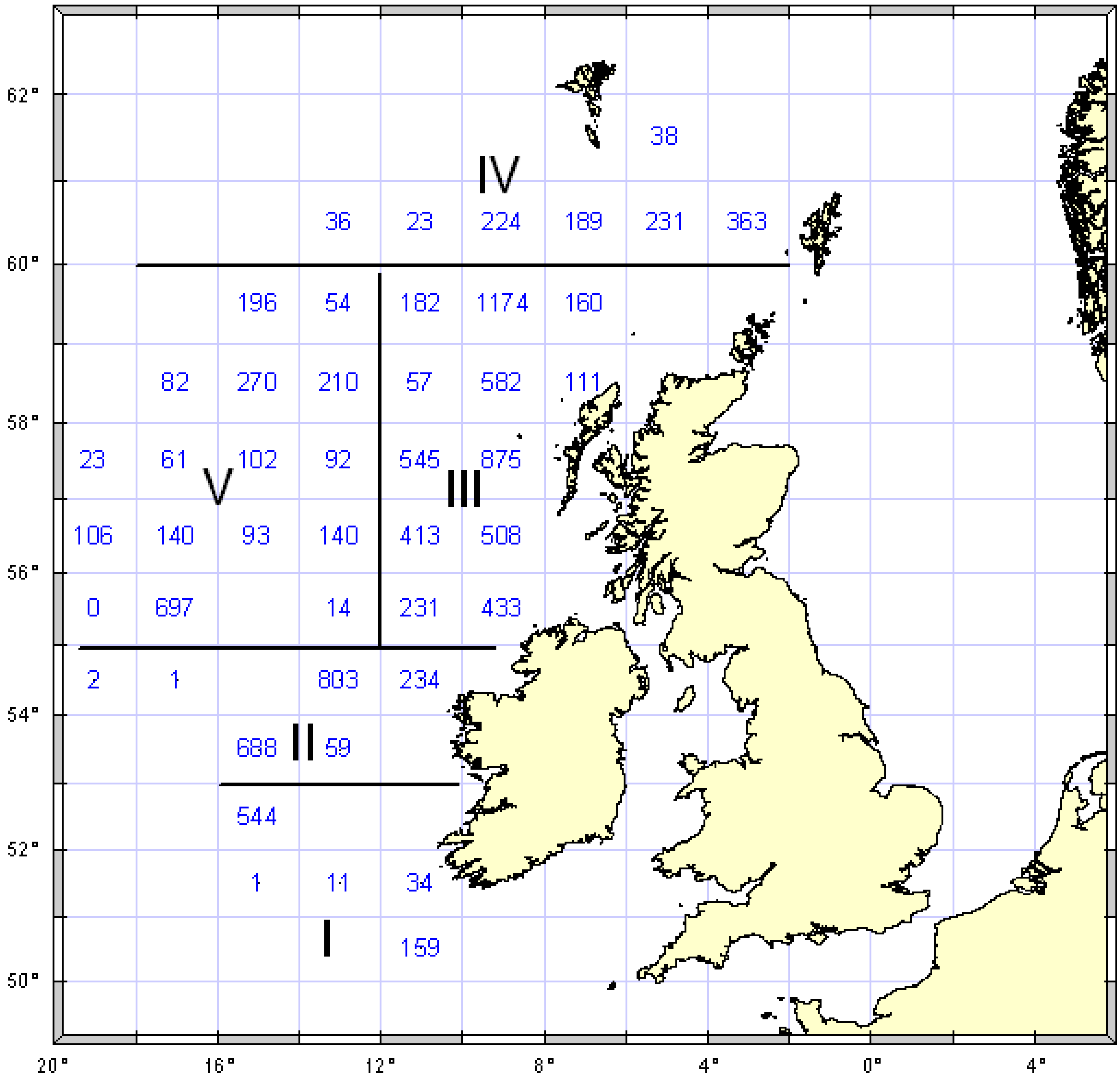


Figure 6. Blue whiting biomass in 1000 tonnes, spring 2007. Marking of sub-areas I-V used in the assessment.

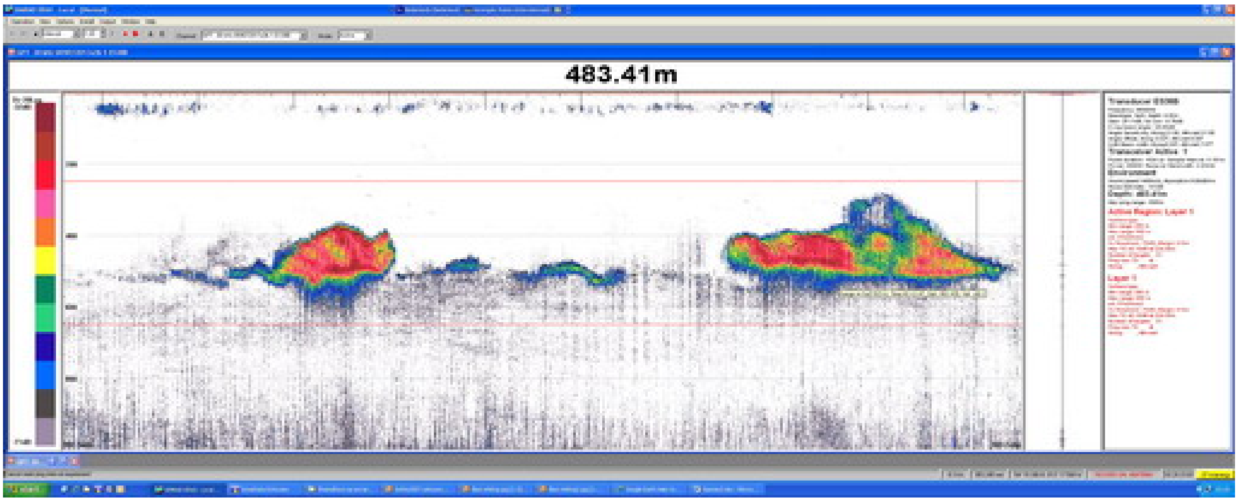


Figure 7. Blue whiting school with acoustic density (s_A) of 279,000 m^2/nm^2 (at 1 nm horizontal resolution) recorded in the northern slopes of the Porcupine Bank. This is the highest acoustic density that has been recorded during the international blue whiting spawning stock surveys.

