FSS Survey Series: 2016/02

Western European Shelf Pelagic Acoustic Survey (WESPAS)

16 June – 30 July, 2016

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1 Introduction

The WESPAS survey program is the consolidation of two existing survey programs carried out by FEAS. The Malin Shelf herring acoustic survey has been carried out annually since 2008 and reports on the annual abundance of summer feeding aggregations of herring to the west of Scotland and north of Ireland from 54°N to 59°N. The boarfish survey has been carried out since 2011 using a chartered fishing vessel and reports on the abundance of spawning aggregations of boarfish from 47°N to 57°N. In 2016 both surveys were combined and carried out onboard the RV *Celtic Explorer* over a 42 day period providing synoptic coverage of shelf waters from 59°N southwards to 47°N.

Age stratified relative stock abundance estimates of boarfish, herring and horse mackerel within the survey area were calculated using acoustic data and biological data from trawl sampling. Stock estimates were submitted to the ICES assessment Working Group for Widely Distributed Stocks (WGWIDE) meeting in August 2016, the Herring Assessment Working Group (HAWG) meeting in March 2017. Survey performance will reviewed at the ICES Planning Group meeting for International Pelagic Surveys (WGIPS) meeting in January 2017.

2 Materials and Methods

2.1 Scientific Personnel

Leg 1	17 June - 30 July	Galway/Galway	**Leg 2**	4 July -17 July	AST	**Leg 3**	17 July -30 July	AST/Falmouth
Organisation	Name	Capacity	Organisation	Name	Capacity	Organisation	Name	Capacity
FEAS	Ciaran O'Donnell	Acoustics (SIC)	FEAS	Graham Johnston	Acoustics (SIC)	FEAS	Ciaran O'Donnell	Acoustics (SIC)
FEAS	Andrew Campbell	Acoustics	FEAS	Cormac Nolan	Acoustics	FEAS	Mike O'Malley	Acoustics
Contractor	Frankie McDaid	Acoustics	Contractor	John Power	Acoustics	Contractor	John Power	Acoustics
FEAS	Turloch Smith^	Biologist	FEAS	Michael McAuliffe^	Biologist	FEAS	Dermot Fee^	Biologist
FEAS	John Enright	Biologist	FEAS	Rob Bunn	Biologist	FEAS	Tobi Rapp	Biologist
FEAS	Tom Szumski	Biologist	FEAS	Ian Murphy	Biologist	Contractor	Sharon Suqrue	Biologist
Contractor	Usna Keating	Biologist	Contractor	Artur Opanowski	Biologist			
IWDG	Hannagh Keogh	MMO	GMIT	Joanne O'Brien	PAM	IWDG	Sean O'Callaghan	PAM
GMIT	Eva McQuillan	Student	IWDG	Sean O'Callaghan	PAM	IWDG	Mick Marrinan	MMO
NUIG	Allan Grassie	Nutirents/Chem	IWDG	Mick Marrinan	MMO	IWDG	John Collins	MMO
			IWDG	John Collins	MMO	UCC	William Hunt	MMO
			BWI	Niall Keogh	SBO	GMIT	Georgina Hunt	Student
			BWI	Killian Coakley	SBO	BWI	Niall Keogh	
			NUIG	Allan Grassie	Nutirents/Chem	NUIG	Sarah Nicholas	Nutirents/Chem
			NUIG	Sarah Nicholas	Nutirents/Chem	NUIG	Eoghan Daly	Nutirents/Chem

^ Deck scientist

2.2 Survey Plan

2.2.1 Survey objectives

The primary survey objectives are listed below:

- Collect single beam acoustic data on boarfish, herring and horse mackerel feeding and spawning aggregations within a pre-determined survey area
- Determine an age stratified estimate of biomass and abundance of target species from survey data
- Collect biological samples from directed trawling on fish echotraces to determine age structure and maturity state of target stocks
- Use vertical CTD casts to determine hydrographic conditions and the extent of shelf frontal regions
- Collect plankton samples using dedicated vertical trawls to determine biomass of zooplankton and the spatial extent of areas of concentration
- Carry out visual surveys to determine the abundance and distribution of marine mammals and seabirds (ESAS) and surface litter.
- Passive acoustic monitoring of marine mammals using a towed hydrophone array
- Use multibeam echosounders (EM2040 & EM302) collect data on the aggregation morphology and behaviour of small pelagics
- Analysis of water samples to determine concentrations of colour dissolved organic material (CDOM) and measurements of Radium isotope concentrations as a tracer to determine the extent of fresh water input.

- Analysis of water samples to determine the composition and spatial distribution of pico and nano plankton populations

2.2.2 Survey design and area coverage

Survey coverage began in the southern Minch and worked northwards before turning west to cover shelf seas from 58°30'N (northern Hebrides) to 47°30'N (northern Biscay) including the Porcupine Bank (Figure 1). Area coverage was based on the distribution of catches from the previous surveys (O'Donnell *et al.* 2011 and 2007).

The survey area was stratified based on acoustic sampling effort strata and geographical stock boundaries. Transect start points were randomised within each stratum. Transect spacing was set at 15 and 7.5 nmi (nautical miles) in open water areas and zig zag transects in the restricted Minch area. Coverage extended from the 50 m contour to the shelf slope (250 m). An elementary distance sampling unit (EDSU) of 1 nmi was used during the analysis of acoustic data. In total the planned survey covered 5,980 nmi using 71 transects relating to a total area coverage of 76,600 nmi^2.

The survey was carried out from 04:00–00:00 each day to coincide with the hours of daylight when target species are most often observed in homogenous schools. During the hours of darkness schools disperse into mixed species scattering layers and are not readily available to acoustic sampling techniques.

Survey design and execution for the WESPAS survey adhere to guidelines laid out in the Manual for International Pelagic Surveys (ICES, 2015).

2.3 Fisheries acoustics

2.3.1 EK60 Calibration

All frequencies of the Simrad EK60 the were calibrated in Killary Harbour on June 17 at the start of the survey. Calibration procedure followed methods laid out in Demer *et al.* (2015). The results of the calibration (38 kHz transducer) are provided in Table 1.

2.3.2 Acoustic array

Equipment settings for the acoustic equipment were determined before the start of the survey program and were based on established settings employed by FEAS on previous surveys (O'Donnell *et al.,* 2004).

Acoustic data were collected using the Simrad EK60 scientific echosounder. The Simrad split-beam transducers are mounted within the vessel's drop keel and lowered to the working depth of 3.3m below the vessel's hull or 8.8 m sub surface. Four operating frequencies were used during the survey (18, 38, 120 and 200 kHz) for trace recognition purposes, with the 38 kHz data used to generate the abundance estimate.

While on survey track the vessel is normally propelled 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. During fishing operations normal two-engine operations were employed to provide sufficient power to tow the net.

2.3.3 Acoustic data acquisition

Acoustic data were recorded onto the hard-drive of the processing unit. The "RAW files" were logged via a continuous Ethernet connection to the vessels server and the EK60 hard drive as a backup in the event of data loss. In addition, as a further back up a hard copy was stored on an external hard drive. Myriax Echoview® Echolog (Version 6) live viewer was used to display the echogram during data collection to allow the scientists to scroll through echograms noting the locations and depths of fish shoals. A member of the scientific crew monitored the equipment continually. Time and location (GPS position) data was recorded for each transect within each strata. This log was used to monitor the time spent off track during fishing operations and hydrographic stations plus any other important observations.

2.3.4 Echogram scrutinisation

Acoustic data was backed up every 24 hrs and scrutinised using Echoview® (V 6) post processing software.

The RAW files were imported into Echoview for post-processing. The echograms were divided into transects. Echotraces belonging to one of the target species (herring, boarfish and horse mackerel) were identified visually and echo integration was performed on the enclosed regions. The echograms were analysed at a threshold of -70 dB and where necessary plankton was filtered out by thresholding at –65 dB.

Partitioning of echograms to identify individual schools was carried out to species level where possible and mixed scattering layers where it was not possible to identify monospecific schools. For scattering layers or mixed schools containing target species the total NASC (Nautical Area Scattering Coefficient) was split by Target strength to provide a species specific NASC value.

The echogram scrutinisation process was carried out by a scientist experienced in scrutinising echograms and with the aid of accompanying trawl catch data.

The allocated echo integrator counts (NASC values) from these categories were used to estimate the herring numbers according to the method of Dalen and Nakken (1983).

The TS/length relationships used predominantly for the Celtic Sea Herring Survey are those recommended by the acoustic survey planning group based at 38 kHz (ICES, 1994):

Herring	TS = 20logL – 71.2 dB per individual (L = length in cm)
Sprat	TS = 20logL – 71.2 dB per individual (L = length in cm)
Mackerel	TS = 20logL – 84.9 dB per individual (L = length in cm)
Horse mackerel	TS = 20logL – 67.5 dB per individual (L = length in cm)
Anchovy	TS = 20logL – 71.2 dB per individual (L = length in cm)

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

Gadoids	TS = 20logL – 67.5 dB per individual (L = length in cm)

2.3.5 Calculation of acoustic abundance

Acoustic data were analysed using the StoX software package recently adopted for WGIPS coordinated surveys (ICES 2016). A description of StoX can be found here: http://www.imr.no/forskning/prosjekter/stox/nb-no. Estimation of abundance from acoustic surveys within StoX is carried out according to the stratified transect design model developed by Jolly and Hampton (1990).

2.4 Biological sampling

A single pelagic midwater trawl with the dimensions of 85 m in length (LOA) and 6 m at the wing ends and a fishing circle of 420 m was employed during the survey (Figure 23). Mesh size in the wings was 2.4 m through to 10 cm in the cod-end. The net was fished with a vertical mouth opening of approximately 25 m, which was observed using a cable linked Simrad FS70 netsonde. The net was also fitted with a Marport depth sensor. 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 hauls were sorted and weighed; fish and other taxa were identified to species level. Fish samples were divided into species composition by weight. Species other than the herring were weighed as a component of the catch. Length frequency and length weight data were collected for each component of the catch. Length measurements of herring, sprat and pilchard were taken to the nearest 0.5 cm below. Age, length, weight, sex and maturity data were recorded for individual herring within a random 50 fish sample from each trawl haul, where possible. 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 and an attempt was made to target marks in all areas of concentration not just high density shoals. No bottom trawl gear was used during this survey. However, the small size of the midwater gear used and its manoeuvrability in relation to the vessel power allowed samples at or below 1m from the bottom to be taken in areas of clean ground.

2.5 Physical Oceanography data collection

Oceanographic stations were carried out during the survey at predetermined locations along the survey track using a calibrated SeaBird 911 rosette sampler. Data were collected from 1 m subsurface and 3-5 m above the seabed.

2.5.1 CTD casts and water sampling

Raw seawater samples were drawn from Niskin bottles mounted (n=21) on the ships CTD system. Typically six depths from just below the surface to 10 m above the maximum bathymetry depth were sampled. Raw samples were collected from the Niskins into 1 ltr brown LDPE bottles. Sub samples were then obtained from the LDPEs.

2.5.2 CDOM filtration and measurement

Samples for the analysis of CDOM content and light absorption characteristics were collected via a filtration system. This method employed a WatsonMarlow 323 peristaltic pump to pull raw seawater samples through a 0.2 um micro pore filter in order to obtain a sample containing only dissolved compounds. These filtered samples were first sub sampled for optical analysis and the remainder was retained in a -200 °C freezer for further optical analysis at the lab. The optical experiment carried out on board determined the light absorption properties of CDOM in each sample. An absorption spectrum of the CDOM present in individual samples was obtained by using an Ocean Optics USB 4000 spectrophotometer coupled with a 1 m liquid wave guide capillary cell (LWCC), supplied by World Precision Instruments, and aa Ocean Optics DH-mini light source.

2.5.3 Pico/nano plankton sampling

An Accuri C6 flow cytometer was used to analyse raw and treated seawater samples to determine the presence and abundance of a number of species of micro planktonic organisms. This instrument employs a combination of the fluorescence and light scattering characteristics of the organisms present to identify and count the populations of the distinct species in each sample. A 2 ml vial of each sample is required for processing. Three duplicate samples of the raw seawater from each depth were processed by the flow cytometer. Firstly an untreated raw sample was processed. Secondly a sample that was treated with a Lysotracker and thirdly a sample that had been fixed with Gluteraldehyde and treated with a DNA staining substance called Sybergreen. Both the Lysotracker and Sybergreen have distinct fluorescence characteristics that help to discriminating between the different organisms in the samples.

2.5.4 Radium isotope measurement

The method employed to determine the Radium content in a seawater sample requires several individual processes. Firstly a volume of raw seawater is simultaneously pumped through a flow meter and a cartridge containing Manganese Oxide (MnO_2). Employing a flow meter means an accurate measurement of the volume filtered by the cartridge. Next the cartridge is flushed with UltraPure water to remove any salts. Then a flow of compressed air is blown through the cartridge to remove excess moisture. The cartridges are then inserted in the RADECC instrument after which they are purged with a measured flow of Helium for 4 to 5 minutes. Then air is pumped through the cartridges to start the flow of Radium particles into the counting mechanism that is the main part of the RADECC system. A laptop running the RADECC (v26) software counts the occurrence of any Radium particles leaving the cartridge. The system is required to run for several hours to enable the software to gather information on the rates of Radium emission. These rates correspond to the radioactive decay of the various Radium isotopes and are critical in assessing the age and provenance of the water mass being analysed. During this survey it was common to filter two 100 ltr volumes, one taken from the surface via the ships underway system and the other from a depth of 50-60 m and below the surface mixed layer.

