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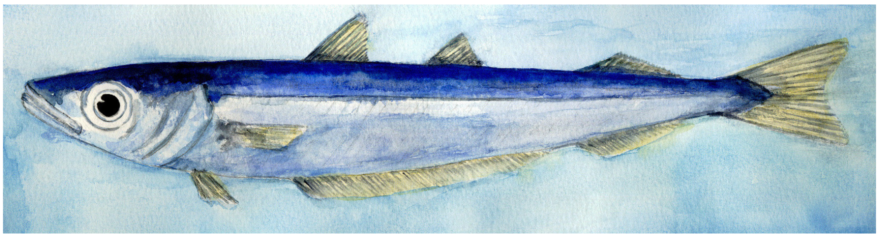

INTERNATIONAL BLUE WHITING SPAWNING STOCK SURVEY SPRING 2009

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Introduction

In spring 2009, 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 sixth coordinated international blue whiting spawning stock survey since 2004. 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 (F. Nansen: Oganin et al. 2009; Celtic Explorer: O'Donnell et al. 2009; M. Heinason: Jacobsen et al. 2009; Tridens: Ybema et al. 2009; Holst et al. 2009).

This report is based on a workshop held after the international survey in Galway, 22–24/4/2009 where the data were analysed and the report written.

Material and methods

Survey planning and Coordination

Coordination of the survey was initiated in the meeting of the Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys (PGNAPES, ICES 2008) 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
Fridtjof Nansen	PINRO, Murmansk, Russia	27/3–11/4
Celtic Explorer	Marine Institute, Galway, Ireland	27/3–16/4
Brennholm	Institute of Marine Research, Bergen, Norway	24/3–06/4
Magnus Heinason	Faroese Fisheries Laboratory, Faroe Islands	02/4–14/4
Tridens	Institute for Marine Resources & Ecosystem Studies, the Netherlands	17/3–30/3

Cruise tracks and trawl stations for each participant vessel are shown in Figure 1. Figure 2 shows combined CTD stations. Survey effort by each vessel is detailed in Table 1. All vessels worked in a northerly direction (Figure 3). Regular communication between vessels was maintained during the survey (via email, InmarSat C and VHF radio) exchanging distribution data, fleet activity and biological information.

Sampling equipment

All vessels employed a single vessel midwater trawl for biological sampling, the salient properties of which are given in Table 5. Acoustic equipment for data collection and processing are also presented in Table 5. The survey and abundance estimate are based on acoustic data collected through scientific echo sounders using 38 kHz frequency. Transducers were calibrated with a standard calibration sphere (Foote et al. 1987) prior to the survey for all vessels, with the exception of the Celtic Explorer which was calibrated post survey. Acoustic settings are summarized in Table 2.

Acoustic Intercalibration

Inter-vessel acoustic calibrations are carried out when participant vessels are working within the same general area and time and weather conditions allow for an exercise to be carried out. The procedure follows the methods described by Simmonds & MacLennan 2007.

Biological sampling
All components of trawl catches were sorted and weighed; fish were identified to species (when possible) and other taxa to higher taxonomic levels. The level of blue whiting sampling of by each vessel is shown in Table 5.

Hydrographic sampling
Hydrographic sampling by way of vertical CTD casts was carried out by each participant vessel (Figure 2 and Table 1) up to a maximum depth of 1,100m in open water. Hydrographic equipment specifications are summarized in Table 5.

Acoustic data processing
Acoustic scrutiny was mostly based on trawl information and subjective categorisation. Post-processing software and procedures differed among the vessels. On Fridtjof Nansen, the FAMAS post processing software was used as the primary post-processing tool for acoustic data. Data were partitioned into the following categories, blue whiting, 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 4.2) 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 plankton & mesopelagic species.

On Brennholm, 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 and characteristics of the recordings.

On Magnus Heinason, acoustic data were scrutinised every 24 hrs on board using Sonar data's Echoview (V 4.3) 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 4.30) post processing software. Data were partitioned into only blue whiting using a new developed detection algorithm. Plankton will be partitioned in a later stage. To monitor transceiver output, a monitoring algorithm was created in Echoview. Both algorithms will contribute to a general Echoview template used in this survey.

Acoustic data analysis
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 200m.

To obtain an estimate of length distribution within each stratum, all length samples within that stratum were used. If the focal stratum was not sampled representatively, additional samples from the adjacent strata were used. In such cases, only samples representing a similar kind of registration that dominated the focal stratum were included. Because this includes a degree of subjectivity, the sensitivity of the estimate with respect to the selected samples was crudely assessed by studying the influence of these samples on the length distribution in the stratum. No weighting of individual trawl samples was used because of differences in trawls and numbers of fish sampled and measurements. The number of fish in the stratum is then calculated from the total acoustic density and the length composition of fish.

The methodology is in general terms described by Toresen et al. (1998). More information on this survey is given by, e.g., Anon. (1982) and Monstad (1986). Traditionally the following target strength (TS) function has been used:

$$TS = 21.8 \log L - 72.8 \text{ dB},$$

where L is fish length in centimetres. For conversion from acoustic density (s_A, $m^2/n.mile^2$) to fish density (ρ) the following relationship was used:

$$\rho = s_A / \langle\sigma\rangle,$$

where $\langle\sigma\rangle = 6.72 \cdot 10^{-7} L^{2.18}$ is the average acoustic backscattering cross section (m^2). The total estimated abundance by stratum is redistributed into length classes using the length distribution estimated from trawl samples. Biomass estimates and age-specific estimates are calculated for main areas using age-length and length-weight keys that are obtained by using estimated numbers in each length class within strata as the weighting variable of individual data.

BEAM does not distinguish between mature and immature individuals, and calculations dealing with only mature fish were therefore carried out separately after the final BEAM run separately for each sub-area. Proportions of mature individuals at length and age were estimated with logistic regression by weighting individual observations with estimated numbers within length class and stratum (variable 'popw' in the standard output dataset 'vgear' of BEAM). The estimates of spawning stock biomass and numbers of mature individuals by age and length were obtained by multiplying the numbers of individuals in each age and length class by estimated proportions of mature individuals. Spawning stock biomass is then obtained by multiplication of numbers at length by mean weight at length; this is valid assuming that immature and mature individuals have the same length-weight relationship.

Results

Inter-calibration results

One inter-vessel acoustic calibration was performed between R/V Celtic Explorer and R/V Magnus Heinason during the 2009 survey. Results are detailed in Appendix 1.

Distribution of blue whiting

Blue whiting were recorded all areas surveyed relating to 9,800 nautical miles of survey transects and an area coverage of 134 thousand square nautical miles (Figures 4–6 and Table 1). The highest concentrations were recorded in the area between the Hebrides, Rockall and Faroe Banks and are consistent with the results from previous surveys. However, when surveyed, the bulk of the stock was located further north in 2009 around the Hebrides and Rosemary banks and less on the slope areas around northwest Ireland as observed in 2008. This can be attributed to the earlier spawning and subsequent northward migration of the stock as reported by the national commercial fleets actively targeting blue whiting within the survey area. Schools with the greatest recorded density were observed by the Magnus Heinason in the north, in the Hebrides sub area (Figure 7a).

In the southern Porcupine area, biomass was of a similar level to that observed in 2008. The northern porcupine core area was found to contain significantly less biomass than during the same time period in 2008. Peak spawning had already taken place in this area and the bulk of the stock had migrated northwards along the shelf edge. This biomass picked up in the Hebrides core area where an increase in biomass was observed compared to 2008. In 2009 over 62% of the total biomass was observed within the Hebrides area, as compared to over 50% in 2008. In the northern extreme, the Faroe/Shetland core area also saw an increase in biomass when compared to 2008.

In the western extremes, biomass within the Rockall sub area was significantly lower than observed in 2008 even though survey effort was increased. Fishing effort within this sub area was higher than observed in previous years. Vessels were observed following actively migrating schools from 20ºW north eastwards along the western slopes of the Rockall Bank ahead of the survey vessels. The main body of blue whiting had already migrated out of the area some days earlier to the northeast when the area was surveyed leaving residual low density schools. The north-eastern migration pathway of this component of the stock would have been contained within the western Faroe/Shetland sub area during the survey.

Area coverage was good and showed an increase of 5% on 2008 mainly in the western periphery. For the first time all sub areas were surveyed by more than one vessel providing a high degree of resolution and transect interlacing (Figure 1). Cooperating vessels also worked within a 4 week window to cover the entire area with good temporal alignment (Figure 3). Good agreement was achieved in terms of recorded acoustic densities within core areas of high abundance but some discrepancies did occur (Figure 5). Differences can be attributed to spatial and temporal heterogeneity in abundance of target schools.

Stock size

The estimated total abundance of blue whiting for the 2009 international survey was 6.07 million tonnes, representing an abundance of 46.7×10^9 individuals (Table 3). The spawning stock was estimated at 6.03 million tonnes and 45.8×10^9 individuals. In comparison to 2008, there is a significant decrease (24%) in the observed stock biomass and a related decrease in stock numbers (31%) within an increased overall survey area (see table below).

		2004	2005	2006	2007	2008	2009	Change from 2008 (%)
Biomass	Total	11.4	8	10.4	11.2	8	6.07	-24.1
(mill. t)	Mature	10.9	7.6	10.3	11.1	7.9	6.03	-23.7
Numbers	Total	137	90	108	104	68	46.7	-31.3
(10^9)	Mature	128	83	105	102	67	45.8	-31.6
Survey area (nm^2)		149,000	172,000	170,000	135,000	127,000	133,900	5.15

The Hebrides core area was found to contain 62% of the total biomass observed during the survey and is relatively consistent with the results from previous surveys (50% in 2008). Rockall and Faroe/Shetland ranked second and third highest contributing 16% and 15% to the total respectively.

		Biomass (million tonnes)				
		2008		2009		
	Sub-area		% of total		% of total	Change (%)
I	S. Porcupine Bank	0.1	1	0.1	2	0
II	N. Porcupine Bank	1.2	15	0.3	5	-75
III	Hebrides	4.13	52	3.8	62	-8
IV	Faroe/Shetland	0.74	9	0.9	15	+22
V	Rockall	1.8	23	1	16	-44

Stock composition

Individuals of ages 1 to 14 years were observed during the survey. Good agreement was achieved across all participants in age estimates of blue whiting (Appendix 3). Stock in the survey area is dominated by age classes 6, 5 and 7 years, of the 2003, 2004 and 2002 year classes respectively, contributing over 75% of spawning stock biomass (Table 4, Figure 8).

The Hebrides area has consistently contributed over 50% to the total SSB over the survey time series. In general the age structure of stock in this area resembled that of the total survey area, with the exception of the Porcupine (N and S) and Rockall sub areas which contained the highest proportion of juvenile fish observed during the survey (Figures 7b & 9).

Juveniles within these areas can be considered as resident and not part of the main body of the migrating stock. Larval retention due to localised hydrographic conditions that encircle these offshore Banks supports a residual year round population. The contribution of these immature fish to the total biomass relates to 0.6% or 39,000t. The low abundance of immature fish within the core Hebrides area is a further signal of poor recruitment within this stock. The presence/absence of immature fish within the core areas is an indication of those that have actively migrated with the main body of the stock.

In 2009, 85% of 2 year old fish (2007 year class) were found to be mature. In addition 15% of 1 year old fish (2008 year class) were also mature. However, it is important to note that the majority of 1 and 2 year old fish encountered were from the Rockall and Porcupine Banks and thus should be considered resident. Due to the lack of immature fish in the main core areas it was not possible to determine if this level of early maturity was observed throughout the stock.

Mackerel distribution

In the years 2004-08 mackerel have been encountered along the shelf slope west of the Hebrides and further south as schools of medium to high density. In 2009, mackerel were found to be distributed widely across the combined survey area and in greater abundance than seen previously. Mackerel were taken in trawl samples from 60ºN north to as far south as 51ºN and west to 15ºW on the Hatton Bank. Ordinarily confined to the shelf slope mackerel were encountered in open waters in depths of between 60-300m forming distinct schools occurring over large areas. Stomach contents revealed mackerel to be actively feeding on mesopelagic fish and were most frequently encountered within this layer. During daylight hours mackerel were discernable as single schools (Figure 7c-d). At night mackerel schools were inclined to disperse through the mesopelagic layer.

The relatively high abundance and wide distribution of mackerel encountered during the survey could be attributed to the current robust state of the mackerel stock. Acoustic registrations of mackerel were encountered by all participants across the survey area and would allow for scrutinisation of this species in future surveys. However, limitations exist regarding the use of multi-frequency analysis in deeper waters due to the extinction of high frequency signals at depth.

