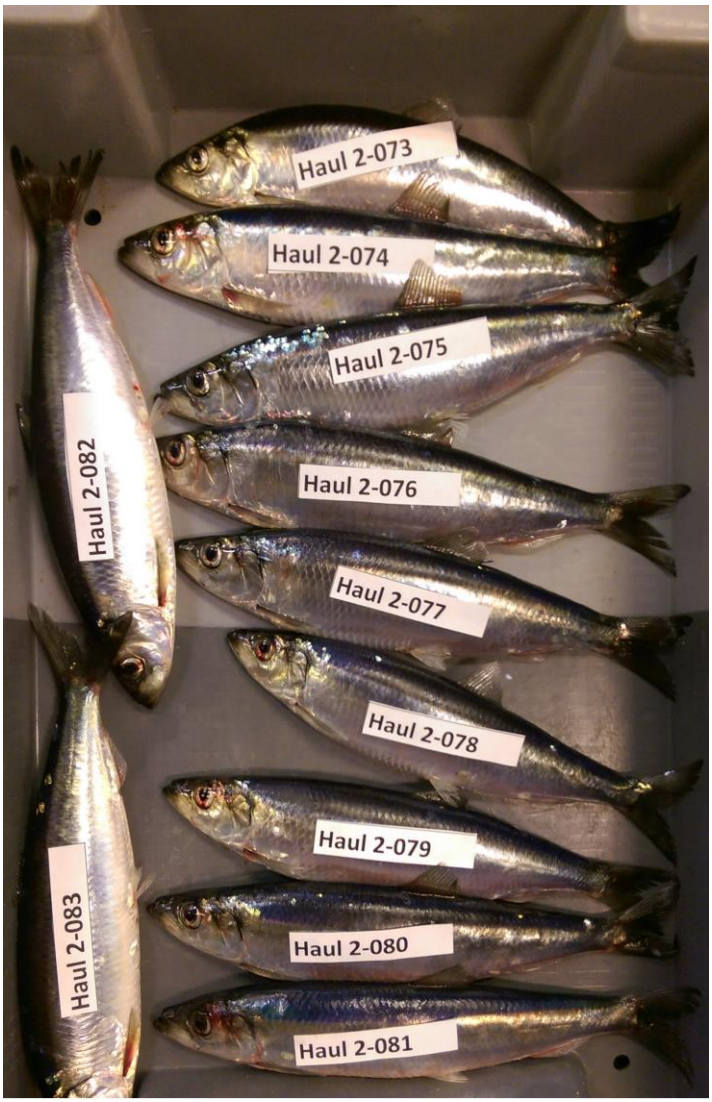
FEAS Survey Series: 2015/04

Northwest Herring Acoustic Survey Report

24th June – 14th July, 2015

RV Celtic Explorer



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1 Introduction

The northwest and west coast (ICES Divisions VIaS & VIIb, c) herring acoustic survey programme was first established in 1994. Prior to acoustic estimation, a larval survey programme was conducted from 1981-1986. In the early 1990s, the ICES herring working group (HAWG) identified the need for a dedicated herring acoustic survey in this area (Anon, 1994). From 1994 to 1996 surveys were carried out on this stock during the summer feeding phase. In 1997 a two-survey spawning survey was established covering both autumn and winter components. In 2004, this was modified to a single spawning stock survey which was carried out early in quarter 1 and continued until 2007. In 2008, it was decided that this survey should be incorporated into the larger coordinated Malin shelf summer survey on recommendation from SGHERWAY and HAWG.

The summer 2015 survey represents the eighth in the new time series (est. in 2008). The survey was coordinated through the ICES Working Group of International Pelagic Surveys (WGIPS). The Irish component was carried out to cover the statistical rectangles between 53°30'-60°30' N and 12°-5° W. This differed to the plans laid out in the WGIPS report (ICES, 2015) due to problems encountered by Marine Scotland Science in securing a charter vessel to cover the northern half of the Malin Shelf. Therefore, for 2015 only Irish data on herring distribution, abundance and age have been used to provide a measure of the relative abundance of herring within the Malin shelf stock complex. Survey data on stock numbers at age are submitted to the ICES Herring Assessment Working Group (HAWG) and used in the annual stock assessment process.

The northwest and west coast (ICES Divisions VIaS & VIIb) herring stock is composed of two spawning components, autumn and winter spawners. Spawning covers a large geographical area and extends over a 4-month period from late September through to late March (Molloy *et al*, 2000). Traditionally, fishing effort has been concentrated on spawning and pre-spawning aggregations. The autumn spawning component, which mostly occurs within VIIb and VIaS, feeds along the shelf break area to the west of the spawning grounds. The larger winter spawning component is found further north in VIa. In VIaS, summer distribution extends from close inshore to the shelf break. Components of the winter spawning fish are known to undertake northward feeding migration into VIaN before returning in the winter to spawn along the Irish coast.

2 Materials and Methods

2.1 Scientific Personnel

Name	Institute	Capacity
Marcin Blaszkowski	FEAS	Biologist
Andrew Campbell	FEAS	Acoustic
Cormac Nolan*	FEAS	Acoustic
Brendan O'Hea	FEAS	Acoustic
Mike O'Malley	MSS	Acoustic
Tobi Rapp	FEAS	Biologist
Turloch Smith	FEAS	Biologist
Dylan Barrett	TTRS**	Biologist
Dylan Ward		Biologist
Melissa Parker	IWDG	MMO
Michael Marrinan	IWDG	MMO

* Chief scientist
** SMART Training Through Research Surveys Scheme

2.2 Survey Plan

2.2.1 Survey objectives

The primary objectives of the survey are listed below:

- Carry out a pre-determined survey cruise track based on the known summer herring distribution
- Collect biological samples from directed trawling on fish echotraces to determine age structure and maturity state of survey stock
- Determine an age stratified estimate of relative abundance and biomass of herring within the survey area (ICES Divisions VIIb & VIaS-N) using acoustic survey techniques
- Collect physical oceanography data as horizontal and vertical profiles from a deployed sensor array.
- Collect detailed morphometric data and genetic tissue samples on individual herring to contribute to stock discrimination studies
- Collect acoustic and biological data on boarfish (*Capros aper*) to feed into the Boarfish Acoustic Survey, 2015.

2.2.2 Area of operation and survey design

The survey focused on the northwest and west coast of Ireland and the west coast of Scotland (ICES Divisions VIaN & VIaS and VIIb) as shown in Figure 1. The survey track started to the southeast of the Isle of Coll, zigzagged north through the Minches (between the Scottish mainland and the Hebrides), then worked progressively southwards in parallel east-west transects, and finished near the mouth of Killary Harbour.

A systematic parallel transect design was adopted for the majority of the survey, with a randomised start point. Transects were positioned running parallel to the lines of latitude and were generally positioned between the 30 m and 250m depth contours. Transect spacing was set at 7.5 nmi in the main body of the survey and at 15 nmi between 57° and 60.5°N. A zigzag design was utilised in the Minches region.

To keep in line with existing survey methodology acoustic data collection was only undertaken during daylight hours (04:00 and 00:00).

In total, the survey covered roughly 3,400nmi. Survey design and methodology adheres to the methods laid out in the WGIPS acoustic survey manual (2015).

2.3 Equipment and system details and specifications

2.3.1 Acoustic array

Equipment settings (Table 1) were determined before the start of the survey and are based on established settings employed on previous surveys (O'Donnell *et al.,* 2004 and 2008).

Acoustic data were collected using the Simrad EK60 scientific echosounder. A Simrad ES-38B (38 kHz) split-beam transducer is mounted within the vessels drop keel and lowered to the working depth of 3.3 m below the vessels hull or 8.8 m below the sea surface. Data were also collected at operating frequencies of 18, 120 and 200 kHz during the survey. Estimates of herring abundance and biomass were derived exclusively from 38 kHz data.

While surveying on track, the vessel is powered using DC twin electric motor propulsion system with power supplied from 1 main diesel engine, so in effect providing "silent cruising" as compared to normal operations (Anon, 2002). Cruising speed is maintained at a maximum of 10Kts (knots) where possible. During fishing operations, normal two engine operations were employed to provide sufficient power to tow the net.

2.3.2 Calibration of acoustic equipment

The EK60 was calibrated in Killary Harbour on the 25th of June before commencing the survey to ensure optimal operation of the echosounder during data logging. A second calibration could not be performed at the end of the survey due to time constraints. The results of the 38 kHz calibration are presented in Table 1. Prior to the survey, the EK60 was last calibrated in April 2015.

2.3.4 Acoustic data acquisition

Acoustic data were recorded onto the hard-drive of the EK60 processing PC. The raw ER60 files were copied via a continuous ethernet connection to the vessels server as a backup in the event of system failure. Further back-up copies were stored on an external HDD and magnetic LTO4 tapes. Myriax Echoview Echolog (Version 4.8) live-viewing software was used to display the echogram during data collection to allow the scientists to monitor target locations and depths of fish shoals in almost real-time. A member of the scientific crew monitored the equipment continually. Time and position were recorded for each transect start/end point within each stratum. The log was also used to record "off track events" such as fishing operations and hydrographic stations.

2.3.5 Echogram scrutinisation

Acoustic data were backed up every 24 hrs and scrutinised using Myriax Echoview (vers. 5.3). The scrutiny process involved the allocation of echotraces (schools) to particular species or species mix categories, based on information from the directed trawl hauls and the schools characteristics and location.

The NASC (Nautical Area Scattering Coefficient) values from each herring echotrace were allocated to one of 4 categories after scrutiny of the echograms. Categories identified on the basis of echotrace scrutiny were as follows:

1. "Definitely herring" echotraces were identified on the basis of captures of herring from the fishing trawls that had sampled the echo-traces directly, and on large echotraces which had the characteristics of "definite" herring traces (i.e. very high intensity (red), narrow inverted tear-shaped marks either directly on the bottom or in mid-water and in the case of spawning shoals very dense aggregations in close proximity to the seabed).

2. "Probably herring" were attributed to smaller echotraces that had not been fished but which had the characteristic of "definite" herring traces.

3. "Herring in a mixture" were attributed to NASC values arising from all fish traces in which herring were thought to be contained, owing to the presence of a proportion of herring within the nearest trawl haul or within a haul which had been carried out on similar echotraces in similar water depths.

4. "Possibly herring" were attributed to small echotraces outside areas where fishing was carried out, but which had the characteristics of definite herring traces.

Echograms were divided into transects, and off track events, including trawl hauls and hydrographic stations, were excluded from further analysis. Echo integration was performed on regions that were defined by enclosing selected parts of the echogram that corresponded to one of the four categories above. The echograms were generally analysed and echo-integrals calculated at a threshold of -70 dB; where necessary heavy backscatter from plankton was filtered out by thresholding at –65 dB.

2.3.6 Biological sampling

A single pelagic multipurpose midwater trawl with the dimensions of 54m in length (LOA) and 8m at the wing ends and a fishing circle of 420m was employed during the survey (Figure 13). Mesh size in the wings was 2.2m through to 4cm in the cod-end. The net was fished with a vertical mouth opening of between 16m and 20m, which was observed using a cable linked "BEL Reeson" netsonde (50 kHz). Spread between the trawl doors was monitored using Scanmar distance sensors, all sensors being configured and viewed through a Scanmar Scanbas system.

All components of the catch from the trawl were sorted; fish and other taxa were identified to species level. Fish samples were segregated by species and each component weighed. For species other than herring, length and weight measurements were taken for 100 individuals in addition to a 300 fish length frequency sample. Age, length, weight, sex, and maturity data were recorded from 100 random herring, a further 100 random length/weight measurements were also taken, in addition to a 300 fish length frequency sample from each trawl. All herring were aged onboard. The appropriate raising factors were calculated and applied to provide length frequency compositions for the bulk of each haul.

Decisions to fish on particular echo-traces were largely subjective, though an attempt was made to target all significant fish mark-types throughout the survey grid regardless of subjective eye-ball classifications. No bottom trawl gear was used during this survey.

2.3.7 Oceanographic data collection

Hydrographic stations were carried out during the survey at predetermined locations along the track. Data on temperature, depth and salinity were collected using a Seabird 911 sampler from 1 m subsurface to full depth.

2.3.8 Marine Mammal Survey

Two marine mammal observers were present on board during the survey and conducted watches, when conditions allowed, from the ships crow's nest located 18m above sea level or alternatively from the bridge of the vessel when environmental conditions prevented access to the crow's nest.

Each day surveys commenced at 07:00 and concluded at 21:00 (surveys were postponed during incumbent weather). Observer effort focused on a 180-degree arc ahead of the ship; however sightings located up to 90 degrees to port and starboard were also included. The observers scanned the area by eye and using 10 X 40 binoculars. Bearings to sightings were measured using an angle board and distances were estimated with the aid of distance measuring stick. Environmental data were recorded every 20 minutes using Logger 2000 software (IFAW 2000). Sightings were also recorded using Logger 2000. Automated position data were obtained through a laptop computer linked to GPS receiver.

As this was a survey onboard a vessel of opportunity, the survey was conducted in 'passing mode' and cetaceans sighted were rarely approached (exceptions being a large group of feeding fin whales and sighting of two basking sharks). Sightings were identified to species level where possible, with species identifications being graded as definite, probable or possible. Where species identification could not be confirmed, sightings were downgraded (e.g. unidentified dolphin / unidentified whale / unidentified beaked whale etc.) according to criteria established for the IWDG's cetacean sightings database (IWDG 2009). Photographs were attempted for all sightings using two ©Cannon Eos cameras with zoom lenses (©Cannon 75-300mm and ©Sigma DG 150-500mm). Identification was verified, where possible, on review of photographs taken, after each day's survey was complete, by matching times on photograph with times of sighting.

The survey covered 6296.8km cruising from the hours 04:00 to 00:00 halting for 4 hours during the night. The survey vessel travelled at an average speed 10 knots when on acoustic survey and 3-4 knots when trawling. The vessel spent the majority of time on acoustic survey, towing on occasion when fish marks were detected. Tows lasted on average 30 minutes (in addition to 20 – 30 minutes for deploying and retrieving the net). CTDs were conducted during some transects and during these the vessel remained stationary for 10 – 20 minutes.

2.4 Analysis methods

2.4.1 Abundance estimates

In 2015, for the first time, acoustic data were analysed using the StoX (2015) software package recently adopted for WGIPS coordinated surveys. StoX is an open source software developed at IMR, Norway to calculate survey estimates from acoustic and swept area surveys. Estimation of abundance from acoustic surveys within StoX was carried out according to the stratified transect design model developed by Jolly and Hampton (1990).

NASC values, assigned according to scrutinisation methods (section 2.3.5), were used to estimate the herring and boarfish numbers according to the method of Dalen and Nakken (1983).

The following TS-length relationships used were those recommended by the acoustic survey planning group (ICES, 1994):

Herring	TS =	$20\log_{10}L - 71.2$ dB per individual (L = length in cm)
Sprat	TS =	$20\log_{10}L - 71.2$ dB per individual (L = length in cm)
Mackerel	TS =	$20\log_{10}L - 84.9$ dB per individual (L = length in cm)
Horse mackerel	TS =	$20\log_{10}L - 67.5$ dB per individual (L = length in cm)

The TS length relationship used for gadoids was a general physoclist relationship (Foote, 1987):

Gadoids TS = $20\log_{10}L - 67.4$ dB per individual (L = length in cm)

For boarfish (*Capros aper*) a species specific TS length relationship was applied based on theoretical swimbladder modelling (Fässler *et al.* 2013).

Boarfish TS = $20\log_{10}L - 66.2$ dB per individual (L = length in cm)

3 Results

3.1 Herring abundance and distribution

Twenty five hauls were carried out during the survey, of which eight contained herring (Figure 2, Table 2). 2,012 herring lengths were taken, together with 1,645 length/weight measurements and 931 individual age and maturity readings. Eight hauls were sampled for the SGHERWAY stock identification project (Figure 2), resulting in 960 body morphometry photographs and otoliths for shape analysis.

3.1.2 Herring biomass and abundance

Herring biomass and abundance are broken down by age, maturity, area and year in tables 4-8.

The total stock biomass (TSB) for the whole surveyed area (the Malin Shelf; VIa and VIIb,c) was estimated at 454,770 t, with an estimated spawning stock biomass (SSB) of 429,870 t. The abundance (or total stock numbers, TSN) was estimated at 2,371.6 million individuals. The time series is presented in table 7 but as this is the only year in the time series where the Celtic Explorer surveyed the entire Malin Shelf, the 2015 estimates are not comparable to previous years.

The overwhelming majority of herring were observed in VIaN: total stock biomass was 399,460 t, spawning stock biomass (SSB) was 191,600 t, and abundance was 2,023 million individuals.

In VIaS VIIb,c, the TSN was 348 million individuals, the TSB was 55,310 t, and the SSB was 42,710 t. The time series is presented in table 8 and all years are comparable. The current estimate is the third highest in the time-series but the split is purely geographically based and is therefore not a reliable indicator of the north-west herring stock (see Discussion).

3.1.3 Herring distribution

In total, 829 herring echotraces were recorded during the survey (Figure 3). Herring schools were mainly located in four distinct areas:

- North of Cape Wrath
- Between the shelf-break and 8° W near St. Kilda
- In ICES statistical rectangle 42E1 and 42E0
- North-west of Donegal

The majority of herring occurred in large, discrete schools in close proximity to the seabed (see Appendix 1 for haul echograms) or in mixed-species assemblages, forming a light scattered layer along the seabed with mackerel and demersal species (Table 2; Appendix 1). These layers often extended for several miles. No herring schools were observed in the upper regions of the water column. More large herring schools were observed in 2015 than recent years (29 schools with NASC > 1,000) but this is a reflection of the increased survey area.

3.1.4 Herring stock structure

A full breakdown of the survey stock structure by age, length, weight, maturity and area is presented in Tables 4-8. Combined maturity analysis indicated that the vast majority of herring encountered during the survey were mature (92% of the TSN). Age analysis of biological samples showed herring within the survey area to be composed of age-groups from 2-8 winter rings (although a single 1-ringer and a single 10-ringer were caught). In 2014, the stock age profile was dominated by 1-, 4- and 5-ringed herring in terms of biomass and abundance. The 4- and 5-ringed cohorts were evident again in 2015, representing 19% of the total biomass as 5-ringers and 22% as 6-ringers (18% and 20% respectively of the total abundance). The dominant cohort in the 2015 survey was 4-ringers, representing 32% of the

total biomass and abundance. No 1-ringed herring were sampled during the 2015 survey, in stark contrast to the 47% of the 2014 abundance estimate that was attributed to 1-ringers. In the past this survey has not reliably quantified 1-ringed herring and apparently large incoming year classes are not always observed in the subsequent year. The catchability of 1-ringers in this survey is low. Very young fish have almost exclusively been caught in the Minches region and their capture is sporadic.

3.2 Other Pelagics

3.2.1 Boarfish

Boarfish (*Capros aper*) were encountered from 30-190 m and were found exclusively close to the shelf-break (Figure 4). The majority of the boarfish that was detected acoustically occurred in small or medium sized schools close to bottom (see Appendix 1; Haul 16 and 19).

Overall, 676 individual length measurements and 302 length/weight measurements were recorded from three hauls. Boarfish length ranged from 10-26.5 cm (Figure 5) with a corresponding weight range of 41-95 g. Mean length was 14.4 cm and mean weight 63 g.

Estimates of boarfish abundance and biomass are not reported here because the data were combined with those collected over a much wider area as part of a dedicated boarfish acoustic survey (see O'Donnell and Nolan, 2015).

3.2.2 Sprat

Sprat were caught in haul 21 near the Stags of Mayo (Figure 4; Appendix 1). Sprat are weighed and measured as part of the biological sampling but are not aged.

3.2.3 Mackerel

Mackerel were encountered in most hauls, occasionally making up over 90% of the total catch. They were distributed over the entire survey area, usually as mixed species scattering layers.

In total 1,442 individual lengths and 777 length/weight measurements were recorded for mackerel from 16 hauls. Length ranged from 19-44 cm with a corresponding weight range of 47-684 g. Mean length was 28.45 cm and mean weight 216 g.