2.1 Zooplankton sampling

Zooplankton sampling was carried out alongside CTD stations as either single cast or replicate vertical tows. A weighted 1 m diameter Hydro-bios ring net was used with a 200 µm mesh size and the net was fitted with a flow meter to determine the volume of water filtered. Vertical plankton tows were carried out to within 5 m of the seabed for stations where total depth was less than 100 m and to a 100 m maximum for all other stations depths.

Single tow stations samples were split in 50:50 for wet and dry processing. Sample splitting was carried out using a plankton sample splitter. The wet component was fixed for further analysis back at the lab. Fixing was carried using a 4% fix volume of buffered formalin. For replicate stations one sample was fixed in its entirety and the second was processed for dry weight.

Dry processing was carried out with each sample filtered through 2000 µm, 1000 µm and 125 µm sieves. For the largest gauge sample (2000 µm) including jellyfish and or krill volume displacement (ml) was measured using a graduated cylinder. For finer gauge samples (1000 and 125 µm) dry weight analysis was carried out. Samples were transferred to petri-dishes and dried onboard (70 °C oven) for a minimum of 24 hrs before sealing and freezer storage. Back in the lab dry weight analysis was carried out on defrosted frozen samples using a Sartorius MSE225S-000-DA fine scale balance (uncertainty of +/- 0.00016g).

2.2 Marine mammal and seabird surveys

2.2.1 Marine mammal abundance and distribution

Three marine mammal observers (MMOs) were present on board during the survey and conducted watches (when conditions allowed) from the ships crow's nest located 19m above sea level or alternatively from the monkey island 14m above sea level or in bridge of the vessel 11m above sea level when environmental conditions prevented access to the upper levels.

Each day surveys commenced at 08:30 and concluded at 20:30, (UTC time stamp) surveys were postponed during incumbent weather or when stations such as trawls or CTD's were taking place. Observer effort focused on a 180° arc ahead of the ship; however sightings located up to 90° 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 a distance measuring stick. Environmental data were recorded every 30 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 on-board a vessel of opportunity, the survey was conducted in 'passing mode' and cetaceans sighted were not actively approached. 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 / beaked whale species etc.) according to criteria established for the IWDG's cetacean sightings database (IWDG 2010). Photographs were attempted for all sightings using ©Cannon Eos cameras with zoom lenses (©Sigma DG 150-500 mm), especially where photo identification images of species such as bottlenose dolphins could be obtained. 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.

2.2.2 Passive acoustic monitoring

A towed hydrophone array was deployed when other activities such as deploying the CTD or trawling were not taking place. The array consisted of a 200 m cable with two hydrophone elements (HP-03) situated 25 cm apart in a fluid filled tube near the end of the cable. The hydrophone cable was connected to a MAGREC HP-27 buffer box within the vessels dry lab which was then connected to two laptop computers to record high frequency and low frequency vocalisations separately. The detection software used during the survey was PAMGUARD. Notes were made on both recording laptops when whistles, clicks or anthropogenic noises were detected through the buffer boxes headphones. This acoustic detection facilitated the collection of additional data during visual surveys and also when off effort during poor surveying environmental conditions or during night time hours.

A rotation system was implemented every survey day where each observer would spend two hours as an MMO, followed by two more on LOGGER and PAM (when the hydrophone was deployed) before concluding with a two hour break period. Each station was completed twice everyday by the three observers when environmental conditions allowed. A fourth MMO was present for leg 3 (17-30 July) allowing for two active observers when on survey effort.

2.2.3 Seabird abundance and distribution

Surveys of seabirds at sea were conducted from the R.V. *Celtic Explorer* between 19 March and 4 April 2016. While on transect, the ship travelled at an average speed of 10 knots, except when increased swell prohibited this. A standardised line transect method with sub-bands to allow correction for species detection bias and 'snapshots' to account for flying birds was used (following the recommendations of Tasker et al. 1984; Komdeur et al. 1992; Camphuysen et al. 2004), as outlined below.

Two observers (a primary observer and a scribe, who also acted as a secondary observer) worked in rotating one hour shifts, surveying from 08:00 to 20:00 hours each day. Surveying ceased when the ship broke track during sample tows, during the deployment of the CTD etc. Environmental conditions, including wind force and direction, sea state, swell height, visibility and cloud cover, and the ship's speed and heading were noted at the start of each survey period and again when significant changes occurred thereafter. No surveys were conducted in conditions greater than sea state six, when high swell made working on deck unsafe, or when visibility was reduced to less than 300 m.

Seabird surveys were conducted from the platform of the monkey island. Observations were conducted from either the port or starboard side depending suitable viewing conditions at the time (e.g. presence of glare). The platform height was 12 m above the waterline, providing an uninterrupted view of the survey area.

The survey area was defined as a 300 m wide band operated on one side (in a 90˚ arc from the bow) and ahead of the ship. This survey band was sub- divided (A = 0-50m from the ship, B = 50-100 m, C = 100-200 m, D = 200-300 m, E = >300 m) to subsequently allow correction of species differences in detection probability with distance from the observer. A fixed-interval range finder (Heinemann 1981) was used to periodically check distance estimates. The area was scanned by eye, with binoculars used only to confirm species identification. All birds seen within the survey area were counted, and those recorded on the water noted as 'in transect'. All flying birds within the survey area were also noted, but only those recorded during a 'snapshot' were regarded as 'in transect'. This method avoids overestimating bird numbers in flight (Tasker et al. 1984). The frequency of the snapshot scan was ship-speed dependent, such that they were timed to occur at the moment the ship passed from one survey area (300 m long x 300 m wide) to the next. Any bird recorded within the survey area that was regarded as being associated with the survey vessel was noted as such (to be excluded from abundance and density calculations). Survey time intervals were set at 1 minute. Additional bird species observed outside the survey area were also recorded and added to the species list for the research cruise, but these will not be included in maps of seabird abundance or density.

In this report we present our daily total count data for each species each day along with the daily survey effort. It is envisaged that this data will be analysed in the future and the seabird abundance (birds per km travelled), and seabird density (birds per km^2) will be mapped per ¼ ICES square (15˚ latitude x 30˚ longitude), allowing comparison to the results of previous seabird surveys in Irish waters (e.g. Hall et al. in press; Mackey et al. 2004; Pollock et al. 1997). Through further analysis, species-specific correction factors will be applied to birds observed on the water. The binomial species names for the birds recorded are presented in the results section, for which taxonomy and nomenclature follows that of the Irish Rare Birds Committee (2014).

3 Results

3.1 Malin Shelf herring

3.1.1 Biomass and abundance

Herring	Abund ('000)	Biomass (t)
Total stock	361,810.0	66,991
Spawning stock	361,484.6	66,951

Herring TSB (total stock biomass) and abundance (TSN) estimates were 69,991 t and 361,810 individuals (CV 31.3%) respectively.

The Malin Shelf survey area was divided into 5 strata representing a total area coverage of 30, 342 nmi^2 (Figure 2 & Table 5). A breakdown of herring stock abundance and biomass by age, maturity and stratum is detailed in Table 3 and Figures 3 & 4. The Malin Shelf survey time series is provided in Table 4.

3.1.2 Stock distribution

A total of 47 trawl hauls were carried out during the survey (Figure 1), with 4 hauls containing >50% herring by weight of catch within the Malin Shelf survey area (Table 2).

Herring distribution was limited to two strata located north of 56°N line of latitude in the (Figure 3). A total 82 echotraces were assigned to herring from these strata with 73% located in stratum 2 (western Hebrides) and 27% in stratum 3 (south Hebrides) as shown in Table 5. Herring within these strata were predominantly located in the deeper waters towards the shelf edge and generally in close proximity to the seabed (Figure 9a). Overall the bulk of the stock was located further north than during the same time period in 2014-2015 and clustered into a relatively small area (Figure 3). The seasonal distribution of herring during the survey period is most commonly observed in 3 particular regions; north of 57°N (west of the Hebrides), between 56-57°N (south and west of Barra Head) and south of 56°N (north and west of Donegal). No herring were observed south of the 56°N line of latitude in 2016 and is unusual for herring at this time of year based on previous observations.

3.1.3 Stock composition

A total of 486 herring were aged from survey samples in addition to 1,472 length measurements and 306 length-weights recorded. Herring age samples ranged from 2-9 winter-rings (Table 3 & Figure 4).

Five winter-ring herring dominated the 2016 survey estimate representing over 28.5% of TSB and 25.2% of TSN (Table 3). Six winter-ring age group were ranked second representing 18.6% of TSB and 16.5% of TSN. The third most dominate age group was three winter-ring class contributing 18.5% to the TSB and 19.5.3% to TSN. Combined these three age classes represented 65.6% of TSB and 61.2% of TSN

Maturity analysis of herring samples indicated 99.9% of fish were mature. Maturity analysis by age class showed that 98% of 2 year old fish were mature, rising to 100% of fish of three years and older(Table 3).

3.2 Boarfish

3.2.1 Biomass and abundance

Boarfish	Abund ('000)	Biomass (t)
TSB estimate	1,157	69,690
SSB estimate	1,108	69,103

Boarfish TSB (total stock biomass) and abundance (TSN) estimates were 69,690 t (CV 19.1%) and 1,157,163 individuals (CV 16.4%) respectively.

The boarfish survey area was divided into 7 strata representing a total area coverage of 52, 693 nmi^2 (Figure 2). A breakdown of boarfish stock abundance and biomass by age, maturity and stratum is detailed in Table 6 and Figures 5 & 6. The boarfish survey time series is provided in Table 8.

4.2.2 Stock distribution

A total of 47 trawl hauls were carried out during the survey (Figure 1), with 15 hauls containing >50% boarfish (Table 2).

A total of 394 echotraces were assigned to boarfish. Boarfish were observed in all survey strata with the exception of one (Table 7). The highest occurrence was in the Celtic Sea (stratum 3) with 59% of all echotraces observed. Overall, the pattern of distribution was similar to previous years for core areas (Figure 5). In northern strata boarfish were predominantly observed close to the seabed on or in close proximity to the shelf slope, a typical distribution for northern stratum (Figure 9b). However, in contrast to previous years aggregations of juvenile were observed in surface waters around the Stanton Bank area (Figures 6 & 9c and Table 7). Prior to this, schools composed exclusively of juvenile boarfish have only been observed in the southern Celtic Sea. On the Porcupine Bank the distribution of boarfish was comparable to previous years with midwater schools observed below the thermocline (Figure 9f). Along the Irish west coast (51-54°N) almost all boarfish encountered were located in deeper waters approaching the 200m depth contour with the exception of a cluster of schools around the 54°N line of latitude. Boarfish were observed in a midwater position along the west coast below the thermocline (Figure 9e). In the Celtic Sea, the Banks complex and shelf edge areas contained the most boarfish observed and is consistent with previous year (Figures 9g-h). The stock appears to have been contained at the southern border with the two southernmost transects recording zeros. However, the PELGAS survey in May reported a higher than normal biomass of boarfish in the northern survey area around 46°N (M. Doray, pers. comm., July, 2016). Overall the total number echotraces was lower in 2016 than in 2015 (394 vs. 652) although acoustic density of echotraces was comparable.

4.2.3 Stock composition

A total of 665 boarfish were aged from survey samples in addition to 3,427 length measurements and 1,817 length-weights recorded. Boarfish age samples ranged from 1-15+ years (Table 6 & Figure 6). Age structure of the stock was determined using an established age length key as the procedure involved in aging boarfish requires a longer time frame than available here.

The 15+ year age class dominated the 2016 boarfish survey estimate representing over 45.8% of TSB and 34.6% of TSN (Table 6). Seven year old fish were ranked second representing 11.5% of TSB and 14.6% of TSN. The third most dominate age group was the nine year olds 9.4% to the TSB and 10.2% to TSN. Combined these three age classes represented 66.8% of TSB and 59.3% of TSN

Maturity analysis of boarfish samples indicated 99.1% of fish were mature. Maturity analysis by age class showed that 85% of 3 year old fish were mature, rising to 100% for fish four years and older (Table 6).

4.3 Horse mackerel

4.3.1 Biomass and abundance

Horse mackerel	Abund ('000)	Biomass (t)
TSB estimate	354.4	69,267.1
SSB estimate	265.2	65,194.3

Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 69,267 t (CV 38.7%) and 354,472 individuals (CV 42.0%) respectively.

The horse mackerel survey area was divided into 7 strata representing the same geographical footprint as the boarfish survey area of 52, 693 nmi^2 (Figure 2). A breakdown of horse mackerel stock abundance and biomass by age, maturity and stratum is detailed in Table 9 and Figures 7 & 8.

4.3.2 Stock distribution

A total of 47 trawl hauls were carried out during the survey (Figure 1), with 2 hauls containing >50% horse mackerel out of 20 containing horse mackerel (Table 2).

A total of 188 echotraces were assigned to horse mackerel. Horse mackerel were observed almost exclusively south of 55°N line of latitude in three of the seven survey strata (Table 10 and Figures 7 & 8). The west coast stratum contained the highest concentration of echotraces. Schools of horse mackerel were most frequently observed on the seabed and most often over a rocky substrate (Figure 9d), and along the west coast were often observed in areas containing boarfish. On the Porcupine Bank horse mackerel and boarfish distribution was closely aligned (Figures 5 & 7). In the Celtic Sea distribution was more widely dispersed with a low number of schools spread over a large area. During previous surveys horse mackerel have been observed in relatively high concentrations along the southwest corner of Ireland and were the focus of international fishing effort. However, during this year's survey this effort along with the distribution of biomass was focused further north along the west coast.