Hydrography

A combined total of 155 CTD casts were undertaken over the course of the survey. However, at this time the group was only able to produce horizontal plots of temperature and salinity due to the absence of a physical oceanographer again at this year's post-cruise meeting. Horizontal plots of temperature and salinity at depths of 10m, 50m, 100 and 200m as derived from vertical CTD casts are displayed in Figures 10-13 respectively.

Porcupine hydrographic transect

The Tridens conducted measurements of temperature and salinity down to a maximum depth of 1000 m in open water and to close to the sea floor on the shelf. This kind of investigation was carried out in order to examine the physical environment of blue whiting within the research area. Unlike birds and mammals fish are unable to maintain a constant body temperature, and thus their bodily functions are ultimately linked to the ambient temperatures. This is particularly true for the development and ripening of the gonads and, hence, the timing of spawning. Temperature differences around 1 °C can already make a difference of several weeks. Furthermore, analysis of the relationship between temperature and salinity can provide information about characteristics and origin of surrounding water masses. This information can then be utilized to describe the climatological regime during the spawning season and may allow for predictions of recruitment in a fish species.

During the current cruise sea surface temperatures (SST) ranged between 10.3 and 11.5 °C within the investigated area. The low temperatures being encountered in areas closer the coast while surface temperatures above the greater depths were generally higher. Illustrated by the standard hydrographic transect conducted across Porcupine Bank at about 53° 18' N (Figure 14).

In the surface layers to about 100 m depth temperatures decrease gradually from > 11.1 °C in the West to < 10.4 °C above the Porcupine Bank, further to the East SST increase again slightly to values > 10.4 °C. Over the deeper waters west of Porcupine Bank temperature was relatively stable change down to 300 – 400 m. Illustrated by the narrowing isothermals, temperatures decrease at a faster rate thereafter. Striking features above the western slope of Porcupine Bank are the steep and almost vertical isothermals that illustrate upwelling of cool waters from the depth. Here, upwelling is predominantly caused by the impingement of tidal currents onto the slopes of Porcupine Bank (Mohn 2000). The upwelled water carries nutrients from depth into the illuminated layers and promotes enhanced production above the bank (McMahon et al. 1995, White et al. 1996, Hillgruber and Kloppmann 1999).

The situation described in Figure 14 is almost identical to the situation found by a German expedition in 1994 at almost exactly the same time of the year and in the same area (Figure 15). As during this cruise the researchers found warmest temperatures in the surface layers west of Porcupine Bank with temperatures declining to the East. Also in 1994 upwelling was discernible above the slopes of Porcupine Banks (Kloppmann et al. 2001). The only striking difference is that almost throughout the complete water masses temperatures were roughly 1°C cooler in 1994 than today.

Based on the high number of blue whiting eggs found in their ichthyoplankton catches Kloppmann et al. (2001) concluded that spawning was at its peak at the respective time of the year. This year, many of the examined blue whiting had spent gonads, indicating that peak spawning in 2009 is already over. It is most likely that the higher water temperatures made blue whiting spawn earlier than observed in the mid 90s of the past century.

Concluding remarks

Main results

- The sixth international blue whiting spawning stock survey shows a significant decrease in stock biomass (24%) and a related decrease in stock numbers (31%) as compared to the previous year's survey.

- The stock in the survey area is dominated by 6, 5 and 7 years, of the 2003, 2004 and 2002 year classes respectively. Together these year classes account for 75% of spawning stock biomass.
- Mean length (29.5 cm) and weight (130 g) are the highest on record in the international survey time series indicating the reliance of the stock on larger older individuals.
- The survey area was increased by 5% from 2008. Core areas were covered with the same intensity as in previous years and increased coverage was achieved in the western Rockall. All sub and core areas were surveyed by more than one vessel providing a high degree of resolution both temporally and spatially.
- The observed shift in distribution northwards can be attributed to an earlier northward migration of the stock in 2009. However, this does not account for the observed decrease in biomass from 2008 to 2009.
- The contribution of immature fish to the total biomass is the smallest observed to date in the main core areas.
- A higher increased proportion of 1 and 2 year old fish (2008 and 2007 year classes) were observed to be mature in the Rockall and Porcupine sub areas than observed previously.

Interpretation of the results

- The 2009 estimate of abundance can be considered robust due to the high degree of inter-vessel coverage and the short time window in which the survey area was covered.
- The precision of the survey index remains unchanged from previous years (Appendix 2).
- Survey timing is fixed annually to coincide with peak spawning of the stock. However, peak spawning is not determined by time but other factors including water temperature. In 2009 the bulk of the stock was located further north than in 2008 indicating an earlier migration northwards. This earlier migration of the stock northwards was contained within the survey area and so was considered not to have adversely affected the precision of the estimate.
- Resident 1 and 2 year olds from the Rockall and Porcupine sub areas were found to contain a higher percentage of mature individuals as compared these areas in previous years. Direct comparison with those within the main body of the migratory stock was not possible due to the absence of 1-year old and the lack of 1 and 2 year olds observed in the core spawning areas.

Recommendations

- As in previous years the possibility of double counting remains an issue during this survey. To increase precision of the abundance index the time frame on which the survey is undertaken needs to be reduced further still.
- It is recommended that the working group not consider the use of 1 and 2 year old fish from the Porcupine and Rockall areas as they may not represent maturity within the entire stock.
- It is recommended that the PGNAPES group review the spawning stock survey design at the meeting in August.
- Taking into account the current international interest in monitoring the mackerel stock it is recommended that the group discuss the potential for mackerel scrutinisation at the August meeting.

Achievements

- Spatial and temporal coverage of core and peripheral areas was the best to date in the international time series.
- Deep sea species identification: Further development of implementation of ecosystem approach in this survey by focusing on deep sea fish species composition and distribution.

- Marine mammal observations: Both a visual and passive acoustic survey were conducted on board Tridens as an ancillary project in 2009. Visual surveys were first established onboard the Celtic Explorer in 2004. Acoustic surveys coupled with visual observations provided a very robust data-set. It is recommended that marine mammal observers carry out visual cetacean surveys during future Blue whiting surveys, as the repetition of these surveys would lead to a better understanding of the diversity and abundance of cetaceans occurring in the blue whiting habitat.
- Good agreement was achieved in age determination of samples across participants.
- Delivery of survey data in the PGNAPES format to Leon Smith was achieved 1 week prior to the post meeting. This allowed for the timely delivery of the combined survey report.

Previous recommendations	Originating from	Status
We have had no dedicated hydrographer present at the post cruise meeting to review the oceanographic data.	April 2007	Still remains an issue. However, Porcupine hydrographic data analysed prior to the 2009 post cruise meeting.
Echoview Template. Leon Smith has updated Template (V9) 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 2009 survey it is recommended the templates are combined	April 2008	Templates were not been exchanged during the 2009 survey
Intercalibration methods to be reviewed and the manual updated to include R-scripts and compatible data formats	April 2008	2009 intercalibrations were executed according to the standard method and R-script was circulated amongst members.
Discussions are to take place in the PGNAPES meeting mismatch between planned and executed survey tracks	April 2007	Has been addressed and was adhered to in 2009.
Discussions are to take place in the PGNAPES meeting on how to use hydrographical data within this group.	April 2006	A sub meeting during the 2009 PGNAPES needs to clarify how to use hydrographic data more effectively.
A member from each participant country should be present at the post cruise meeting to present the survey data and ensure the timely production of the combined cruise report	April 2008	Russian members were not present at the 2009 meeting.

References

Anon. (Monstad et al.), 1982. Report of the International acoustic survey on blue whiting in the Norwegian Sea, July/August 1982. ICES CM 1982/H:5.

Foote, K. G., Knudsen, H. P., Vestnes, G., MacLennan, D. N., and Simmonds, E. J. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Coop. Res. Rep. 144: 1–57.

Godø, O. R., Heino, M., Søiland, H., Alvarez, J., Dahl, M., de Lange, J., Gullaksen, O., Tangen, Ø. & Torkelsen, T. 2002. Blue whiting survey during spring 2002. Working Document to The Northern Pelagic and Blue Whiting Fisheries Working Group, Vigo, Spain, 29 April–8 May 2002. 27 pp.

Heino, M., Godø, O. R., Søiland, H., Nygaard, J. E., Alvarez, J., de Lange, J., Drivenes, L., Gullaksen, O., Tangen, Ø. and Torkelsen, T. 2003. Blue whiting survey during spring 2003. Working Document to The Northern Pelagic and Blue Whiting Fisheries Working Group, Copenhagen, 29 April–8 May 2003.

Heino, M. , Søiland, H., Dahl, M., Pedersen, G., Alvarez, J., Anthonypillai, V., Hovland, T., de Lange, J., Meland, E. S., Myklevol, S., Svendsen, B. V., Tangen, Ø., Torkelsen, T., Stowasser, G. and Varne, R. 2005. Blue whiting survey during spring 2005. Toktrapport/Havforskningsinstituttet/ISSN 1503-6294/Nr. 5 – 2005.

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

Hillgruber, N. and M. Kloppmann (1999). Distribution and feeding of blue whiting *Micromesistius poutassou* larvae in relation to different water masses in the Porcupine Bank area, west of Ireland." Marine ecology progress series **187**: 213-225.

Holst, J.C, Anthonypillai, V., Tangen, O., Kristiansen, J. and Meland, E. 2009. Blue whiting survey during spring 2009.

ICES 2007a. Report of the Northern Pelagic and Blue Whiting Fisheries Working Group. ICES CM 2007/ACFM:29.

ICES 2007b. Report of the Planning Group on Northeast Atlantic Pelagic Ecosystem Surveys (PGNAPES). ICES CM 2007/RMC:07, Ref. LRC, ACFM, ACE.

Jacobsen, J. A., Joensen, M.M., Mortensen, E. and Skúvadal, F. 2009. Joint investigations on blue whiting south of the Faroes and in the area west of the British Isles. March-April 2009. R/V Magnus Heinason Faroese Fisheries Laboratory, Tórshavn, the Faroes.

Kloppmann M., Mohn C. and J. Bartsch (2001). The distribution of blue whiting eggs and larvae on Porcupine Bank in relation to hydrography and currents. Fisheries Research 50, 89-109.

McMahon, T., Raine, R., Titov, O. and S. Boychuk (1995). Some oceanographic features of northeastern Atlantic waters west of Ireland. ICES J. Mar. Sci. 52, 221-232.

Mohn, C. (2000). Über Wassermassen und Strömungen im Bereich des europäischen Kontinentalrandes westlich von Irland. Dissertation, Universität Hamburg, Germany, 138 pp.

Monstad, T., 1986. Report of the Norwegian survey on blue whiting during spring 1986. ICES CM 1986/H:53.

O'Donnell, C., Mullins, E., Johnston, G., Saunders, R., Beattie, S., McCann, K., Brikt, Z, and O'Leary, E. 2009. Irish Blue Whiting Acoustic Survey Cruise Report 2009. Marine Institute, Ireland.

Oganin., I., Ignashkin, V. and Firsor, Y.. 2009. Report of the Russian survey on blue whiting during spring 2009.

Pedersen, G., Pedersen, R. and Torkelsen, T. 2006. *In situ* target strength measurements of blue whiting. Appendix 7 in Heino et al. 2006.

Simmonds, J. and Mac Lennan D. 2007. Fisheries acoustics, theory and practice. Second edition. Blackwell publishing

.Toresen, R., Gjøsæter, H. and Barros de, P. 1998. The acoustic method as used in the abundance estimation of capelin (*Mallotus villosus* Müller) and herring (*Clupea harengus* Linné) in the Barents Sea. Fish. Res. 34: 27–37.

Totland, A. and Godø, O.R. 2001. BEAM – an interactive GIS application for acoustic abundance estimation. In T. Nishida, P.R. Kailola and C.E. Hollingworth (Eds): Proceedings of the First Symposium on Geographic Information System (GIS) in Fisheries Science. Fishery GIS Research Group. Saitama, Japan.

White, M., C. Mohn and M. Orren (1998). Nutrient distributions across the Porcupine - Bank, ICES J. Mar. Sci. 55 , 1082-1094.

Ybema S., Pasterkamp T.,, Bakker K., Balle J.D. , Gastauer S., Tribuhl S., Van Assendelft C., Armstrong E., Thaarup F., Kloppman M. and O'Brien J. 2009. Cruise report hydro acoustic survey for blue whiting (*Micromesistius poutassou*), 17- 2009. Institute for Marine Resource & Ecosystem Studies, IJmuiden, The Netherlands.

Table 1. Survey effort by vessel. March-April 2009.