3.3 Oceanography

A total of 40 CTD casts were made during the survey (Figure 1). All data were compiled to produce horizontal plots of temperature and salinity at the following depths; 5m, 20m, 40m and 60m subsurface (Figures 6-9). The hydrographic data showed that, similar to previous years, the upper regions of the water column (5 & 20 m) in VIaS (northwest Ireland) were warmer than the VIaN region (c. 13 °C cf. 11 °C north of 57°N; Figure 6 and 7). On average, the surface waters were roughly 1 °C cooler than the same time last year. At 40 and 60 m, the water temperature was much cooler throughout most of the survey sector (c. 10.5 °C), indicating that the water was well-stratified thermally in most regions (Figure 9). The results again showed that generally the water salinity decreased gradually from the shelf-break (c. 35.4 ppt) towards land (c. 34 ppt) at all depths surveyed through the survey region (Figures 6-9). Salinity was fairly uniform throughout the water column, varying by approximately 0.1 to 0.5 ppt between the upper layers and 60 m with the more saline water extending slightly further eastward at 60m. In general, the spatial pattern of temperature variation was similar to previous years, with coastal waters around northwest Ireland being predominantly warmer

than those in the northern and shelf-break regions. And it was in those cooler areas where the majority of the herring was encountered (Figure 10).

3.4 Marine Mammal and Seabird Survey

Of the 21 days at sea, surveys were carried out on 18 days with varying degrees of success. Over 208 survey hours were completed with a total of 80 separate sightings. Sightings were deemed to be separate sightings, and recorded, when both surveyors were positive that there was no replication. Environmental data was collected at a total of 541 stations.

For the majority of this survey, the sea-state remained between 2 and 5 (86% of all stations) allowing for good surveying conditions. Exceptional conditions (sea-state </=1) were experienced at 2% of all stations while adverse conditions (sea-state 6-8) were experienced at 12% of all stations (Table 10). Daily maximum and minimum are depicted in Figure 12. Swell height, for the majority of this survey was light to moderate (67% of all stations). Heavier conditions were experienced at 31% of all stations while there was no swell experienced at 2% of all stations (Table 11 and Figure 13). For the majority of the survey visibility was moderate to excellent (6km->20km for 88% of all stations) with the remainder being </=5km (Table 12 and Figure 14). On 88% of stations there was no rainfall, with intermittent heavy rainfall at 14% and fog experienced at 4% of all stations (Table 13). These recordings should be viewed with caution as on occasions recorders neglected to change precipitation while recording.

3.4.1 Marine Mammals

In total 80 sightings were recorded that included 10 separate species (basking shark and unidentified beaked whale included) and an estimated 415 individuals (group size was determined visually and erred on the conservative side). Table 14 gives a breakdown of the number of each species recorded. Seven sightings were recorded within the Irish economic exclusion zone while the majority of sightings (73) were recorded in Scottish waters between the Inner and Outer Hebrides and west of the Outer Hebrides. Figure 15-17 show the position of each sighting on a weekly basis.

3.4.2 Seabirds

Seabird species seen around the survey vessel were recorded and identified where possible. 13 seabird species were recorded during the survey:

Bonaparte's gull	(*Chroicocephalus philadelphia*)
Collared dove	(*Streptopelia decaocto*)
Fulmar	(*Fulmarus glacialis*)
Gannet	(*Morus bassanus*)
Great black backed gull	(*Larus marinus*)
Great skua	(*Stercirarius skua*)
Guillemot	(*Uria aalge*)
Herring gull	(*Larus argentatus*)
Kittiwake	(*Rissa tridactyla*)
Lesser black backed gull	(*Larus fuscus graellsii*)
Puffin	(*Fratercula arctica*)
Razorbill	(*Alca torda*)
Storm petrel	(*Hydrobates pelagicus*)

4 Discussion and conclusions

4.1 Discussion

This is the first year that the StoX program has been used to estimate the abundance and biomass of herring for this survey instead of the nationally developed R package described in previous reports. To test the accuracy and ensure consistency the 2015 herring abundance and biomass were calculated using both the old and new methods. The results compared favourably between methods and a detailed description of the comparison will appear in the next WGIPS report (January 2016). It should be noted that minor improvements to the NWHAS 2015 StoX script may be applied during the 2016 WGIPS meeting which could result in (small) discrepancies between the numbers reported here and the final WGIPS tables. While switching to the StoX protocol the opportunity to improve the stratification of the survey was also taken. Previously each ICES rectangle was considered a stratum but now four statistically meaningful strata have been mapped based on previous herring distributions. This means however that the results will no longer be reported by ICES rectangle. The boundary between VIaN and VIaS was included in the new strata design to ensure biomass\abundances could be reported separately for those areas.

In terms of the current survey, all components of the work program were completed as planned. The estimates of biomass and abundance had acceptable degrees of precision and the acoustic analyses were supported by a high number of trawl hauls. All four frequencies of the EK60 echosounder were calibrated successfully prior to beginning the planned cruise track but no inter-calibration with the boarfish acoustic survey could be conducted due to time constraints. This will no longer be a problem in 2016 as both surveys are to be combined on the Celtic Explorer.

The Celtic Explorer covered the whole Malin Shelf (i.e. VIaN, VIaS and VIIb) this year due to logistical problems at Marine Scotland. As such the 2015 estimates presented here are not directly comparable to previous years. As always the true picture will be reported from the next meeting of WGIPS in January 2016. At least two stocks of herring mix in the survey area in the summer months (WESTHER Final Report). Work is ongoing to produce separate survey indices for herring of West of Scotland (VIaN) and West of Ireland (VIaS/VIIbc) origin. This involves body and otolith morphology recorded according to SGHERWAY protocol and subsequent discriminant analyses. In the meantime, splitting the two stocks purely geographical (as has been done in the past along the 56° N line) shows that the TSB in VIaS/VIIbc has increased substantially from 9 kt in 2015 to over 55 kt in 2016. However, a purely geographical split is now widely considered as inappropriate.

4.2 Conclusions

- The Irish portion of the survey covered the whole Malin Shelf this year.
- Robust estimates of herring abundance (2,371 mill.) and biomass (TSB 455k t) were calculated using the new StoX open source software.
- The vast majority of herring were distributed within ICES area VIaN.
- Eight herring hauls were sampled, using the SGHERWAY protocol, for later stock discrimination.
- The survey successfully tracked the 2009 and 2010 year classes but the dominant cohort were 4-ringers, which represented 32% of the total abundance and biomass. No 1-ringed fish were observed.
- CTD data indicated that coastal waters around northwest Ireland were warmer than those in the northern and shelf-break regions and were overall cooler than the same

time the previous year. The majority of herring seemed to be concentrated in cooler water but in-depth analyses of the correlations between temperature and herring distribution were not performed.

- Boarfish data was recorded and added to the coverage of the 2015 boarfish acoustic survey.

5 Acknowledgements

We would like to express our thanks and gratitude to Antony Hobin (Captain) and all the crew of the Celtic Explorer for their good will and professionalism during the survey. Thanks also to Dylan Barrett (SMART: Training Through Research Surveys Scheme), who was an asset to the scientific crew. Aodhan Fitzgerald and all in RV OPS provided excellent planning and logistic support as always.

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Tables

Table 1. Survey settings and calibration report (38kHz) for the Simrad ER60 echosounder. Northwest herring survey, June\July 2015.

Calibration Version: 2.1.0.12

Date: 6/25/2015

Comments:
38kHz Killary

Reference Target:
TS -33.52 dB Min. Distance 17.00 m
TS Deviation 5.0 dB Max. Distance 22.00 m

Transducer: ES38B Serial No.
Frequency 38000 Hz Beamtype Split
Gain 25.96 dB Two Way Beam Angle -20.6 dB
Athw. Angle Sens. 21.90 Along. Angle Sens. 21.90
Athw. Beam Angle 6.95 deg Along. Beam Angle 6.90 deg
Athw. Offset Angle -0.03 deg Along. Offset Angle -0.05 deg
SaCorrection -0.67 dB Depth 8.80 m

Transceiver: GPT 38 kHz 009072033933 1-1 ES38B
Pulse Duration 1.024 ms Sample Interval 0.193 m
Power 2000 W Receiver Bandwidth 2.43 kHz

Sounder Type:
EK60 Version 2.4.3

TS Detection:
Min. Value -50.0 dB Min. Spacing 100 %
Max. Beam Comp. 6.0 dB Min. Echolength 80 %
Max. Phase Dev. 8.0 Max. Echolength 180 %

Environment:
Absorption Coeff. 8.9 dB/km Sound Velocity 1504.3 m/s

Beam Model results:
Transducer Gain = 25.82 dB SaCorrection = -0.67 dB
Athw. Beam Angle = 6.93 deg Along. Beam Angle = 6.91 deg
Athw. Offset Angle =-0.06 deg Along. Offset Angle=-0.04 deg

Data deviation from beam model:
RMS = 0.15 dB
Max = 0.69 dB No. = 3 Athw. = -0.4 deg Along = -1.3 deg
Min = -0.67 dB No. = 2 Athw. = 0.1 deg Along = -0.2 deg

Data deviation from polynomial model:
RMS = 0.11 dB
Max = 0.74 dB No. = 3 Athw. = -0.4 deg Along = -1.3 deg
Min = -0.54 dB No. = 2 Athw. = 0.1 deg Along = -0.2 deg

Table 2. Catch composition and position of hauls undertaken by the RV *Celtic Explorer.* Northwest herring survey, June\July 2015. Latitude and longitude in decimal degrees.

No.	Date	Time	Lat. N	Lon. W	Target Depth (m)	Bottom Depth (m)	Bulk Catch (kg)	Sampled Catch (kg)	Herring %	Boarfish %	Mackerel %	Blue Whiting %	Others^ %
1	27/06/2015	09:13	58.000	-5.900	31	81	12.8	12.8	0.0	0.0	0.0	0.0	100.0
2	28/06/2015	09:03	59.900	-4.300	130	140	6000.0	139.3	98.3	0.0	1.7	0.0	0.0
3	30/06/2015	09:26	58.900	-5.900	95	100	1000.0	143.3	88.4	0.0	11.3	0.0	0.3
4	30/06/2015	13:50	58.900	-4.600	10	75	41.7	41.7	0.0	0.0	0.0	0.0	100.0
5	02/07/2015	17:06	57.700	-8.500	155	155	750.0	117.3	99.5	0.0	0.0	0.5	0.0
6	02/07/2015	22:58	57.500	-9.400	150	190	12.2	12.2	0.0	0.0	6.6	54.8	38.6
7	03/07/2015	20:37	56.900	-8.900	90	118	6.6	6.6	0.0	2.3	84.6	1.5	11.7
8	04/07/2015	15:01	56.700	-8.500	122	127	2000.0	117.3	93.4	0.0	6.2	0.0	0.4
9	04/07/2015	19:43	56.700	-7.400	207	212	74.9	74.9	0.0	0.0	1.1	96.4	2.6
10	05/07/2015	13:33	56.400	-8.500	133	138	146.9	146.9	57.7	0.0	41.7	0.1	0.5
11	06/07/2015	14:24	56.100	-8.300	107	112	250.0	196.8	82.8	0.0	17.2	0.0	0.0
12	06/07/2015	18:45	56.100	-7.700	117	123	5.8	5.8	5.4	0.0	64.5	0.0	30.1
13	07/07/2015	13:42	56.000	-9.100	150	200	0.4	0.4	0.0	0.0	100.0	0.0	0.0
14	08/07/2015	05:24	55.800	-7.100	43	45	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	08/07/2015	10:53	55.500	-6.700	10	70	6.2	6.2	0.0	0.0	76.7	0.0	23.3
16	09/07/2015	06:15	55.500	-9.000	89	94	108.0	108.0	18.4	52.3	27.8	0.0	1.4
17	09/07/2015	12:43	55.400	-8.800	85	95	246.4	246.4	45.9	0.0	51.3	0.0	2.8
18	10/07/2015	09:50	55.300	-9.200	99	104	63.9	63.9	0.0	0.0	99.9	0.0	0.1
19	11/07/2015	09:31	54.900	-10.200	120	130	4000.0	87.2	0.0	100.0	0.0	0.0	0.0
20	11/07/2015	15:32	54.900	-9.100	65	70	200.0	128.0	0.1	0.0	99.9	0.0	0.0
21	12/07/2015	13:58	54.400	-9.900	13	83	0.5	0.5	0.0	0.0	0.0	0.0	100.0
22	13/07/2015	05:50	54.100	-10.700	85	180	97.2	97.2	0.0	98.7	0.7	0.0	0.6

Table 3. Length-frequency of herring hauls used in the analysis. Northwest herring survey, June\July 2015.

Length (cm)	Haul 2	Haul 3	Haul 5	Haul 8	Haul 10	Haul 11	Haul 16	Haul 17
16	-	-	-	-	-	-	-	-
16.5	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
17.5	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
18.5	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
19.5	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
20.5	-	-	-	-	-	-	-	-
21	-	-	1	-	-	-	-	-
21.5	-	-	-	-	-	-	-	1
22	-	-	-	-	-	-	-	4
22.5	-	-	-	-	-	-	-	7
23	-	-	-	-	1	9	-	29
23.5	-	-	-	-	1	6	-	13
24	1	1	-	-	5	20	1	29
24.5	1	4	-	-	1	9	1	27
25	7	5	-	-	7	32	3	35
25.5	1	8	-	1	2	9	3	37
26	11	21	1	11	12	34	1	38
26.5	7	28	3	11	8	8	7	23
27	11	60	18	33	37	38	12	42
27.5	13	34	19	37	31	31	19	34
28	53	50	39	60	60	60	22	60
28.5	46	17	26	26	15	11	23	23
29	60	19	60	23	28	7	5	14
29.5	39	11	23	3	3	4	4	5
30	32	3	18	5	7	1	1	2
30.5	8	1	5	-	3	-	-	-
31	4	-	1	-	1	-	-	-
31.5	-	-	-	-	-	-	-	-
32	2	-	-	-	-	-	-	-
32.5	-		-	-	-	-	-	-
Division	**VIaN**	**VIaN**	**VIaN**	**VIaN**	**VIaN**	**VIaN**	**VIaS**	**VIaS**

Table 4. Abundance, biomass, maturity, mean weight and mean length by age of herring in **the entire Malin Shelf (VIa, VIIb,c)**. Northwest Herring Acoustic Survey, June\July 2015.

Age (winter rings)	Numbers (millions)	Biomass (kt)	Maturity	Weight (g)	Length (cm)
0	0.00	0.00		0.0	0.0
1	0.00	0.00		0.0	0.0
2	212.47	29.73	0.48	139.9	25.0
3	396.55	70.08	0.85	176.7	26.9
4	747.12	144.12	0.99	192.9	27.7
5	423.14	85.61	0.98	202.3	28.3
6	476.25	100.20	1.00	210.4	28.8
7	90.10	19.44	0.97	215.8	29.3
8	23.93	5.13	1	214.5	29.1
9+	2.09	0.46	1	220.0	30.0
Immature	190.21	24.90		130.9	24.6
Mature	2,181.43	429.87		197.1	28.0
Total	2,371.64	454.77	0.92	191.8	27.7

Table 5. Abundance, biomass, maturity, mean weight and mean length by age of herring in **West of Scotland (VIaN).** Northwest Herring Acoustic Survey, June\July 2015.

Age (winter rings)	Numbers (Mill)	Biomass (kt)	Maturity	Weight (g)	Length (cm)
0	0.00	0.00			
1	0.00	0.00			
2	121.64	18.83	0.58	154.8	25.8
3	324.96	59.59	0.92	183.4	27.3
4	649.84	126.93	0.99	195.3	27.9
5	377.64	77.29	0.98	204.7	28.4
6	442.14	93.44	1.00	211.3	28.9
7	83.10	18.06	0.97	217.3	29.4
8	22.56	4.86	1.00	215.3	29.1
9+	2.09	0.46	1.00	220.0	30.0
Immature	89.12	12.29		137.9	25.1
Mature	1,934.83	387.16		200.1	28.2
Total	2,023.96	399.46	0.96	197.4	28.0

Table 6. Abundance, biomass, and maturity by age of herring in **VIaS and VIIb,c.** Northwest Herring Acoustic Survey, June\July 2015.

Age (winter rings)	Numbers (Mill)	Biomass (kt)
0	0.00	0.00
1	0.00	0.00
2	90.83	10.89
3	71.58	10.49
4	97.29	17.19
5	45.50	8.32
6	34.11	6.76
7	7.00	1.39
8	1.38	0.28
9+	0.00	0.00
Immature	101.09	12.61
Mature	246.60	42.71
Total	347.69	55.31

Table 7. Historic survey time-series for areas **VIaS and VIIb**. Abundance (millions), TSB and SSB (tonnes), age in winter rings. Northwest herring survey, June\July 2015.

Winter rings	2008	2009	2010	2011	2012	2013	2014	2015
0	-	-	-	-	-	-	-	-
1	6.1	416.4	16.5	44.6	25.9	-	-	-
2	75.9	81.3	292.8	86.3	360.9	49.7	36.6	90.8
3	64.7	11.4	85.2	146.8	92.8	103.5	19.3	71.6
4	38.4	15.1	63.2	28.9	42.9	108.1	23.4	97.3
5	22.3	7.7	43.2	5.7	8.0	26.9	9.8	45.5
6	26.2	7.1	27.3	4.3	3.7	6.8	3.1	34.1
7	9.1	7.5	19.0	4.8	3.5	4.1	0.6	7.0
8	5.0	0.4	12.5	2.1	2.1	1.8	0.4	1.4
9	3.7	0.9	5.5	1.4	1.3	0.7	0.1	-
10+	-	-	-	0.8	1.1	0.2	-	-
TSN (mil)	251.4	547.7	565.2	325.7	542.2	301.7	120.0	347.7
TSB (t)	44,611	46,460	82,100	40,700	68,300	45,500	15,100	55,315
SSB (t)	43,006	20,906	81,400	28,600	42,600	34,300	8,600	42,710
CV	34.2	32.2	-	-	-	-	-	-

Survey coverage: VIaS & VIIb

Table 8. Historic survey time-series for **all areas** surveyed. Abundance (millions), TSB and SSB (tonnes), age in winter rings. Northwest herring survey, June\July 2014. Note that the 2011-2014 survey coverage in VIaN was much greater than that in 2010 and the 2015 survey covered the whole Malin Shelf area.

Winter rings	2008^	2009^	2010*	2011*	2012*	2013*	2014*	2015**
0	-	-	-	-	-	-	-	**0**
1	6.1	416.4	524.8	82.1	608.3	-	-	0
2	75.9	81.3	504.3	202.5	451.5	96.2	214.7	212.5
3	64.7	11.4	133.3	752.0	444.6	254.3	166.3	396.5
4	38.4	15.1	107.4	381.0	516.1	265.8	380.0	747.1
5	22.3	7.7	103.0	110.8	180.3	78.7	352.1	423.1
6	26.2	7.1	83.7	124.0	115.4	26.9	125.0	476.2
7	9.1	7.5	57.6	118.4	116.9	18.5	18.9	90.1
8	5.0	0.4	35.3	70.7	83.8	10.8	9.7	23.9
9	3.7	0.9	17.5	41.6	56.3	4.1	4.7	0.0
10+	-	-	-	25.6	42.0	1.2	0.0	2.1
TSN (mil)	251.4	547.7	1,566.9	1,908.7	2,615.0	756.6	2,386.8	2,371.6
TSB (t)	44,611	46,460	192,979	313,305	397,797	118,946	294,200	454,770
SSB (t)	43,006	20,906	170,154	284,632	325,835	92,700	200,200	429,870
CV	34.2	32.2	24.7	22.4	22.8	21.5	28.6	Now produced by age

^ Survey coverage: VIaS & VIIb
* Survey coverage: VIaS, VIIb & part of VIaN,
** Survey coverage: VIa & VIIb

Table 10. Breakdown of sea-state during MMO surveys. Northwest herring acoustic survey, June\July 2015.

Beaufort scale	No. stations	% of total No. stations
1	10	2
2	113	21
3	128	24
4	123	23
5	98	18
6	39	7
7	22	4
8	8	1
Total	**541**	**100**

Table 11. Recorded swell height at MMO stations. Northwest herring acoustic survey, June\July 2015.