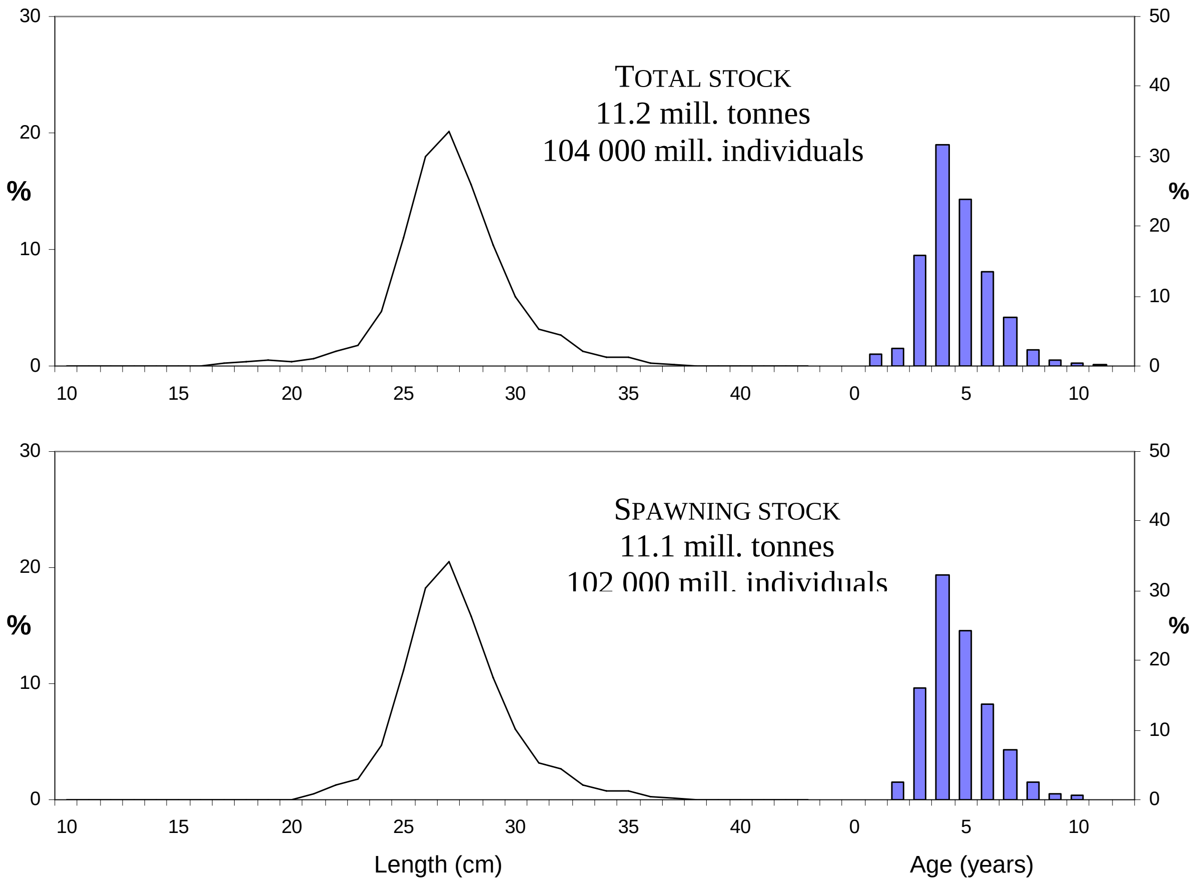


Figure 8. Length and age distribution in the total and spawning stock of blue whiting in the area to the west of the British Isles, spring 2007.

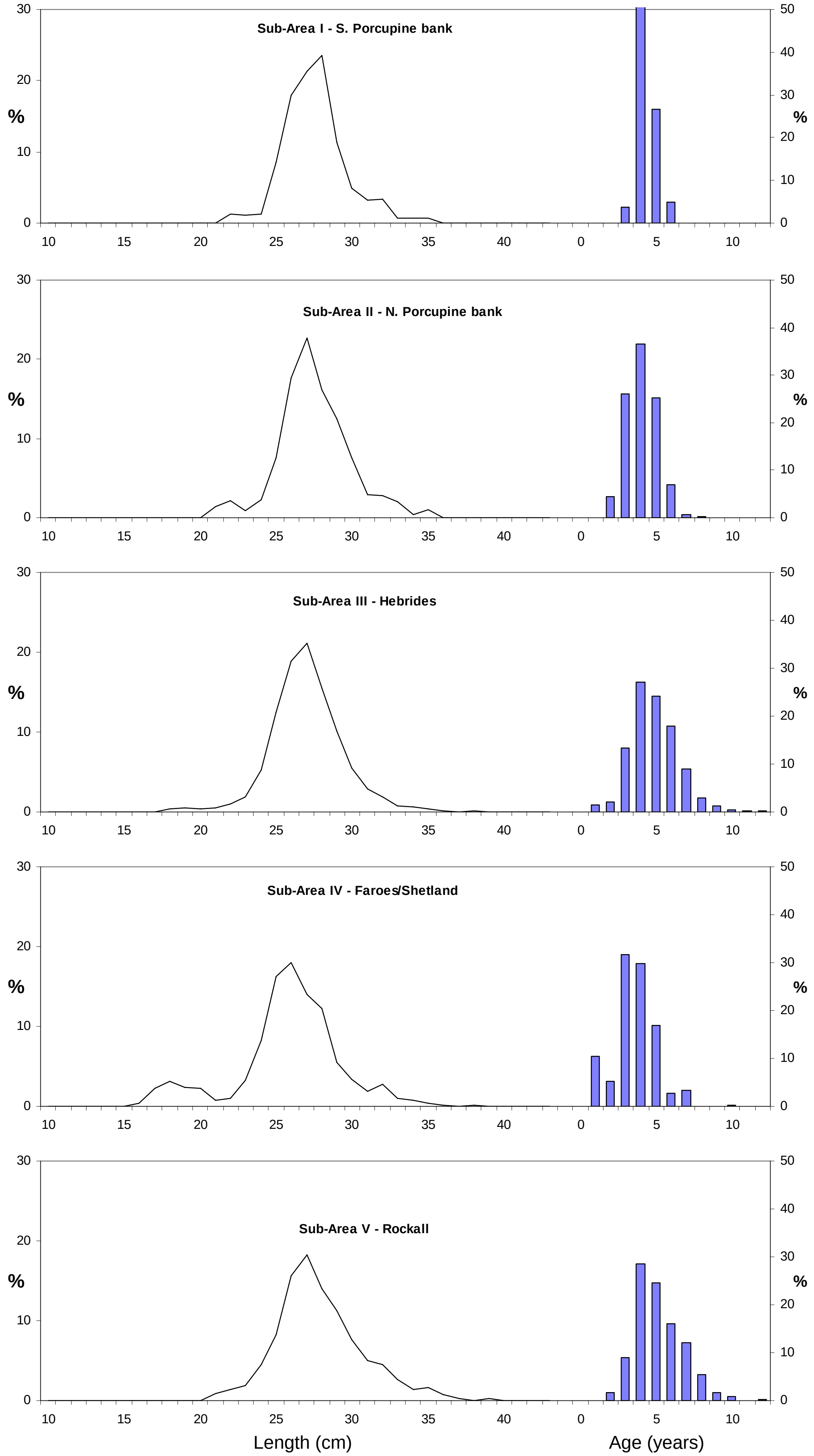

Sub-Area I - S. Porcupine bank
Sub-Area II - N. Porcupine bank
Sub-Area III - Hebrides
Sub-Area IV - Faroes/Shetland
Sub-Area V - Rockall
%
Length (cm)
Age (years)

Figure 8. Length and age distribution of blue whiting by sub-areas (I–V), spring 2007.