Vessel	Effective survey period	Length of cruise track (nm)	Trawl stations	CTD stations	Aged fish	Length-measured fish
Fridtjof Nansen	28/3–11/4	2,110	21	69	1377	4,855
Celtic Explorer	27/3–16/4	2,475	23	27	950	2,850
Brennholm	24/3–06/4	2,007	12	11	280	999
Magnus Heinason	02/4–14/4	1,353	11	28	208	821
Tridens	17/3–30/3	1,853	11	25	450	1,935
Total		9,798	78	160	3,265	11,460

Table 2. Acoustic instruments and settings for the primary frequency. March-April 2009.

	Fridtjof Nansen	Celtic Explorer	Brennholm	Magnus Heinason	Tridens
Echo sounder	Simrad ES60	Simrad EK 60	Simrad EK 60	Simrad EK 500	Simrad EK 60
Frequency (kHz)	**38**, 120	**38**, 18, 120, 200	**38**	**38**	**38**
Primary transducer	ES38B	ES 38B	ES 38B	ES38B	ES 38B
Transducer installation	Hull	Drop keel	Hull	Hull	Towed body
Transducer depth (m)	4.5	8.7	6	3	7
Upper integration limit (m)	10	15	15	7	12
Absorption coeff. (dB/km)	10.1	9.9	9.8	10	9.7
Pulse length (ms)	1.024	1.024	1.024	Medium	1.024
Band width (kHz)	2.425	2.425	2.425	Wide	2.43
Transmitter power (W)	2000	2000	2000	2000	2000
Angle sensitivity (dB)	21.9	21.9	21.9	21.9	21.9
2-way beam angle (dB)	-20.73	-20.6	-20.6	-20.9	-20.6
Sv Transducer gain (dB)				27.22	25.11
Ts Transducer gain (dB)	25.57	25.55	26.5	27.35	
s_A correction (dB)	-0.61	-0.65	-0.65		-0.67
3 dB beam width (dg)					
alongship:	6.99	6.39	7.10	7.02	6.99
athw. ship:	6.99	6.67	7.10	6.86	6.96
Maximum range (m)	750	1000	900	750	750
Post processing software	FAMAS	Sonardata Echoview	LSSS	Sonardata Echoview	Sonardata Echoview

Table 3. Assessment factors of blue whiting. March-April 2009.

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	9428	0.75	1.1	72	0.1	0.1	90	105	26.8	10.6
II N. Porcupine Bank	23542	2.5	2.7	94	0.3	0.3	98	116	29.0	12.7
III Hebrides	33305	28.8	29.0	99	3.8	3.8	100	130	30.0	114.1
IV Faroe/Shetland	14891	6.0	6.1	98	0.9	0.9	100	142	30.0	60.4
V Rockall	52734	7.4	7.9	95	1.0	1.0	99	127	29.0	19.0
Tot.	133900	45.5	46.7	97.4	6.0	6.1	98.4	117	28.5	

Table 4. Stock estimate of blue whiting, March-April 2009.

Length	Age in years (year class)										Numbers	TSB	Mean	Prop.
	1	2	3	4	5	6	7	8	9	10+		Biomass	weight	mature*
(cm)	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	(*10-6)	(10^6 kg)	(g)	(%)
16.0 – 17.0	2										2	0	22	0
17.0 – 18.0	47										47	1	26	0
18.0 – 19.0	124	2									126	4	31	0
19.0 – 20.0	247	5									252	9	38	0
20.0 – 21.0	195	60									255	11	43	0
21.0 – 22.0	92	88									180	9	50	50
22.0 – 23.0	11	288	7								306	18	60	75
23.0 – 24.0	20	345	66	13							444	29	64	100
24.0 – 25.0		308	150	8	35						501	36	73	100
25.0 – 26.0		177	232	193	82	48					732	60	82	100
26.0 – 27.0		57	359	483	474	73					1446	137	95	100
27.0 – 28.0		20	252	1225	2023	911	173	48			4652	481	103	100
28.0 – 29.0		25	41	1663	4210	2359	698	145	41		9182	1048	114	100
29.0 – 30.0			31	639	4372	3385	1623	373	31		10454	1325	127	100
30.0 – 31.0				252	1835	3634	1562	490	104	13	7890	1086	138	100
31.0 – 32.0				41	785	2017	1206	464	85	41	4639	710	153	100
32.0 – 33.0				51	179	748	772	415	95	17	2277	384	168	100
33.0 – 34.0				13	35	316	556	403	80	54	1457	275	189	100
34.0 – 35.0				27	28	154	156	96	151	46	658	137	208	100
35.0 – 36.0						78	120	109	199	55	561	130	232	100
36.0 – 37.0						15	64	68	37	111	295	73	248	100
37.0 – 38.0						17	18	13	23	78	149	41	272	100
38.0 – 39.0							13	39	21	13	86	25	293	100
39.0 – 40.0								11	15	22	48	15	324	100
40.0 – 41.0								2		35	37	13	347	100
41.0 – 42.0										18	18	9	494	100
42.0 – 43.0										7	7	3	356	100
43.0 – 44.0														
44.0 – 45.0										4	4	1	402	100
TSN (10^6)	2747	3384	3147	6617	16067	15764	8970	4685	2891	514	46705	6069.3		
TSB (10^6 kg)	29.1	94.5	102.6	517.9	1710.5	1855.9	1026.1	435.9	170.3	127.1	6069.9			
Mean length (cm)	19.9	23.8	26.2	28.2	29.1	30.1	30.9	31.8	33.5	36.1	29.5			
Mean weight (g)	39.4	68.7	90.3	112.4	121.7	134.9	147.4	162.9	193.1	246	130			
% mature*	15	85	100	100	100	100	100	100	100	100				
% of SSB	15	85	100	100	100	100	100	100	100	100				

* Percentage of mature individuals per age or length class

Table 5. Country and vessel specific details, March-April 2009.

	Fridtjof Nansen	Celtic Explorer	Brennholm	Magnus Heinason	Tridens
Trawl dimensions					
Circumference (m)	716	768	2400	640	1120
Vertical opening (m)	50	50	140	40	30-70
Mesh size in codend (mm)	16	20	40	40	±20
Typical towing speed (kn)	3.2-4.2	3.5-4.0	3.5-4.0	3.0-4.0	3.5-4.0
Biological sampling					
Length Only					200
Lenth/Weight	200	100	70	100	
Length/Weight/Sex/Maturity	100	50	30	100	50
Hydrographic sampling					
CTD Unit	SBE911	SBE911	SBE911	SBE911	SBE911
Standard sampling depth (m)	1000	1000	1000	1000	1000

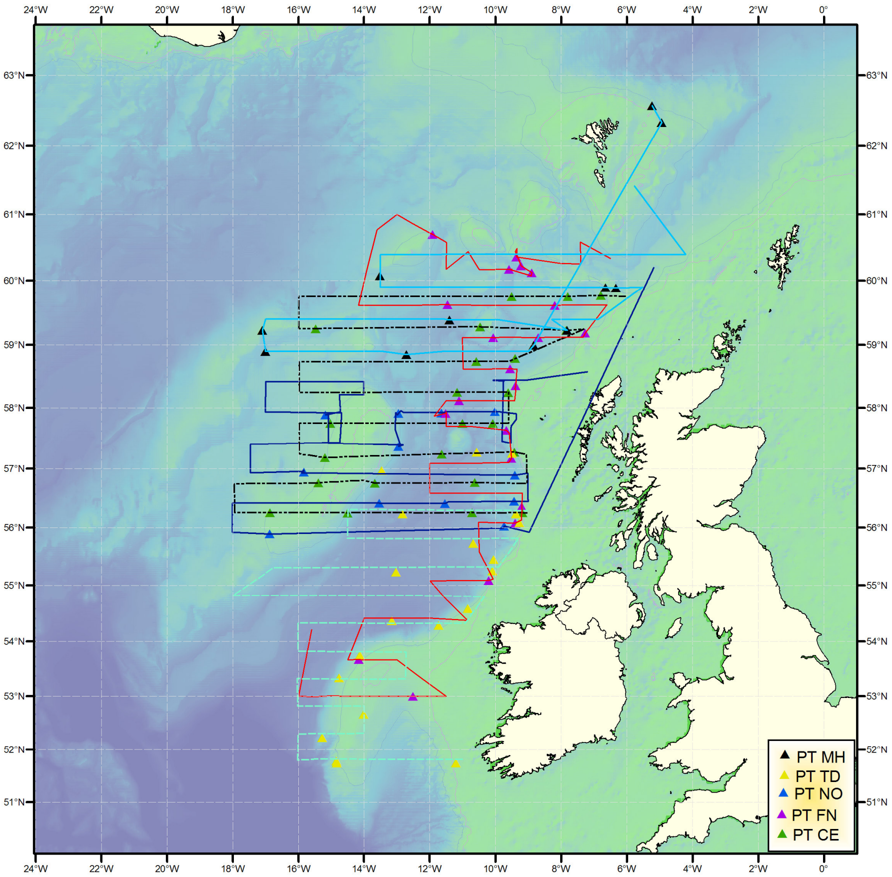


Figure 1. Combined vessel cruise tracks and trawl stations. PT: Indicates pelagic trawl station. CE: Celtic Explorer; MH: Magnus Heinason; TD: Tridens; FN: Fridtjof Nansen: NO: Brennholm. March-April 2009.

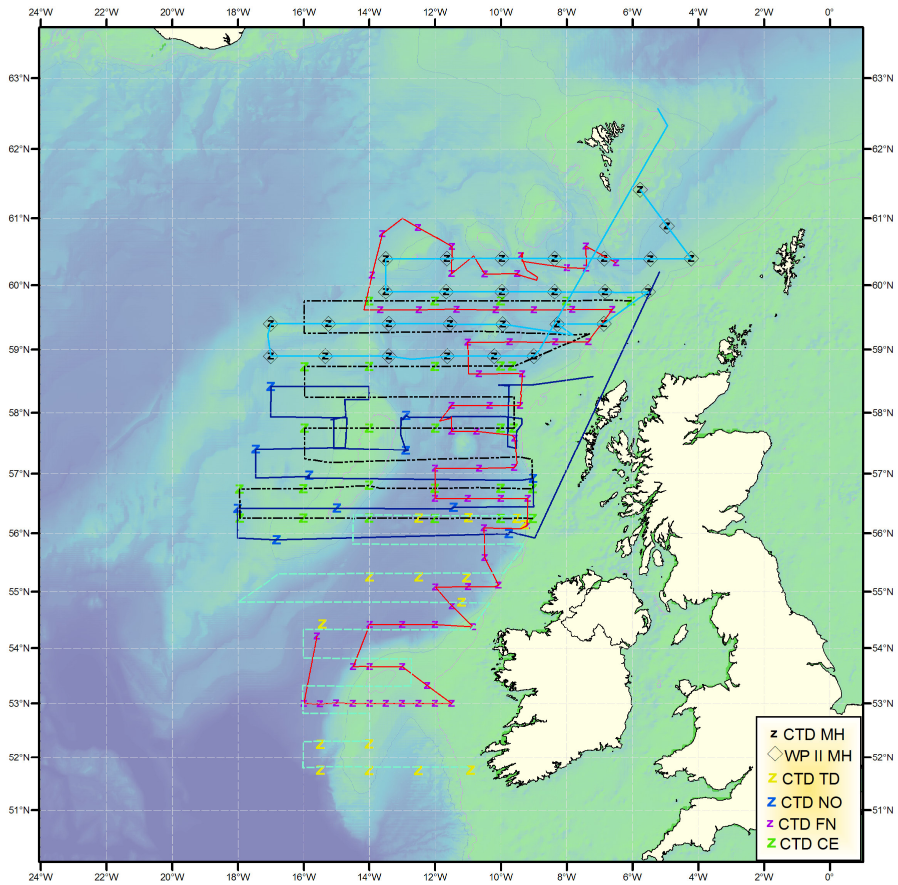


Figure 2. Combined CTD stations overlaid onto vessel cruise tracks. WP II: Indicates plankton trawl. CE: Celtic Explorer; MH: Magnus Heinason; TD: Tridens; FN: Fridtjof Nansen: NO: Brennholm. March-April 2009.