Swell height (m)	Wave description	No. stations	% of total No. stations
0	no swell	9	2
1	light	246	45
2	moderate	117	22
3	heavy	169	31
Total		**541**	**100**

Table 12. Recorded visibility at MMO stations. Northwest herring acoustic survey, June\July 2015.

Visibility (km)	No. stations	% of total no. stations
<1	50	9
1-5	22	4
6-10	129	24
11-15	117	22
16-20	122	23
>20	101	19
Total	**541**	**100**

Table 13. Recorded precipitation at MMO stations. Northwest herring acoustic survey, June\July 2015.

Precipitation	No. Stations	% of total No. stations	Notes
None	442	82	Occasional light intermittent rainfall in very short showers
Rainfall	77	14	Generally rainfall was intermittent heavy rainfall
Fog	22	4	Fog generally accompanied by intermittent light rainfall
Total	**541**	**100**	

Table 14: Breakdown of species and number of individuals recorded during marine mammal observation. Northwest herring acoustic survey, June\July 2015.

Species	Scientific Name	No. of Sightings	No. of Individuals
Common Dolphin	*Delphinus delphis*	43	325
Minke Whale	*Balaenoptera acutorostrata*	11	11
Fin Whale	*Balaenoptera physalus*	1	12
Bottlenose Dolphin	*Tursiops truncatus*	2	5
White beaked Dolphin	*Lagenorhynchus albirostris*	5	15
Harbour Porpoise	*Phocoena phocoena*	3	3
Risso's Dolphin	*Grampus griseus*	2	15
Northern Bottlenose Whale	*Hyperoodon ampullatus*	1	2
Unidentified Beaked Whale	-	1	2
Unidentified Small Whale	-	2	2
Unidentified Dolphin	-	4	17
Basking Shark	*Cetorhinus maximus*	5	6
Total		80	415

Figures

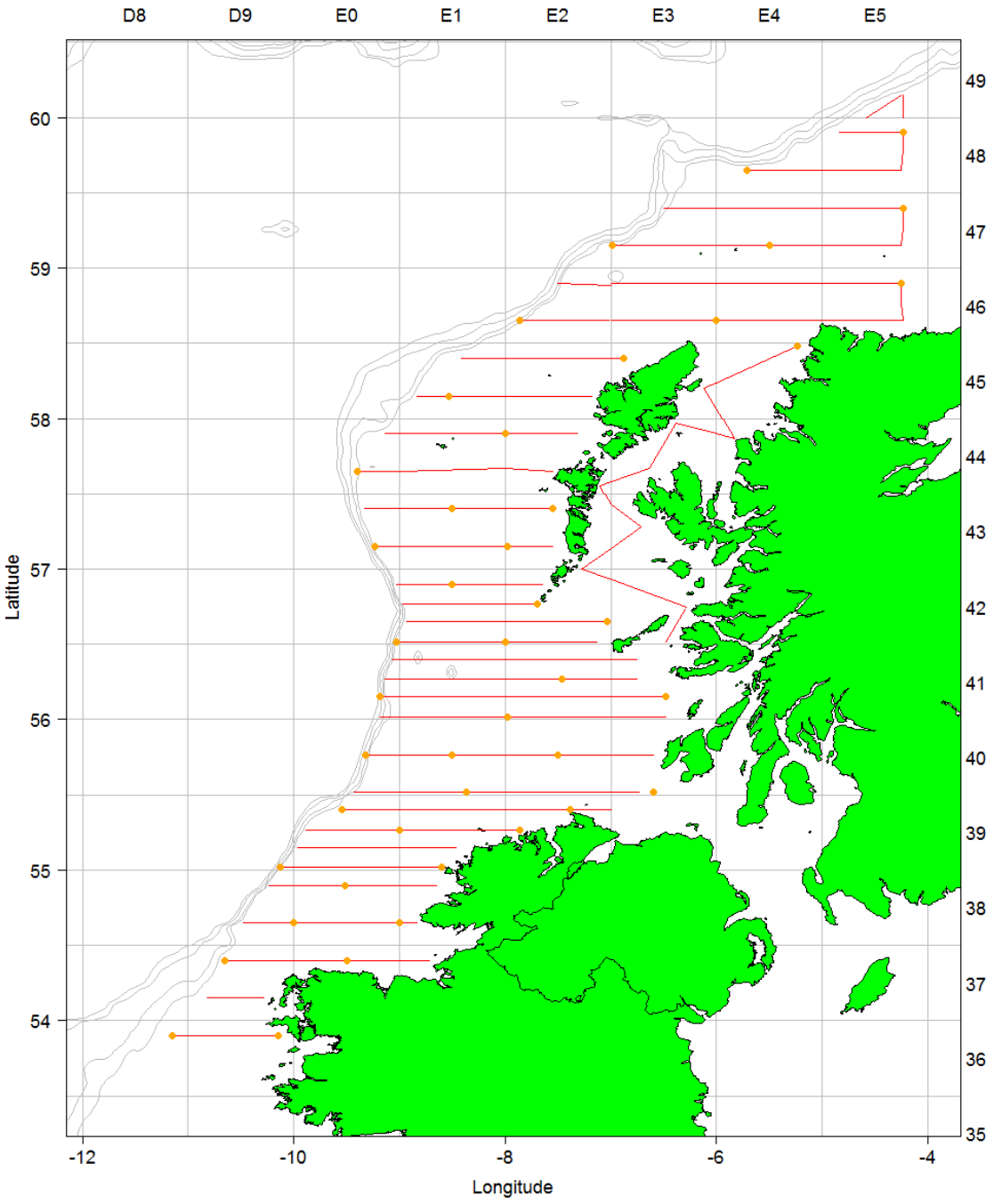


Figure 1. RV Celtic Explorer cruise track during the Northwest herring survey, June\July 2015 (excluding inter-transect segments). Orange circles are hydrographic stations.

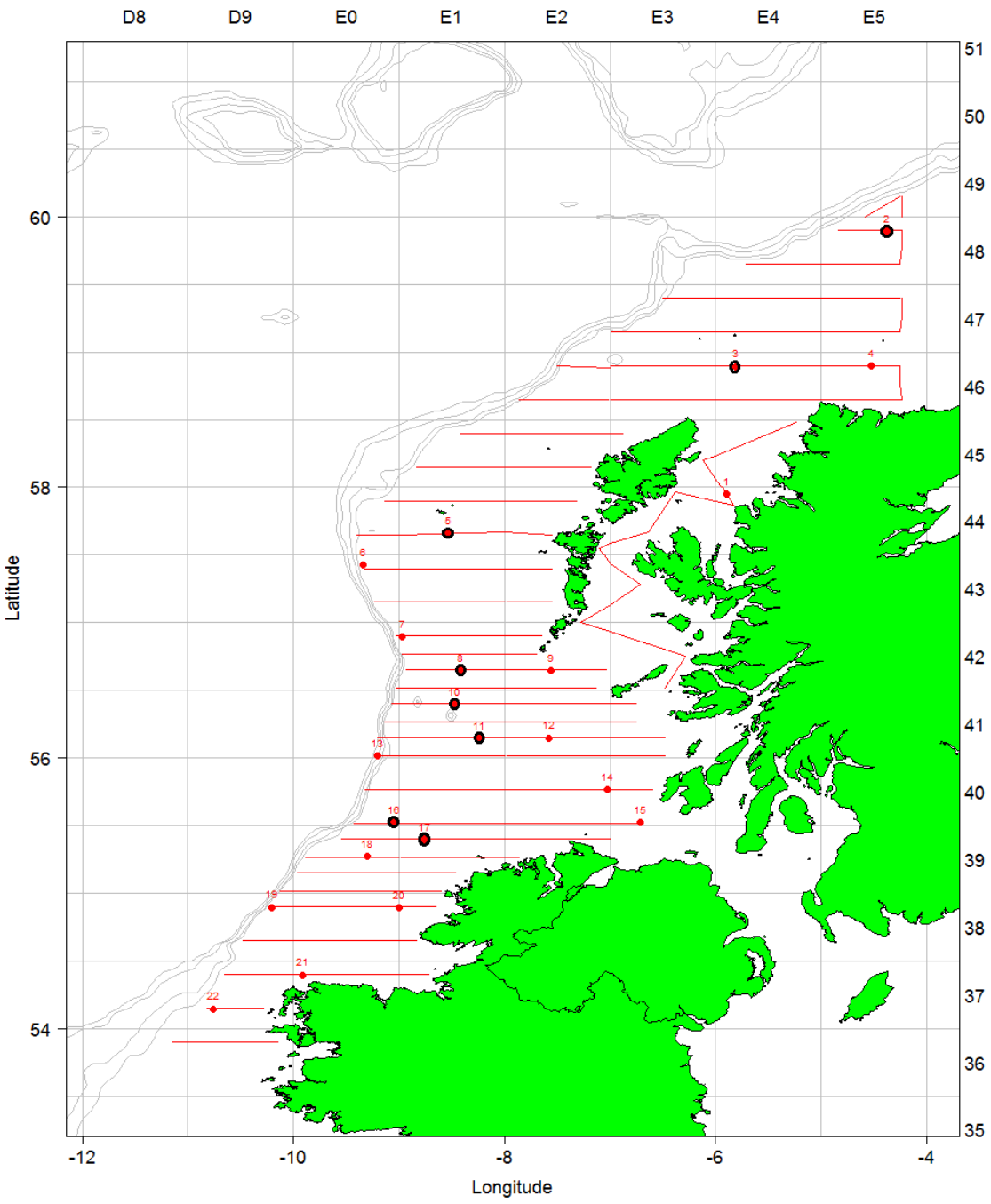


Figure 2. RV Celtic Explorer fishing trawl stations. Northwest herring survey, June\July 2015. SGHERWAY sampled hauls are indicated in black.

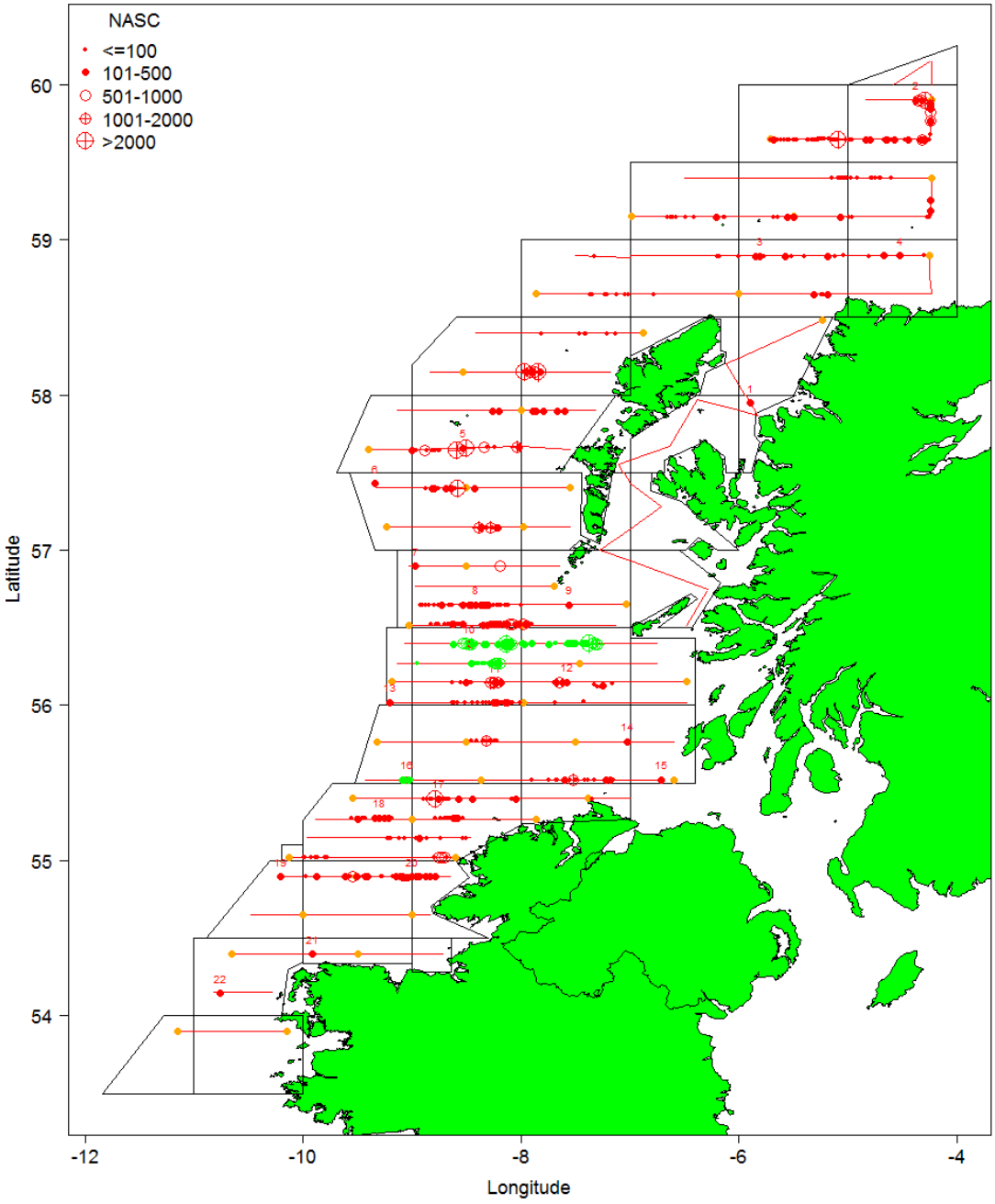


Figure 3. NASC plot of herring distribution during the 2015 survey. Red circles represent single herring schools ("definitely" and "probably" herring categories). Green circles represent herring occurring in mixed schools.

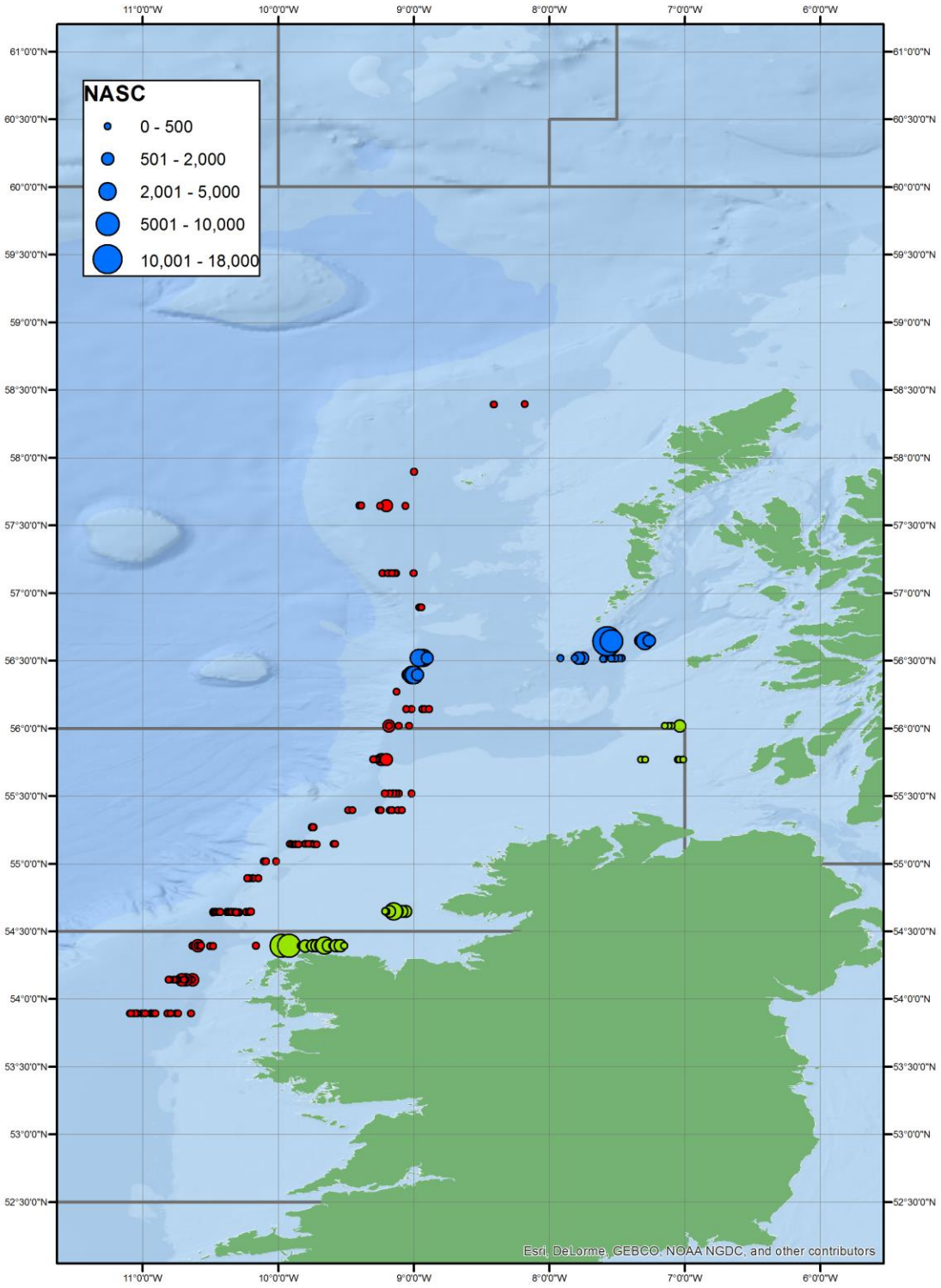


Figure 4. NASC plot of boarfish (red, *Capros aper*), blue whiting (blue, *Micromesistius poutassou*) and sprat (green, *Sprattus sprattus*) distribution during the 2015 Northwest herring survey.

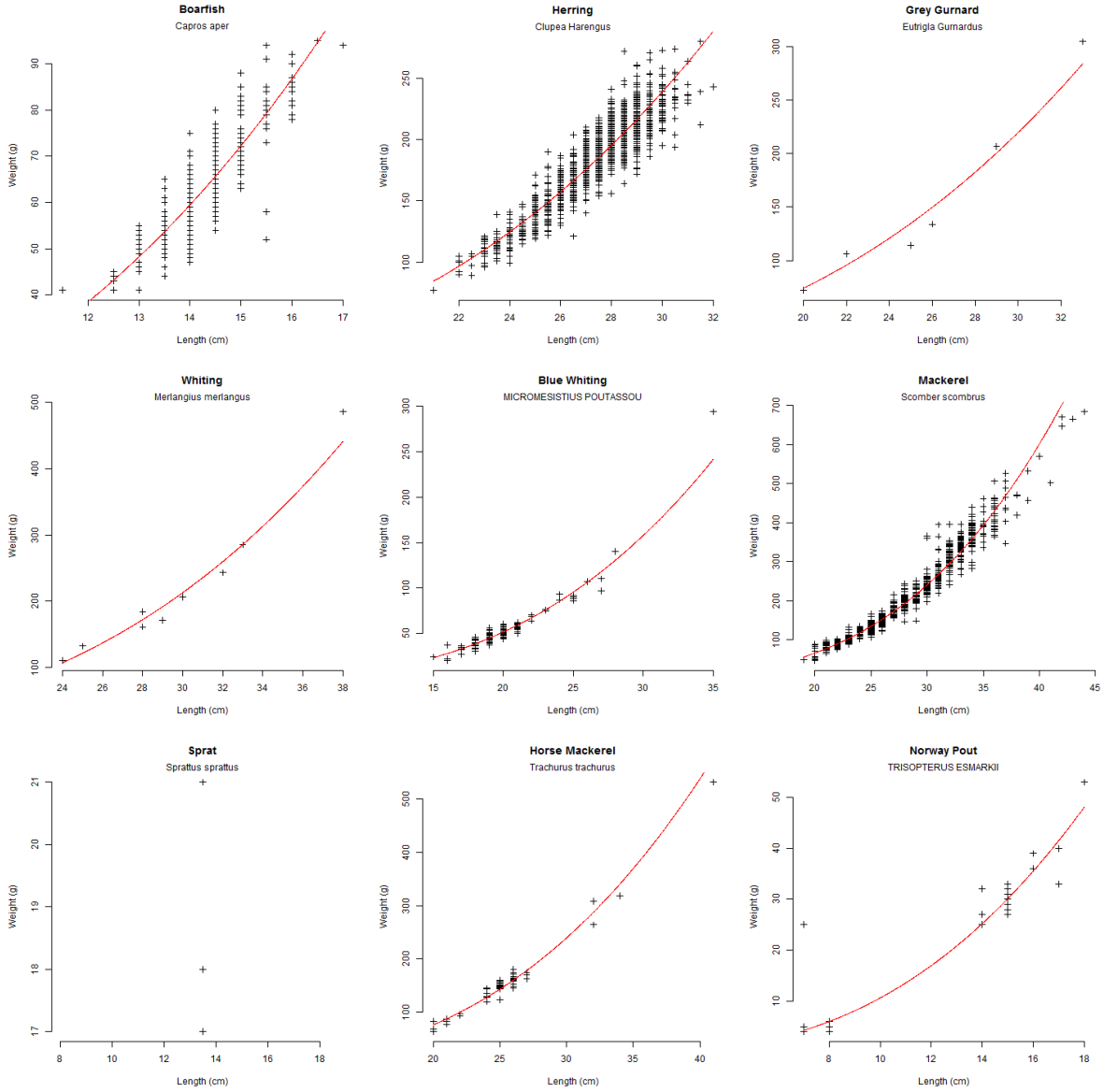


Figure 5. Length-weight plots of most abundant species sampled during the Northwest herring acoustic survey, June\July 2015.