Appendix 1. Inter-calibration between R/V Magnus Heinason and R/V Celtic Explorer

Acoustic inter-calibration between R/V Celtic Explorer and R/V Magnus Heinason was conducted on April 7 between the Rosemary Bank and the Hebrides shelf break from about N59°05’ W09°05’ to N58°45’ W08°45’. The weather was fairly favourable with moderate wind (18–20kt from WSW) and moderate swell (about 2 metres from W). The main acoustic features in the area were (1) up to 200 metres thick layer of blue whiting in depths between 400 and 600 metres that was strongest towards the end of the transect, (2) a layer of presumed macro-zooplankton from depth 300 metres downward, partly mixed with the blue whiting layer, and (3) plankton and mesopelagic fish, in the uppermost 200 metres.

The inter-calibration was the run over 25 nautical miles between 02:48-05:47 GMT. Vessels were cruising SSE at parallel courses, with the distance between the tracks being 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. The recordings show a fair qualitative agreement. Regression model suggests that intercept is not significantly different from zero. Regression forced through the origin has high coefficient of determination (R^2) and a slope that is significantly larger than one; the model suggests that Magnus Heinason records some 19% higher acoustic densities for blue whiting than Celtic Explorer. This is a rather large difference. Closer scrutiny of the echograms suggests that the difference can be traced to two sources. First, the echograms from Celtic Explorer showed sudden disappearances of blue whiting echoes for a range of about six nautical miles. These lasted for some tens of seconds at time, while other echoes (including the false bottom recording) were unchanged. The likely reason for this phenomenon is behavioural response (diving) to some vessel noise. This was not visible in recordings of Magnus Heinason. Second, echograms suggest that spatial heterogeneity was contributing to the different recordings. As the vessels were sailing 0.5 nm apart, this is entirely reasonable.

Before 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 nm apart. Celtic Explorer towed for 60 minutes at depths of 420–520 metres and caught 222 kg of blue whiting. Magnus Heinason towed in the same depth for the same time and caught 170 kg of blue whiting.

As seen in Fig. 3, blue whiting in the catch of Celtic Explorer were larger in mean length (mean±sd length: 27.4±2.1 cm) compared to the blue whiting in the catch of Magnus Heinason (26.6±2.1cm). The difference in means was statistically significant (p=0.0002). Although spatial heterogeneity may contribute to the difference, the results suggest that Celtic Explorer is somewhat more efficient in capturing large blue whiting. The difference is similar to the difference recorded in inter-calibrations between Magnus Heinason and G. O. Sars in 2005–2006.

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 Celtic Explorer are taken as the independent variable and those from Magnus Heinason as the dependent variable. n=25.

Model	Parameter	Estimate	Std. Error	t value	Pr(>|t|)	R^2 (%)
Intercept estimated	Intercept	-176	189	-1.36	0.361	97.0
	Slope	1.220	0.044	5.01	<0.001	
Intercept=0	Slope	1.193	0.033	5.91	<0.001	98.2

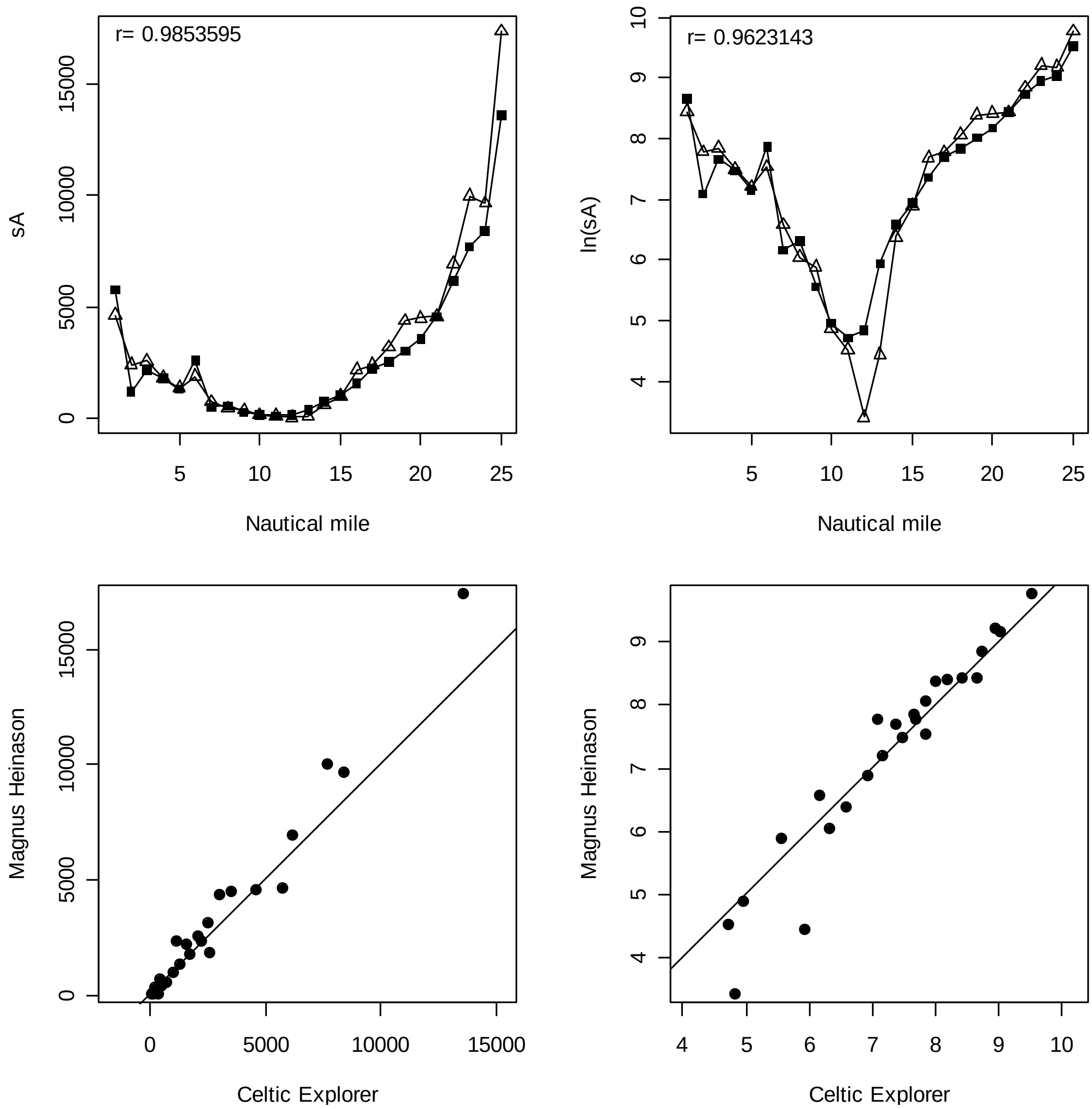


Figure 1. Comparison of blue whiting acoustic densities recorded by Magnus Heinason (open triangles) and Celtic Explorer (squares). The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