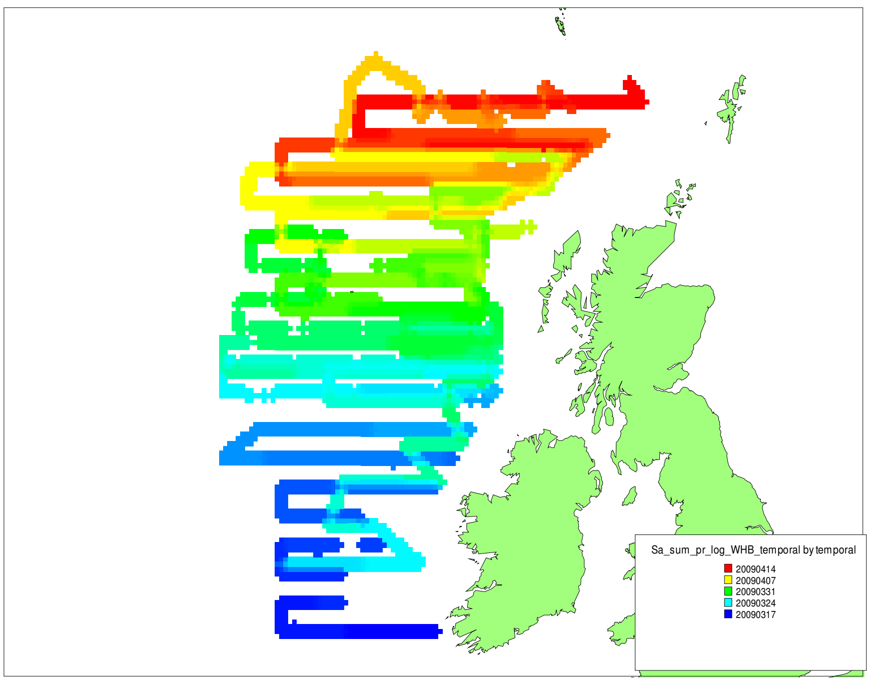


Figure 3. Temporal progression of the combined survey, 17 March–14 April 2009.

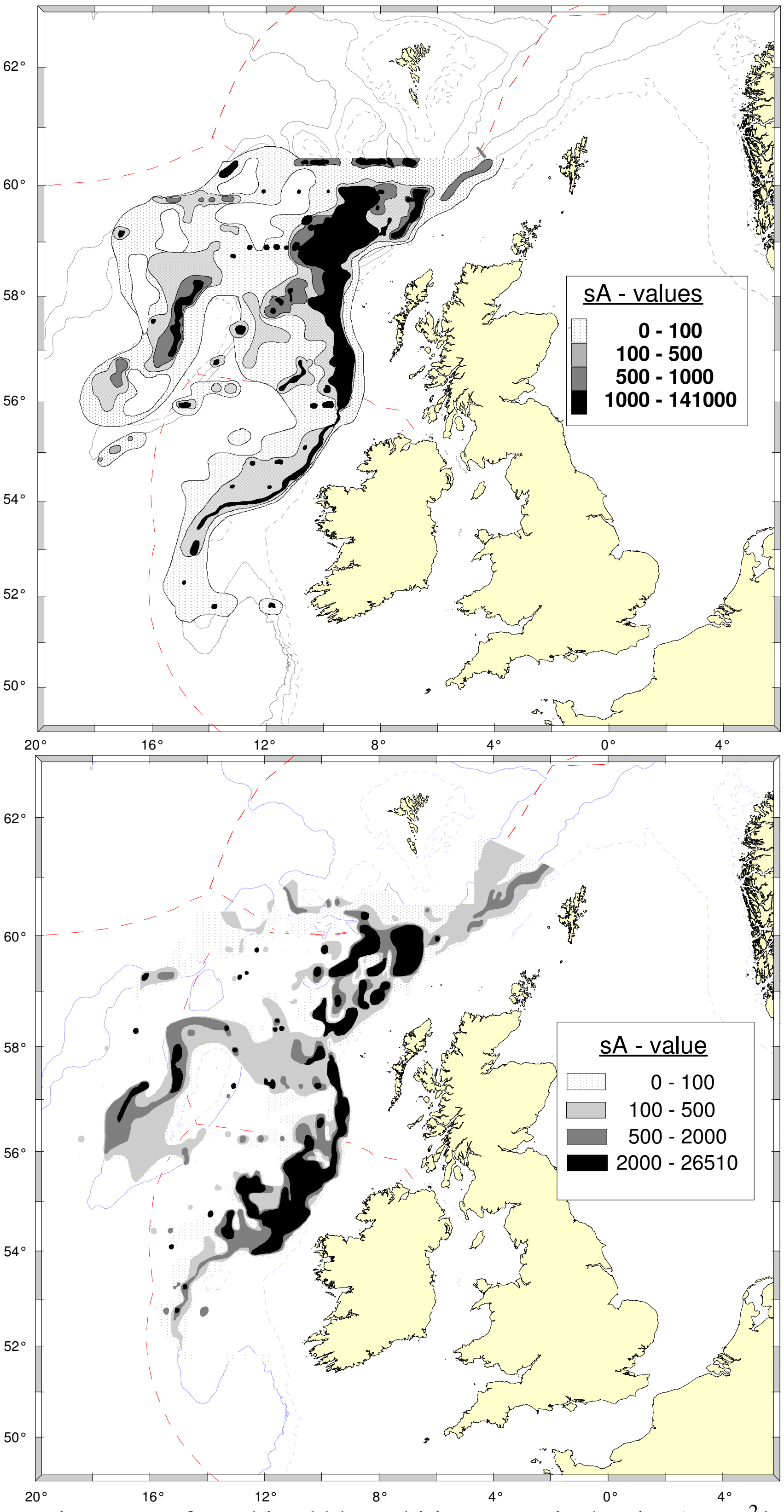


Figure 4. Schematics maps of combined blue whiting acoustic density (s_A, m^2/nm^2) in March-April 2008 (lower panel) and 2009 (upper panel).

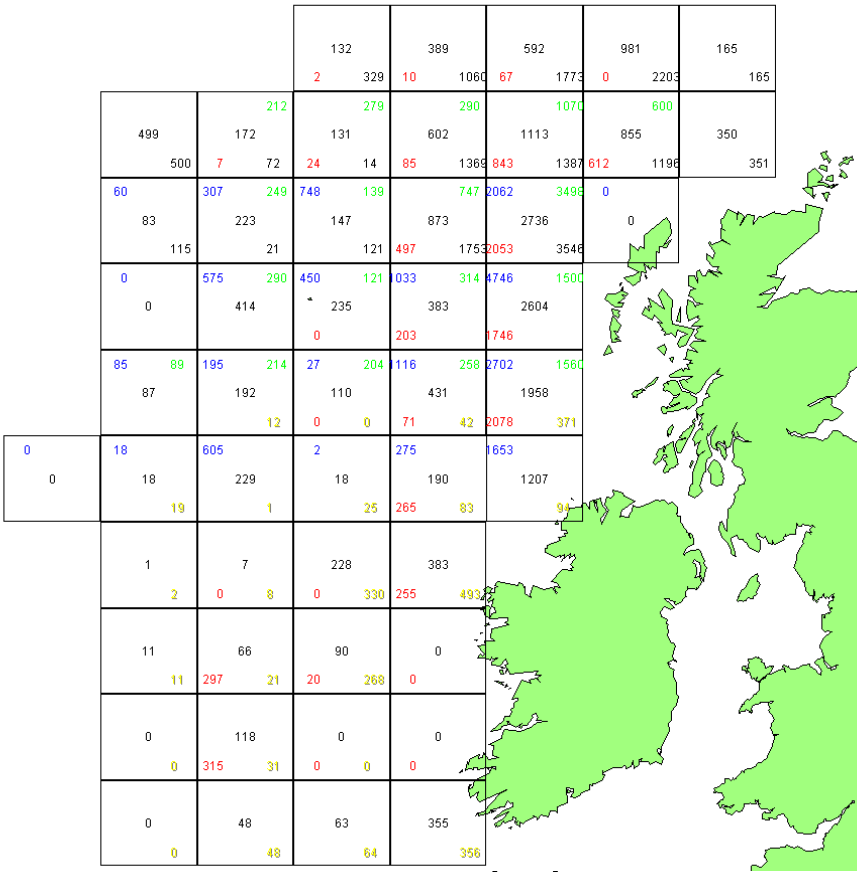


Figure 5. Mean blue whiting acoustic density (s_A, m^2/nm^2) for all vessels combined and for each individual vessel: Celtic Explorer: green, Magnus Heinason: grey, Netherlands: yellow, Fridtjof Nansen: red, Brennholm: blue. Combined totals are displayed in the middle of the square in bold black. March-April 2009.

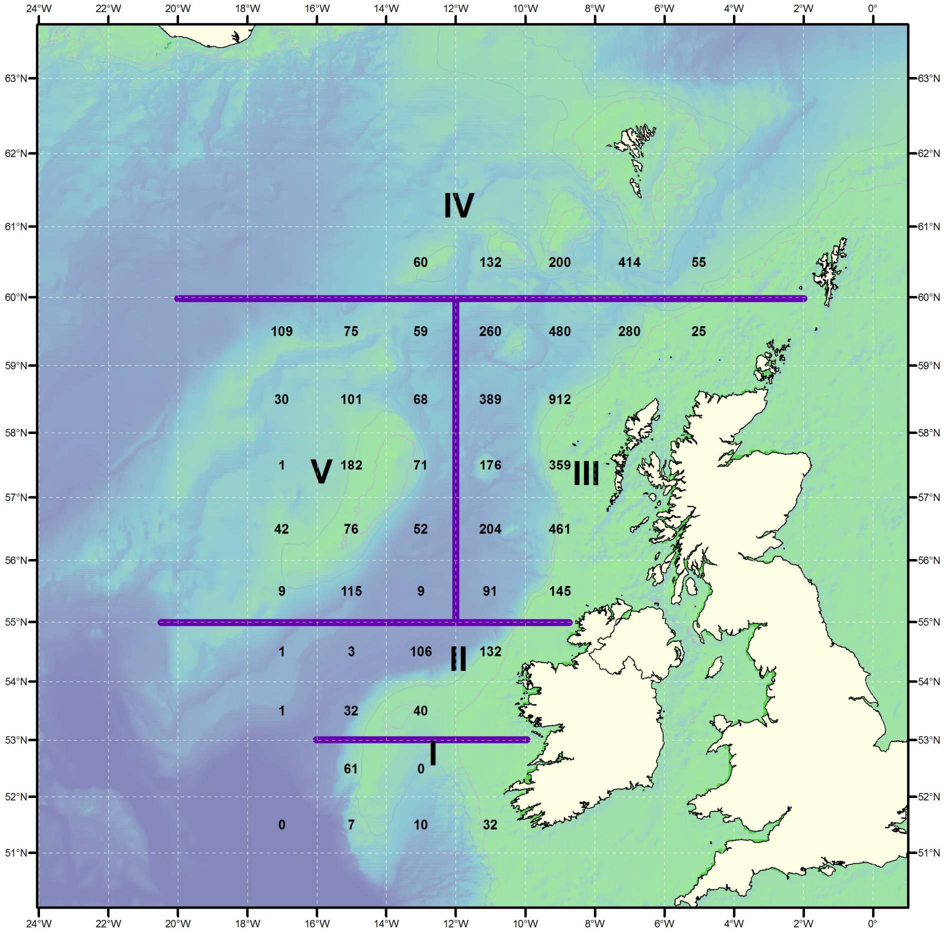
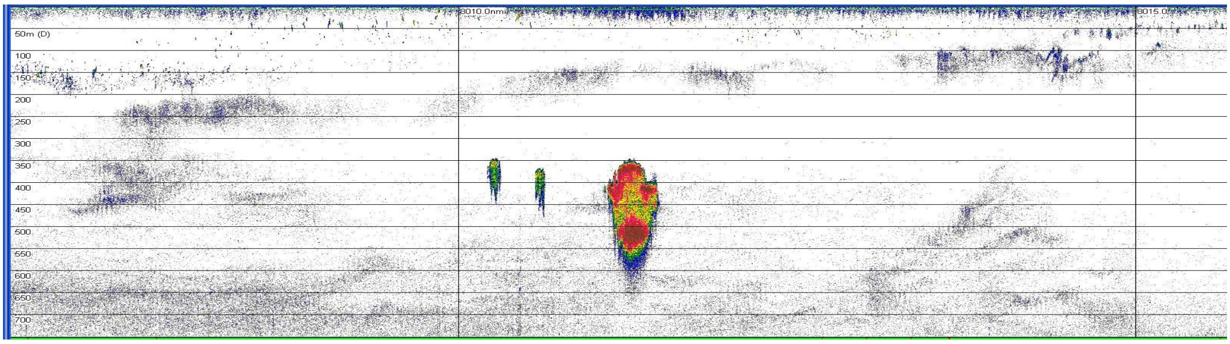
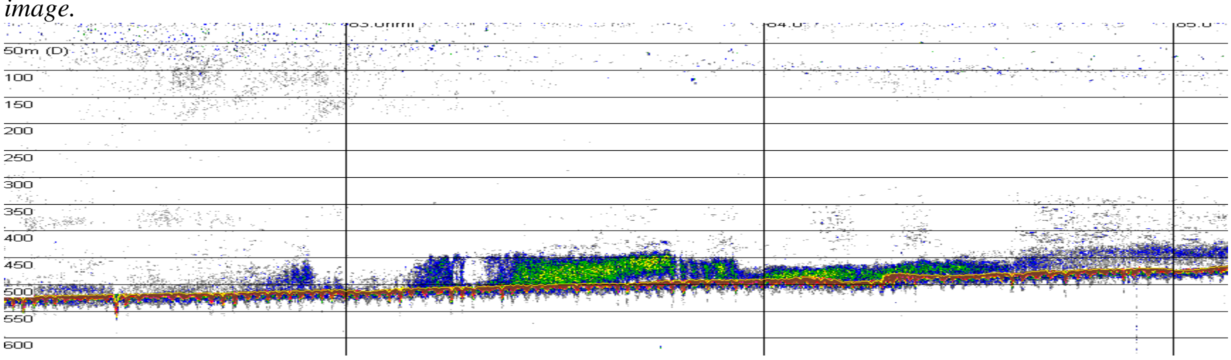