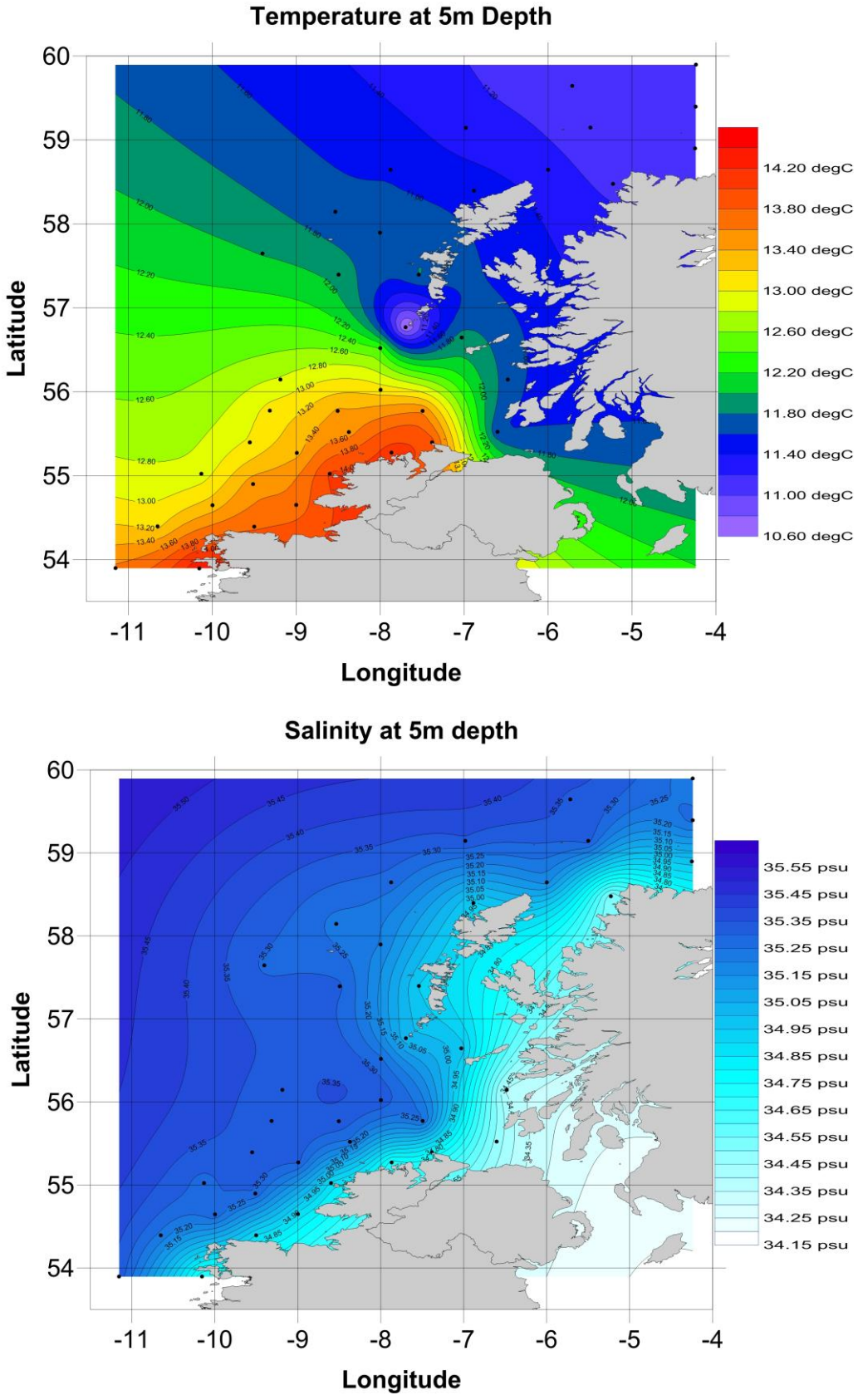


Figure 6. Horizontal temperature (top panel) and salinity (bottom panel) at 5m subsurface as derived from vertical CTD cast data (black squares). Northwest herring survey, June/July 2015.

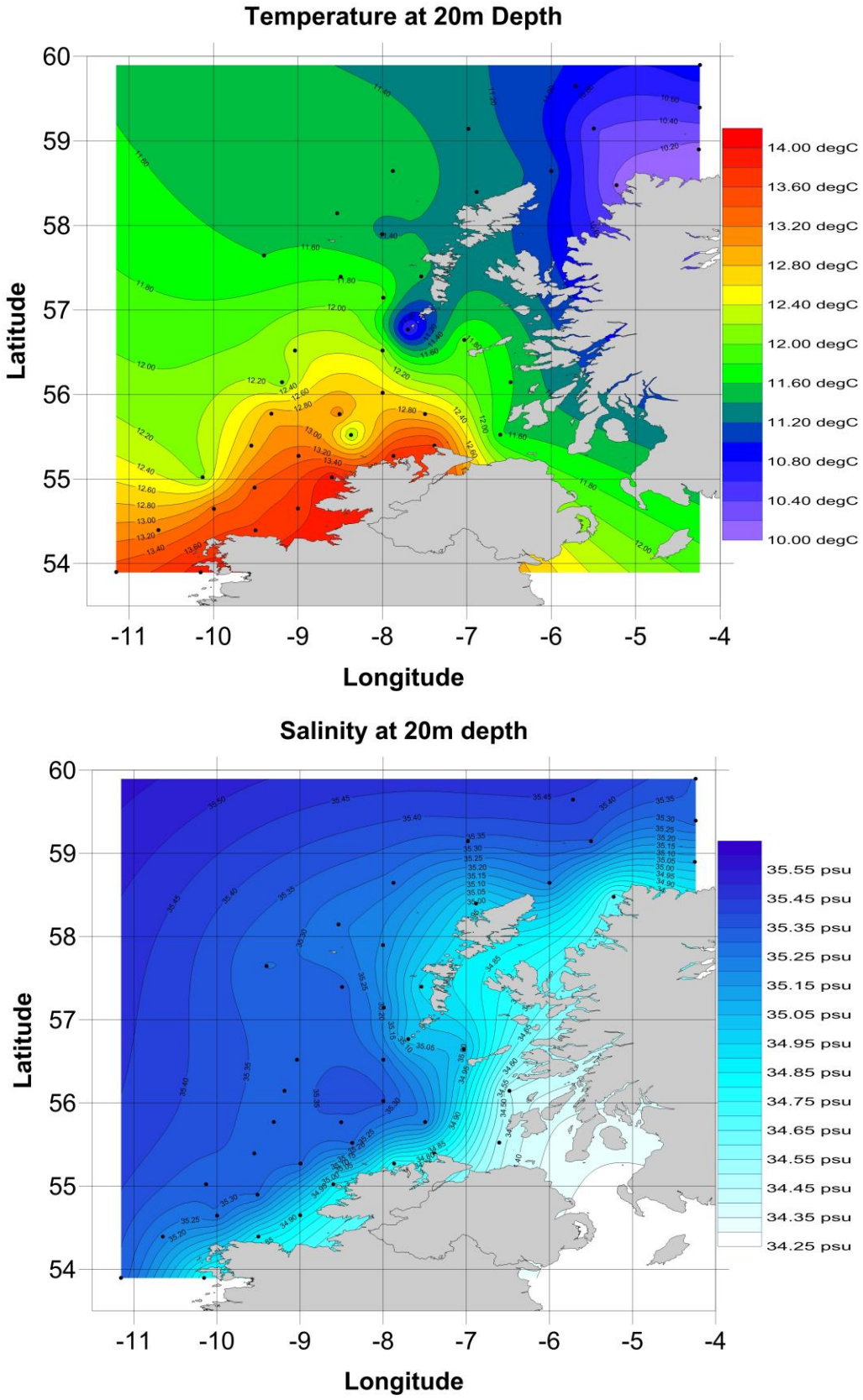


Figure 7. Horizontal temperature (top panel) and salinity (bottom panel) at 20m subsurface as derived from vertical CTD cast data (black squares). Northwest herring survey, June/July 2015.

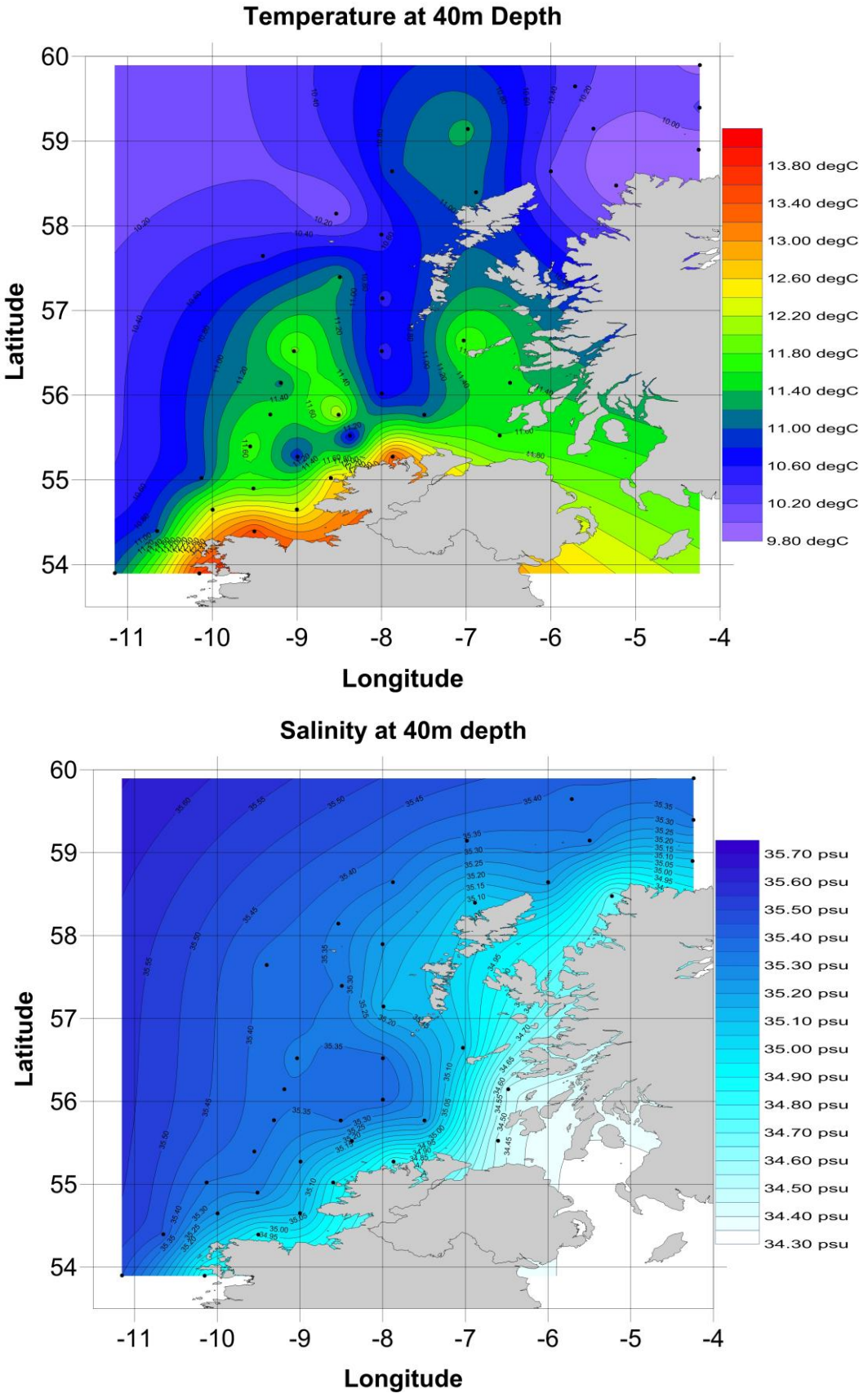


Figure 8. Horizontal temperature (top panel) and salinity (bottom panel) at 40m subsurface as derived from vertical CTD cast data (black squares). Northwest herring survey, June/July 2015.

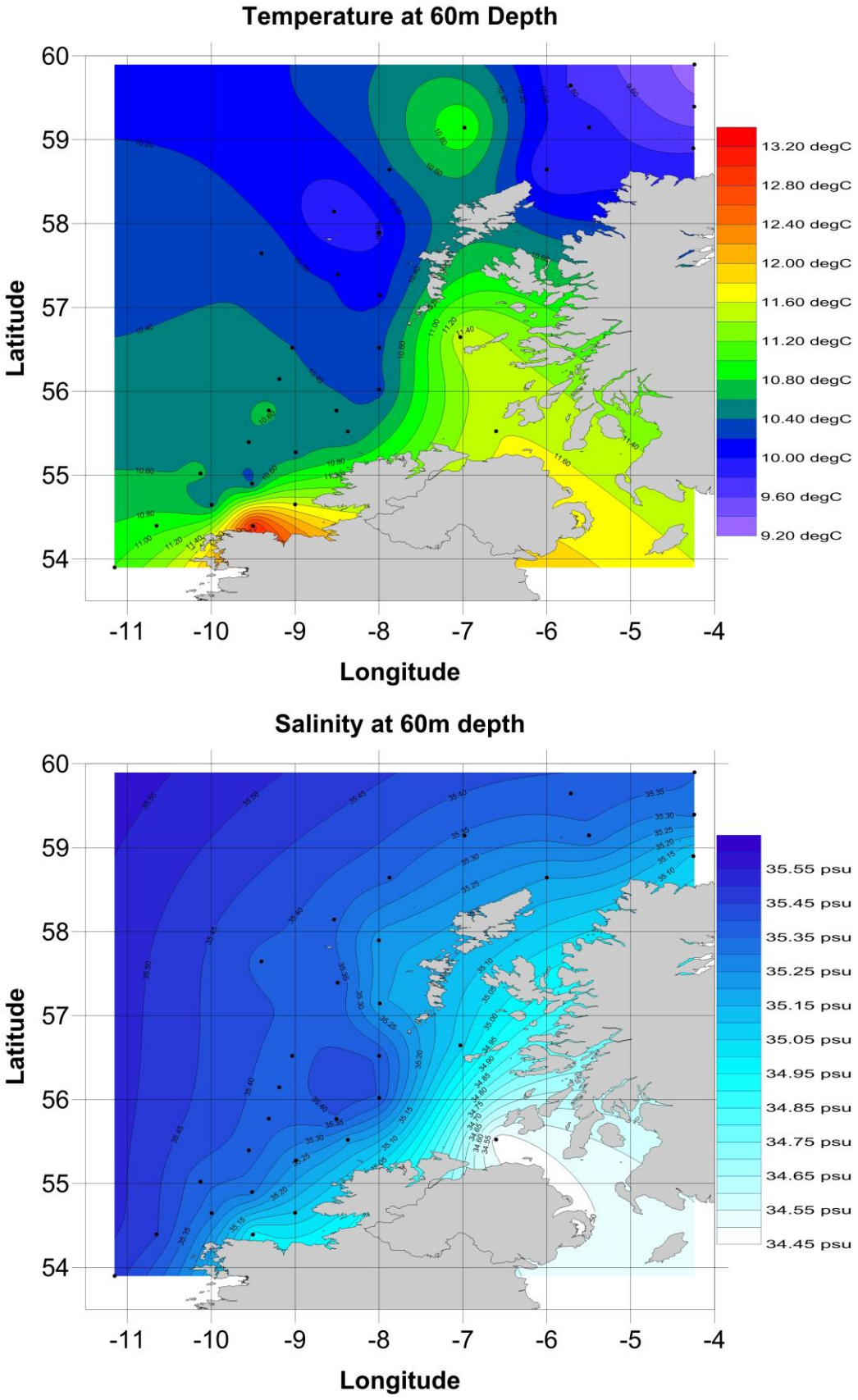


Figure 9. Horizontal temperature (top panel) and salinity (bottom panel) at 60m subsurface as derived from vertical CTD cast data (black squares). Northwest herring survey, June/July 2015.

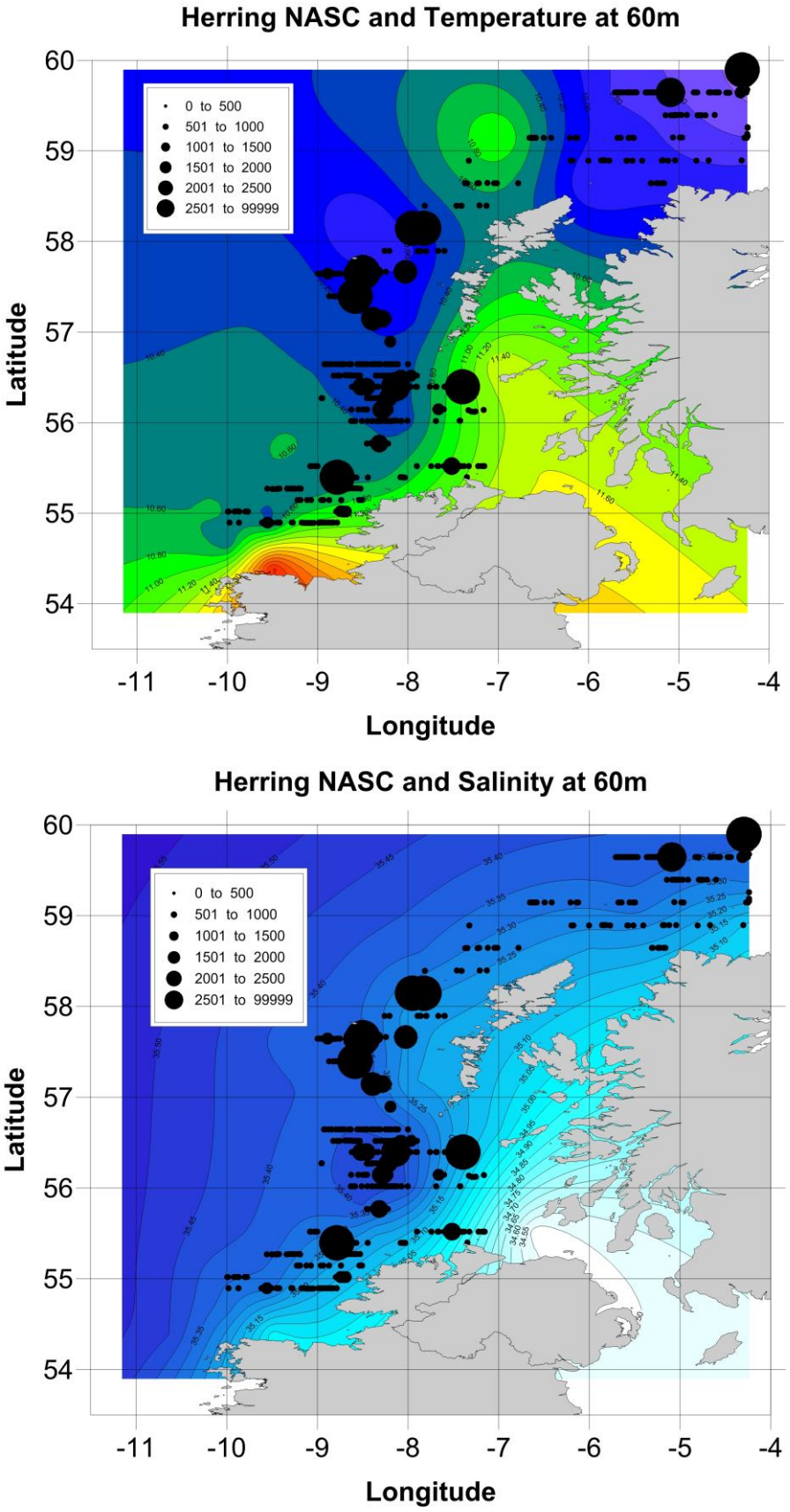


Figure 10. Horizontal temperature (top panel) and salinity (bottom panel) at 60m subsurface overlaid with herring NASC values. Northwest herring survey, June/July 2015.