4.3.3 Stock composition

A total of 392 horse mackerel were aged from survey samples in addition to 641 length measurements and 392 length-weights recorded. Horse mackerel age samples ranged from 1-21 years (Table 9 & Figure 8). Age structure of the stock was determined using a combination of aged otoliths and an age length key from commercial landings data.

The 8 year age class dominated the 2016 horse mackerel survey estimate representing over 23.9% of TSB and 18.8% of TSN (Table 9). Seven year old fish were ranked second representing 17.2% of TSB and 11.4% of TSN. The third most dominate age group was the four year olds 12.3% to the TSB and 12.2% to TSN. Combined these three age classes represented 53% of TSB and 42.5% of TSN

Maturity analysis of horse mackerel samples indicated 94% of fish were mature. Maturity analysis by age class showed that 18% of 2 year old fish were mature, rising to 100% for fish three years and older (Table 9).

4.4 Oceanographic sampling

4.4.1 CTD sampling

In total 77 of the planned 84 CTD casts were carried out (Figure 10). Horizontal temperature and salinity maps for the survey area are provided for depths 5 m, 20, 40 and 60 m in Figures 11-14 respectively.

Hydrographic conditions encountered during the survey showed the influence of warmer waters at the surface further south and cooler waters further north as would be expected during the summer months. Exceptions were observed along coastal margins where the influence of riverine inputs was evident in terms of lower temperature and reduced salinity. Below the thermocline (35-55m) and at the seabed the influence of warmer water from the south was limited to south of 53°N and was interrupted by the presence of a finger of cooler water extending into the mid Celtic Sea.

The distribution of herring, boarfish and horse mackerel as determined from acoustic density was overlaid with temperature and salinity profiles at 50m subsurface and from near seabed (3-5m) to recreate the conditions in which these species observed (Figures 15-17 respectively).

4.4.2 CDOM

CDOM sampling was undertaken at 75 of the 77 oceanographic stations during the survey. Analysis of samples is currently underway. Figure 19 shows a typical absorption spectrum of CDOM in coastal and offshore environments taken during the survey. Noticeable in the figure is the characteristic exponential increase in absorption with decreasing wavelength. This increased absorption continues into the extreme ultra violet. Also evident are the subtle variations (arrowed) of the spectral slope seen for samples from different depths at the same station. These variations relate to the predominant molecular size of the CDOM compounds in each sample. Comparison of these slopes also gives an indication of the history and source of this material.

4.4.3 Pico/nano plankton sampling

Sampling of pico and nano plankton communities was carried out at 75 of the 77 oceanographic stations during the survey. The software that controls the Accuri C6 flow cytometer is able to graphically display the optical and physical characteristics of the organisms present in any sample. The forward scattering of incident light gives an indication on the size of an organism whereas the side scatter of the light relates to the shape of that particular organism. The three fluorescence sensors are set to respond to different colours of fluorescence, orange, green and red, and help to differentiate between the photosynthetic pigments that are unique to the individual species of plankton that are being studied. Figure 20 shows the graphical display of the pico/nano plankton population at a single depth at one station. Gated in red are two distinct populations of organisms. Further analysis is currently on-going.

4.4.4 Radium isotope measurements

Radio isotope sampling was carried out at 15 of the 77 oceanographic stations during the survey. An analysis of the samples is currently on-going.

4.1 Zooplankton biomass

Plankton samples were collected at each of the 77 hydrographic stations during the survey. Species composition analysis is currently underway using chemically fixed samples. Dry weight biomass for zooplankton on a per station basis is shown in Figure 18.

Zooplankton biomass (dry weight) was highest north of the 53°N line of latitude as compared to southern latitudes and particularly to the west of the Hebrides where the bulk of herring stock was also located. In general, to the west of Ireland and the Porcupine Bank biomass was overall lower in comparison to the larger survey area. However, in one particular area around 53°'30N a higher abundance of zooplankton was observed and in this area a higher abundance of horse mackerel was also observed. The presence of higher value stations along the west coast is aligned with the western and the oceanic side of the Irish Shelf Front boundary area. In the Celtic Sea zooplankton biomass appeared relatively uniform overall with a slightly higher values observed over the Banks then at the shelf edge stations.

4.2 Marine mammals and seabirds

4.2.1 Visual abundance survey

Total survey effort amounted to over 334 survey hours over the entire survey. Survey effort was divided into two components; Leg 1 carried out over 14 days (17-30 June) by a single observer and a second block (legs 2) carried out over 27 days by 2-3 observers (3-30 July). Environmental data was collected at total1,029 stations (396 and 633 respectively).

Sixty-two sightings of 8 cetacean species, 1 seal species and 1 shark species were recorded, totalling 416 individuals were observed during the Leg 1 survey (Table 11, Figures 21 & 22). Common dolphins (Delphinus delphis) were the most frequently encountered and abundant species observed, with 14 sightings of 248 individuals. Large numbers of common dolphins >100 and >50 were recorded on two occasions. White beaked dolphins (Lagenorhynchus albirostris) were the second most frequently observed species with 14 sightings of 95 individuals. All sightings of white-beaked dolphins were recorded to the northwest and west of Scotland. A lone male killer whale (Orcinus orca) was observed off the island of Coll.

White beaked dolphins (Lagenorhynchus albirostris) were observed feeding with a humpback whale (Megaptera novaeangliae) and common dolphins (Delphinus delphis) off the north east Outer Hebrides. Seven encounters of unidentified dolphins were sighted throughout the survey, and a single unidentified large whale blow was sighted off the Rockall Trough.

During the Leg 2 survey 180 sightings of 9 cetacean species, totalling 1,227 individuals were recorded (Table 11, Figure 22). Common dolphins were the most frequently recorded and abundant species sighted making up 70.6% of all sightings and 83% of all individuals counted. Minke whales were the second most frequently sighted cetacean, accounting for at 8.3% of sightings, while bottlenose dolphins were the second most abundant species, accounting for 7% of all individuals counted.

Baleen whale sightings (minke, humpback, fin and large baleen whales) accounted for 11.6% of the total sightings logged while dolphin sightings (common, striped, bottlenose and unidentified dolphins) accounted for 78.8% of the total.

The majority of the sightings recorded were within the Irish Economic Exclusion Zone with 158 records while the remaining 22 sightings were recorded in English or French waters West of Cornwall and Brittany.

4.2.2 Passive acoustic monitoring

Data collected during the survey is currently being processed.

4.2.3 Seabird abundance and distribution

A total of 129 hours and 53 minutes (7,793 minutes) of seabird surveys was conducted across 24 days between 5th and 29th July 2016 with an average of 5 hours and 24 minutes (324 minutes) surveyed per day, ranging from a minimum of 1 hour 25 minutes (85 minutes) to a maximum of 8 hours 45 minutes (525 minutes). No surveys were conducted on 17th July during the mid-cruise break to undertake a crew change at Castletownbere.

A total of 18 additional counts of seabirds associating with the survey vessel conducted across 15 dates between 5th and 29th July comprised of 15 counts made during daytime fishing hauls and 3 during daytime CTD stations.

A cumulative total of 10,920 individual seabirds of 26 species was recorded, of which 4533 were noted as ‘off survey’, outside of dedicated survey time or associating with the vessel and as such will be excluded from future analysis of abundance and density. A synopsis of daily totals for all seabird species recorded is presented in Table 12. In addition, daily totals for 5 species of migrant terrestrial birds recorded on or around the vessel are also presented (Table 13).

Discussion and Conclusions

4.3 Discussion

The objectives of the survey were carried out successfully and as planned. Good weather conditions dominated for the majority of the survey allowing for extended marine mammal and seabird survey effort. Good weather afforded time for the recovery of previously deployed marine mammal acoustic moorings. Overall, weather induced downtime amounted to 24 hours over the 42 day survey period.

Herring distribution was concentrated into an area to the west of the Hebrides in VIaN with no herring observed south of 56°N in VIaS or VIIb,c in contrast to previous years. In 2015 the biomass of VIaS or VIIb,c was 55,000 t. Survey effort (transect miles), survey trawls and temporal coverage were similar in both years. The overall stock biomass was 85% lower than in 2015. However, it should be noted that in 2015 survey coverage extended to cover all of VIa and a large proportion of the stock was located in the northern extension bordering the 4°W line of longitude that separates the North Sea stock. This particular area has sporadic high abundances of herring and can strongly influence the annual estimate of biomass in of VIaN . In 2016 coverage reverted back to a northern boundary of 59°N. The age profile of survey samples in 2016 is consistent with dominant year's classes observed in 2015 with the 4-6 year old dominating the stock. The distribution of herring occurred in the area where the most zooplankton biomass was observed which is entirely plausible given the stock is feeding at this time.

The geographical distribution of boarfish observed during the survey was comparable to 2015 and earlier years in the time series. However, the acoustic density and number of echotraces assigned to boarfish was much lower following the on-going trend in this survey. Trawling effort was comparable and representative sampling was carried out ensuring a more than adequate number of trawls were carried out to verify echotrace composition and for stock composition analysis. The overall biomass estimate was 70% lower than during the same time and for the same survey effort in 2015. The age distribution of the stock is comparable with the previous survey and dominated by the oldest age classes.

Horse mackerel biomass was found to be highest along the Irish west coast with smaller but significant amounts on Porcupine Bank and in the Celtic Sea. As this is the first time that an age stratified abundance was calculated for horse mackerel and so it is not possible to compare with previous work. However, in terms of observed distribution a lack of fish was observed in the northwest Celtic Sea, a normal hotspot saw a corresponding increase along the west coast. This apparent change in distribution was also evident from the location of international fishing vessels actively targeting horse mackerel. This survey will continue to provide a relative abundance estimate for horse and paired with survey in the Bay of Biscay has the potential to provide a measure of the stock over a large geographical area.

Hydrographic conditions in surface waters were as to be expected during the summer months with warmer waters dominating more southern latitudes and well stratified water masses with a strong thermocline. Thermocline depth ranged from 35-55m depending on location. Zooplankton biomass (dry weight) provided a useful insight into conditions encountered during this survey and correlation to the distribution of both spawning and feeding aggregations of target species. Further analysis of the data is currently underway. Analysis of composition of fixed station samples indicate the dominance of horse mackerel larvae as would be expected during peak spawning. However, the low numbers of boarfish larvae encountered was unexpected given that July is considered as peak boarfish spawning season (N. Harith, pers. comm, Sept, 2016).

4.4 Conclusions

- Herring biomass was lower than at the same time in 2015 when comparing the same geographical areas surveyed. No herring were observed south of 56°N and is unusual in recent time series.
- Herring TSB (total stock biomass) and abundance (TSN) estimates were 69,991 t and 361,810 individuals (CV 31.3%) respectively.
- The age profile of dominant age classes within the stock is comparable to 2015.
- The three most dominant year classes (5, 6 and 4 winter ring fish) and represented over 65% of the TSB.
- Boarfish distribution showed a similar pattern to that observed in previous years with biomass observed in all strata surveyed albeit in reduced amounts.
- Boarfish TSB (total stock biomass) and abundance (TSN) estimates were 69,690 t and 1,157,163individuals (CV 16.4%) respectively.
- The overall biomass estimate for boarfish was 70% lower than during the same time and for the same survey effort in 2015. This is a sharp decrease in a single year continuing the overall downwards trend observed in this time series
- Horse mackerel estimate is considered as reliable and will be developed further. This survey has the potential to provide a measure of the stock over a large geographical area if aligned with other co-occurring surveys.
- Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 69,267.1 t and 354,472 individuals (CV 42.0%) respectively.
- Horse mackerel age structure is comparable to the profile of landings with the exception that the survey contains a larger proportion of smaller individuals than is observed during the fishery.

4.5 Recommendations

- In 2017 it is recommended that this survey begins in the south and works in a northerly direction. This will allow closer temporal alignment than currently exists with co-occurring surveys in Scotland (herring) and France (boarfish and horse mackerel). A southern start point would also eliminate questions regarding the containment of the boarfish stock along the southern boundary.
- In 2017 that zooplankton sampling be continued and developed after a successful pilot in 2016.
- Survey continues to report on horse mackerel acoustic abundance for the development of a wider area index. Linking with the PELGAS survey through WGACEGG provides an opportunity for both boarfish and horse mackerel in this regard.
- In 2017, potential areas of non-containment be surveyed, specifically the Celtic Deep area.

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5 Tables and Figures

Table 1. Calibration report: Simrad EK60 echosounder at 38 kHz.

Echo Sounder System Calibration Report

Vessel :	RV Celtic Explorer	Date :	16.06.16
Echo sounder :	Drop Keel	Locality :	Killary Harbour
Type of Sphere : CU 64	TS Sphere: -33.50 dB	Depth(Sea floor)	32 m

Calibration Version 2.1.0.12

Comments:
Weather conditions good

Reference Target:

TS	-33.50 dB	Min. Distance	15.0m
TS Deviation	5 dB	Max. Distance	22.0m

Transducer: ES38B Serial No.