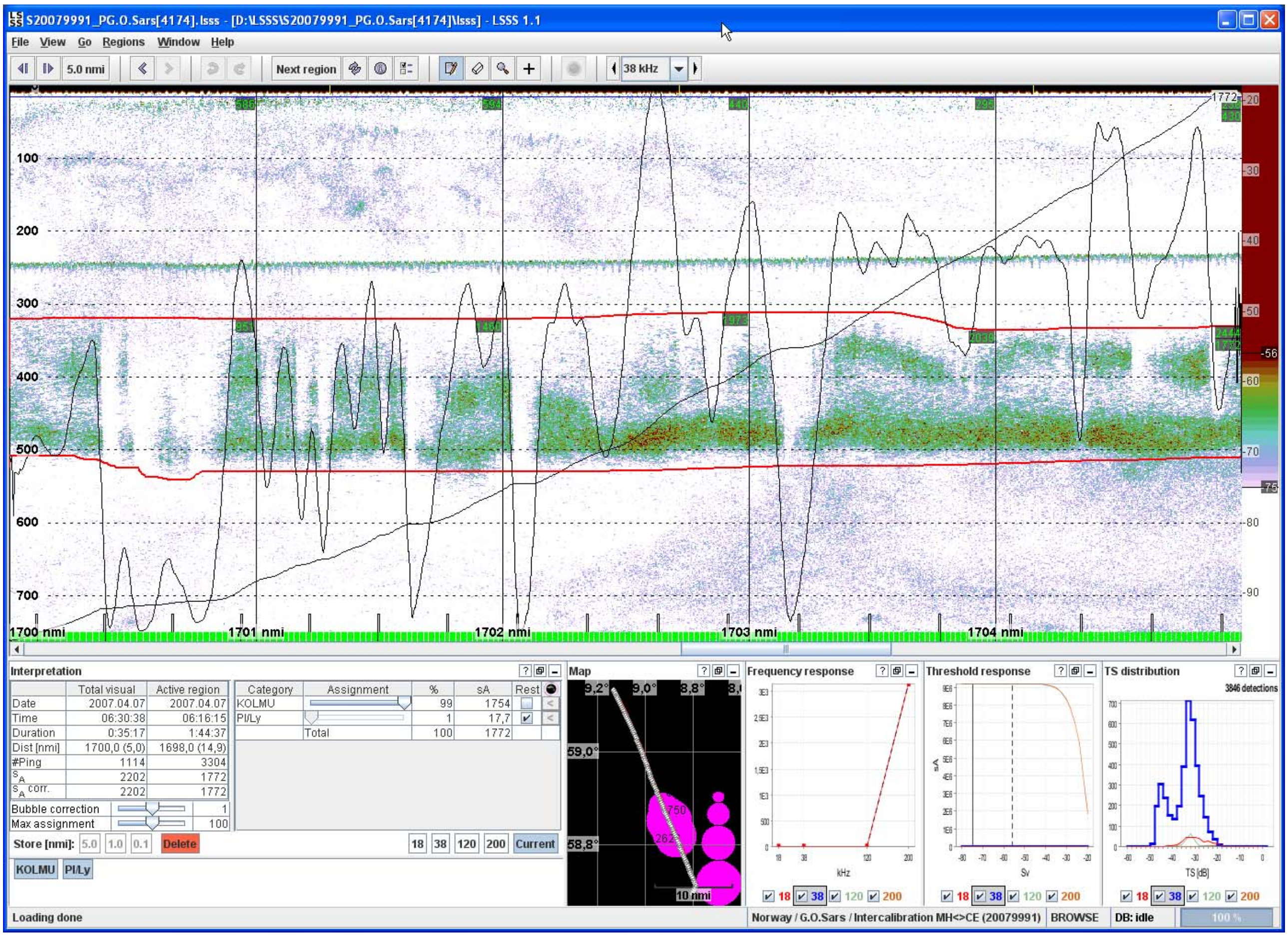


Figure 2. Echogram from Celtic Explorer showing intermittent dissappearance of blue whiting echoes. This phenomenon was virtually absent in the recordings from Magnus Heinason.