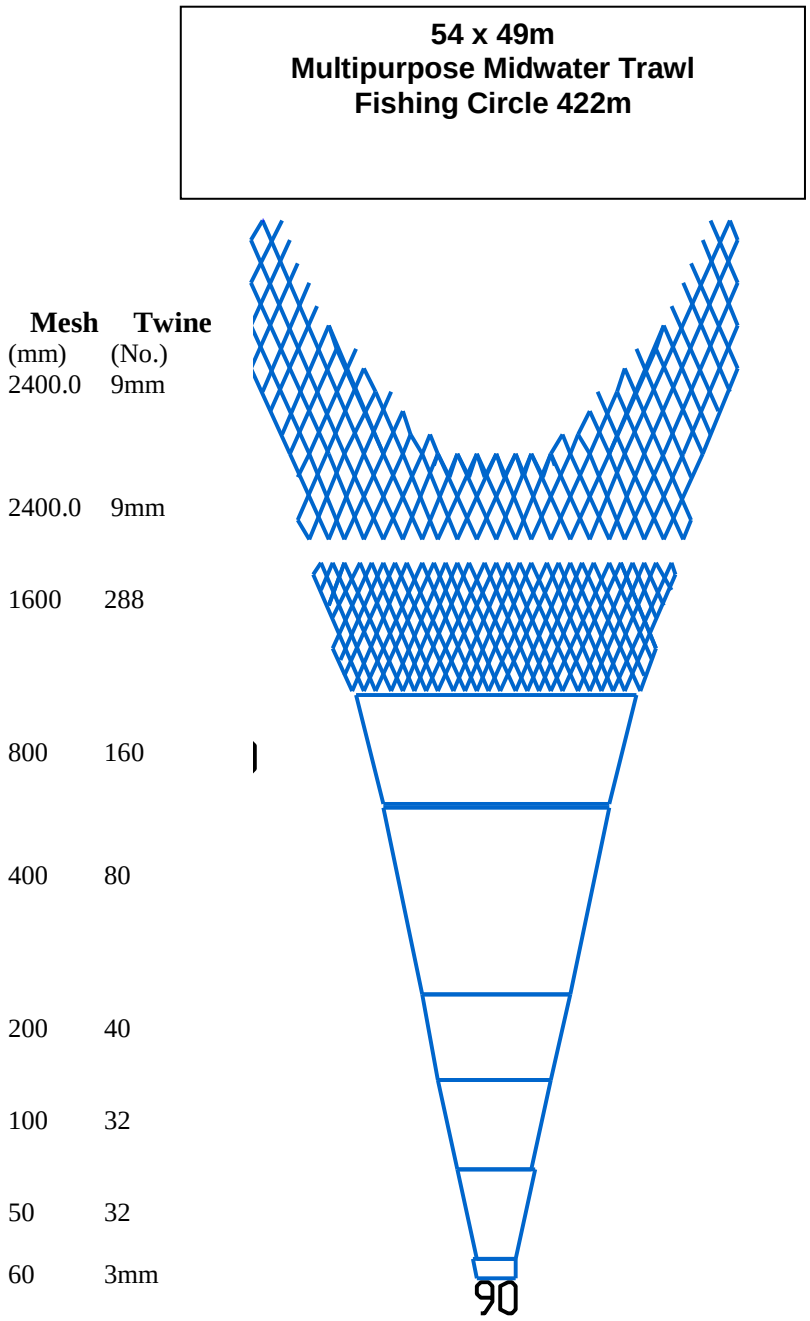


Figure 11. Celtic Explorer multi-purpose midwater trawl employed during the Northwest herring acoustic survey, June\July 2015.

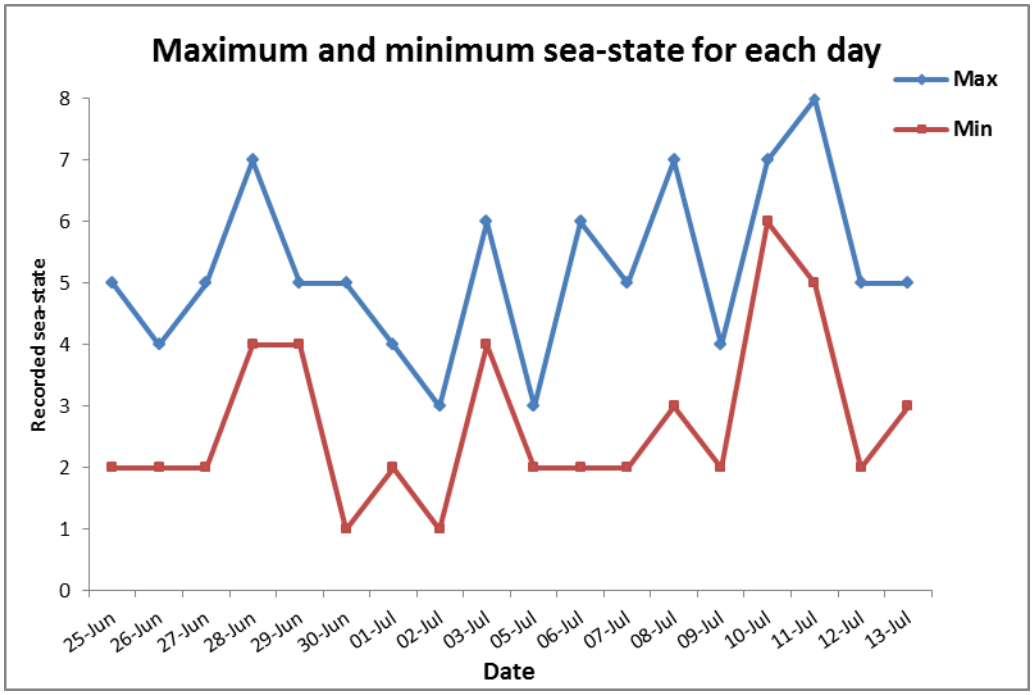


Figure 12. Plot of daily maximum and minimum sea-state. Northwest herring acoustic survey, June\July 2015.

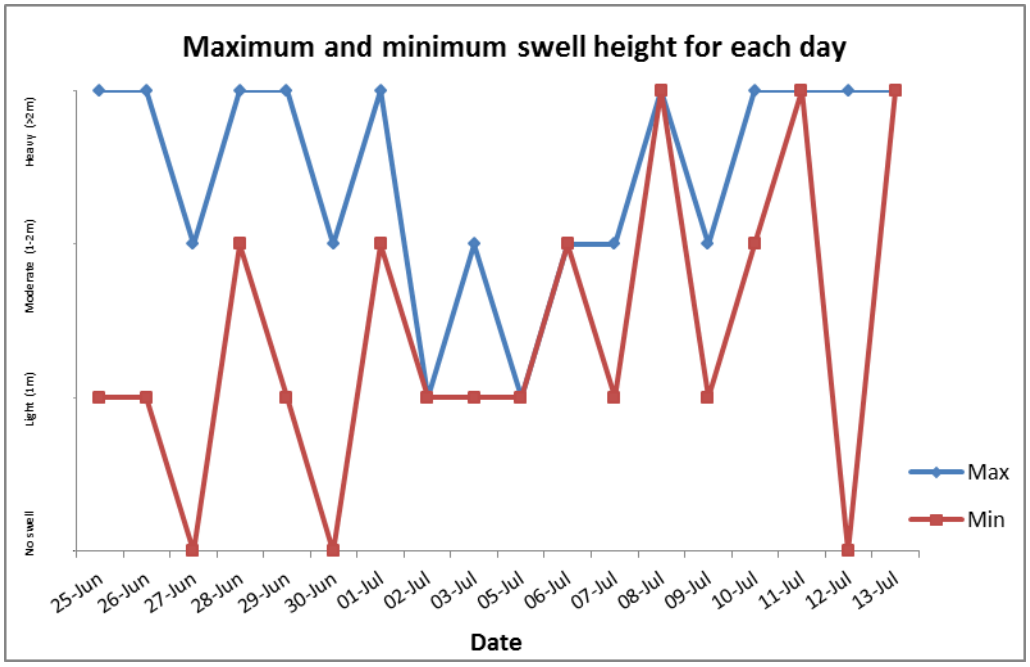


Figure 13. Plot of daily maximum and minimum swell height. Northwest herring acoustic survey, June\July 2015.

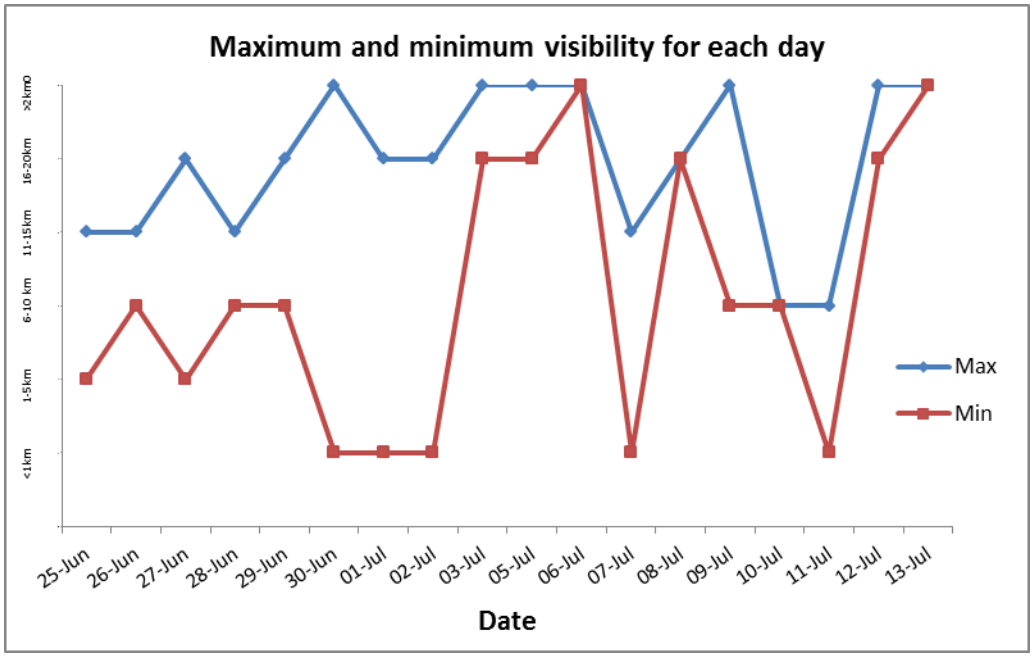


Figure 14. Plot of daily maximum and minimum visibility. Northwest herring acoustic survey, June\July 2015.

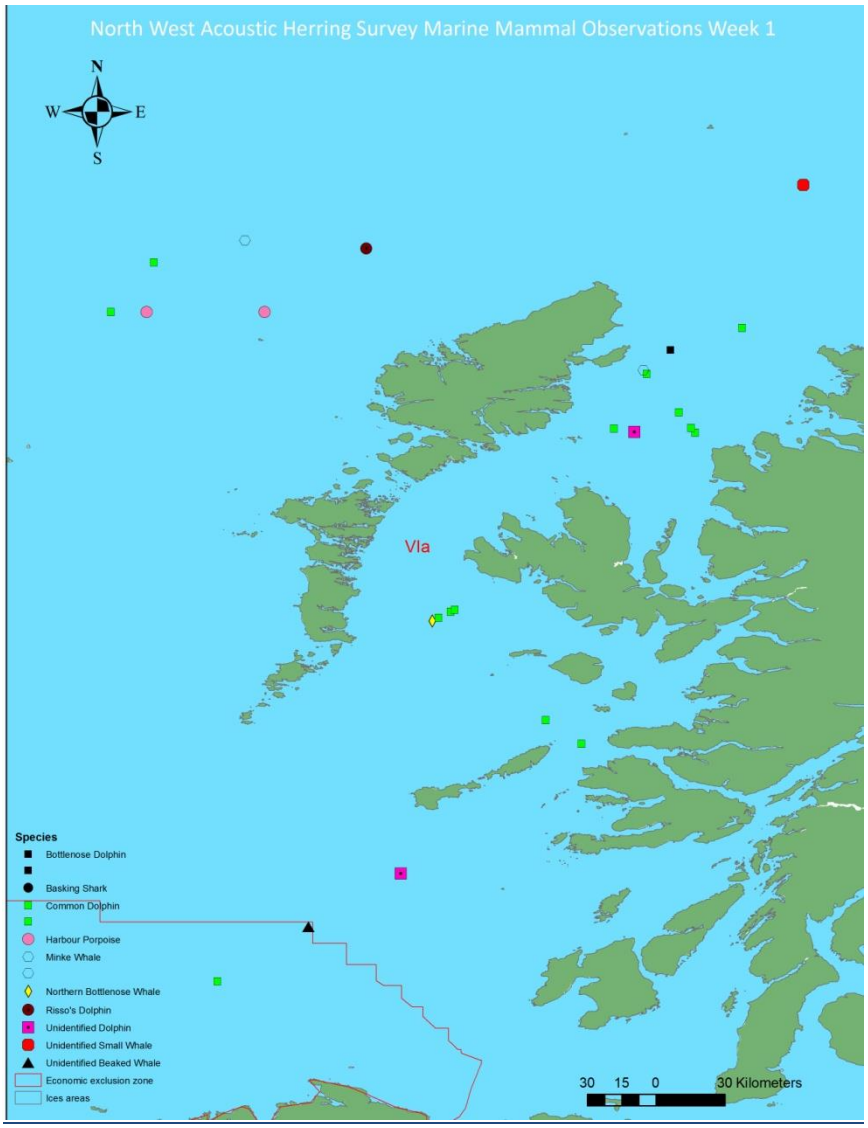


Figure 15. Distribution of cetacean sightings recorded during Week 1 of the Northwest herring acoustic survey, June\July 2015.

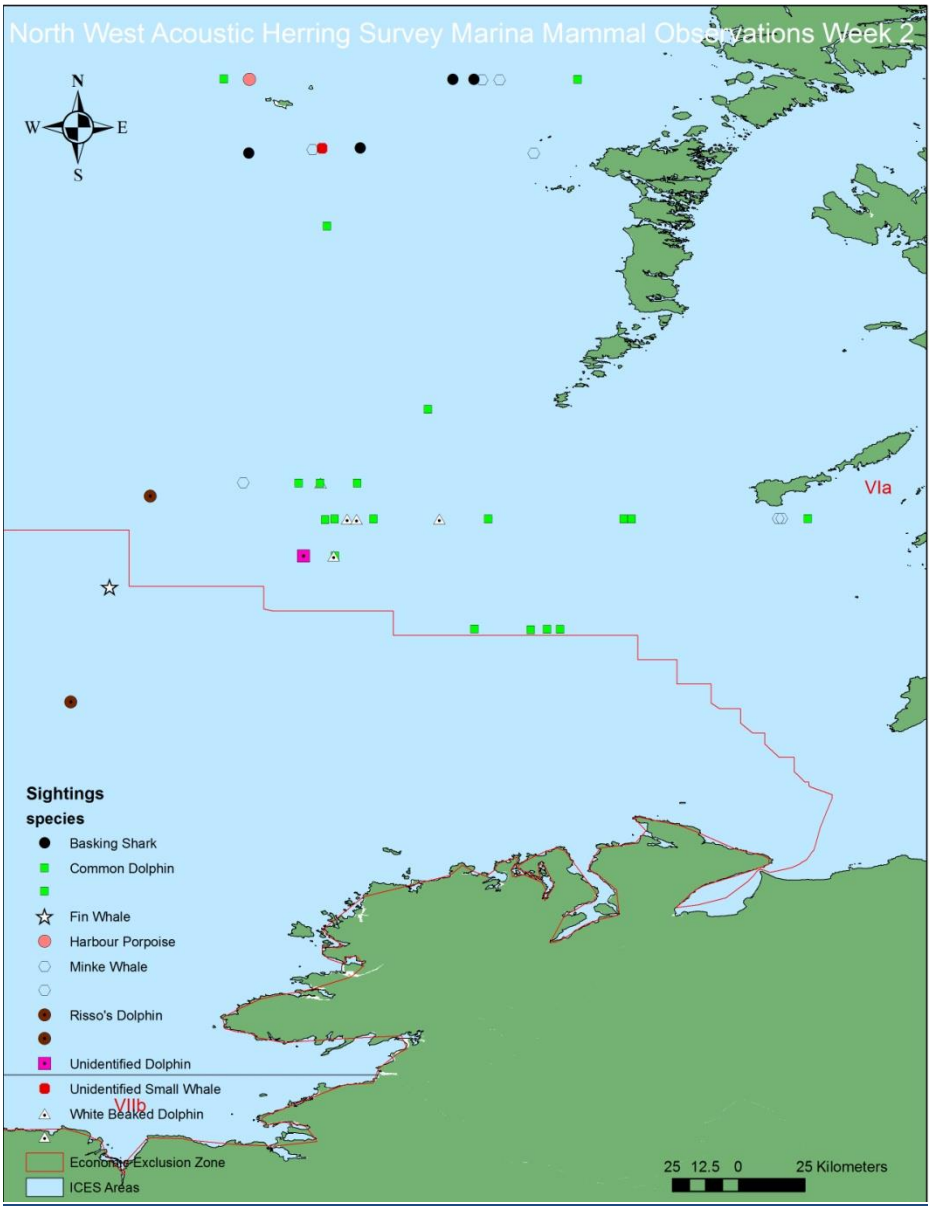


Figure 16. Distribution of cetacean sightings recorded during Week 2 of the Northwest herring acoustic survey, June\July 2015.