Frequency	38000 Hz	Beamtype	Split
Gain	25.88 dB	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	6.75 deg	Along. Beam Angle	6.69 deg
Athw. Offset Angle	-0.04 deg	Along. Offset Angl	-0.03 deg
SaCorrection	-0.70 dB	Depth	8.80 m

Transceiver: GPT 38 kHz 009072033933 1 ES38B

Pulse Duration	1.024 ms	Sample Interval	0.192 m
Power	2000 W	Receiver Bandwidth	2.43 kHz

Sounder Type:
ER60 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.	9.0 dB/km	Sound Velocity	1502.4 m/s

Beam Model results:

Transducer Gain =	25.72 dB	SaCorrection =	-0.62 dB
Athw. Beam Angle =	6.99 deg	Along. Beam Angle	6.95 deg
Athw. Offset Angle =	-0.04 deg	Along. Offset Angl	-0.05 deg

Data deviation from beam model:
RMS = 0.12 dB
Max = 0.29 dB No. = 83 Athw. = -2.9 deg Along = -2.3 deg
Min = -0.59 dB No. = 156 Athw. = 2.5 deg Along = -4.1 deg

Data deviation from polynomial model:
RMS = 0.08 dB
Max = 0.44 dB No. = 169 Athw. = 3.9 deg Along = -3.1 deg
Min = -0.34 dB No. = 156 Athw. = 2.5 deg Along = -4.1 deg

Comments :
Flat calm conditions
Wind Force : 12 kn. **Wind Direction :** NE
Raw Data File: C:\Program files\Simrad\Scientific\EK60\Data\Calibration\WESPAS 2016\Drop Keel
Calibration File: C:\Program files\Simrad\Scientific\EK60\Data\Calibration\WESPAS 2016\Drop Keel

Calibration : Ciaran O'Donnell

Table 2. Catch table from directed trawl hauls.

No.	Date	Lat. N	Lon. W	Time	Bottom (m)	Target btm (m)	Bulk Catch (Kg)	Boarfish %	Mackerel %	Herring %	H Mack %	Others^ %
1	18.06.16	56.70	-6.39	12:03	75	25	8		9.0			91.0
2	19.06.16	58.21	-5.40	09:44	124	20	104					
3	19.06.16	58.51	-5.99	14:58	55	0-46	1					100.0
4*	19.06.16	58.55	-7.03	23:10	86	0-35	165					100.0
5	20.06.16	58.30	-7.96	13:51	108	0-30	1,200		8.0	92.0		
6	21.06.16	58.06	-8.73	08:51	142	0-10	1,500		3.0	97.0		
7	22.06.16	57.54	-8.43	07:10	155	0-8	2,000		10.0	89.0		1.0
8*	22.06.16	57.30	-9.20	15:24	145	15-35	3,000	4.0	25.0	70.0		1.0
9*	23.06.16	57.05	-9.15	10:27	182	15-65	1,000	95.0	5.0			
10	24.06.16	56.55	-7.30	11:44	126	20-45	1,500	100.0				
11	24.06.16	56.43	-8.78	21:42	141	0-4	3		100.0			
12*	25.06.16	56.30	-8.10	11:32	173	0-5	3,000					100.0
13	25.06.16	56.18	-8.23	22:28	133	0-15	5		100.0			
14	26.06.16	55.93	-7.45	15:18	122	13-25	150	100.0				
15*	27.06.16	55.68	-8.41	08:19	96	30-45	750	97.0			3.0	
16	27.06.16	55.68	-8.02	11:03	88	0-7	0					
17*	28.06.16	55.19	-9.88	14:46	140	15-40	1,200	98.0			1.0	1.0
18	29.06.16	55.19	-8.28	00:00	45	13-35	89		91.0		1.0	8.0
19	05.07.16	54.44	-9.97	15:38	90	0-15	41		16.0		1.0	83.0
20	05.07.16	54.20	-10.68	22:29	180	0-30	700		3.4		96.5	0.1
21	06.07.16	53.70	-10.85	12:59	148	63-83	600	87.8			11.8	0.4
22	07.07.16	53.70	-13.68	14:05	280	4-12	2					100.0
23	08.07.16	53.20	-13.40	08:59	216	0-5	3					100.0
24	08.07.16	53.19	-14.01	13:57	170	95-105	2	3.1				96.9
25	08.07.16	53.20	-14.18	16:15	170	100-110	7					100.0
26	13.07.16	53.21	-10.69	11:29	120	0-20	150		61.4		1.2	37.4
27	13.07.16	53.21	-11.01	15:00	130	5-20	171	0.03	10.0	0.6	1.5	87.9
28	14.07.16	52.96	-11.05	09:21	132	0-8	5					100.0
29	15.07.16	52.71	-11.78	08:37	160	5-10	0.281	42.0				58.0
30	17.07.16	51.21	-10.21	20:36	128	15-25	15	0.1				99.9
31	18.07.16	50.96	-11.08	10:42	176	0-8	180	100.0				
32	18.07.16	50.96	-9.84	17:29	124	13-30	0					
33*	18.07.16	50.96	-9.55	20:02	116	15-35	130	96.1			3.6	0.3
34	19.07.16	50.72	-10.98	22:41	194	180	0					
35	20.07.16	50.46	-8.13	15:37	121	15	83		5.7		5.3	89.0
36	21.07.16	49.96	-10.38	17:30	127	0-18	3		0.3		0.4	99.3
37	22.07.16	49.86	-7.97	09:49	77	0-15	1,000	93.3	0.4		6.3	
38	22.07.16	49.72	-8.82	15:18	100	0-9	4					100.0
39	23.07.16	49.47	-10.82	15:50	160	60	6		69.9			30.1
40	23.07.16	49.47	-10.40	13:08	130	0-15	131	91.3				8.7
41	23.07.16	49.47	-8.77	21:52	147	0-75	36					100.0
42	24.07.16	49.22	-10.53	16:34	149	0-10	27					100.0
43	25.07.16	49.97	-9.77	06:42	112	0-10	255	79.4			0.0	20.5
44	25.07.16	48.96	-8.19	15:49	150	0-15	1,000	97.3				2.7
45	26.07.16	48.46	-9.37	14:25	146	0-15	149	97.7				
46	26.07.16	48.46	-7.72	22:21	171	0-35	110	0.2			50.5	49.3
47	27.07.16	48.22	-8.45	17:19	185	0-10	1,200	100.0				

* Trawl camera
^ Including pelagic, demersal fish and invertebrate

Table 3. Malin Shelf herring stock estimate (VIaN- partial, VIaS, VIIb).

Length (cm)	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12+	Numbers (*10-3)	Biomass ('000 t)	Mn Wt (g)	Mature (%)
11.5																0
12																0
12.5																0
13																0
13.5																0
14																0
14.5																0
15																0
15.5																0
16																0
16.5																0
17																0
17.5																0
18																0
18.5																0
19																0
19.5																0
20																0
20.5																0
21																0
21.5		526											526	55.2	105	100
22		769											769	78.6	102	92
22.5		261	1410										1672	173.2	104	84
23		441	4920										5361	567.9	106	100
23.5		3846	10593										14438	1741.2	121	100
24			12430										12430	1498.4	121	100
24.5			12985										12985	1653.4	127	100
25			8234	2061									10294	1428.5	139	100
25.5			5618	5531									11149	1674.4	150	100
26			1567	11733									13300	2059.3	155	100
26.5			3131	12489	1696	777							18094	3099.8	171	100
27			121	12398	8496	1468							22483	4071.1	181	100
27.5			2575	13661	8766	6117	1334						32453	6018.2	185	100
28				6813	24081	13543	9313						53749	10675.4	199	100
28.5				2582	29093	14297	11559						57531	11842.9	206	100
29				529	16887	16337	10869	2166					46789	9855.8	211	100
29.5				410	4127	11811	11616	546					28511	6127.9	215	100
30					2457	4885	6798	540	405				15084	3397.7	225	100
30.5					1266		1876						3142	712.3	227	100
31						731			84				815	200.2	246	100
31.5							235						235	59.9	255	100
TSN (1000)		5843.0	63584.0	68207.0	96869.0	69966.0	53600.0	3252.0	489.0				361810.0			
TSB (t)		662.1	8265.3	11860.5	19640.2	14532.5	11239.5	677.0	114.2					66991.4		
Mean length (cm)		23.0	24.5	26.8	28.3	28.7	29.0	29.3	30.2							
Mean weight (g)		113.3	130.0	173.9	202.8	207.7	209.7	208.2	233.7						185.1	
% mature*		98	100	100	100	100	100	100	100							
SSB (t)		650.3	8236.5	11860.5	19640.2	14532.5	11239.5	677.0	114.2					66950.7		
SSN (1000)		5739.0	63362.6	68207.0	96869.0	69966.0	53600.0	3252.0	489.0				361484.6			

Table 4. Malin Shelf herring survey time series 2008-2016. Survey coverage: ^: VIaS & VIIb, * : VIaS, VIaN & VIIb, **: Via & VIIb

Winter rings	2008^	2009^	2010*	2011*	2012*	2013*	2014*	2015**	2016*
0	-	-	-	-	-	-	-	-	-
1	6.1	416.4	524.8	82.1	608.3	-	1115.4	4.93	-
2	75.9	81.3	504.3	202.5	451.5	96.2	214.7	162.05	58.43
3	64.7	11.4	133.3	752	444.6	254.3	166.3	291.68	635.84
4	38.4	15.1	107.4	381	516.1	265.8	380	580.67	682.07
5	22.3	7.7	103	110.8	180.3	78.7	352.1	487.25	968.69
6	26.2	7.1	83.7	124	115.4	26.9	125	513.42	699.66
7	9.1	7.5	57.6	118.4	116.9	18.5	18.9	143.85	536
8	5	0.4	35.3	70.7	83.8	10.8	9.7	33.37	32.52
9	3.7	0.9	17.5	41.6	56.3	4.1	4.7	0	4.89
10+	-	-	-	25.6	42	1.2	0	8.32	-
TSN (mil)	251.4	547.7	1,566.90	1,908.70	2,615.00	756.6	2,386.80	2,225.5	3,618.10
TSB (t)	44,611	46,460	192,979	313,305	397,797	118,946	294,200	449,343	66,991
SSB (t)	43,006	20,906	170,154	284,632	325,835	92,700	200,200	425,392	66,951
CV	34.2	32.2	24.7	22.4	22.8	21.5	28.6	28.6	31.3

Table 5. Herring biomass and abundance by strata

Strata	Name	Area (nmi²)	Transects	Abun ('000)	Bio (t)
1	Minches	2,897.3	11	0	0.0
2	W Hebrides	6,133.6	7	283,064	52,654.9
3	SW Hebrides	4,754.7	7	78,746	14,336.5
4	NW Coast	2,150.9	2	0	0.0
5	W Coast	4,647.3	6	0	0.0
6	N Malin	2,888.0	2	0	0.0
	Total	23,471.8	35	361,810	66,991.4

Table 6. Total boarfish stock estimate.

Length (cm)	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Numbers (000's)	Biomass (t)	Mn Wt (g)	Mature (%)
7		10.5														1330	10.5	8	0
7.5	41.1	29.4														7483	70.5	9	0
8		228														20669	228	11	0
8.5		134.4	41.6													13797	176	13	0
9			61													3566	61	17	0
9.5			221.4											5.9		11656	227.3	20	82
10			500.6	74.6											56.2	29061	631.5	22	100
10.5			134.8	856.3	77.7											42161	1068.8	25	100
11				161												6046	161	27	100
11.5					92.2	29.2	24.2									4408	145.6	33	100
12						337.1	157		29.6							14209	523.8	37	100
12.5							1991	734								64729	2725	42	100
13							1708.8	1765.3	1128.4							99447	4602.4	46	100
13.5							3578	1028.1	742							102620	5348.1	52	100
14							581.1	2119.4	3861.5	1697	269	417			166.6	157601	9111.6	58	100
14.5									576.5	3603.1	58.5	381	142.5	275.7	7087.3	179565	12124.5	68	100
15								65.6	194	476.4	461.9	1090.9	3211.8	788.3	6601.6	173850	12890.5	74	100
15.5										109.2	157.3	214.7	153.7	183.1	7931.5	109912	8749.7	80	100
16										264.1		50.7	51.7		4966.6	60303	5333.1	88	100
16.5															3331.3	34867	3331.3	96	100
17											362.1				1133.2	14139	1495.3	106	100
17.5															369.1	3334	369.1	111	100
18															261.1	2071	261.1	126	100
18.5															44.4	342	44.4	130	100
19																			
19.5																			
TSN (1000)	4580	35746	45460	43588	5962	10042	169001	112599	117624	96608	16960	31951	48688	18280	400074	1157163			
TSB (t)	41.1	402.3	959.3	1091.9	169.8	366.4	8040	5712.4	6532.1	6149.9	1308.8	2154.3	3559.7	1253.1	31949		69690		
Mean length (cm)	7.5	8.07	9.75	10.53	10.96	11.96	13.09	13.36	13.78	14.44	15.14	14.75	15.01	14.86	15.32				
Mean weight (g)	8.97	11.26	21.1	25.05	28.49	36.48	47.57	50.73	55.53	63.66	77.17	67.42	73.11	68.55	79.86				
% mature*	0	0	85	100	100	100	100	100	100	100	100	100	100	100	100				
SSB	0.0	0.0	816.9	1091.9	169.9	366.3	8040.1	5712.4	6532.0	6149.8	1308.8	2154.3	3559.7	1251.9	######	69103.0			

Table 7. Boarfish biomass and abundance by strata.