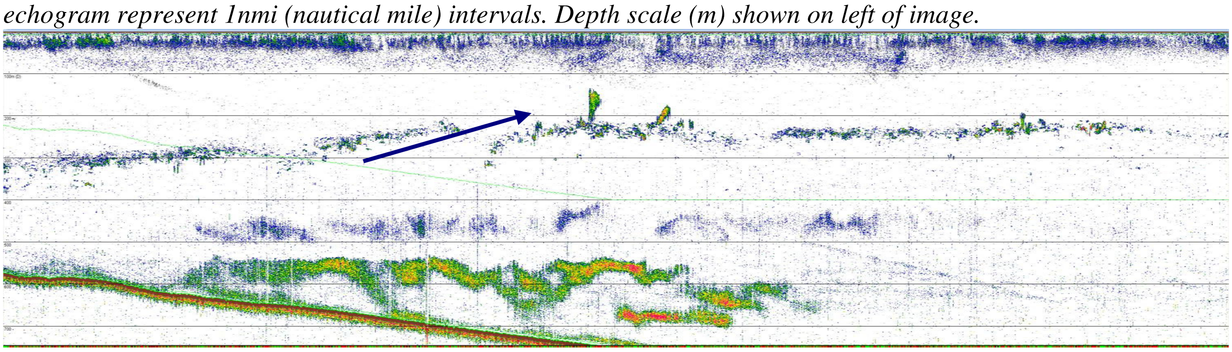
Figure 6. Blue whiting biomass in 1000 tonnes by sub-area as used in the assessment. March-April 2009.



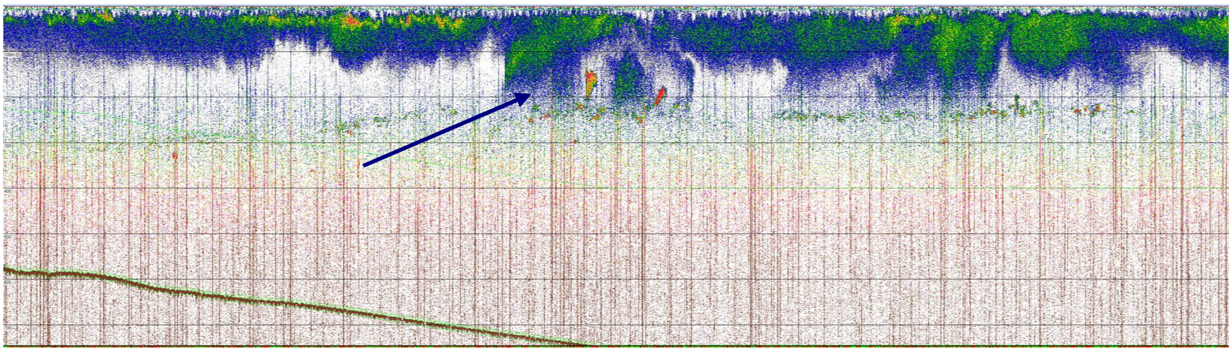
a). The *highest density schools of blue whiting recorded by the RV Magnus Heinason during the combined International survey. NASC value 140,578. Located on the northeast of the Rosemary Bank (55°54N & 10°40W). Vertical bands on echogram represent 1nmi (nautical mile) intervals. Depth scale (m) shown on left of image.*



b). *Low to medium density schools of blue whiting containing juveniles, typical of those encountered along the south-western slopes of the Rockall Bank (56°43N & 15°23W) by the RV Celtic explorer. Vertical bands on echogram represent 1nmi (nautical mile) intervals. Depth scale (m) shown on left of image.*



c). *Echograms recorded by the Tridens at 38 kHz clearly shows a number of distinct fish layers, with plankton from 0 to 100m,a layer containing mackerel and mesopelagics from 150 to 300m and blue whiting from 500 to 700m.*



d) The same echogram at 120 kHz, organisms can only be resolved to a depth of around 250m before noise becomes the dominant part of the return signal, completely obscuring any organisms present.

Figure 7. Blue whiting echograms encountered by the Magnus Heinason during the survey (a), Celtic Explorer (b) and mackerel echograms recorded by Tridens (c-d). March-April 2009.

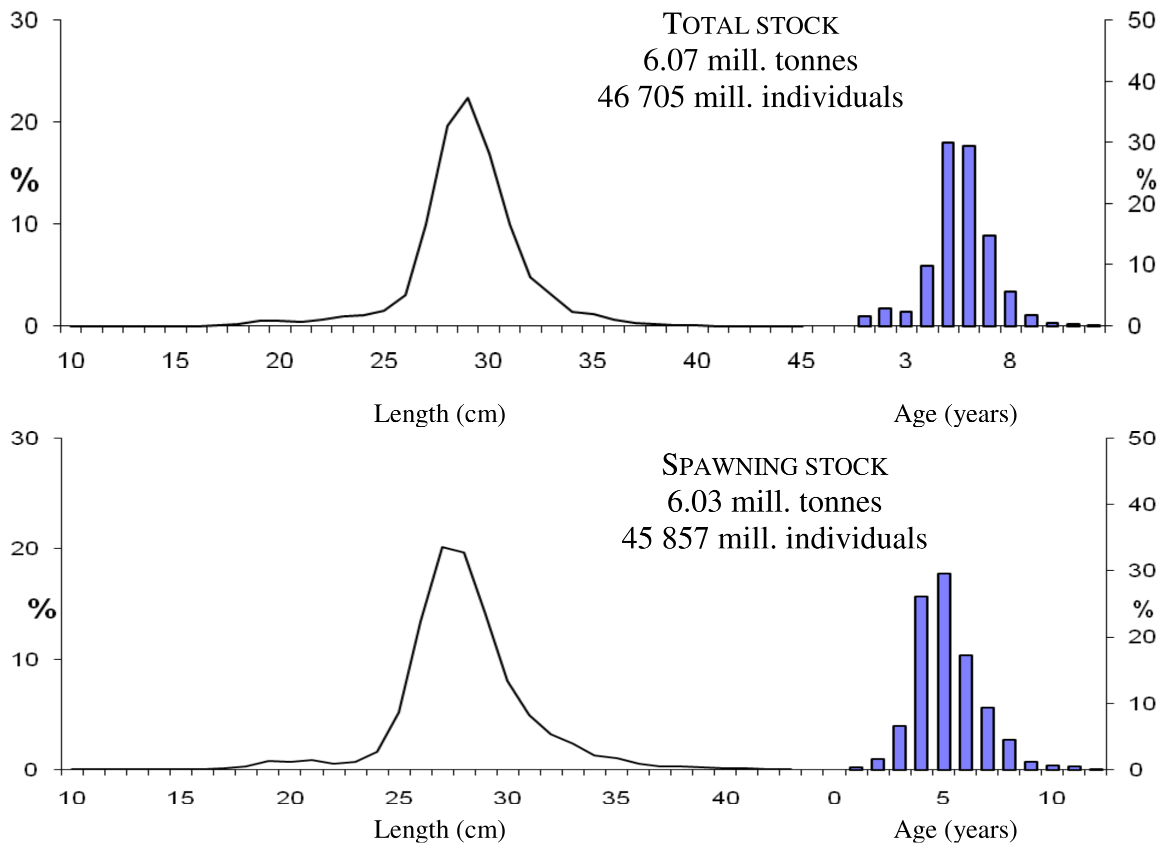


Figure 8. Length and age distribution in the total and spawning stock of blue whiting in western waters. March-April 2009.

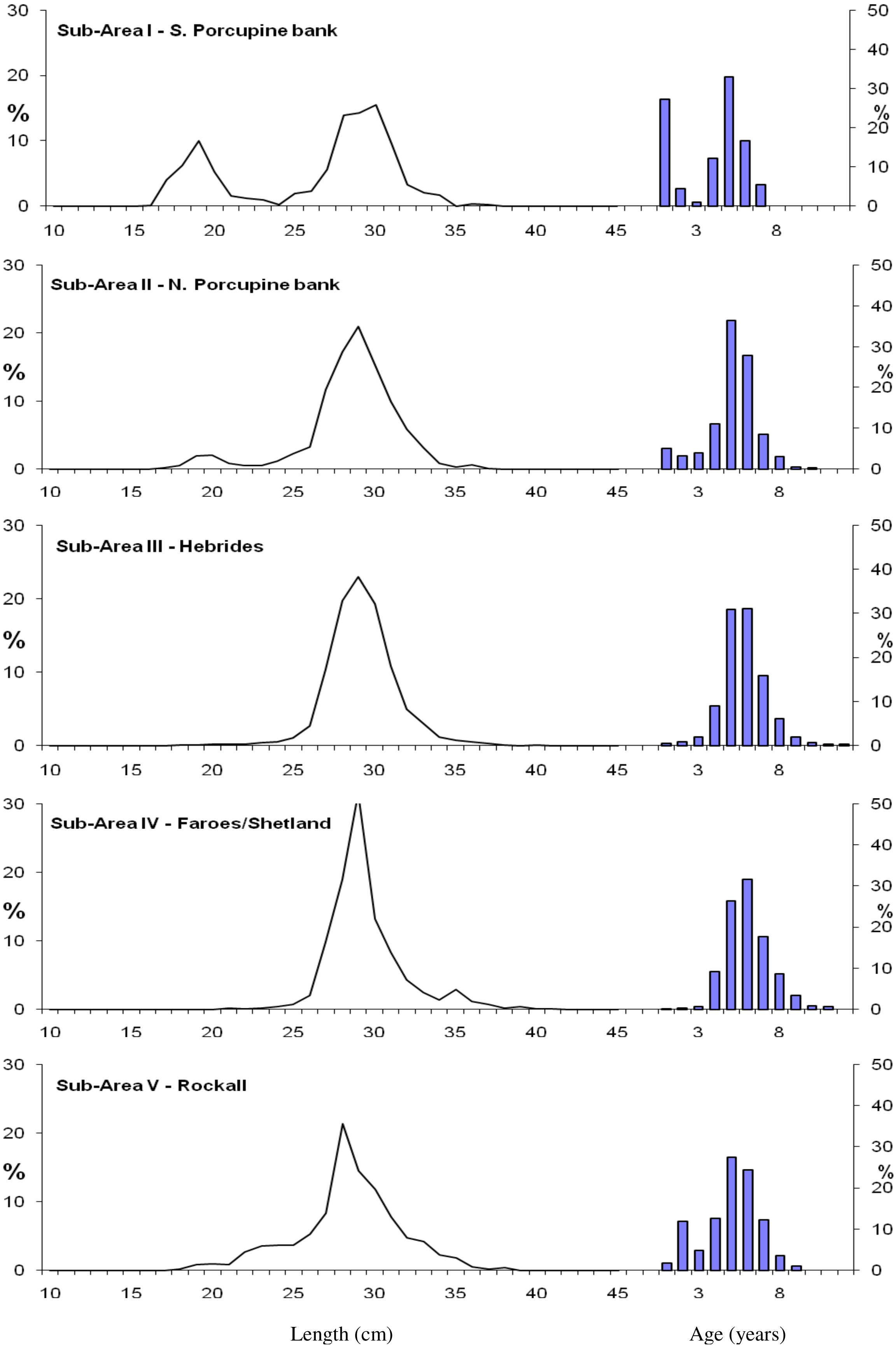


Figure 9. Length and age distribution (numbers) of blue whiting by sub-areas (I–V). March-April 2009.