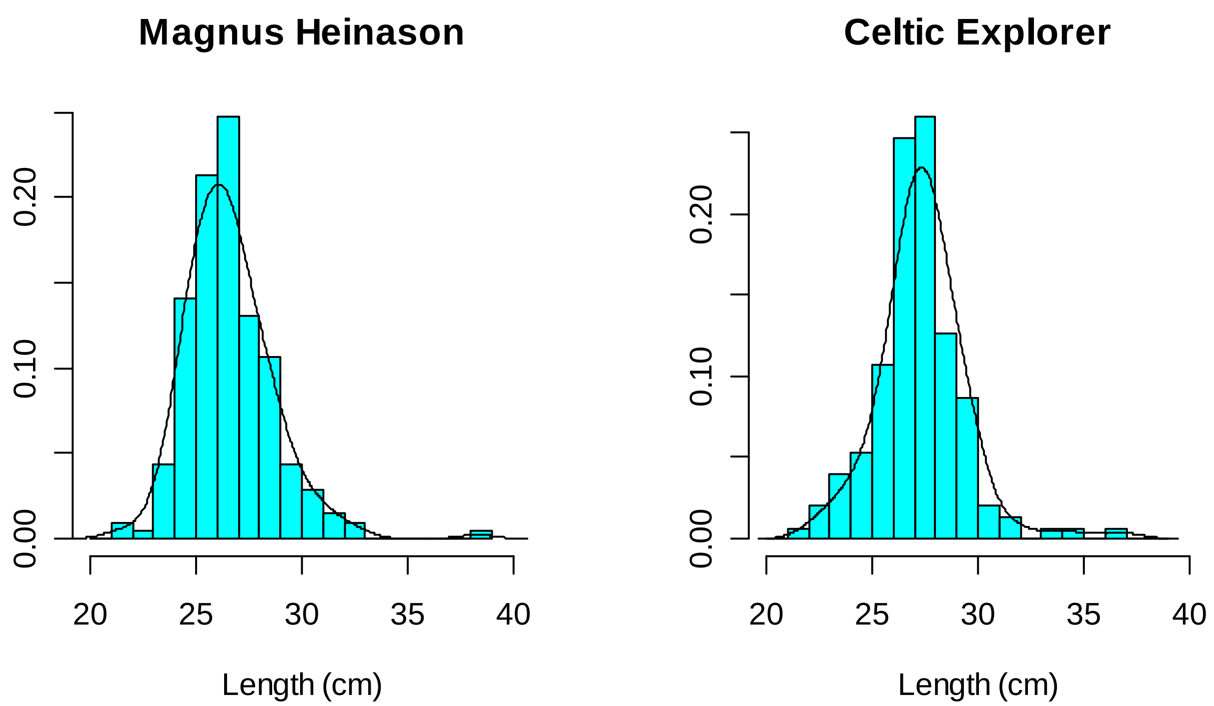
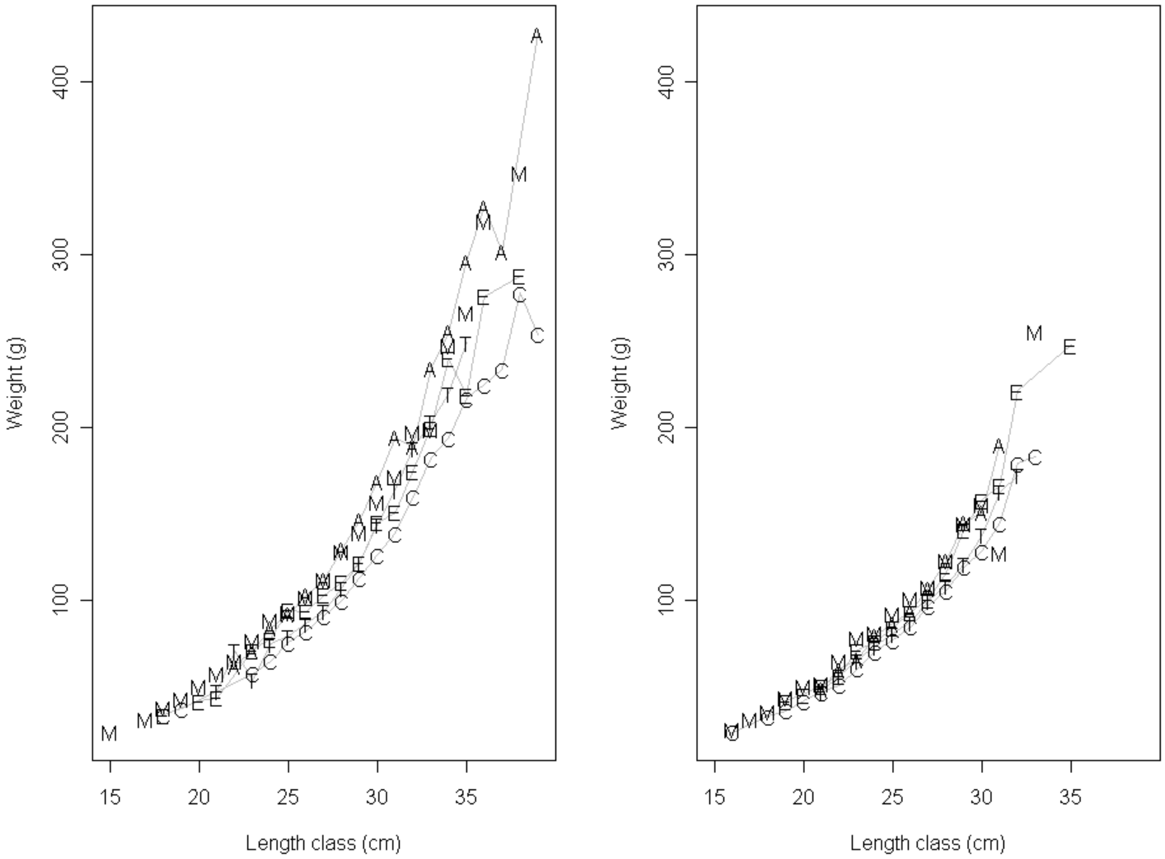
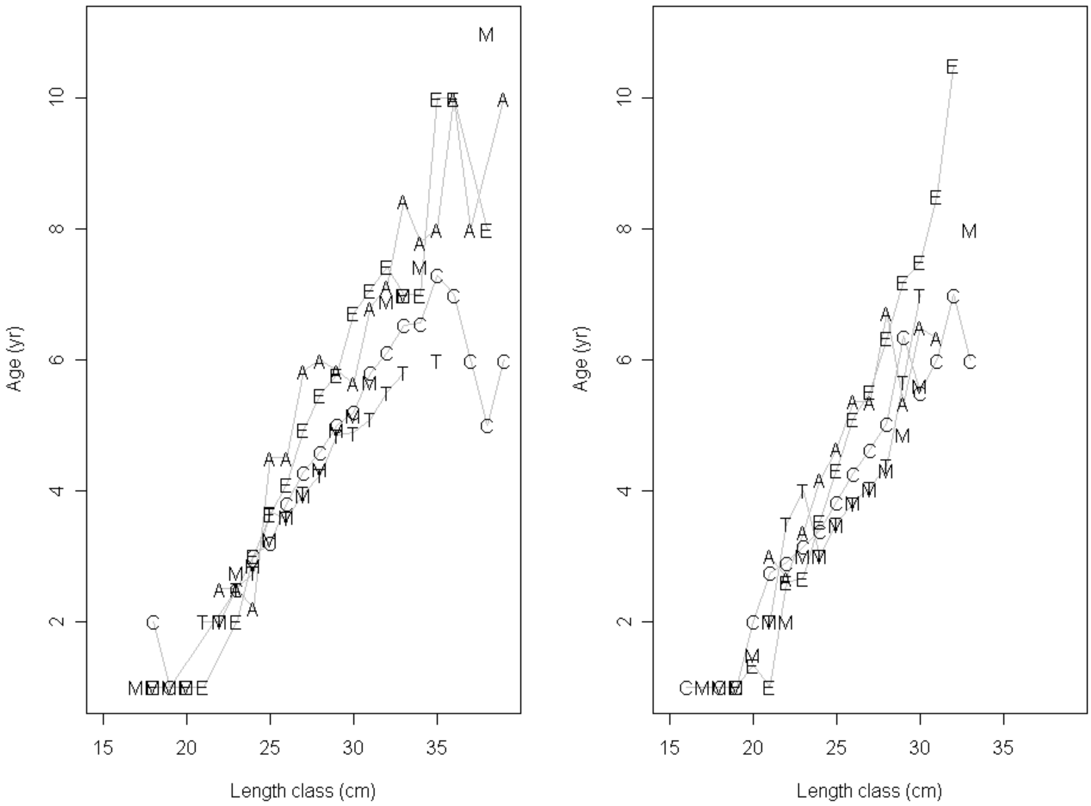


Figure 3. Length distributions from the trawls hauls by Magnus Heinason and Celtic Explorer. Smoothing is obtained by normal kernel density estimates. Celtic Explorer: n=150; Magnus Heinason: n=206.