Strata	Name	Area (nmi²)	Transects	Abun ('000)	Bio (t)
1	W Hebrides	2,287.1	5	8.8	526.4
2	S Hebrides	1,860.7	7	100.3	6,444.1
3	W Coast	15,211.3	20	283.4	19,540.4
4	Porcupine Bk	5,977.2	6	155.5	10,743.4
5	Celtic Sea	25,067.7	16	567.1	31,953.7
6	N Stanton	1,394.4	4	42.0	482.1
7	S Stanton	894.8	2	0	0
	Total	52,693.3	60	1,157	69,690.1

Table 8. Boarfish survey time series. Note: 2016 CV estimate calculated using StoX.

Age (Yrs)	2011	2012	2013	2014	2015	2016
0	-	-	-	-	-	-
1	5.0	21.5	-	-	198.5	4.6
2	11.6	10.8	78.0	-	319.2	35.7
3	57.8	174.1	1,842.9	15.0	16.6	45.5
4	187.4	64.8	696.4	98.2	34.3	43.6
5	436.7	95.0	381.6	102.3	80.0	6.0
6	1,165.9	736.1	253.8	104.9	112.0	10.0
7	1,184.2	973.8	1,056.6	414.6	437.4	169.0
8	703.6	758.9	879.4	343.8	362.9	112.6
9	1,094.5	848.6	800.9	341.9	353.5	117.6
10	1,031.5	955.9	703.8	332.3	360.0	96.6
11	332.9	650.9	263.7	129.9	131.7	17.0
12	653.3	1,099.7	202.9	104.9	113.0	32.0
13	336.0	857.2	296.6	166.4	174.0	48.7
14	385.0	655.8	169.8	88.5	108.0	18.3
15+	3,519.0	6,353.7	1,464.3	855.1	1,195.0	400.1
TSN ('000)	11,104	14,257	9,091	3,098	3,996	1,157
TSB (t)	670,176	863,446	439,890	187,779	232,634	69,690
SSB (t)	669,392	861,544	423,158	187,654	226,659	69,103
CV	21.2	10.6	17.5	15.1	17.0	16.4

Table 9. Horse mackerel stock estimate.

Length	Age (years)																					Numbers	Biomass	Mn Wt	Mature
(cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	(000's)	(t)	(g)	(%)
13	4.2	17.6																				921	21.7	24	0
14	23.1	107.6																				5042	130.7	26	0
15		404.3																				11957	404.3	34	0
16		1130.2																				28147	1130.2	40	7
17		1260.6																				26075	1260.6	48	10
18		806.2																				14157	806.2	57	7
19		513.5																				7578	513.5	68	0
20		86.1																				1136	86.1	76	20
21		394.5																				4409	394.5	89	100
22		183.7																				1834	183.7	100	100
23			271.8																			2384	271.8	114	100
24			35.4	196.3																		1874	231.7	124	100
25			145.1	11.9																		1119	157	140	100
26				437.4	2475.2																	18670	2912.6	156	100
27				2104.3	438.6																	14612	2542.8	174	100
28			248.3	5815.2		1287.9																35045	7351.5	210	100
29						280.8	1685.5															8897	1966.3	221	100
30								12510														52586	12509.7	238	100
31							753	2963.7	1007.2				606.7	420								22481	5750.7	256	100
32							3698.1	223.5		221	2454.3		525.2		1106.7							27996	8228.7	294	100
33							5598.9	133.3			157.8	991.3	134.5	4221.5	604.4	347.8						39618	12189.6	308	100
34							226.4	378.3				2376.2		114.9							263.7	9976	3359.5	337	100
35									1625.5	324				1234.6	140.4							9370	3324.6	355	100
36														78.6			2056.3					5554	2134.9	384	100
37														589								1379	589	427	100
38																					247.9	552	247.9	450	100
39														280.3								552	280.3	508	100
40														131.6								276	131.6	477	100
41																									
42																155.5						276	155.5	564	100
TSN (1000)	1075	100180	4928	43487	19047	7551	40597	66638	8517	1776	9499	10563	4655	21144	6484	1645	5348				1339	354472			
TSB (t)	27.2	4904.2	700.6	8565	2913.8	1568.7	11962	16208	2632.7	545	2612.2	3367.5	1266.5	7070.5	1851.5	503.4	2056.3				511.7		69267.1		
Mean length (cm)	13.82	16.92	24.71	27.45	26.17	28.17	31.84	30.29	33.21	33.6	32.06	33.66	31.61	33.69	32.56	34.51	36				35.65				
Mean weight (g)	25.3	49.0	142.2	197.0	153.0	207.8	294.7	243.2	309.1	306.9	275.0	318.8	272.1	334.4	285.6	306.0	384.5				382.19			195.41	
% mature*	0	18	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100				100				
SSB	0.0	858.6	700.6	8565.1	2913.8	1568.7	11961.9	16208.5	2632.7	545.0	2612.1	3367.5	1266.4	7070.5	1851.5	503.3	2056.3				511.6	65194.1			

Table 10. Horse mackerel biomass and abundance by strata.

Strata	Name	Area (nmi²)	Transects	Abun ('000)	Bio (t)
1	W Hebrides	2,287.1	5	0	0
2	S Hebrides	1,860.7	7	0	0
3	W Coast	15,211.3	20	255.9	50,360.7
4	Porcupine Bk	5,977.2	6	47.4	8,253.1
5	Celtic Sea	25,067.7	16	51.2	10,653.3
6	N Stanton	1,394.4	4	0	0
7	S Stanton	894.8	2	0 0	0
	Total	52,693.3	60	354.5	69,267.1

Table 11. Marine mammal sightings, counts and group size ranges for cetaceans sighted during the survey.

Species	No. Sightings	No. Individuals	Range of Group Size
Fin Whale	4	5	1 to 2
Humpback Whale	2	2	
Minke Whale	29	31	1 to 2
UnID Whale	2	2	
UnID Large Baleen Whale	5	6	1 to 2
Harbour Porpoise	4	7	1 to 2
Striped Dolphin	2	11	1 to 10
Common Dolphin	162	1290	1 to 100
White-beaked Dolphin	14	95	1 to 20
Bottlenose Dolphin	7	93	1 to 40
Risso's Dolphin	2	7	1 to 6
Pilot Whale	15	95	1 to 15
Killer Whale	1	1	
UnID Dolphin	18	59	1 to 15
Sowerby's Beaked Whale	1	3	
UnID Beaked Whale	1	1	
UnID Cetacean	4	7	1 to 4
Grey Seal	6	7	1 to 2
Basking Shark	6	8	1 to 3

Table 12. Totals for all seabird species recorded between 5th and 29th July 2016.

Vernacular Name	Scientific Name	On Survey	Off Survey	Total
Fulmar	*Fulmarus glacialis*	1216	792	2008
Cory's Shearwater	*Calonectris diomedea*	282	306	588
Great Shearwater	*Puffinus gravis*	70	45	115
Sooty Shearwater	*Puffinus griseus*	15	43	58
Manx Shearwater	*Puffinus puffinus*	1111	826	1937
Macaronesian Shearwater	*Puffinus baroli*	0	1	1
Wilson's Storm-petrel	*Oceanites oceanicus*	9	4	13
European Storm-petrel	*Hydrobates pelagicus*	957	921	1878
Leach's Storm-petrel	*Oceanodroma leucorhoa*	3	0	3
Gannet	*Morus bassanus*	2345	941	3286
Shag	*Phalacrocorax aristotelis*	0	1	1
Grey Phalarope	*Phalaropus fulicarius*	17	0	17
Pomarine Skua	*Stercorarius pomarinus*	2	3	5
Arctic Skua	*Stercorarius parasiticus*	1	1	2
Long-tailed Skua	*Stercorarius longicaudus*	3	3	6
Great Skua	*Stercorarius skua*	16	22	38
Puffin	*Fratercula arctica*	194	105	299
Razorbill	*Alca torda*	12	0	12
Guillemot	*Uria aalge*	47	10	57
Common Tern	*Sterna hirundo*	1	0	1
Arctic Tern	*Sterna paradisaea*	16	9	25
Kittiwake	*Rissa tridactyla*	50	170	220
Lesser Black-backed Gull	*Larus fuscus*	14	246	260
Herring Gull	*Larus argentatus*	0	6	6
Yellow-legged Gull	*Larus michahellis*	0	1	1
Great Black-backed Gull	*Larus marinus*	6	77	83
Total		6387	4533	10920

Table 13. Totals of migrant terrestrial bird species recorded between 5th and 29th July 2016.

Vernacular Name	Scientific Name	Total
Whimbrel	*Numenius phaeopus*	1
Turnstone	*Arenaria interpres*	1
Dunlin	*Calidris alpina*	17
Racing Pigeon	*Columba livia* domest.	1
Swift	*Apus apus*	1
Total		21

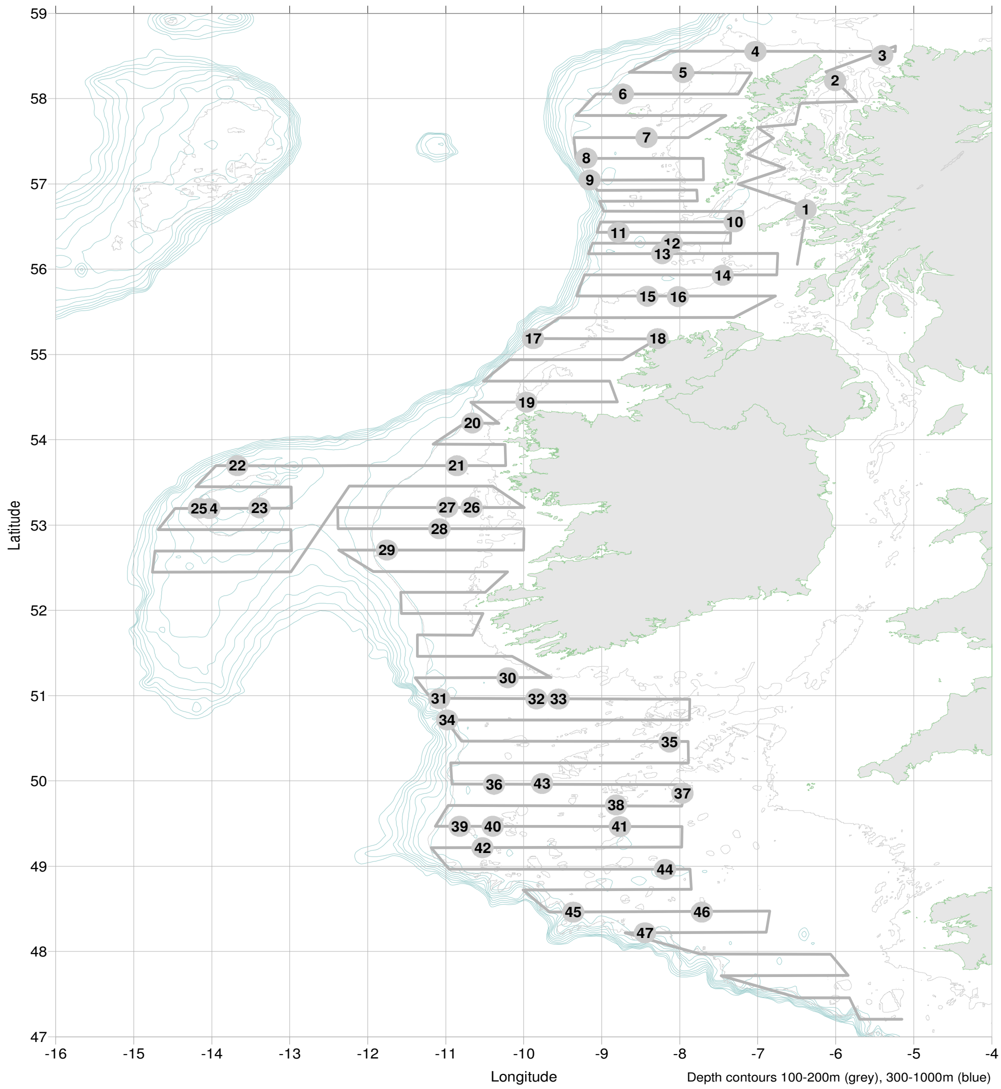


Figure 1. Survey cruise track (grey line) and numbered directed pelagic trawl stations. Corresponding catch details are provided in Table 2.