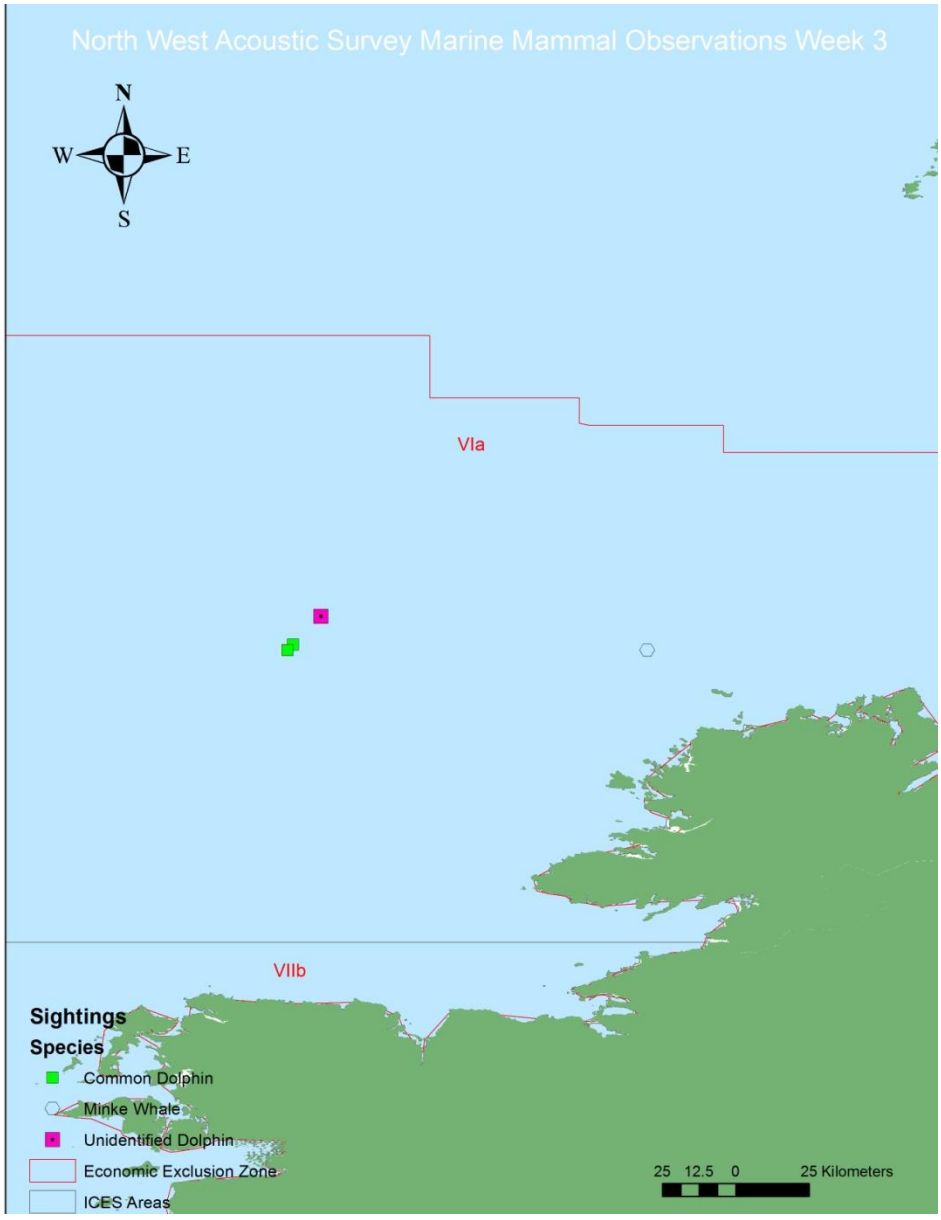
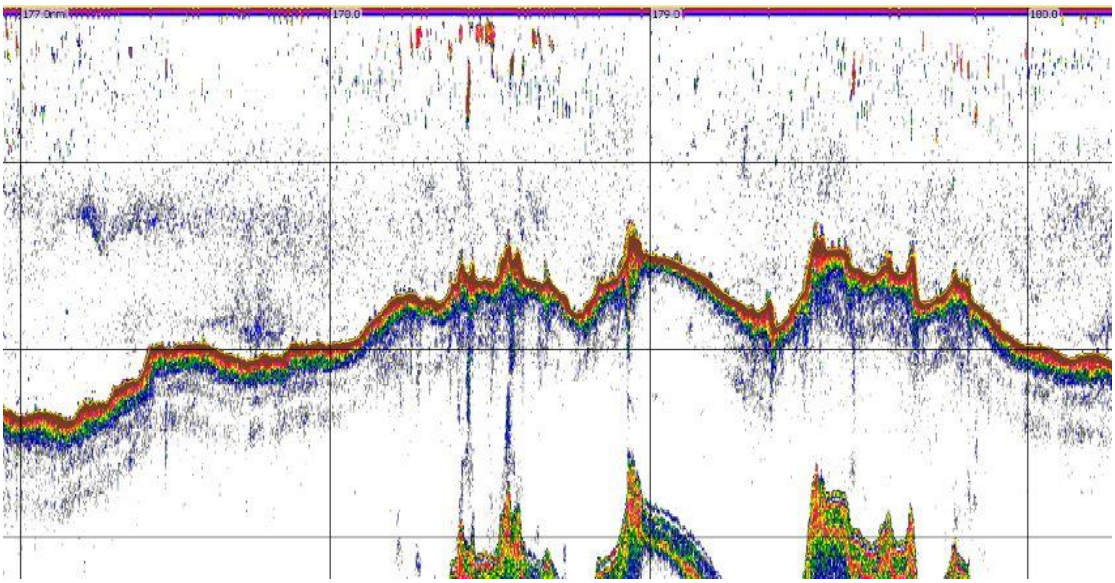
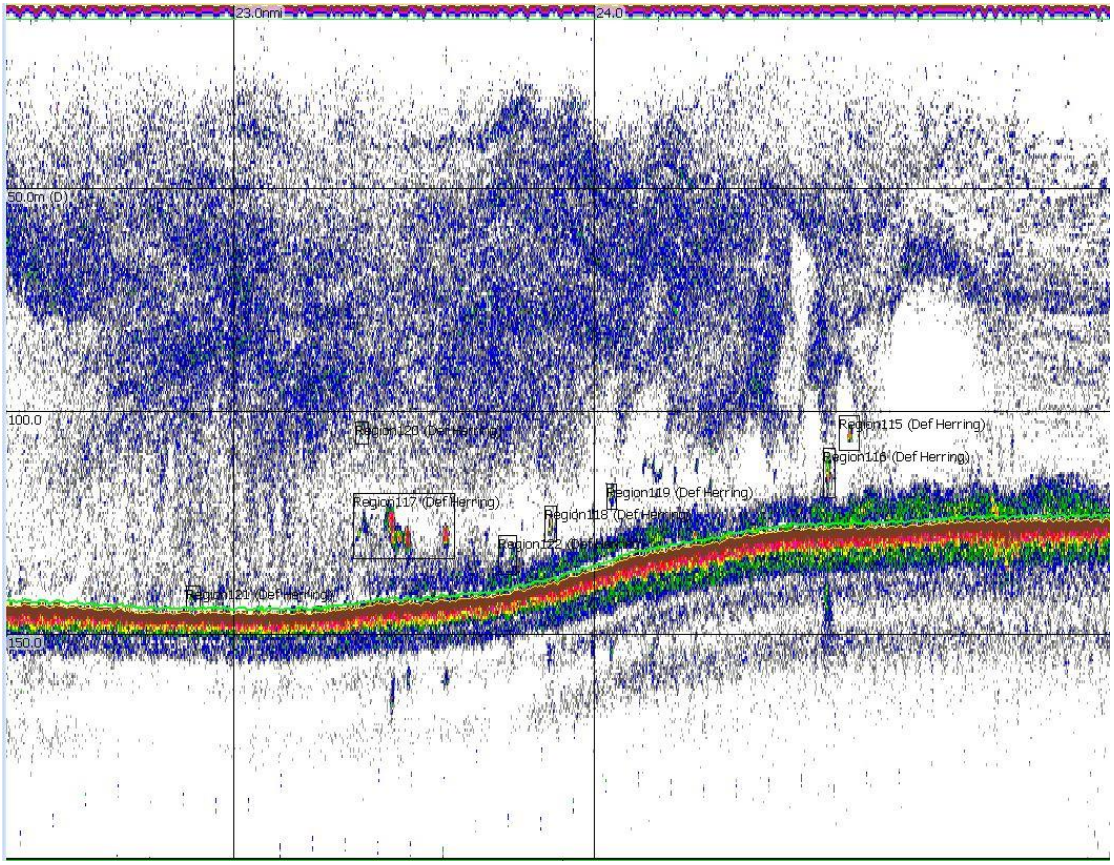


Figure 17. Distribution of cetacean sightings recorded during Week 3 of the Northwest herring acoustic survey, June\July 2015.

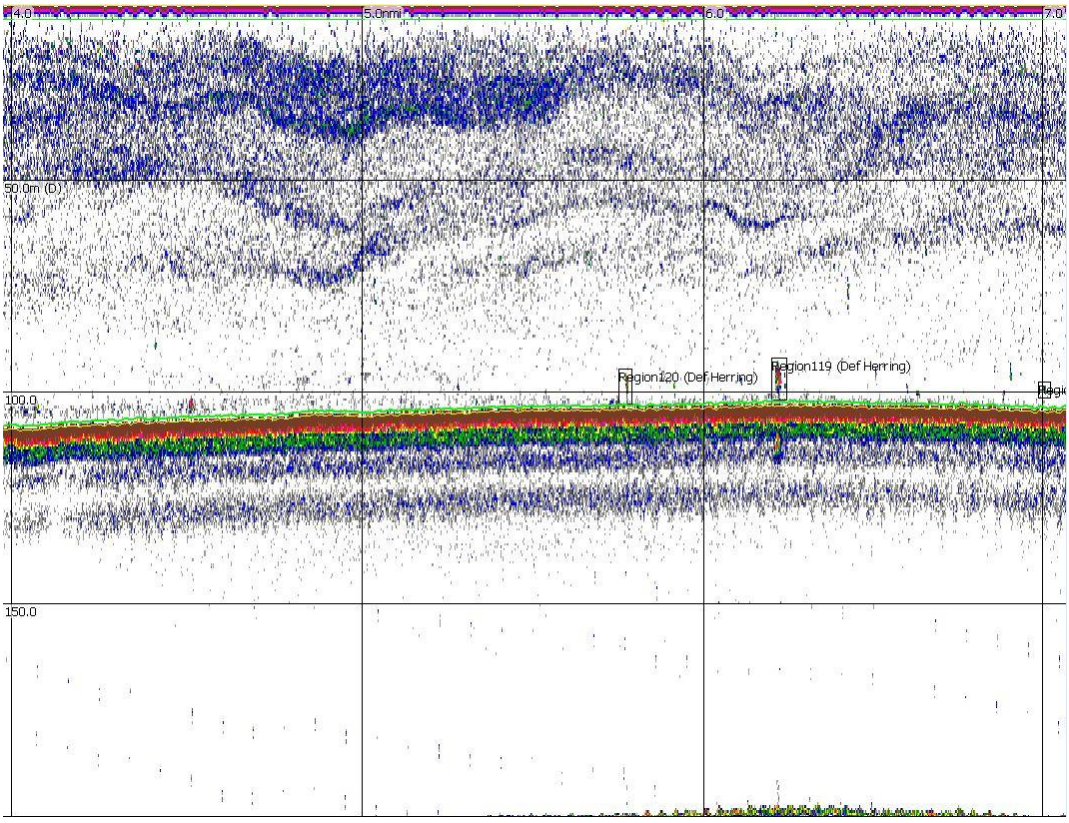
Appendix 1: Echograms prior to fishing



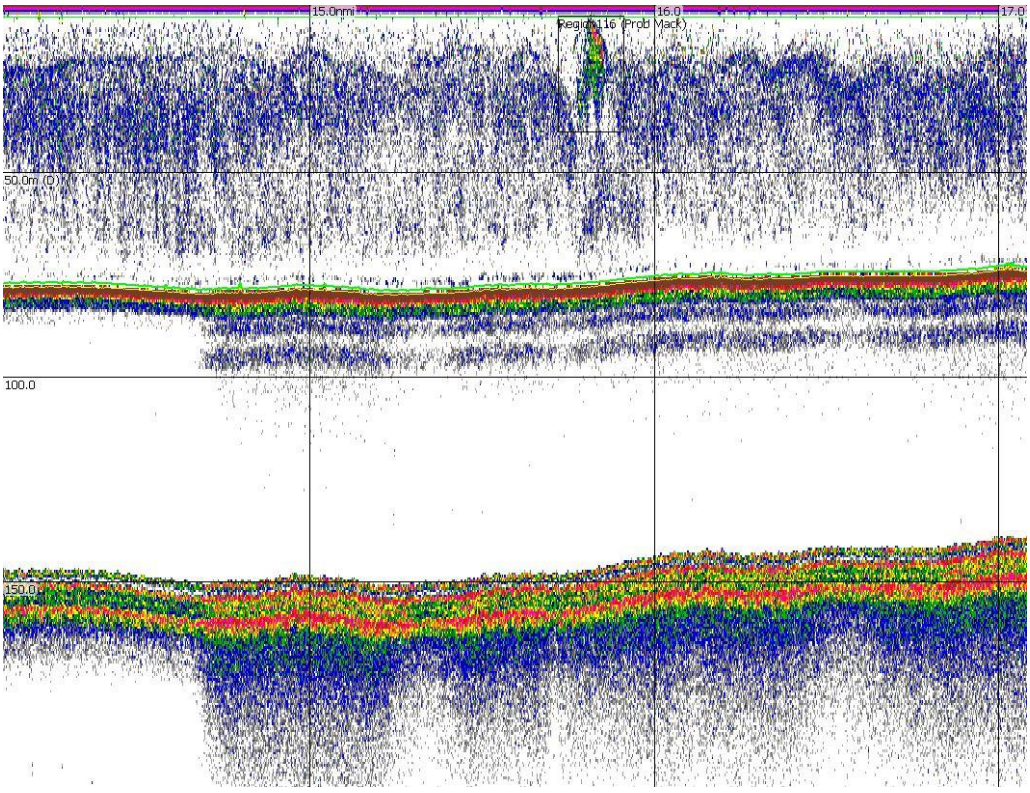
Haul 1. 27/6/15. some scattered, mid-water marks in the Minch. The largest of the original marks were not seen again once the net was in the water. Two small marks yielded 12 kg of small sandeel and unidentified fry. Vertical lines represent 1 nmi, horizontal lines represent 50m depth.



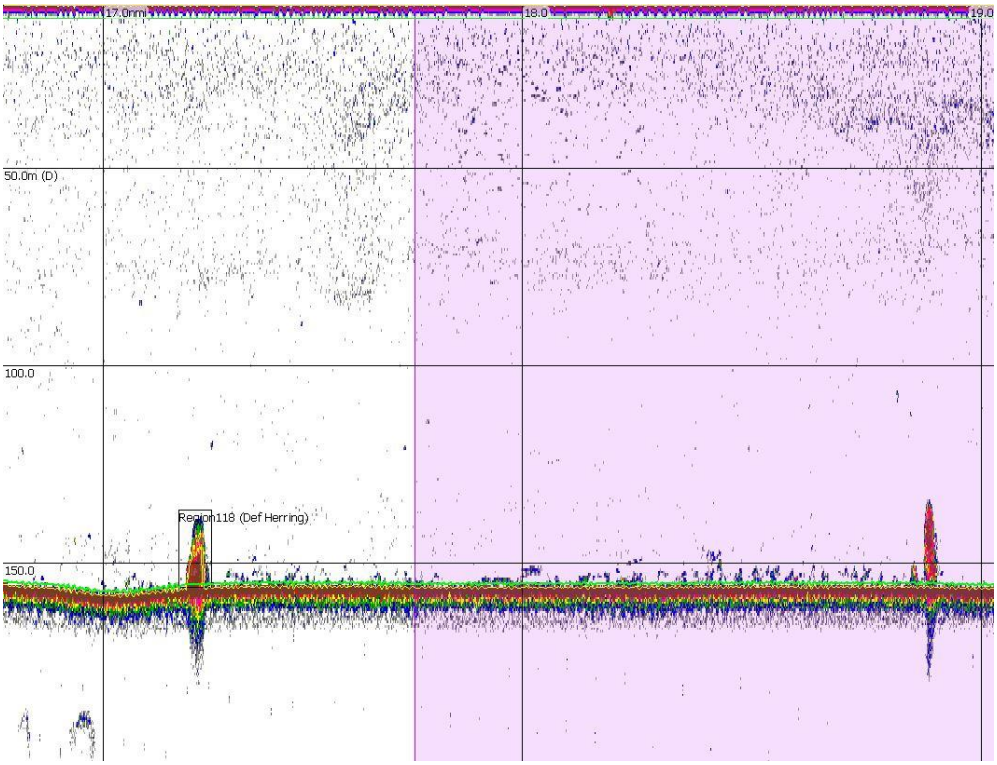
Haul 2. 28/6/16. These marks close the bottom in the north east corner of the survey are yielded 6 t of almost pure herring.



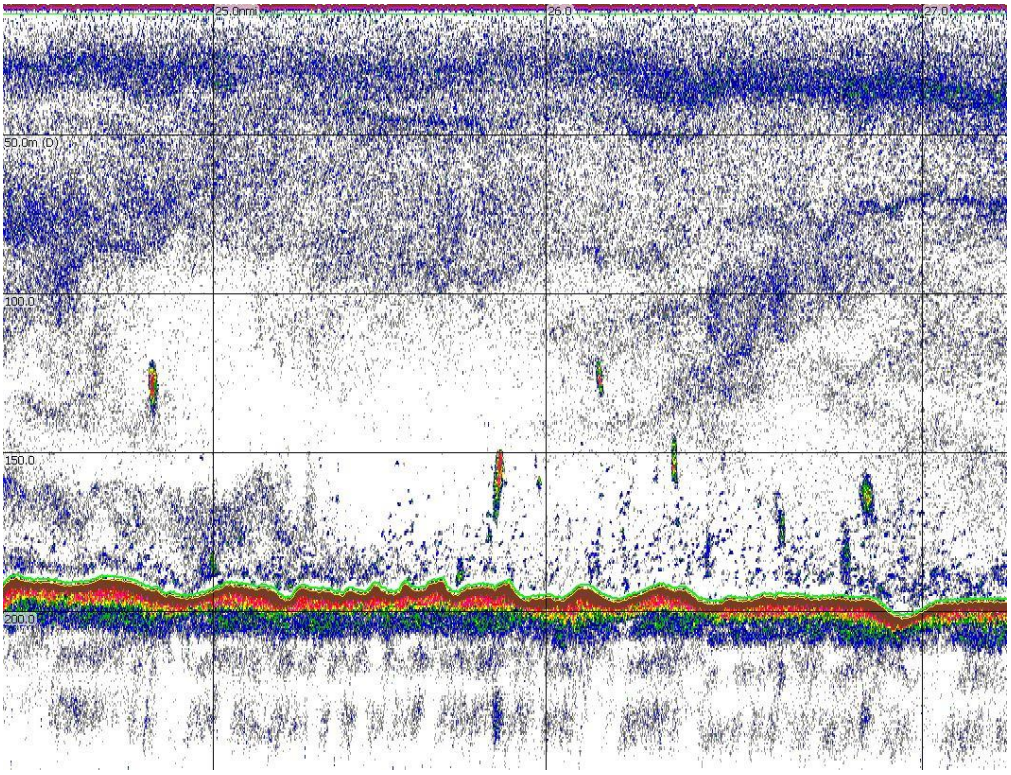
Haul 3. 30/6/15. A number of small bottom marks north east of Cape Wrath yielded almost 900 kg of herring and 100 kg of mackerel.



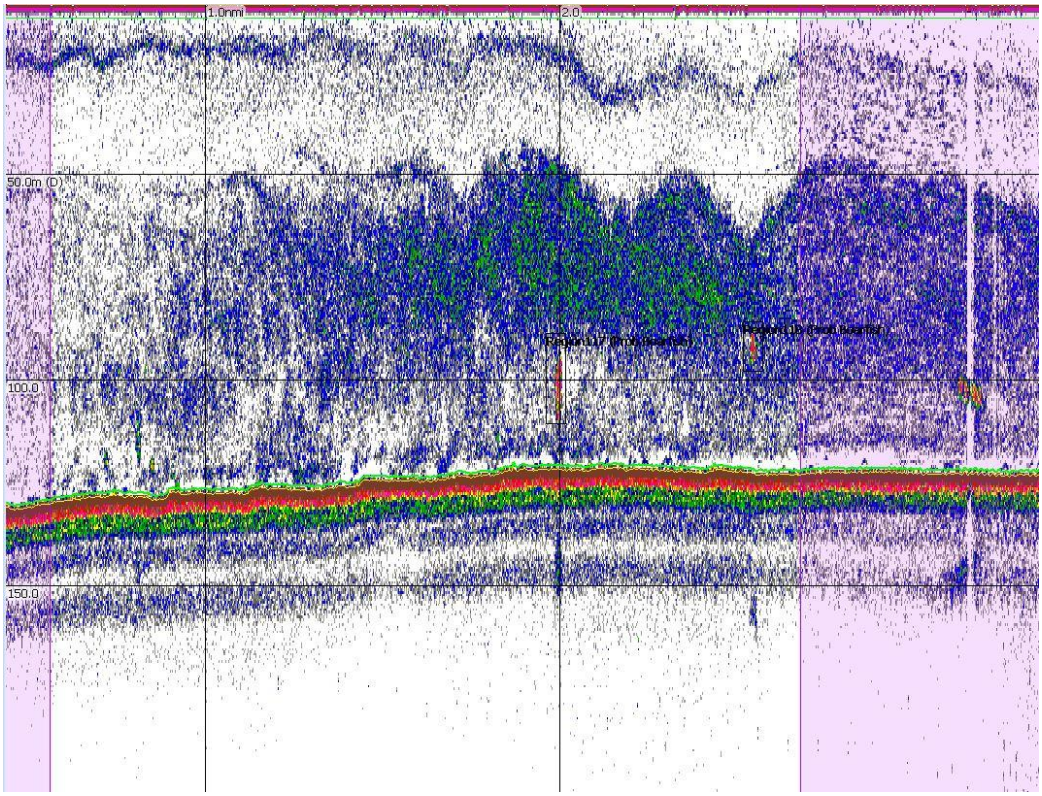
Haul 4. 30/6/15. This large, diffuse mark north of Cape Wrath was not seen on the headline transducer after the gear was deployed.