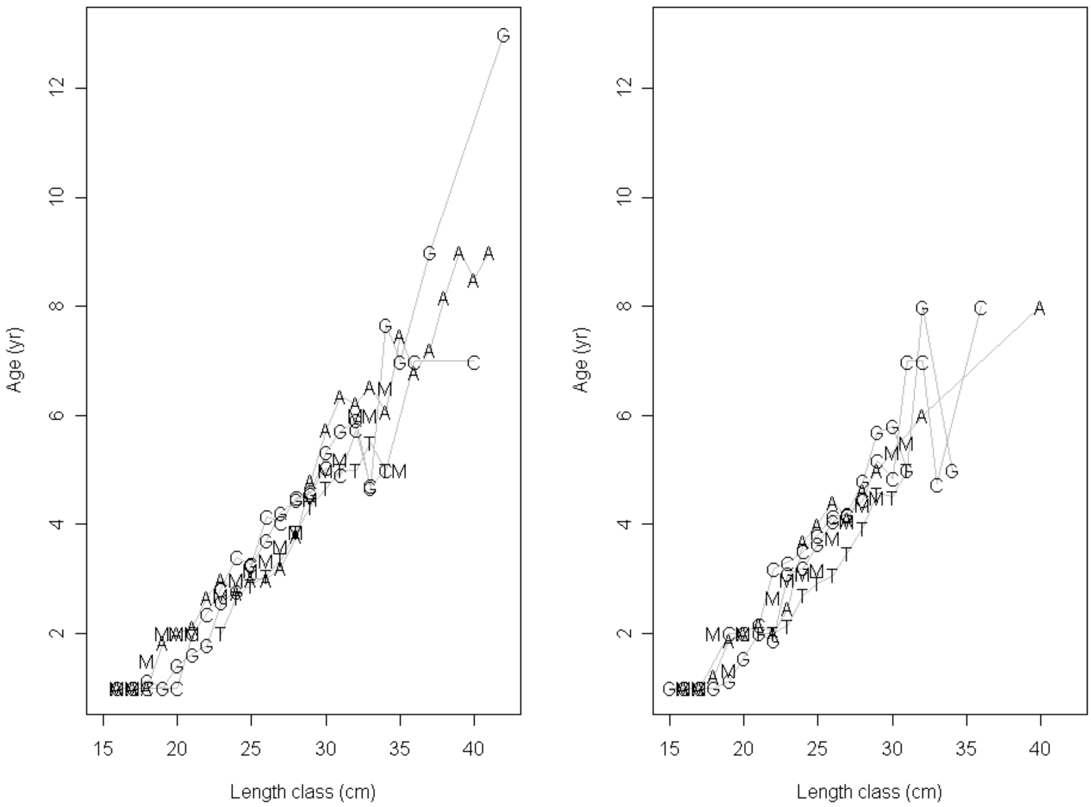
Appendix 2. Comparisons of biological data among the participating vessels



Vessel-specific length–weight relationships for female (left) and male (right) blue whiting in 2007. The letter codes are derived from the vessel names (A=Atlantida, C=Celtic Explorer, E=Eros, M=Magnus Heinason, T=Tridens). There is more variability among the vessels for females than for males, probably because gametes make potentially a larger proportion of body weight in females.



Vessel-specific length–age relationships for female (left) and male (right) blue whiting in 2007. The letter codes are derived from the vessel names (A=Atlantida, C=Celtic Explorer, E=Eros, M=Magnus Heinason, T=Tridens). The differences between smallest and largest mean age for the core length groups are often more than 1 year. Differences this large are unexpected. While it is possible that the vessels have consistently observed blue whiting with different growth rates, it could be that age readings are drifting apart. The differences observed in 2006 were less striking (below).



Appendix 3. Uncertainty in the acoustics observations and its consequences to stock estimates

Stock estimates calculated from trawl-acoustic surveys are subject to many sources of errors, both of observational and structural nature (this issue is discussed from the blue whiting spawning stock survey perspective in Heino 2004). Total uncertainty is practically impossible to characterize, but some sources of uncertainty are quite amenable to quantification. Here the purpose is to estimate observation error originating from observing spatially and temporally heterogeneous blue whiting registrations through acoustic measurements along survey tracks covering a limited part of the survey area.

For the purpose of calculating stocks estimates, acoustic data (acoustics density (s_A) representing blue whiting, in m^2/nm^2) from each vessel are expressed as average values over 5 nm stretches of survey track. Acoustic density for each survey stratum is calculated as an average across all observations within a stratum, weighted by the length of survey track behind each observation (some observations represent more or less than 5 nm). Normally, these values are then converted to stratum-specific biomass estimates based on information on mean length of fish in the stratum and the assumed acoustic target strength; the total biomass estimate is the sum of stratum-specific estimates.

Here we do not attempt to repeat the whole estimation procedure, but instead characterize uncertainty in global mean acoustic density estimate. Since mean size of blue whiting does not vary very much in the survey area, uncertainty in mean acoustic density should give a good, albeit conservative, estimate of uncertainty in total stock biomass.

We use bootstrapping to characterize uncertainty in the mean acoustic density. Bootstrapping is done by stratum, treating observations from all vessels equally and using lengths of survey track behind each observation as weights when calculating mean density. With 1000 such bootstrap replicates for each stratum, we can calculate 1000 bootstrap estimates of mean acoustic density, weighted by the stratum areas. Bootstrapped mean acoustic density is the mean of these 1000 bootstrap estimates, and confidence limits can be obtained as quantiles of that distribution.

Figure 1 shows the results of this exercise with the data from the 2007 survey. Mean acoustic density over the survey area is 729 m^2/nm^2, with 95% confidence interval being 553…845 m^2/nm^2. Relative to the mean, the approximate 95% confidence limits are –20%...+22%, and 50% confidence limits are –7.6%...+7.2%. This suggests that we might as well have estimated the blue whiting biomass to be one million tons more or less, and even errors in the magnitude of 2 million tons are not too unlikely. The origin of this high uncertainty is the fact that the majority of blue whiting are observed in very small areas. A single stretch of cruise track with the school shown in Figure 7 in the main text contributes 13% to the total cumulative acoustic density (Figure 2) and about 4.3% to estimated mean acoustic density; the difference mostly originates from the fact that this observation represents only 2 nm stretch of cruise track. This observation gave acoustic density at 140 000 m^2/nm^2, which has to be compared against the stratum level means shown in Figure 5 in the main text. In other words, if we did not happen to cover this particular school, the stock estimate would have been significantly less than currently estimated.

For 2006 the situation is much less extreme (Figure 1), as no single observation is as influential as in 2007 (Figure 2); the highest observation makes 2.7% of the cumulative sum. The approximate 95% confidence limits relative to the mean are –10%...+11%, and 50% confidence limits are –3.8%...+3.6%. Year 2005 is an intermediate case, with the approximate 95% confidence limits being –13%...+16%, and 50% confidence limits –5.8%...+5.5%. The highest observation makes 5.7% of the cumulative sum in 2005. Results from 2004 are almost as precise as those from 2006, and the approximate 95% confidence limits are –11%...+13%, and 50% confidence limits –4.1%...+3.7%. The highest observation makes 4.5% of the cumulative sum in 2004.