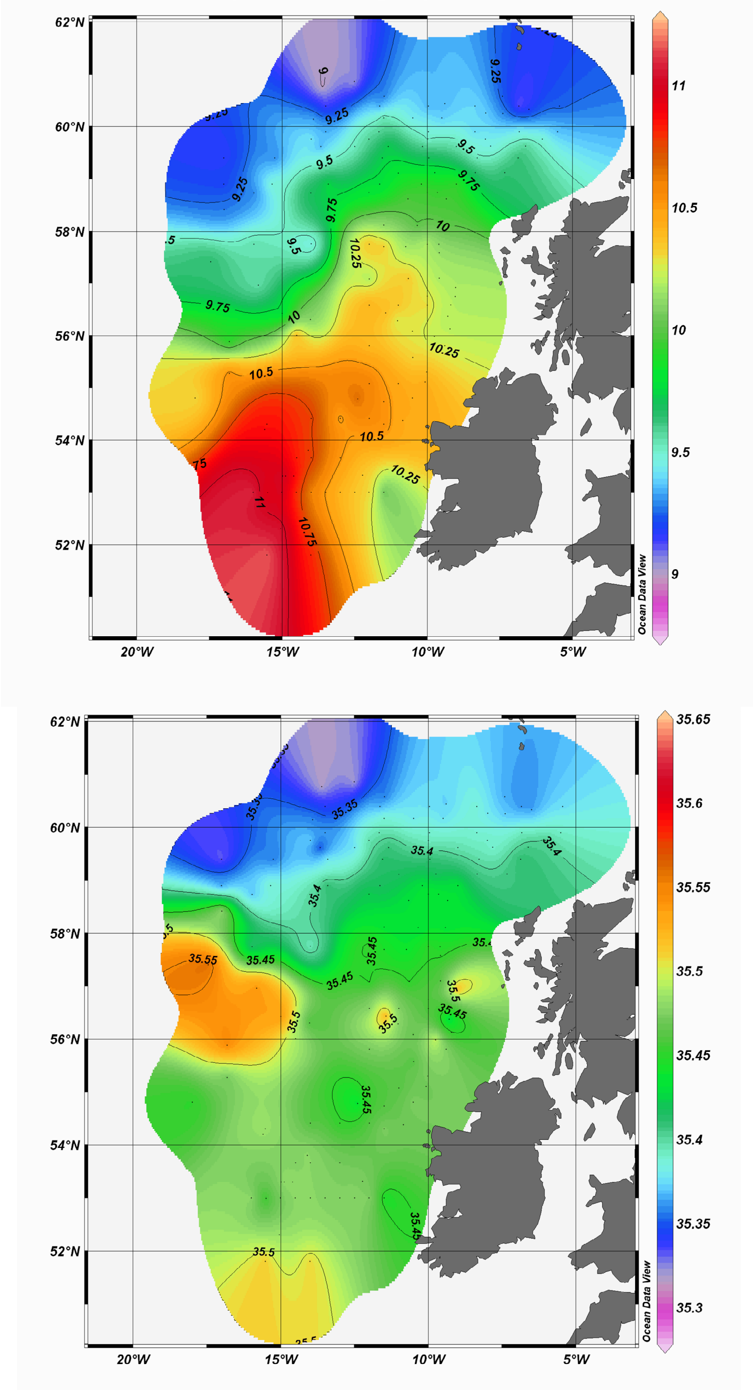


Figure 10. Horizontal temperature (top panel) and salinity (bottom panel) at 10m subsurface as derived from vertical CTD casts. March-April 2009.

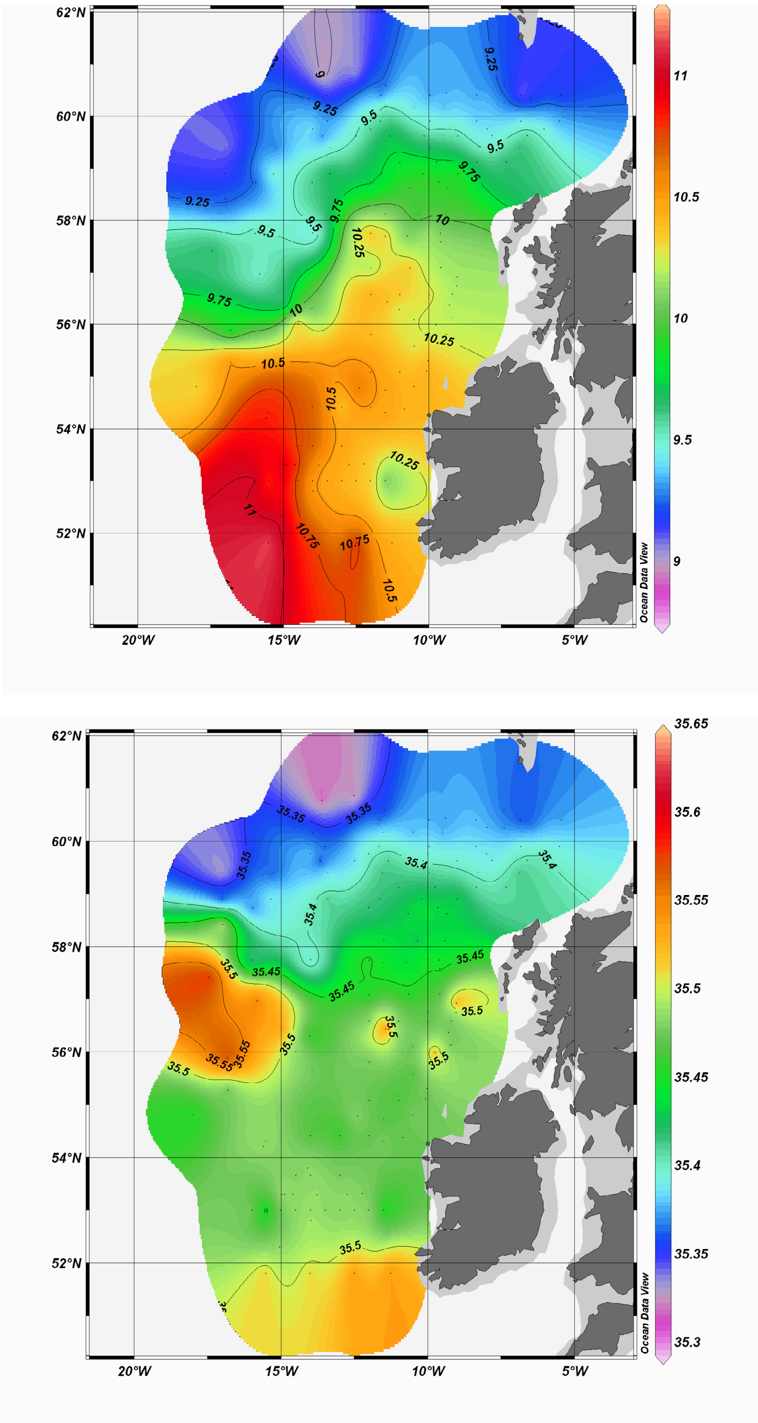


Figure 11. Horizontal temperature (top panel) and salinity (bottom panel) at 50m as derived from vertical CTD casts. March-April 2009.

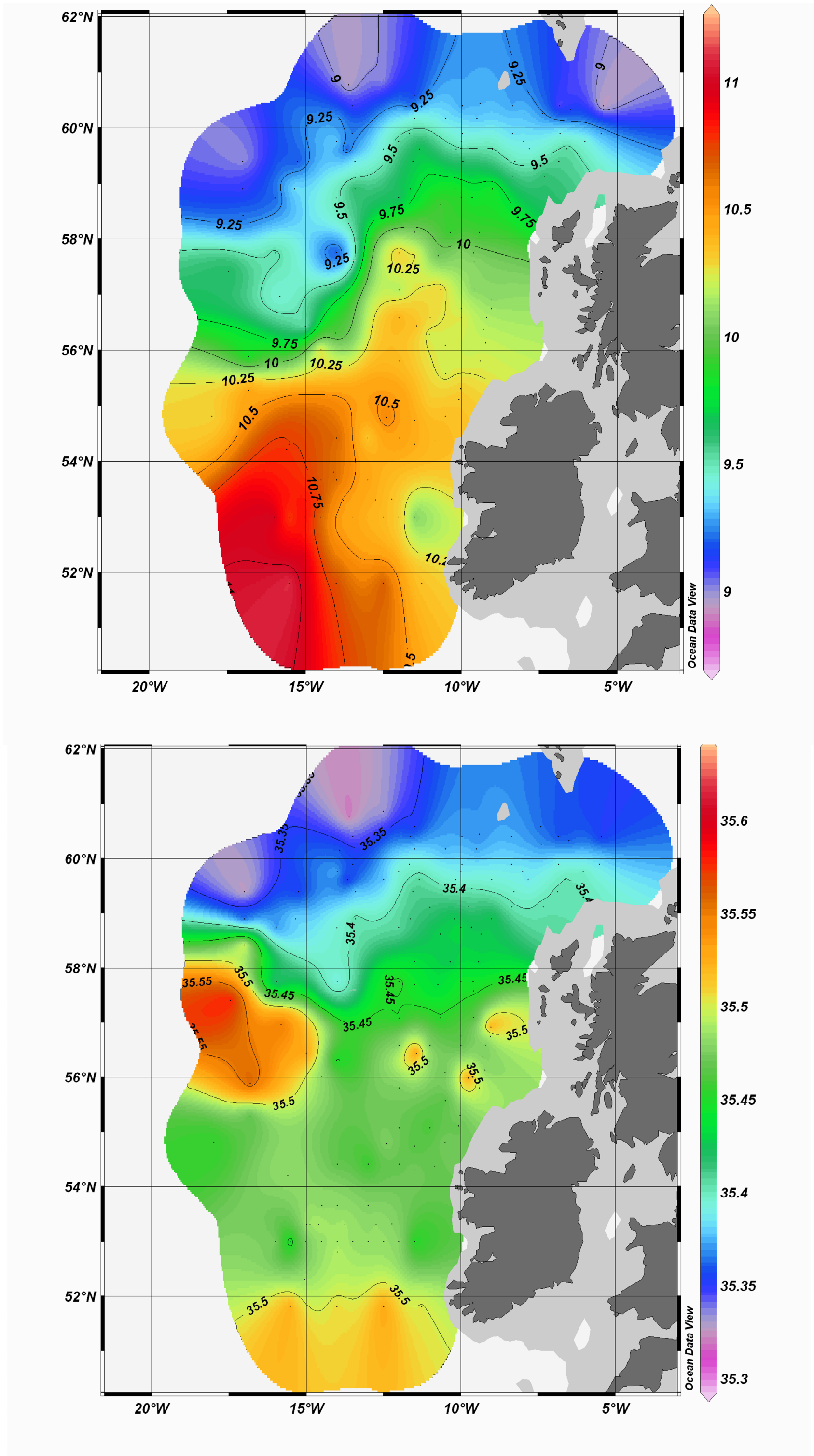


Figure 12. Horizontal temperature (top panel) and salinity (bottom panel) at 100m as derived from vertical CTD casts. March-April 2009.