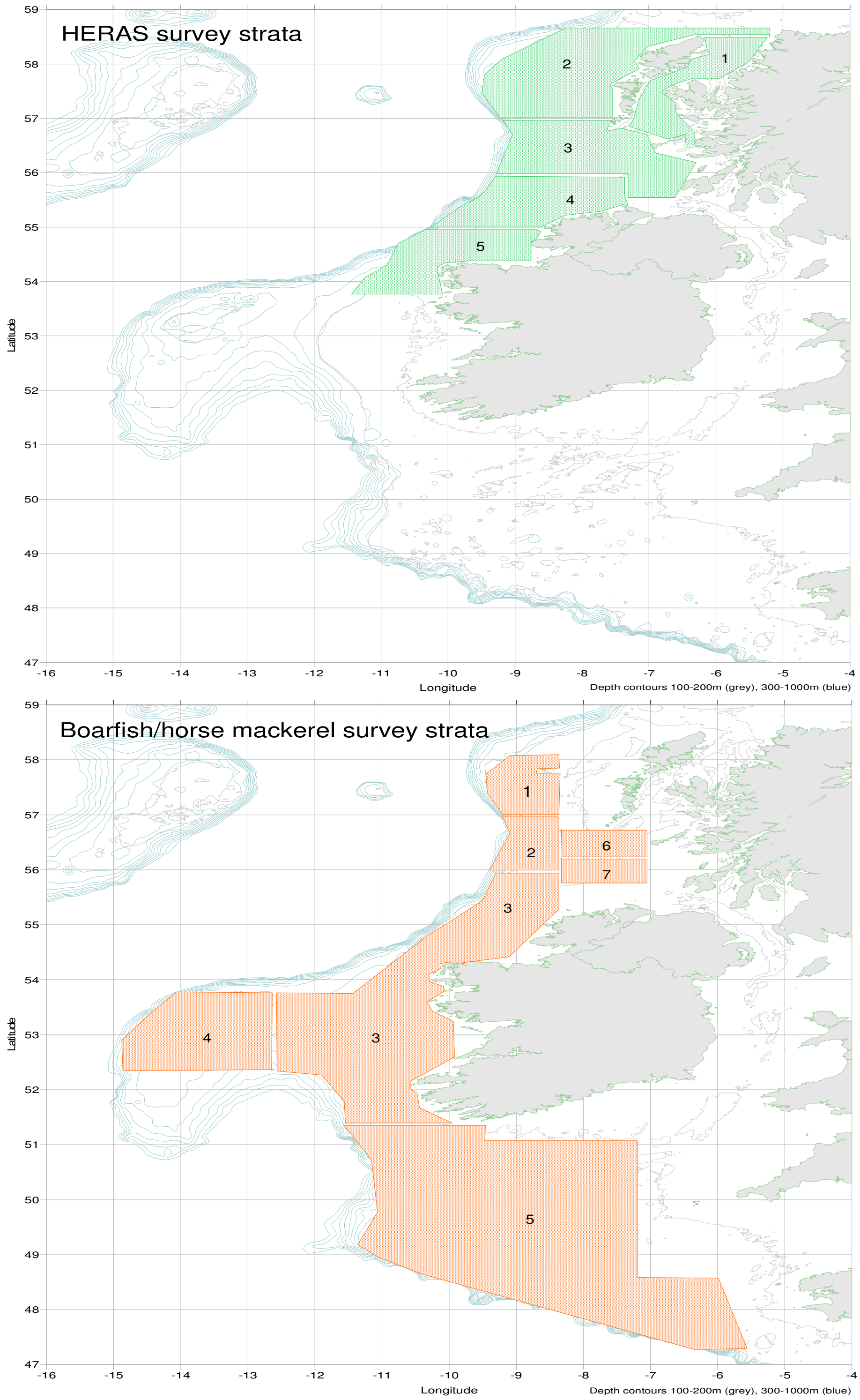


Figure 2. Acoustic sampling area stratification as applied during the calculation of species specific acoustic abundance.

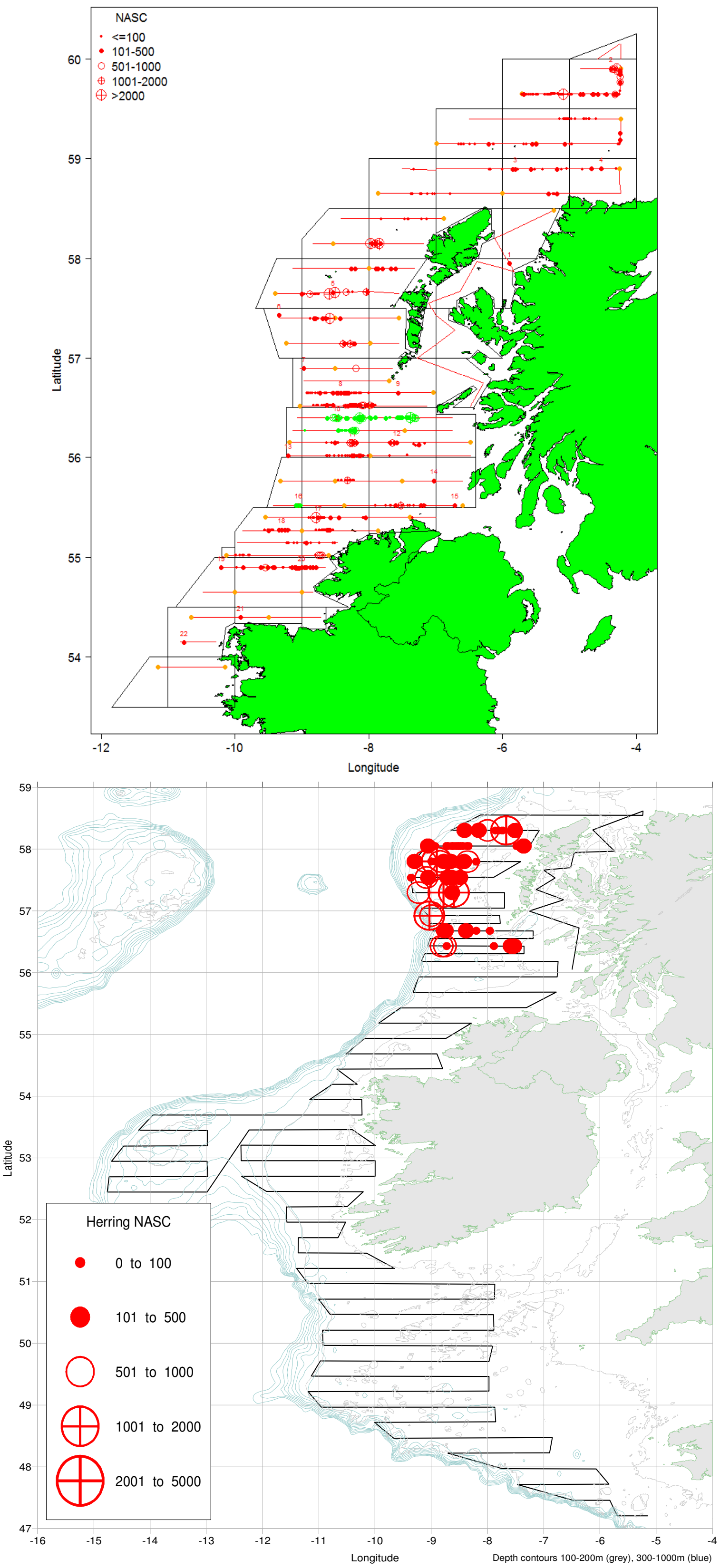


Figure 3. Malin Shelf herring distribution by NASC (Nautical area scattering coefficient). Top panel 2015, bottom panel 2016.

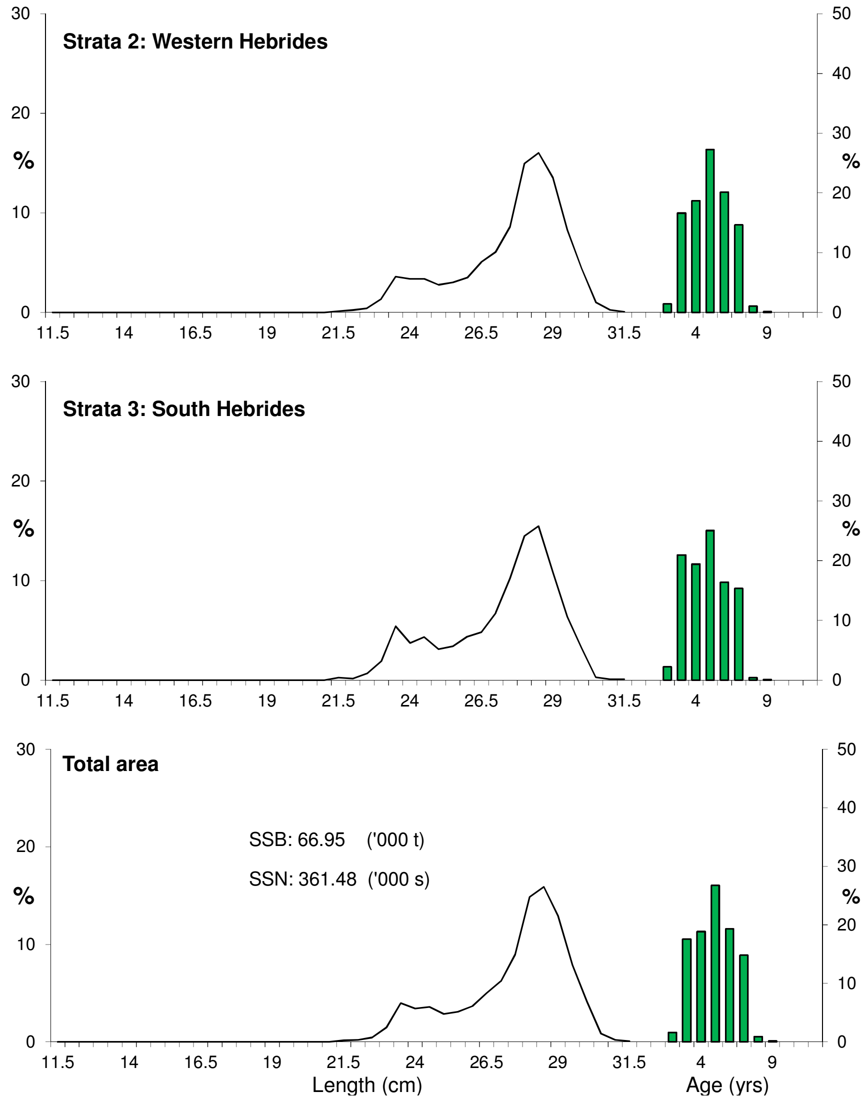


Figure 4. Length and age distribution of Malin Shelf herring by stratum and total survey area.

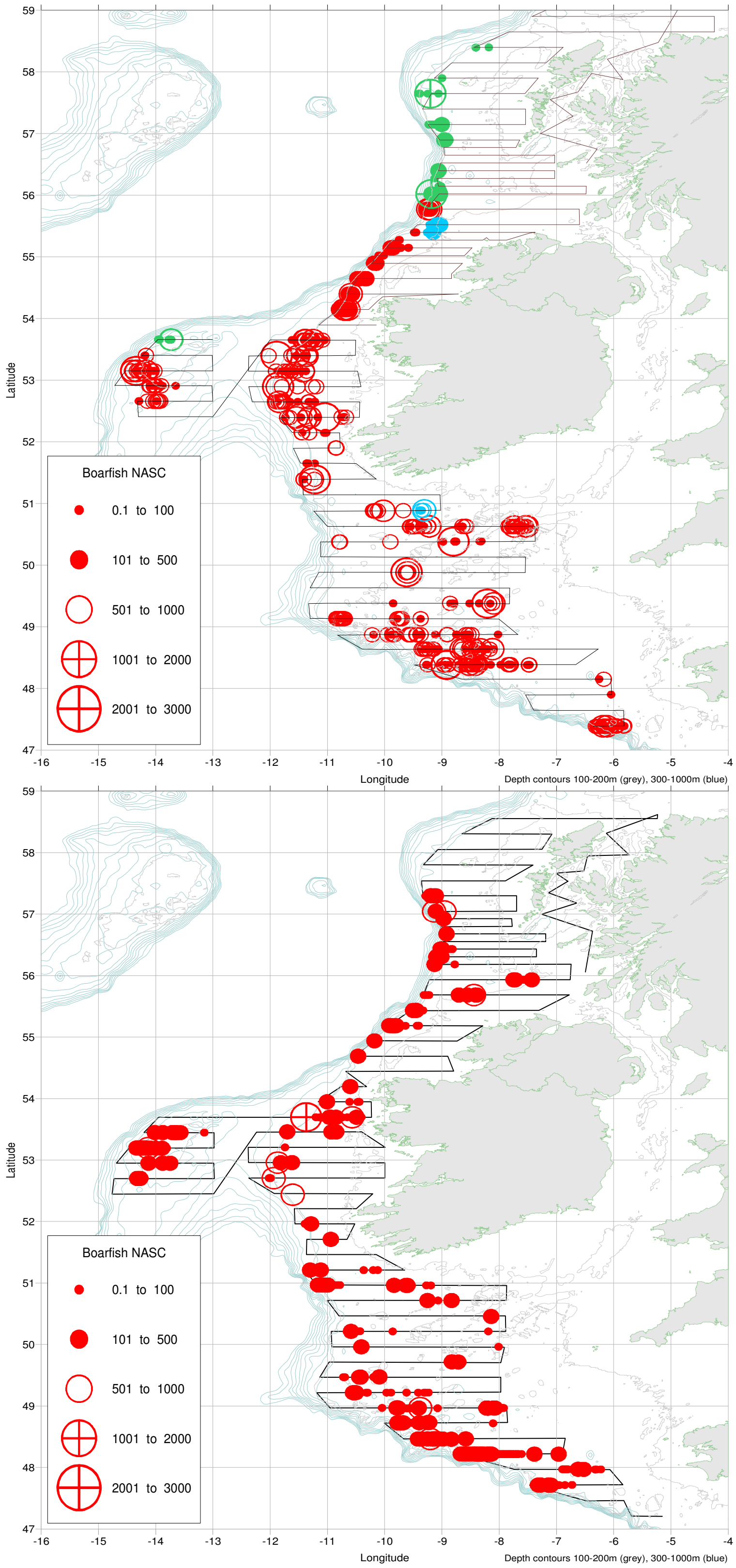


Figure 5. Boarfish distribution by NASC (Nautical area scattering coefficient). Top panel 2015 (Categories: red; def, green; prob and blue mix spp), bottom panel 2016.