Figure 3 summarizes these results and puts them in the biomass context. Acoustic uncertainty was relative stable in 2004–2006, but exploded in 2007. This is caused by a few very high density estimates: in 2007, three highest values account for more than 20% of total cumulative acoustic density, while in other years the cumulative distribution is initially much less steep.

The practical consequence of these results is that we cannot say with any confidence that stock size has increased from 2006 to 2007, despite the best estimates reported on page 6 suggesting a modest increase of about 8%. Indeed, we cannot say that the estimate is different from the estimates in any of the years before.

Sensitivity of results to few observations is unavoidable when observing a spatially highly heterogeneous stock. The best way to combat this is to maintain sufficiently high sampling effort, in particular in areas where dense aggregations can be expected.

References:

Heino, M. 2004: Norwegian acoustic surveys on blue whiting spawning stock. In: *Improvement of instrumental methods for stock assessment of marine organisms. Proceedings of the Russian-Norwegian Workshop on Hydroacoustics, 11-14 November 2003, Murmansk, Russia* (ed. Chernook, V.), pp. 76-83. PINRO Press, Murmansk.

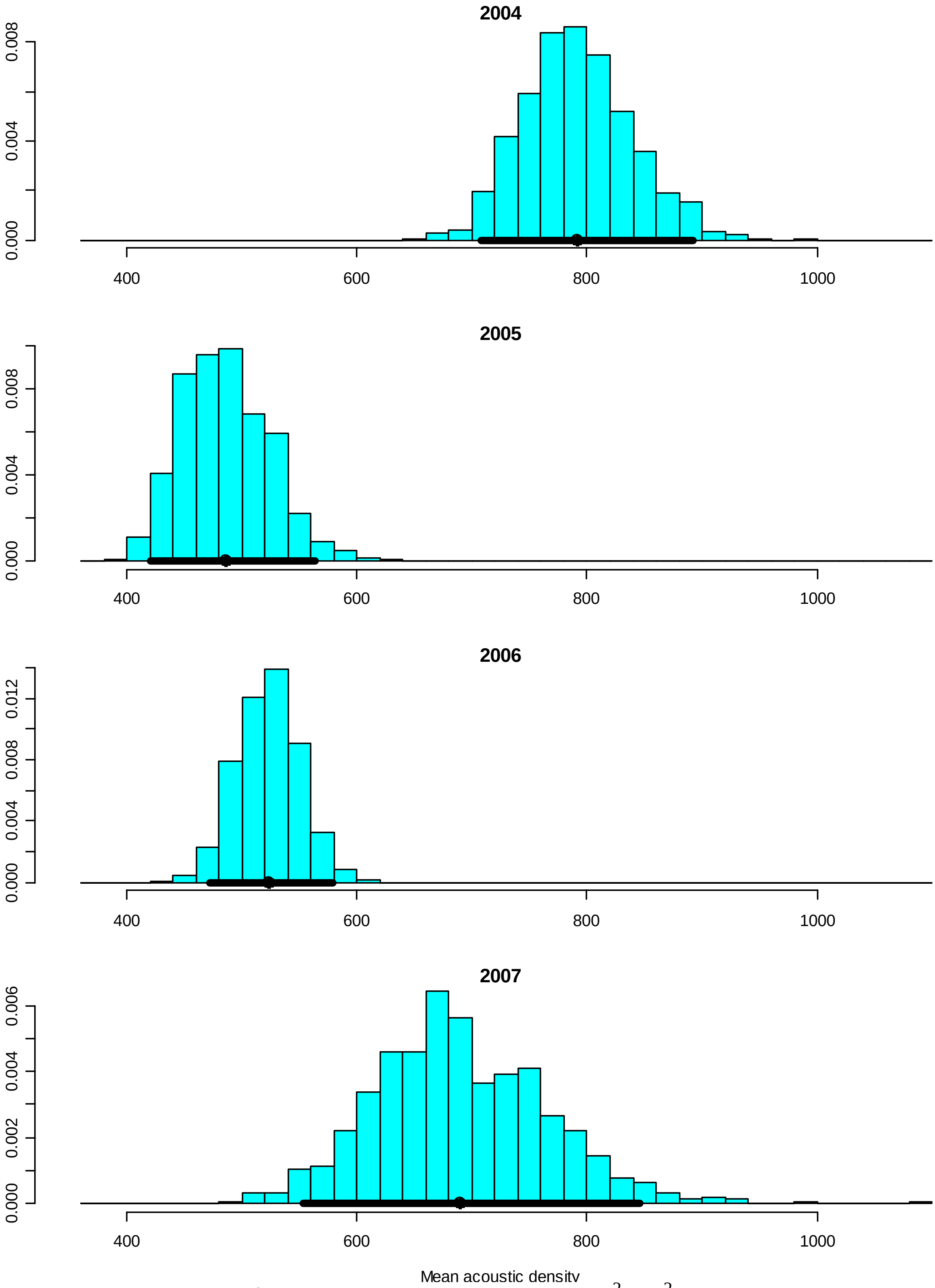


Figure 1. Distribution of mean acoustic density (in m^2/nm^2) based on 1000 bootstrap replicates of acoustic data from blue whiting surveys. Mean acoustic density is indicated with a black dot on the x-axis, while the horizontal bar shows 95% confidence limits.