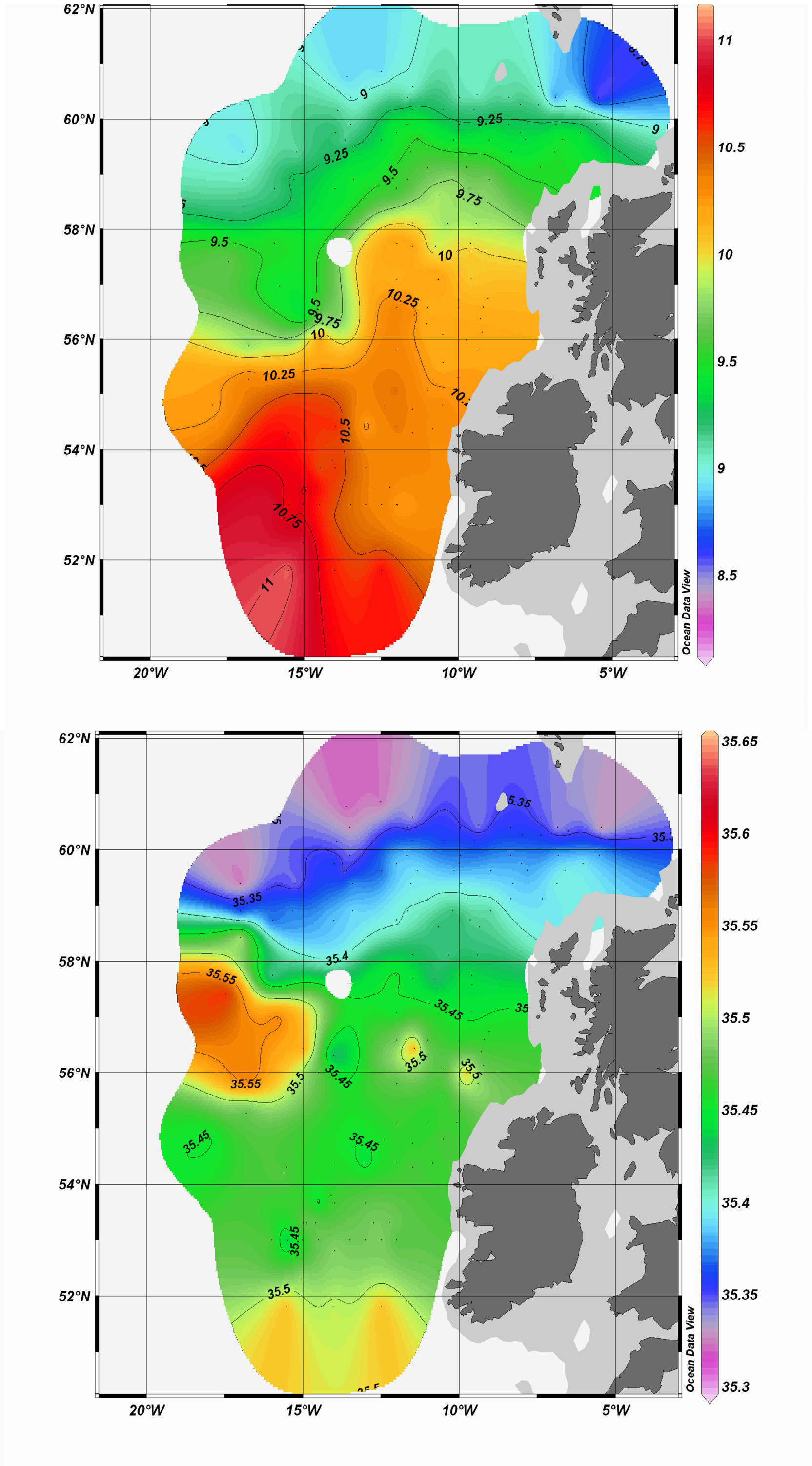


Figure 13. Horizontal temperature (top panel) and salinity (bottom panel) at 200m as derived from vertical CTD casts. Yellow circles indicate CTD positions. March-April 2009.

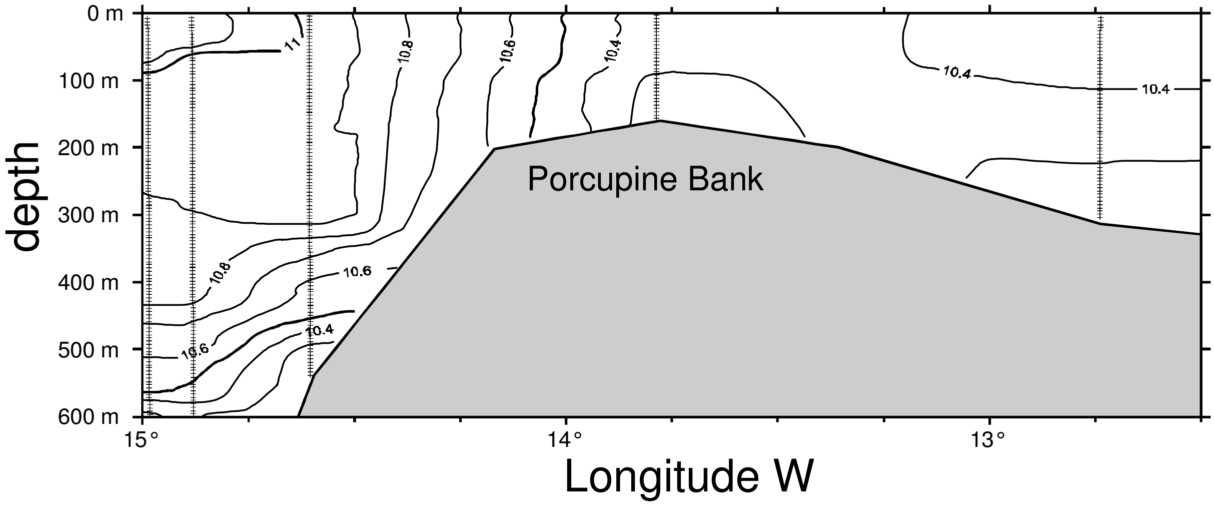


Figure 14. Temperature distribution along a transect across Porcupine Bank in the upper 600 m during the 2009 Hydroacoustic Survey on Blue Whiting with Dutch RV Tridens

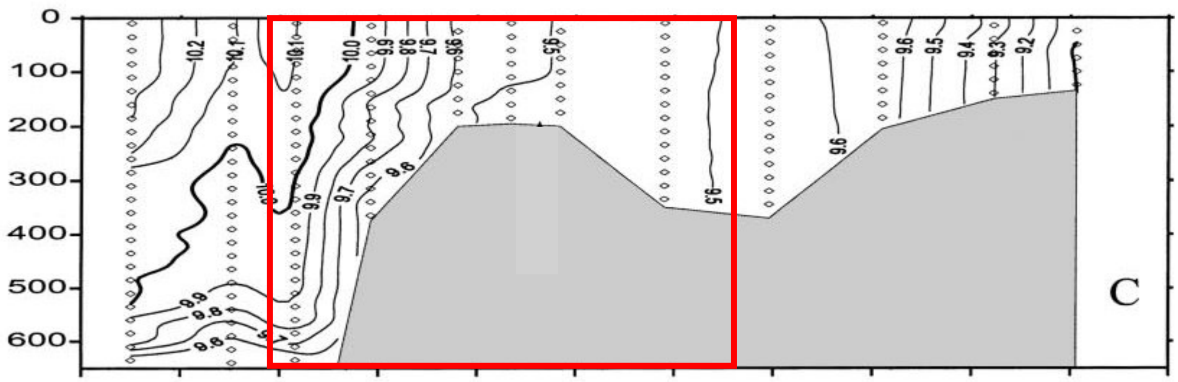


Figure 15. Temperature distribution along a transect across Porcupine Bank in the upper 650 m during the 1994 survey on blue whiting eggs and larvae with German RV Heincke. The red box indicates the area that has been sampled with CTD probes during the 2009 Tridens cruise.

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

Acoustic inter-calibration between R/V Celtic Explorer and R/V Magnus Heinason was conducted on 9 April at 06:00 to the northeast of the Rosemary Bank at position 59º 14N & 008º 21W. The first 10nmi transect was conducted with the M. Heinason acting as the lead vessel cruising at 8 knots in a south easterly direction. A second 10nmi transect was carried out with the Explorer as the lead vessel. Weather conditions were moderate with winds of 20-25 knots from the SE and a northerly swell of 2-2.5 m.

The main acoustic features in the area were (1) patchy schools of blue whiting in depths between 360 and 420 metres recorded intermittently throughout out the exercise, (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 exercise was carried out based on the acoustic registrations of blue whiting only.

The inter-calibration was the run over 20nmi over 2 transects between 06:00-09:25 GMT. Vessels were cruising SSE at parallel courses, with the distance between the tracks being about 0.5 nm to take best advantage of the weather conditions.

Data analysis focused on acoustic densities (c, 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 allocated to blue whiting. The recordings show variable agreement. Overall mean s_A values observed by both vessels were relatively low. The Magnus Heinason tended to record much higher acoustic densities during the first 1-9nmi than the Explorer on what appears to be similar registrations. At the end of the first transect the Celtic Explorer recorded its highest registration during the exercise whereas the Magnus Henson reported a zero value for the same log interval. During the first section of the second transect the Magnus Heinason recorded a single registration over 6 miles whereas the Celtic Explorer low but consistent values. Agreement was more closely aligned from 17-20nmi. Vessel cruise tracks are closely aligned for both vessels each of the 10nmi transects (Figure 2). The degree of variability between vessels over a closely aligned cruise track may be accounted for to a degree by spatial heterogeneity of the patchy schools encountered during the exercise.

At the end of the acoustic inter-calibration a comparative trawl exercise was undertaken. Both vessels turned and towed in parallel over the reciprocal course at a distance of about 0.5 nm apart. Celtic Explorer actively towed for 20 minutes at depths of 410–460 m and caught 400 kg of blue whiting. Magnus Heinason towed in the same depth for the same time and caught 7 kg of blue whiting.

The blue whiting in the catch of Celtic Explorer were larger overall as (mean length: 30.30.cm, range 22.5-37 cm) compared to the blue whiting in the catch of Magnus Heinason (mean length: 28.25cm, range 20-35cm) as shown in Figure 3. It is difficult to draw any conclusions from the trawl data due to the large difference in the weight of the catch. As described earlier the distribution of schools within the area was patchy. In this case it appears that the Explorer encountered one of these schools and the Magnus Heinason did not.

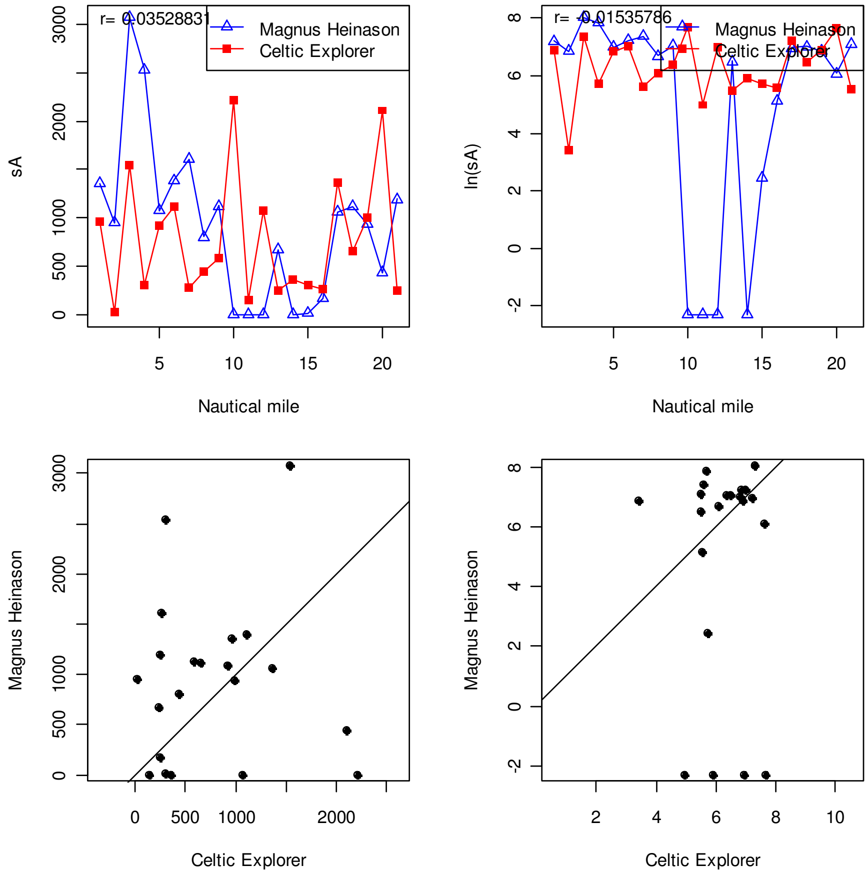


Figure 1. Comparison of blue whiting acoustic densities recorded by Magnus Heinason (open triangles) and Celtic Explorer (squares). The lower panels give same data as scatterplots. The diagonals are drawn as continuous lines.

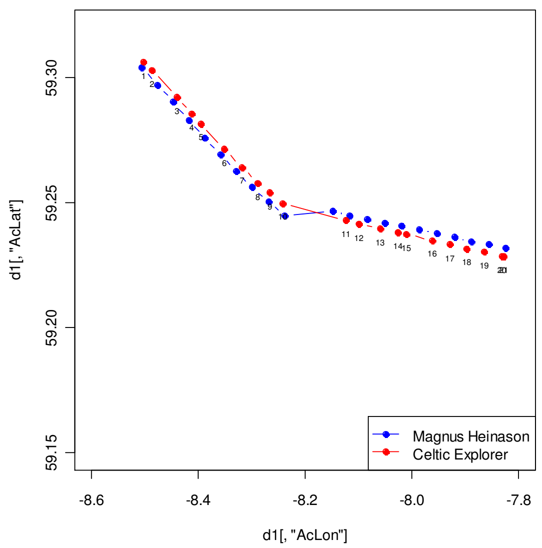


Figure 2. Intercalibration track followed by the Magnus Heinason (blue diamonds) and Celtic Explorer (red diamonds).