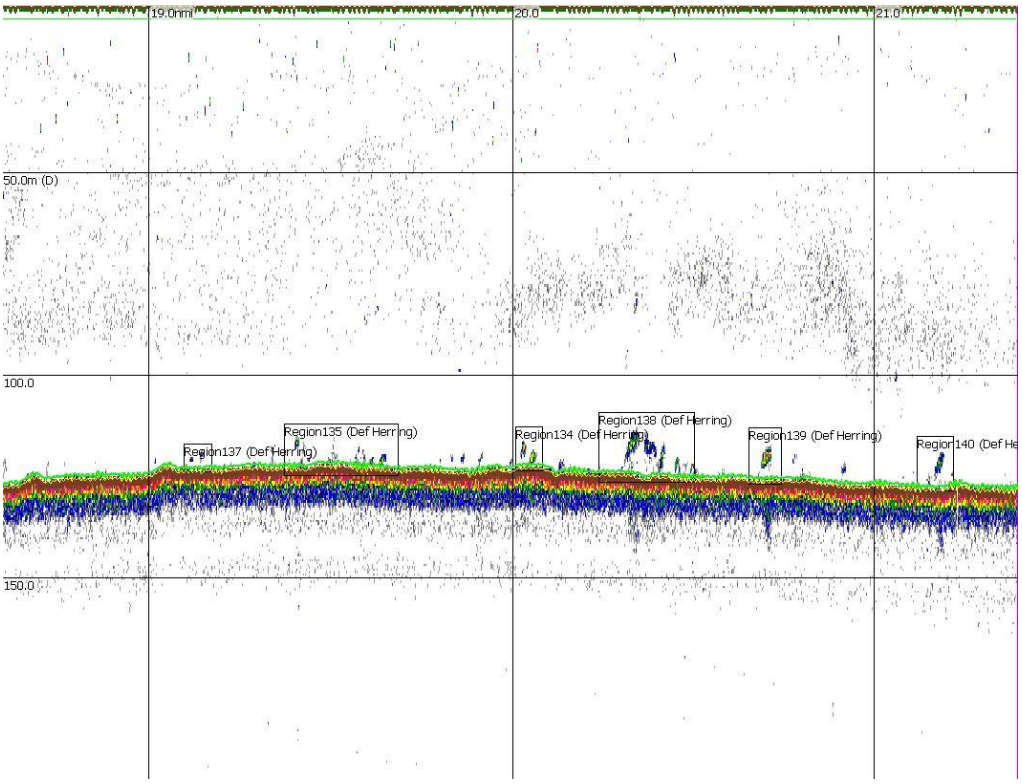
Haul 5. 02/7/15. Two typical herring marks south of St. Kilda, one on transect and one off. These marks had broken up once the net was in the water but one part containing 750 kf of herring was captured.



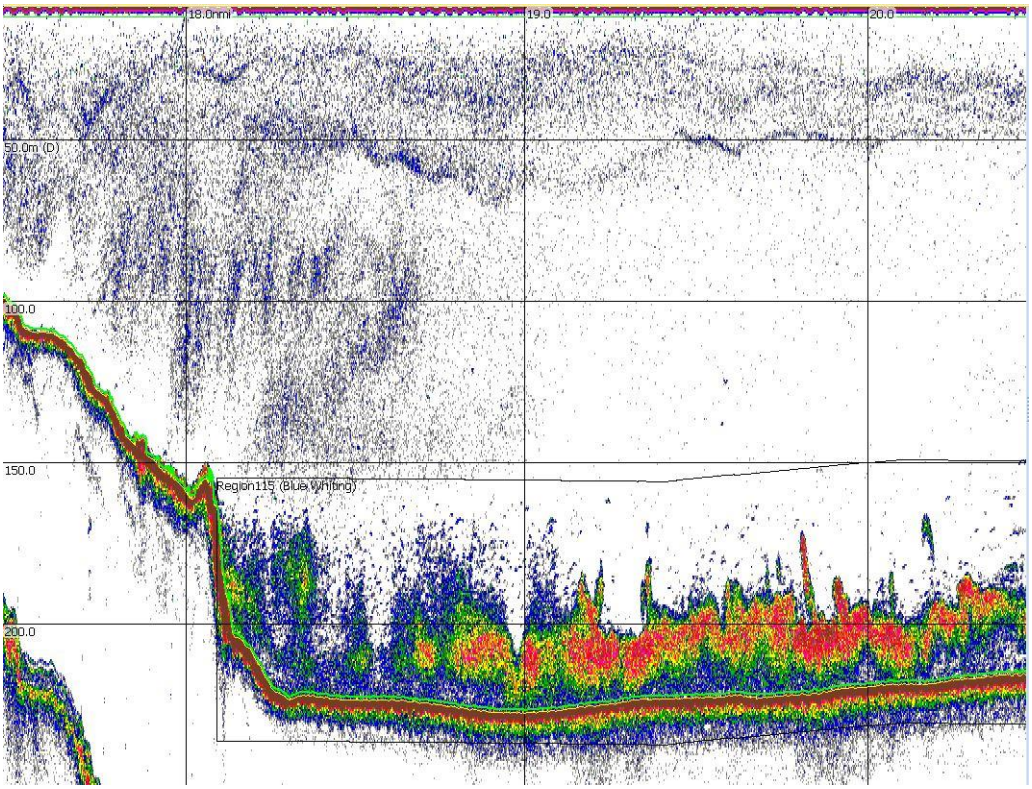
Haul 6. 02/7/15. Seven midwater marks at 150 – 175 m on the slop south east of St. Kilda. Not seen again once the net was in the water



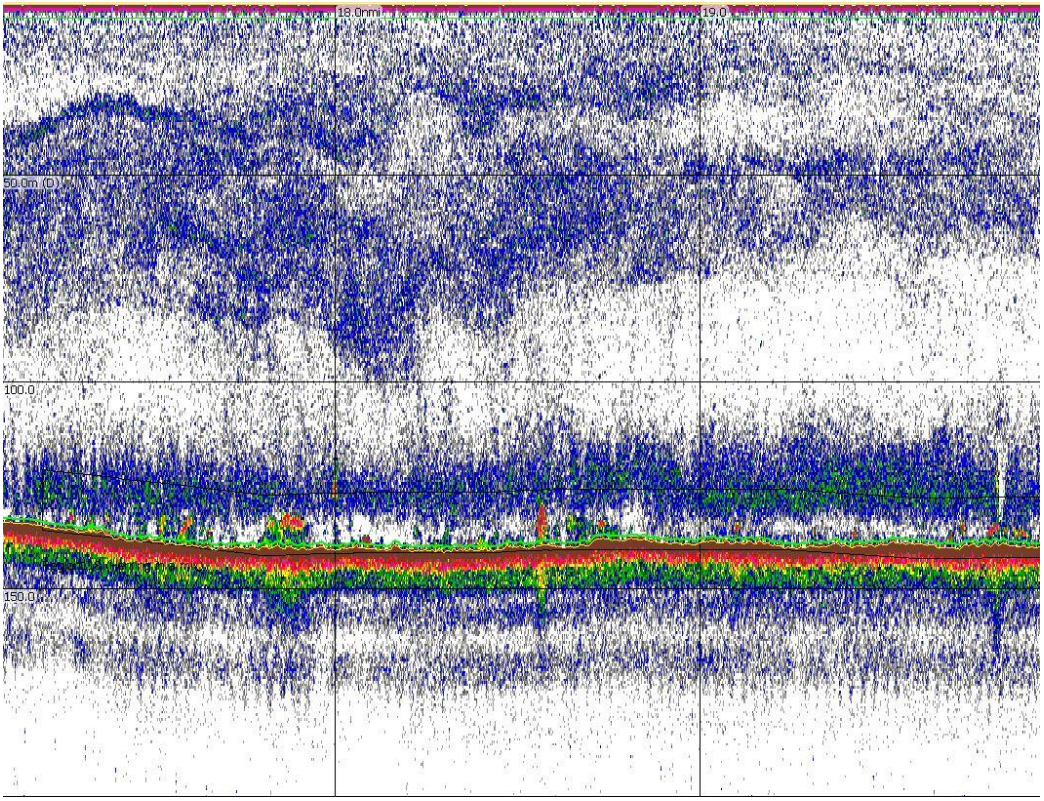
Haul 7. 03/7/15. Another few mid-water marks on the shelf edge in stat rectangle 42E1 that had disappeared on the second pass. Boarfish?



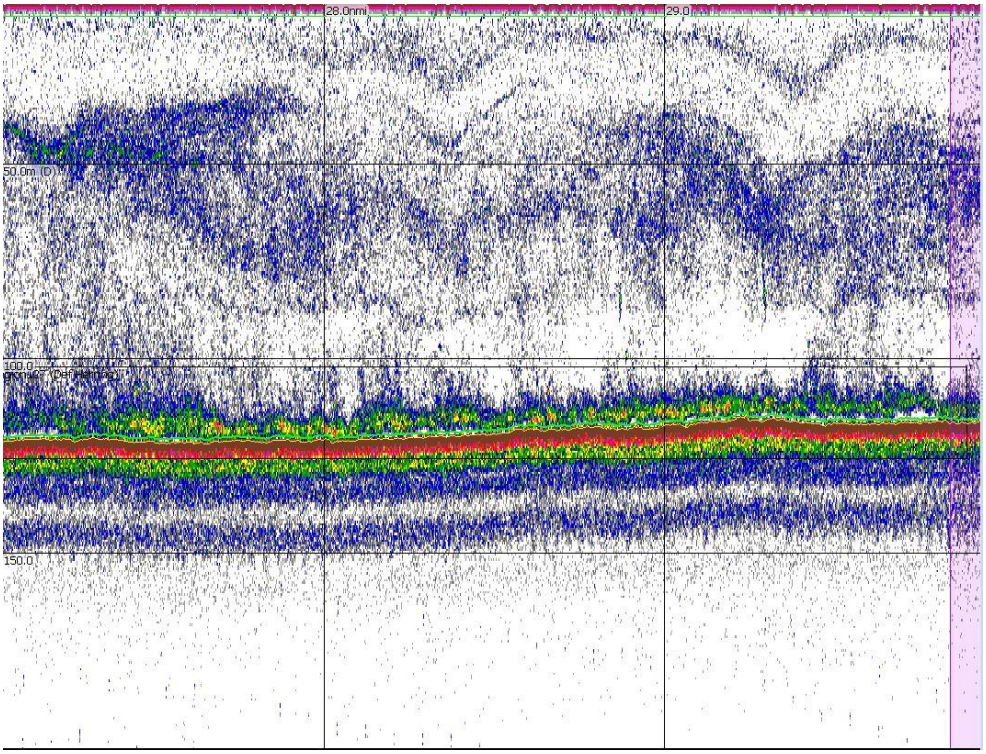
Haul 8. 04/7/15. Series of small marks in 125m of water also in 42E1. Sample contained roughly 1,850 kg of herring and 125 kg of mackerel.



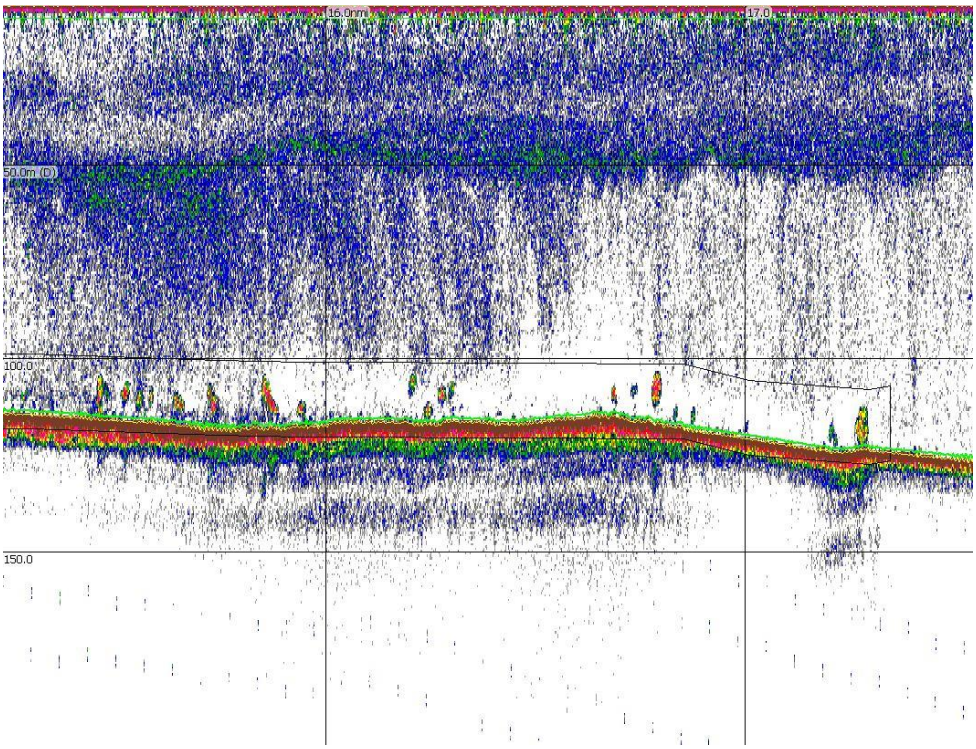
Haul 9. 04/7/15. This depression south of Barra was, unusually, filled with juvenile blue whiting.



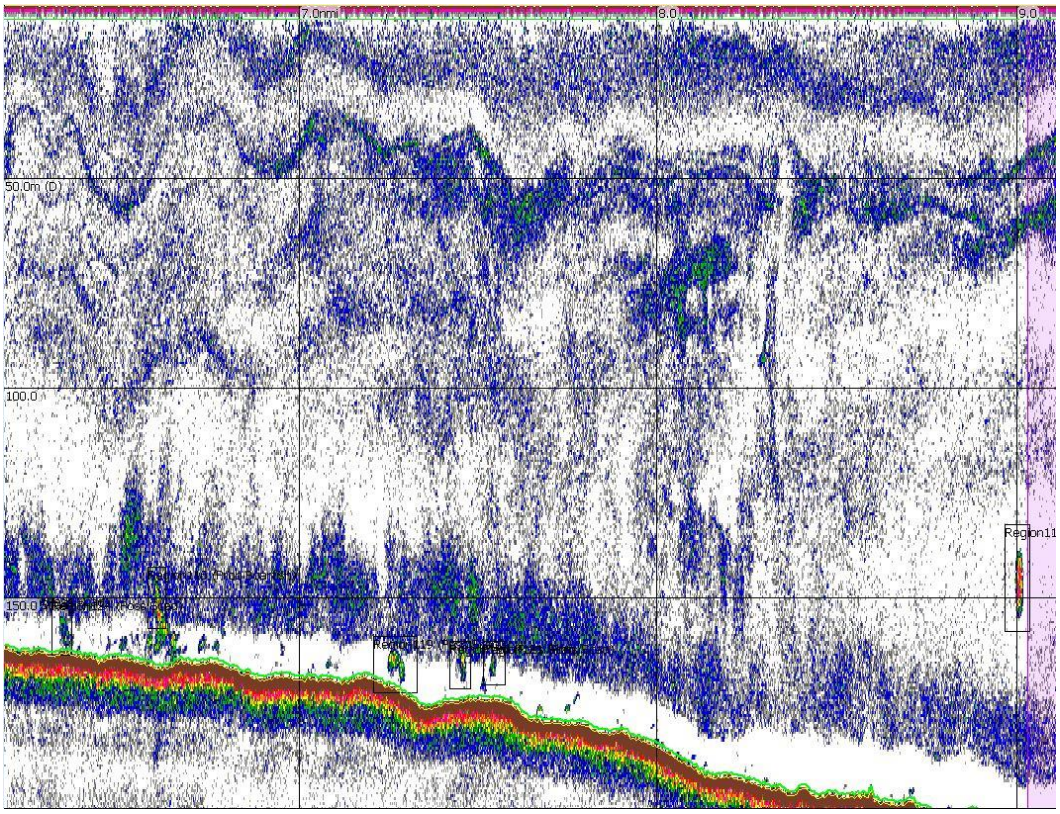
Haul 10. 05/7/15. A number of these scattered bottom marks were observed passing over the footrope in stat rectangle 41E1 but the net contained just 147 kg; 85 kg herring and 61 kg mackerel.



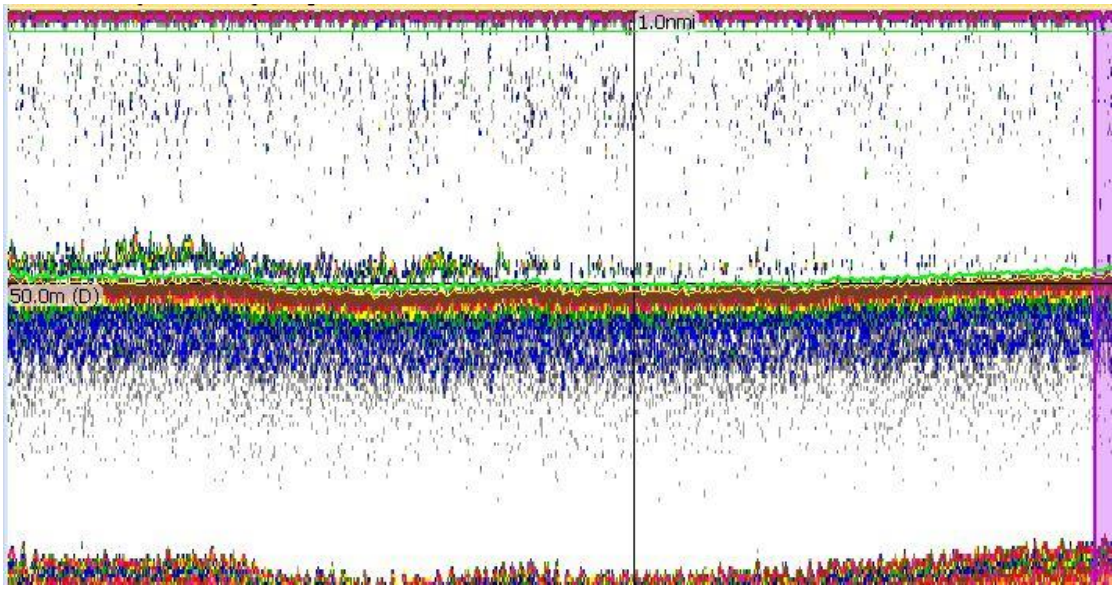
Haul 11. 06/6/15. This thin layer at 125m in stat rectangle 41E1 yielded 250 kg of herring (80%) and mackerel (20%).