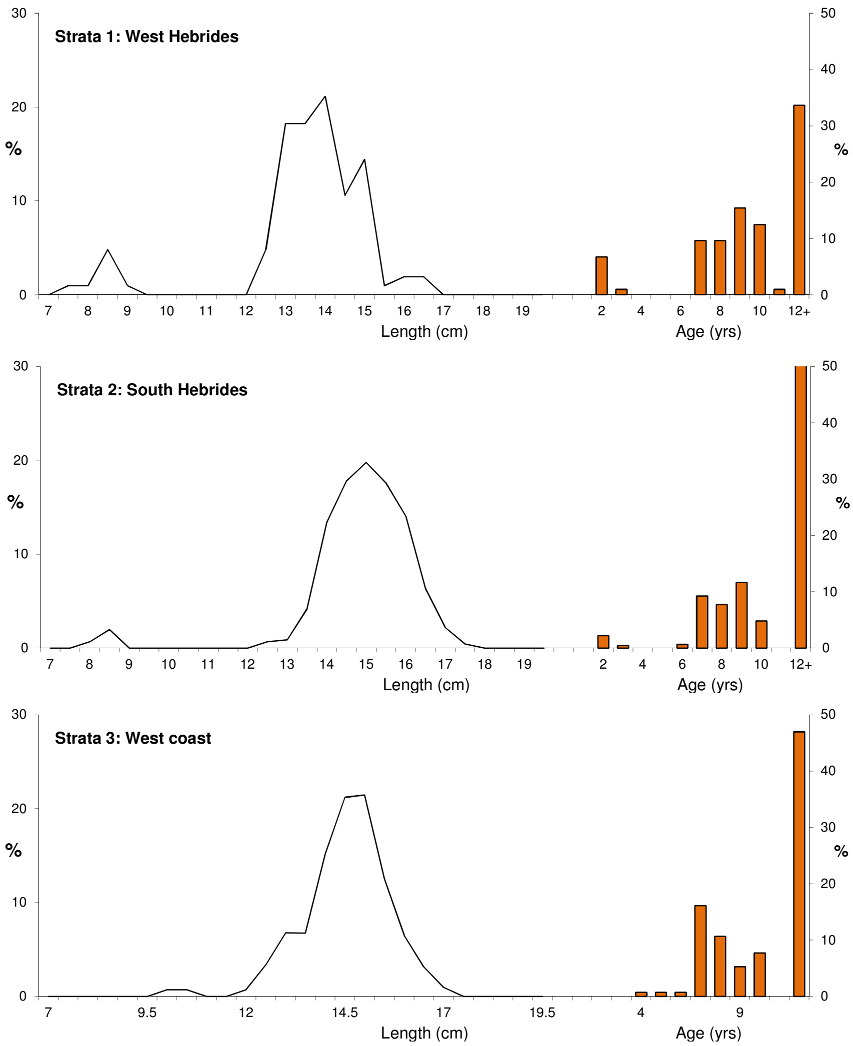


Figure 6. Length and age distribution of boarfish by stratum and total survey area.

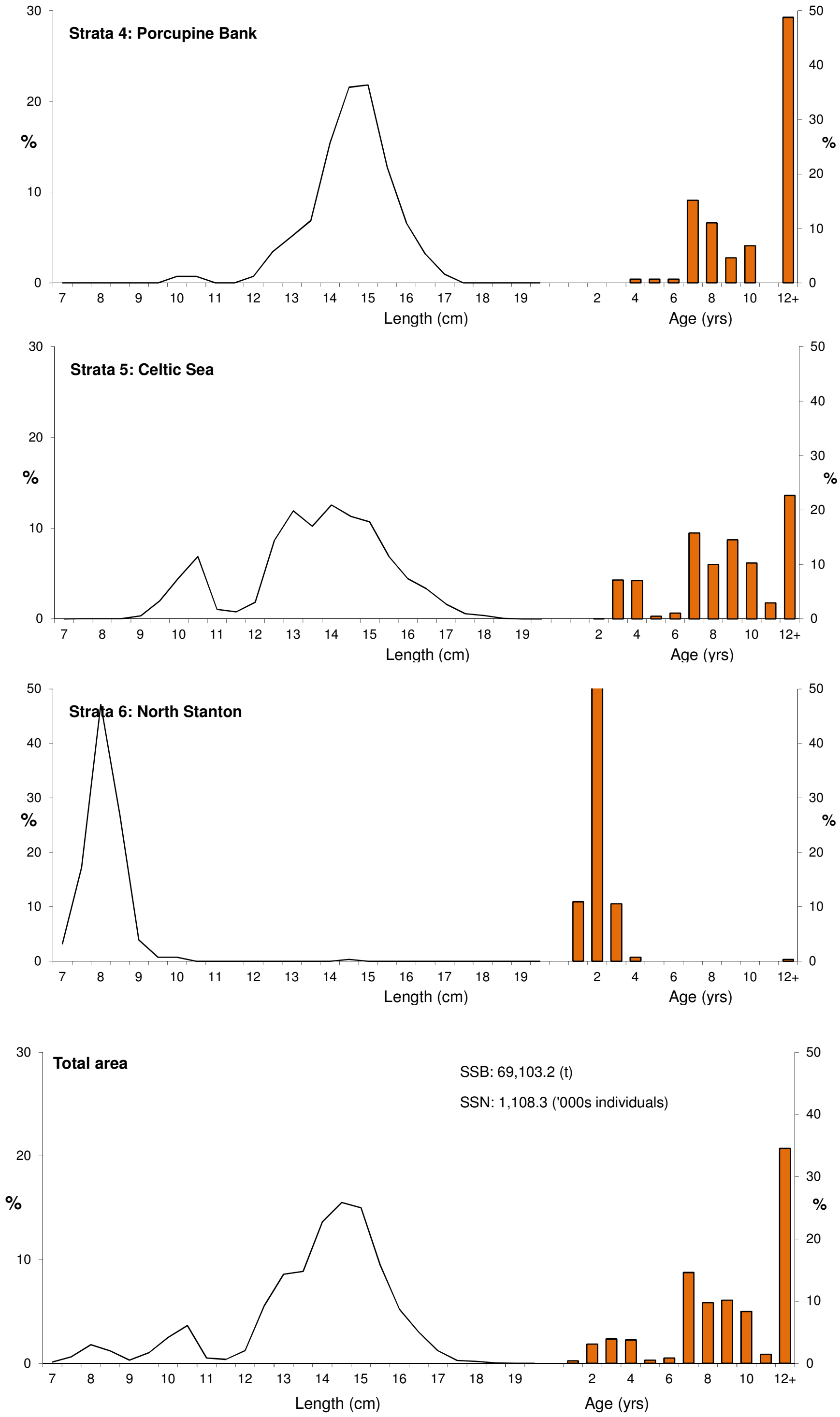


Figure 6. cont.

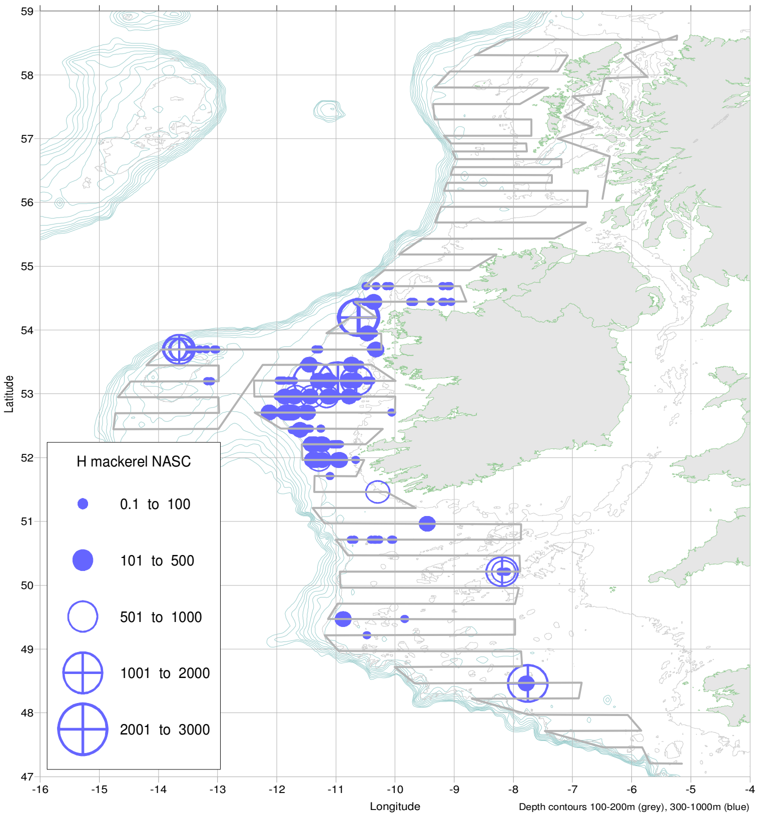


Figure 7. Horse mackerel distribution by NASC (Nautical area scattering coefficient).

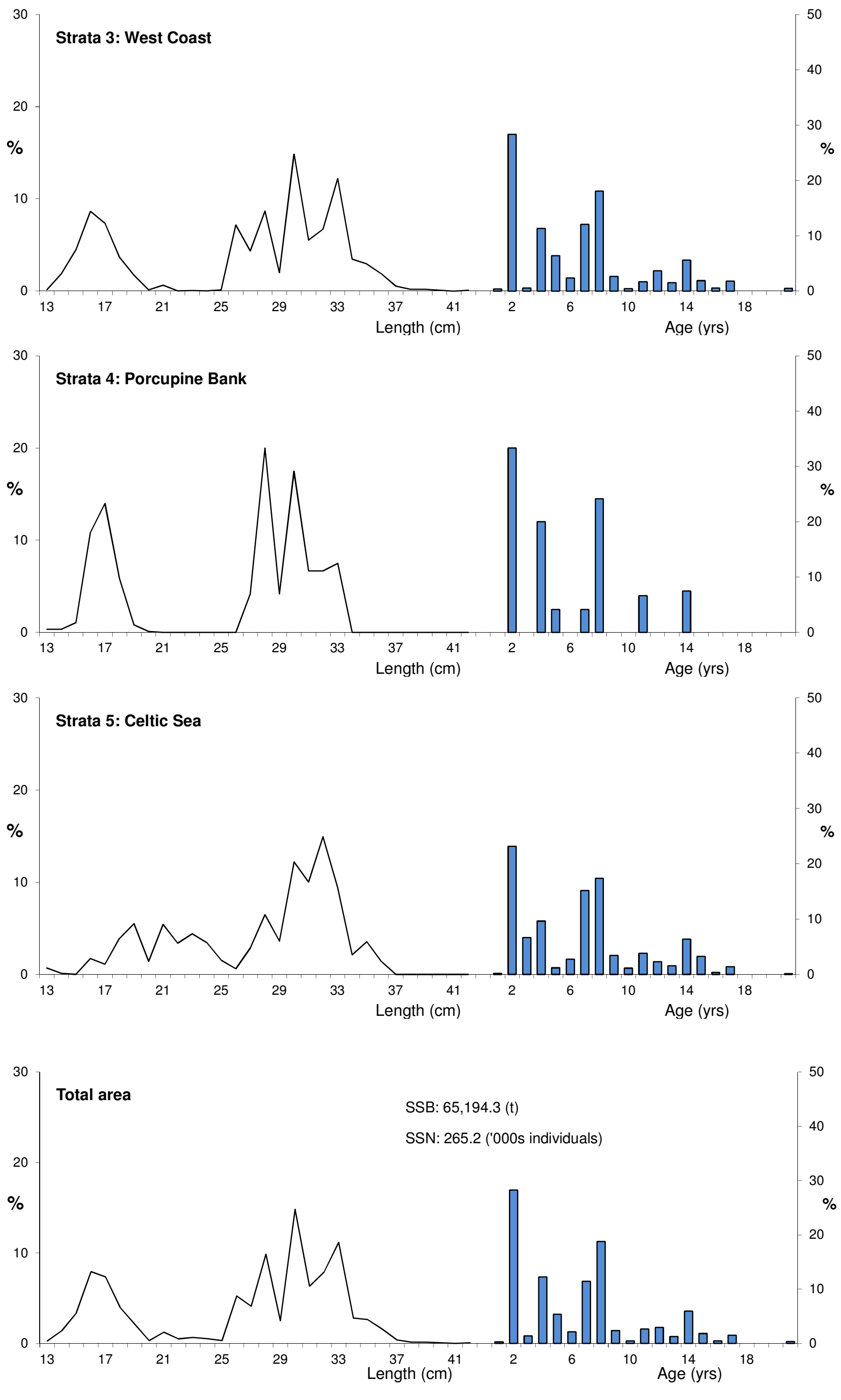
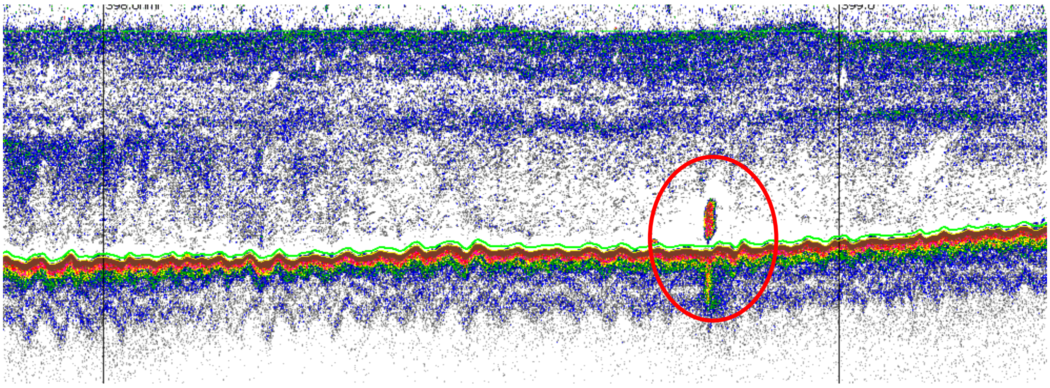
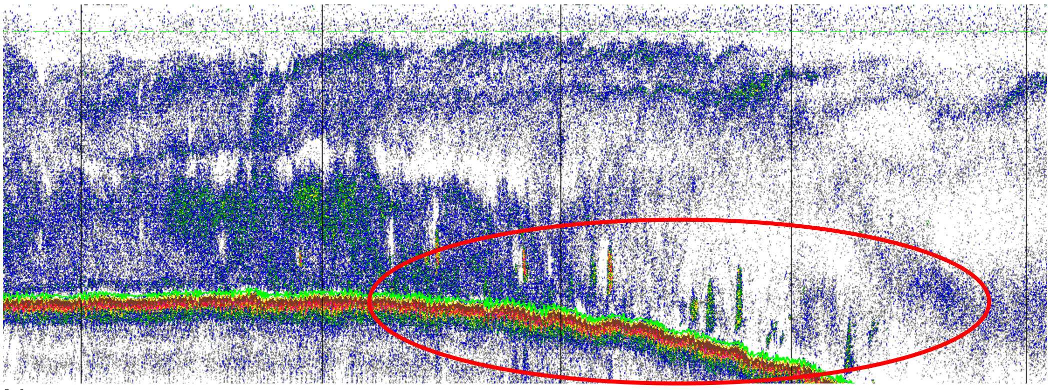