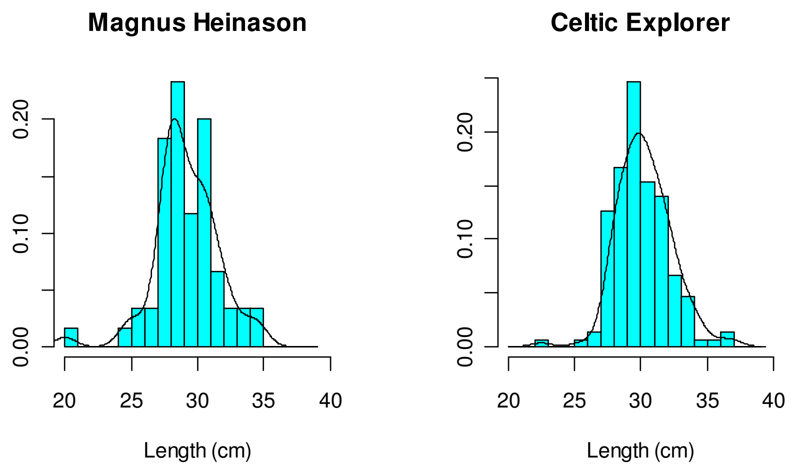


Figure 3. Length distributions from the trawls hauls by Magnus Heinason (mean length 28.25cm) and Celtic Explorer (mean length 30.30cm). Smoothing is obtained by normal kernel density estimates.

Appendix 2. Uncertainty in the acoustic observations and its implications on the stock estimate

Mikko Heino, Institute of Marine research & University of Bergen, Norway

The exercise to estimate uncertainty in acoustic blue whiting observations and the consequences of this uncertainty to stock estimates is repeated using the same procedure as in previous years (Appendix 3 in Heino et al. 2007 and Appendix 4 in O'Donnell et al. 2008).

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 it is not attempted to repeat the whole estimation procedure, but instead uncertainty in global mean acoustic density estimate is characterized. 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.

Bootstrapping is used here 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, 1000 bootstrap estimates of mean acoustic density, weighted by the stratum areas, are calculated. 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 2009 survey as well five earlier international surveys. Mean acoustic density over the survey area is 378 m^2/nm^2, with 95% confidence interval being 334…424 m^2/nm^2. Relative to the mean, the approximate 95% confidence limits are –11%...+12%, and 50% confidence limits are –4.3%...+4.1%. This is similar level of acoustic uncertainty as observed in 2004–2006 and 2008, but much less as observed in 2007. This is caused by a few very high density observations in 2007, with three highest values accounting for more than 20% of total cumulative acoustic density. In other years there are no observations that are as influential.

Figure 2 summarizes the results and puts them in the biomass context. The results clearly show that the observed decline in biomass from 2008 to 2009 is more than could be expected from uncertainty arising from spatial heterogeneity. In other words, within the considered domain of uncertainty, the decline is statistically significant. Similarly, one can conclude with reasonable certainty that the estimate for 2009 is the lowest one in the time series.

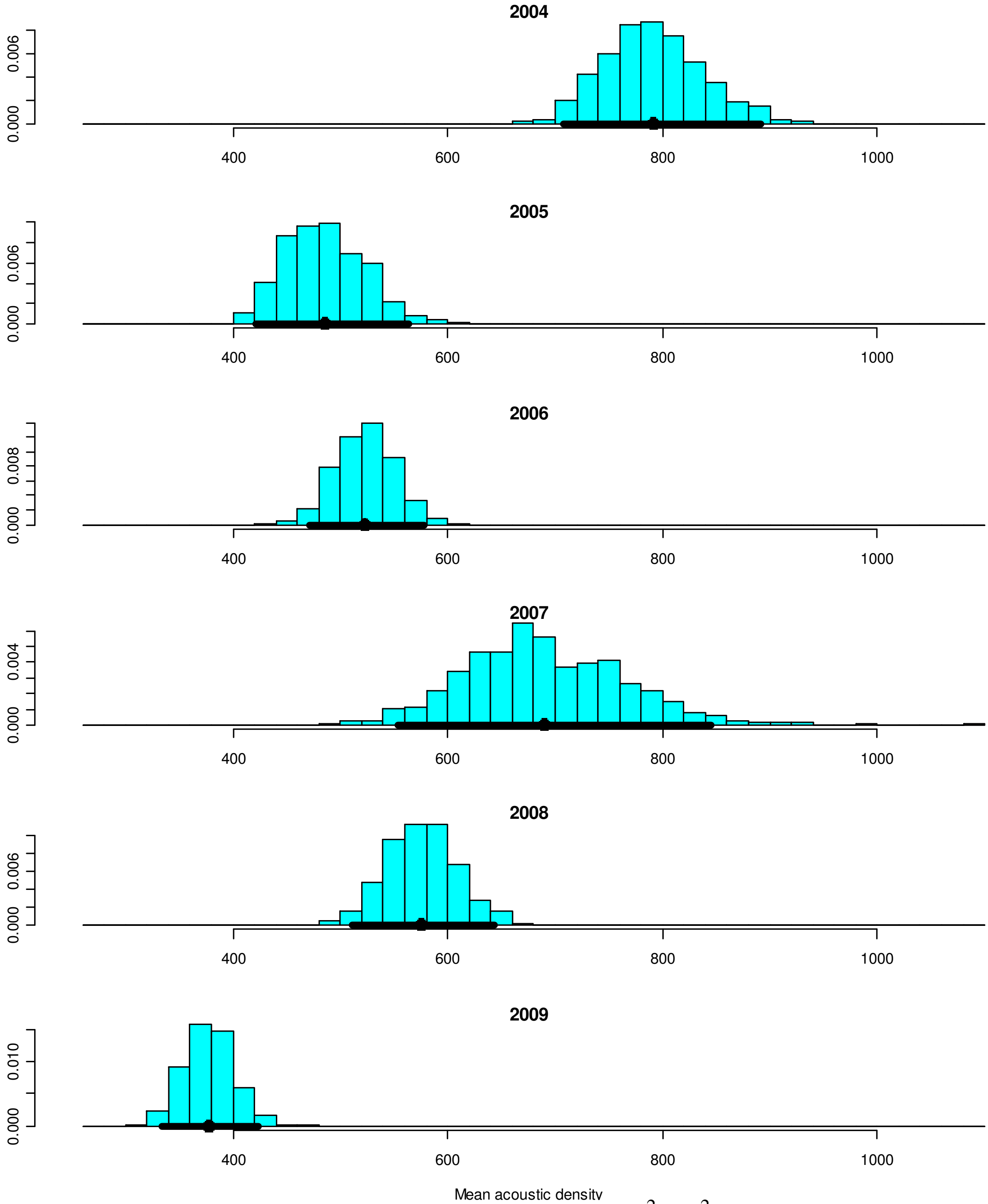


Figure 1. Distribution of mean acoustic density (in m^2/nm^2) based on 1000 bootstrap replicates of acoustic data from blue whiting surveys. Mean acoustic density is indicated with a black dot on the x-axis, while the horizontal bar shows 95% confidence limits.

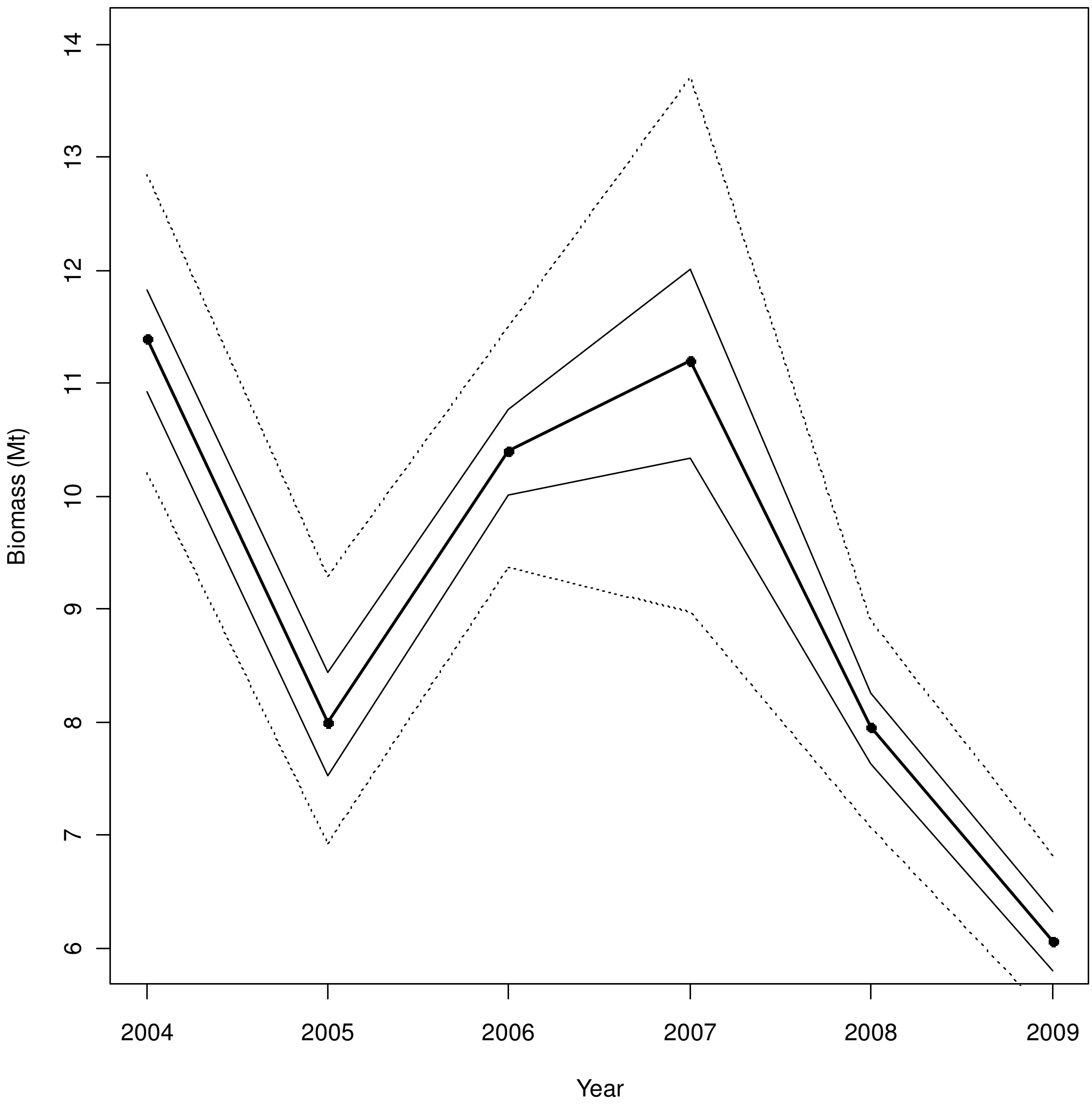


Figure 2. Approximate 50% and 95% confidence limits for blue whiting biomass estimates. The confidence limits are based on the assumption that confidence limits for annual estimates of mean acoustic density can be translated to confidence limits of biomass estimates by expressing them as relative deviations from the mean values. These confidence limits only account for spatio-temporal variability in acoustic observations.

Appendix 3. Review of age determination of blue whiting by national participants.

A review in the consistency of age readings was carried out by Øyvind Tangen using the data collected during the 2009 survey. Results show close agreement between all participants through ages 1-6 year. For older age classes 7-11 years some anomalies were observed with readings from the Netherlands and the Faroes.

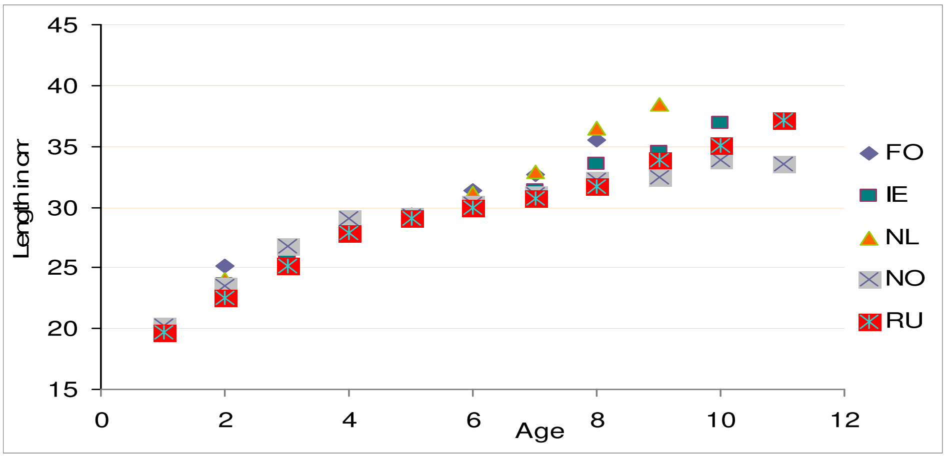


Figure 1. Profile of national age estimates as determined from otolith reading of trawl samples carried out during the blue whiting survey 2009.