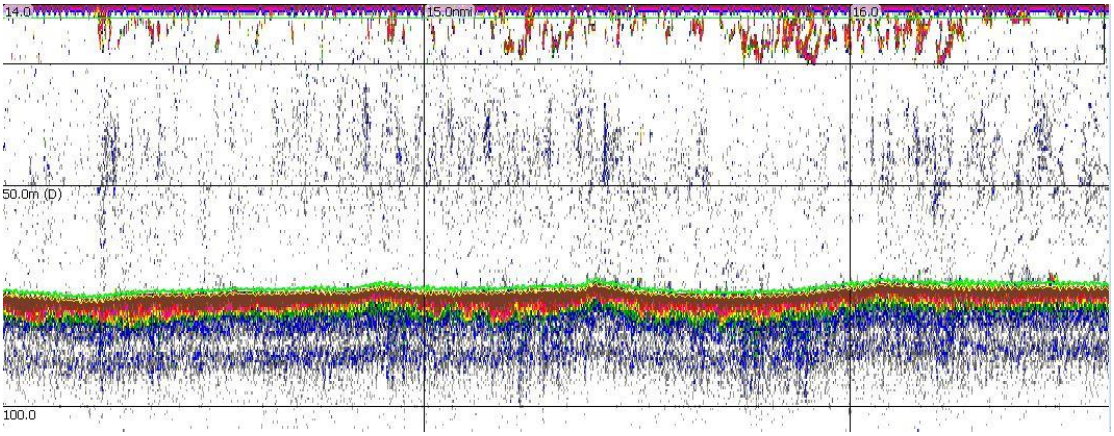
Haul 12. 6/7/15. These marks were encountered just west of haul 11 but were not seen on the headline transducer.



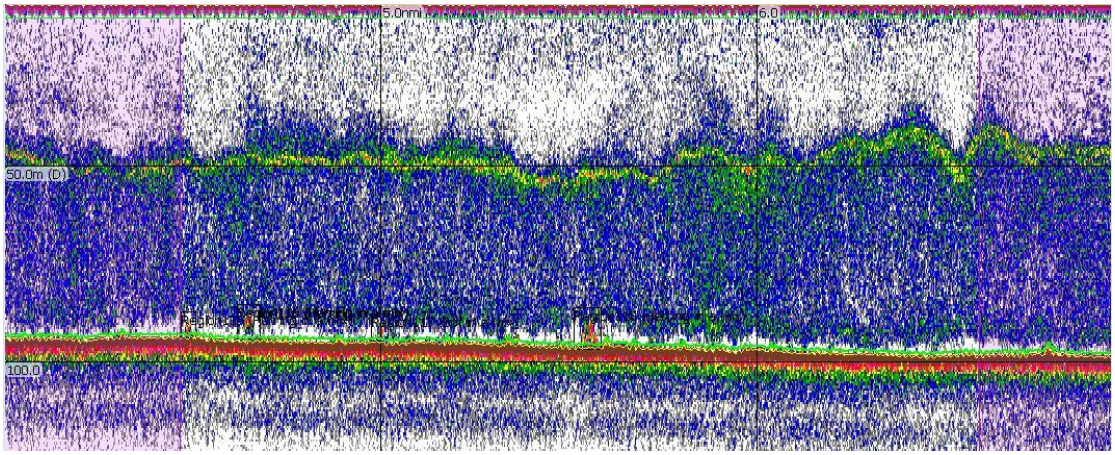
Haul 13. 7/7/15. Marks on the slope, both mid-water and bottom. Nothing seen on headline transducer.



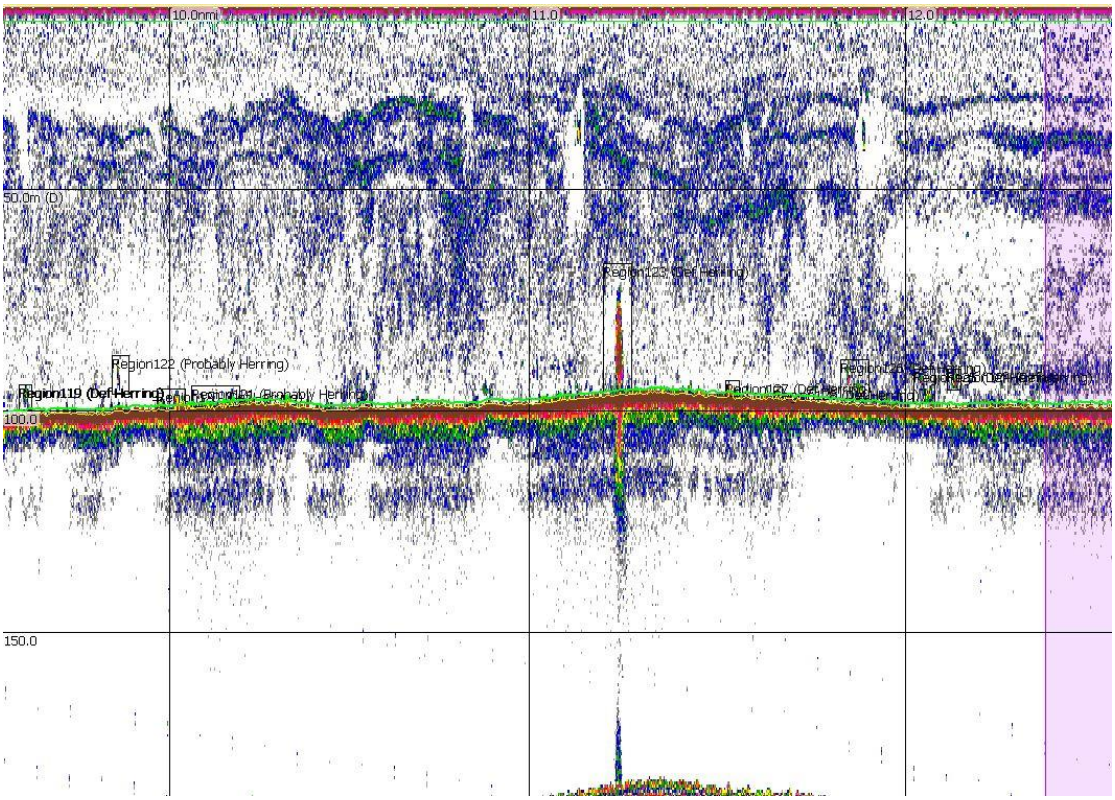
Haul 14. 8/7/15. Void haul.



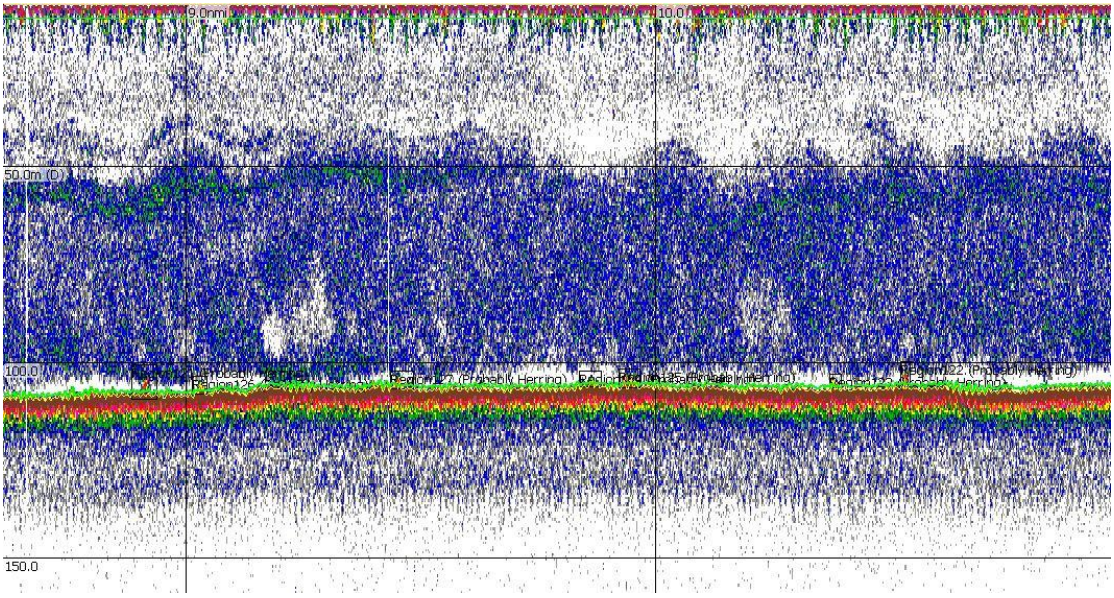
Haul 15. 8/7/15. Almost nothing was in the cod end of the net after towing through this light scattering for 20 minutes.



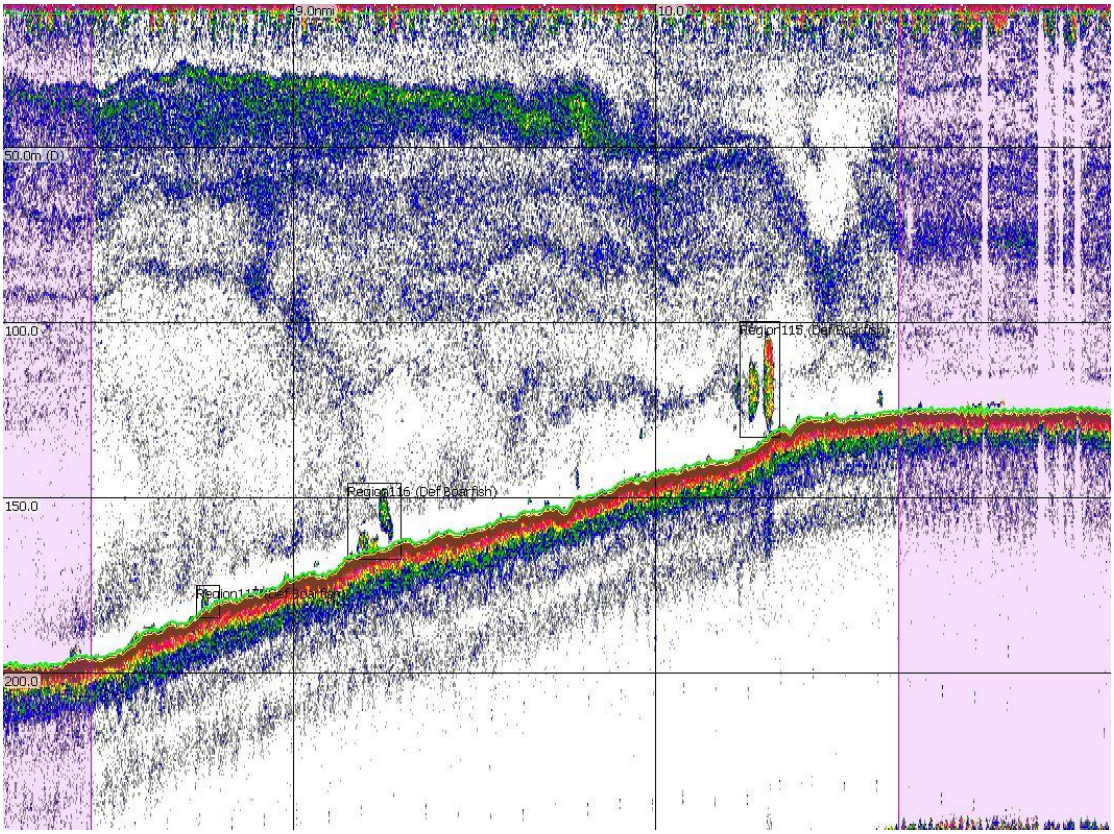
Haul 16. 9/7/15. One of these small marks north west of Donegal yielded a very mixed 100 kg sample. Mostly boarfish, herring and mackerel.



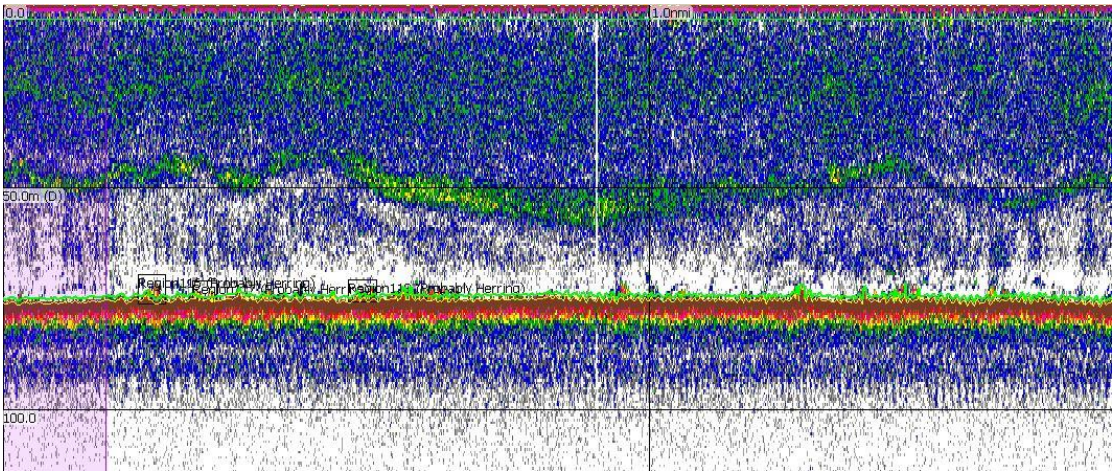
Haul 17. 9/7/15. This pillar of herring had broken up on the second pass but one of the pieces was seen passing over the footrope on the headline transducer.



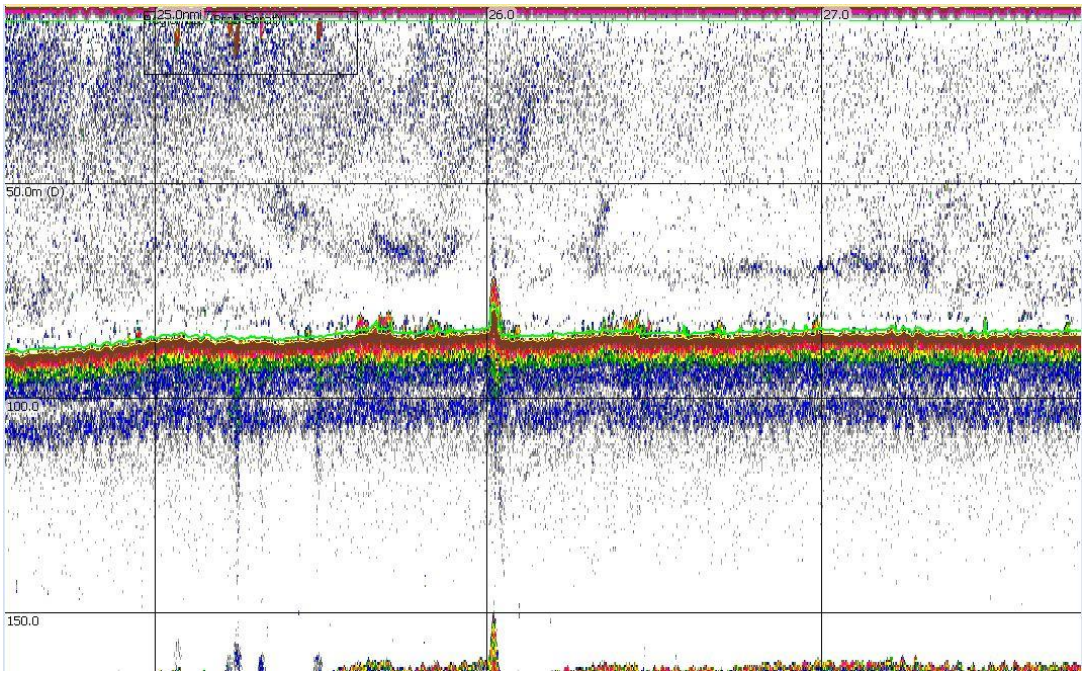
Haul 18. 10/7/15. Very small marks near the previous two hauls, not seen again once the net was deployed.



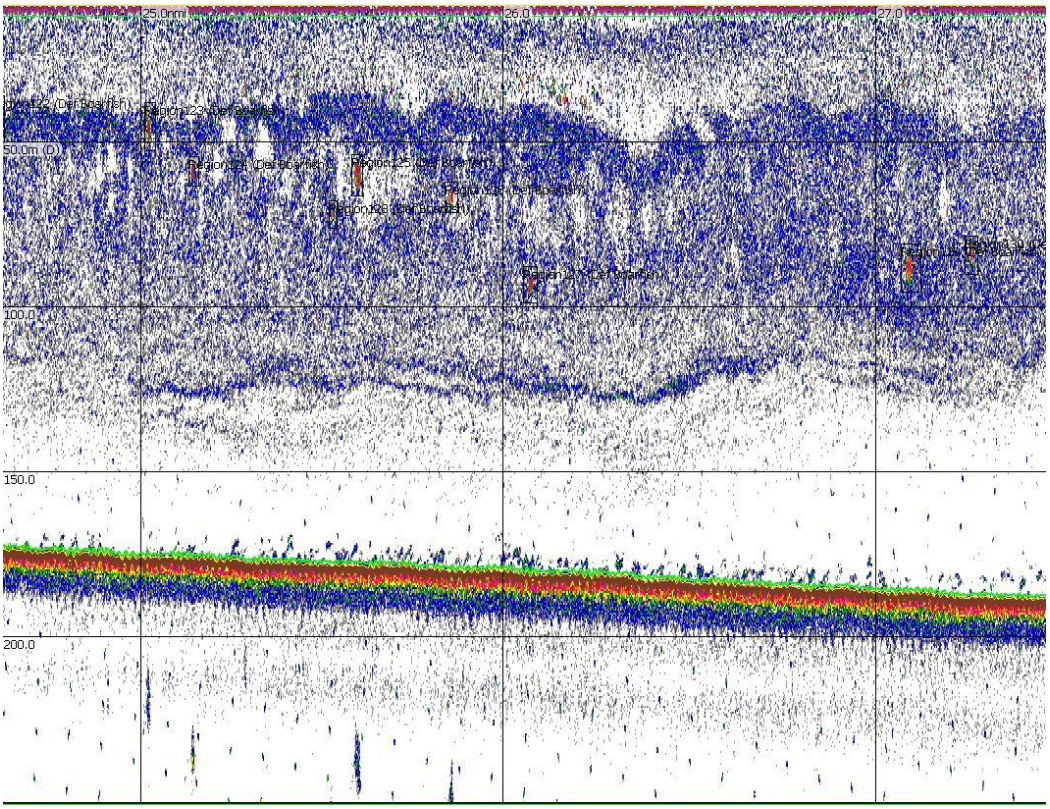
Haul 19. 11/7/15. Marks close to the shelf edge west of Donegal. Three of these marks were captured and yielded roughly 3 t of boarfish.



Haul 20. 11/7/15. Another series of small marks West of Donegal (stat rectangle 38E1). Nothing seen entering the net on the headline transducer. 200 kg of mackerel.



Haul 21. 12/7/15. These surface marks near the Stags were targeted and produced meshed sprat.



Haul 22. 8/7/15. Numerous boarfishmarks high in the water column on the slope west of Achill.

Appendix 2: List of cetacean species recorded within the Irish EEZ

Atlantic White-Sided Dolphin	*Lagenorhynchus acutus*
Beluga	*Delphinapterus leucas*[†]
Blue Whale	*Balaenoptera musculus*
Bottlenose Dolphin	*Tursiops truncatus*
Common Dolphin	*Delphinus delphis*
Cuvier's Beaked Whale	*Ziphius cavirostris*
False Killer Whale	*Pseudorca crassidens*
Fin Whale	*Balaenoptera physalus*
Gervais' Beaked Whale	*Mesoplodon europaeus**
Harbour Porpoise	*Phocoena phocoena*
Humpback Whale	*Megaptera novaeangliae*
Killer Whale	*Orcinus orca*
Minke Whale	*Balaenoptera acutorostrata*
Northern Bottlenose Whale	*Hyperoodon ampullatus*
Northern Right Whale	*Eubalaena glacialis*
Pilot Whale (long-finned)	*Globicephala melas*
Pygmy Sperm Whale	*Kogia breviceps*
Risso's Dolphin	*Grampus griseus*
Sei Whale	*Balaenoptera borealis*
Sowerby's Beaked Whale	*Mesplodon bidens*
Sperm Whale	*Physeter macrocephalus*
Striped Dolphin	*Stenella coeruleoalba*
True's Beaked Whale	*Mesplodon mirus*
White-Beaked Dolphin	*Lagenorhynchus albirostris*

[†] *Vagrant*
** Recorded only from Stranding*