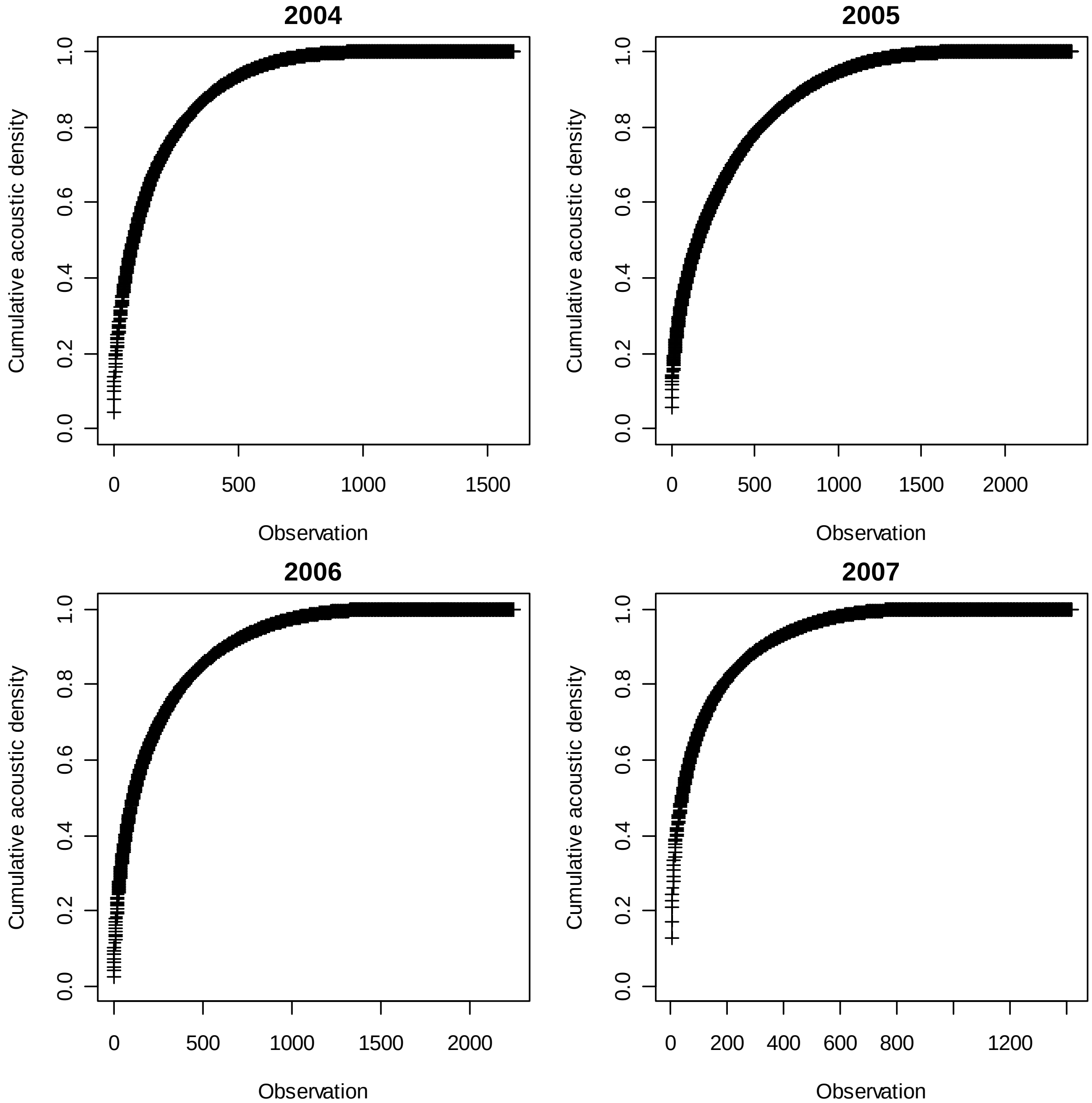


Figure 2. Normalized cumulative distribution of acoustic values sorted in decreasing order. Initial steepness of these curves indicates how influential single observations are. Notice that in these graphs, variation in length of survey track behind each observation is not considered, nor is the stratification of the survey area.

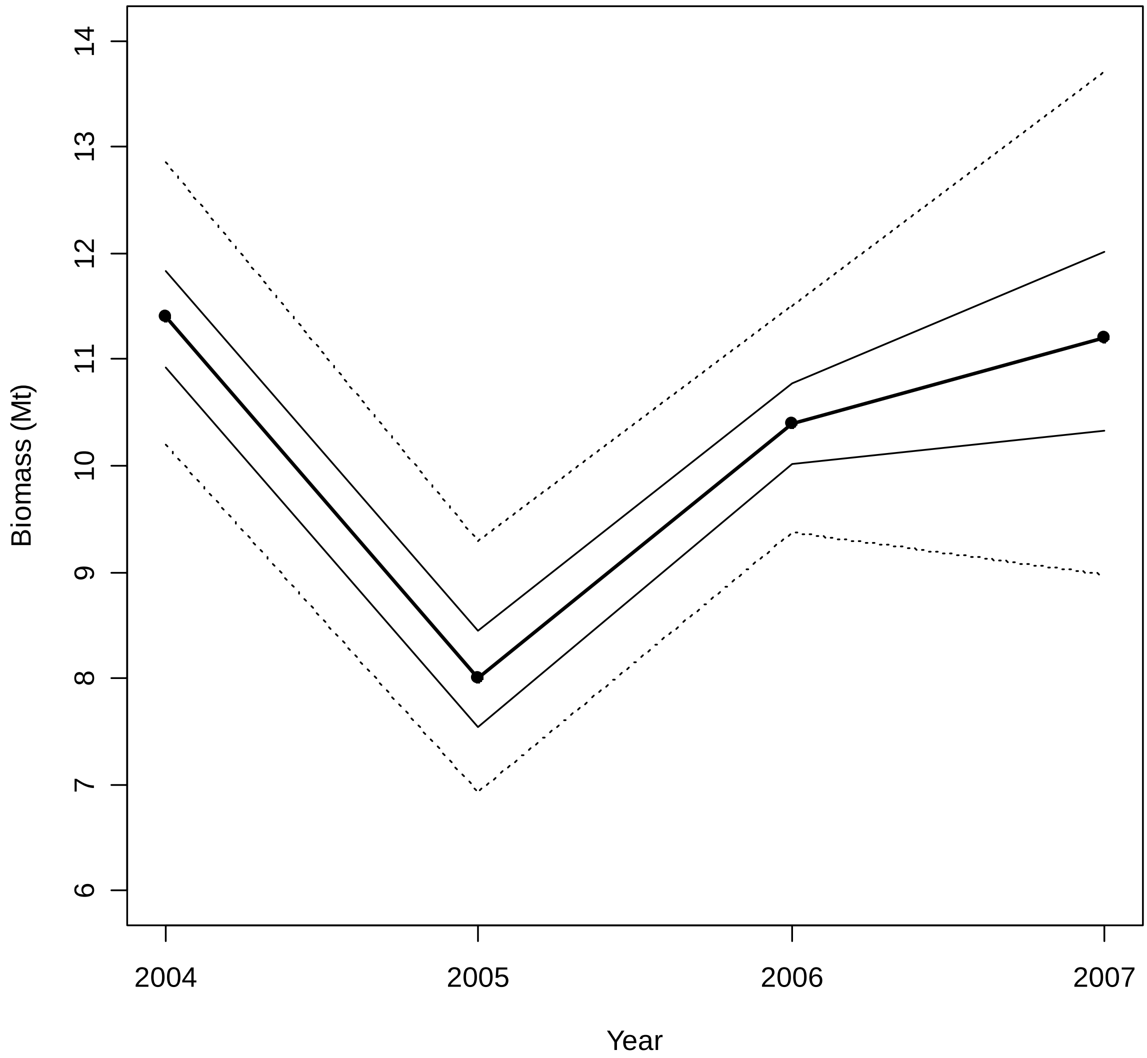


Figure 3. Approximate 50% and 95% confidence limits for blue whiting biomass estimates. The confidence limits are based on the assumption that confidence limits for annual estimates of mean acoustic density can be translated to confidence limits of biomass estimates by expressing them as relative deviations from the mean values. These confidence limits only account for spatio-temporal variability in acoustic observations.