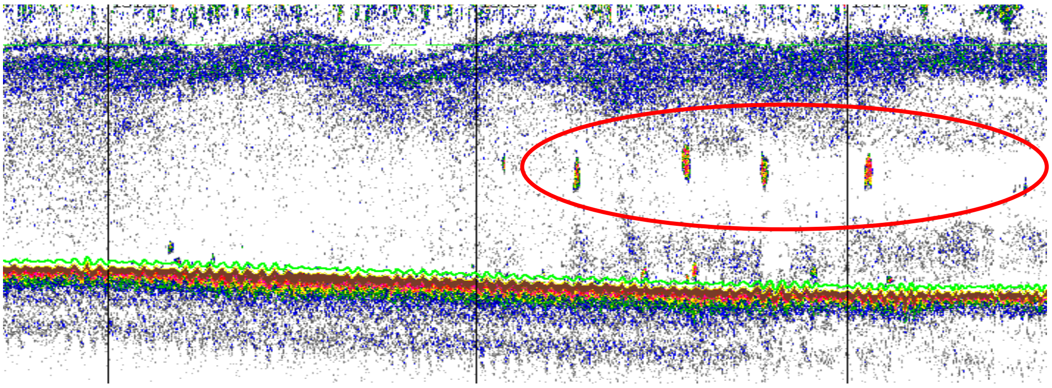
Figure 8. Length and age distribution of horse mackerel by stratum and total survey area.



a). *Haul 05, West of the Hebrides. A typical herring school encountered in this area. Water depth 108 m.*

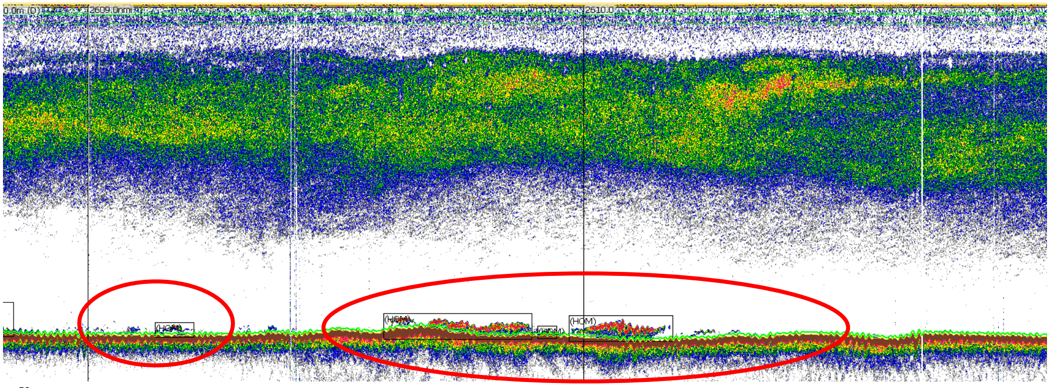


b). *Haul 09, Shelf slope. Medium density boarfish schools along the shelf slope, water depth 180 m.*

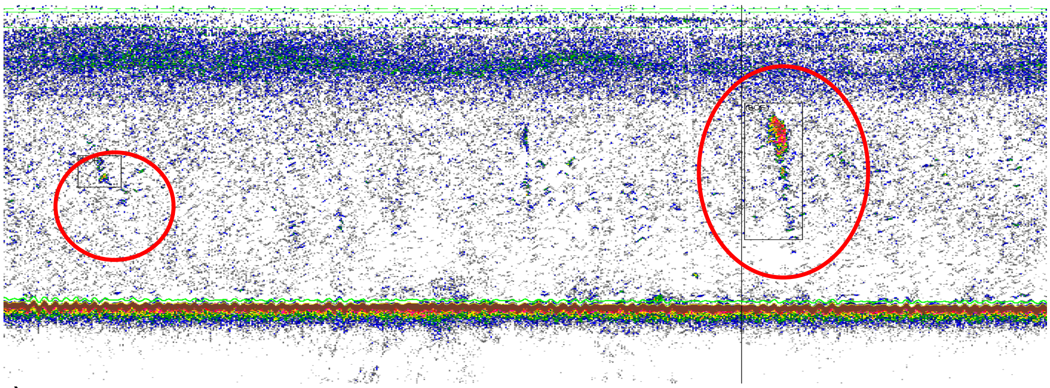


c). *Haul 15. Stanton Bank area. Near surface schools of juvenile boarfish, water depth 96 m.*

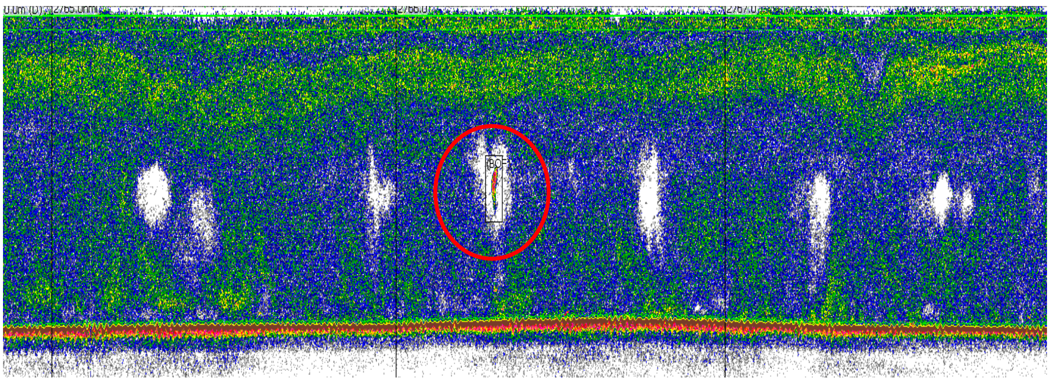
Figures 9a-l. Echotraces recorded on an EK60 echosounder (38 kHz) with images captured from Echoview. Note: Vertical bands on echogram represent 1nmi (nautical mile) intervals.



d). *Haul 22. Typical horse mackerel schools observed over hard substrate, water depth 180 m.*

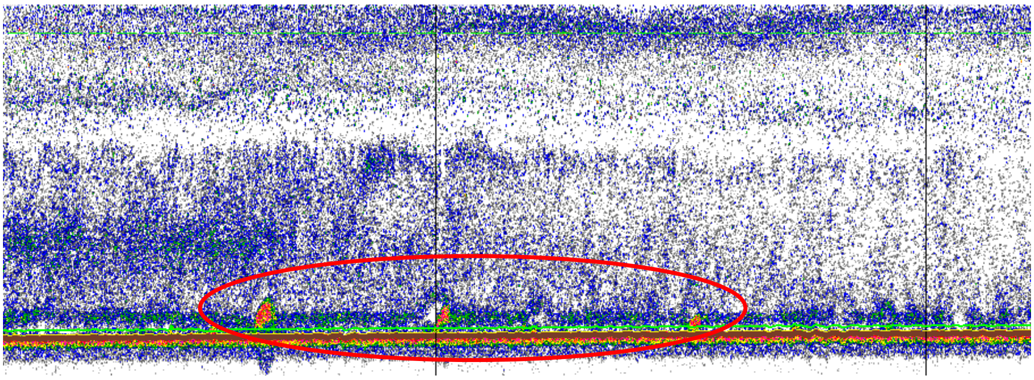


e). *Haul 21. Midwater boarfish schools, water depth 148 m.*

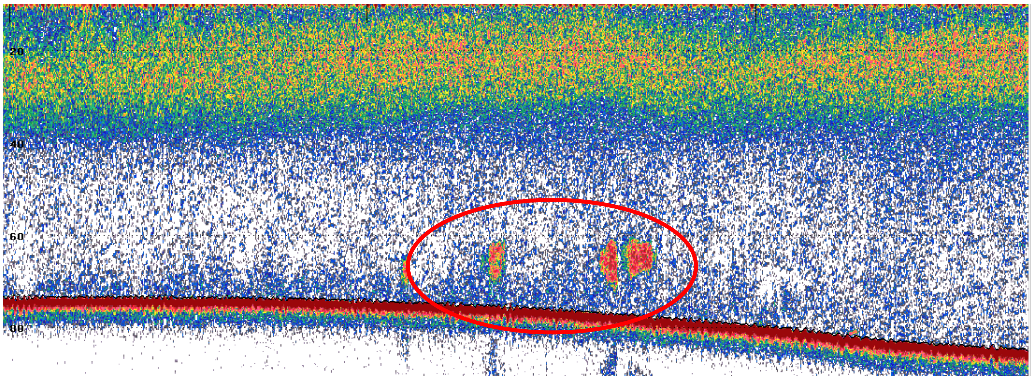


f). *Haul 24. Porcupine Bank boarfish midwater schools, water depth 170 m.*

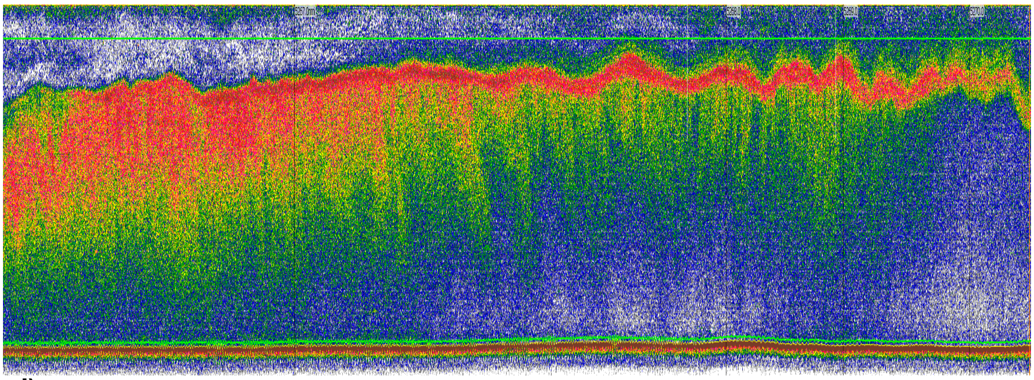
Figures 9a-k. cont



g). *Haul 31. Southwest coast boarfish bottom schools, water depth 176 m.*

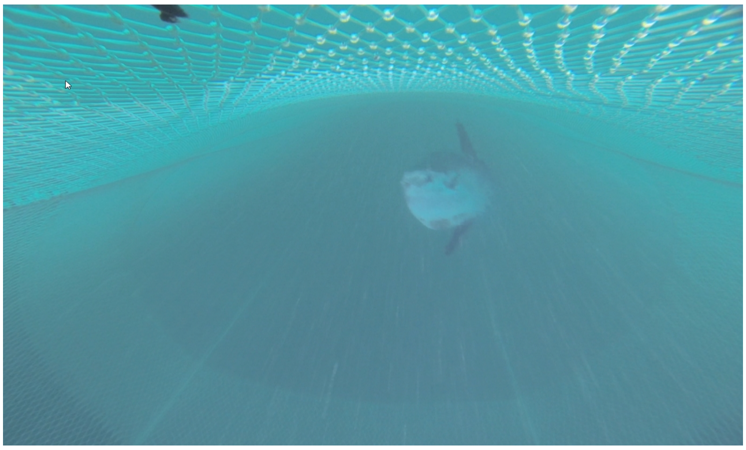


h). *Haul 37. Eastern Celtic Sea, Jones' Bank. Boarfish, water depth 77 m.*



j). *Haul 41. Mid Celtic Sea. High density echotrace recorded over 57 nmi composed primarily of salps. Water depth 147 m.*

Figures 9a-k. continued.



k). *Haul 37. Eastern Celtic Sea sunfish bycatch, water depth 77 m.*

Figures 9a-k. continued.

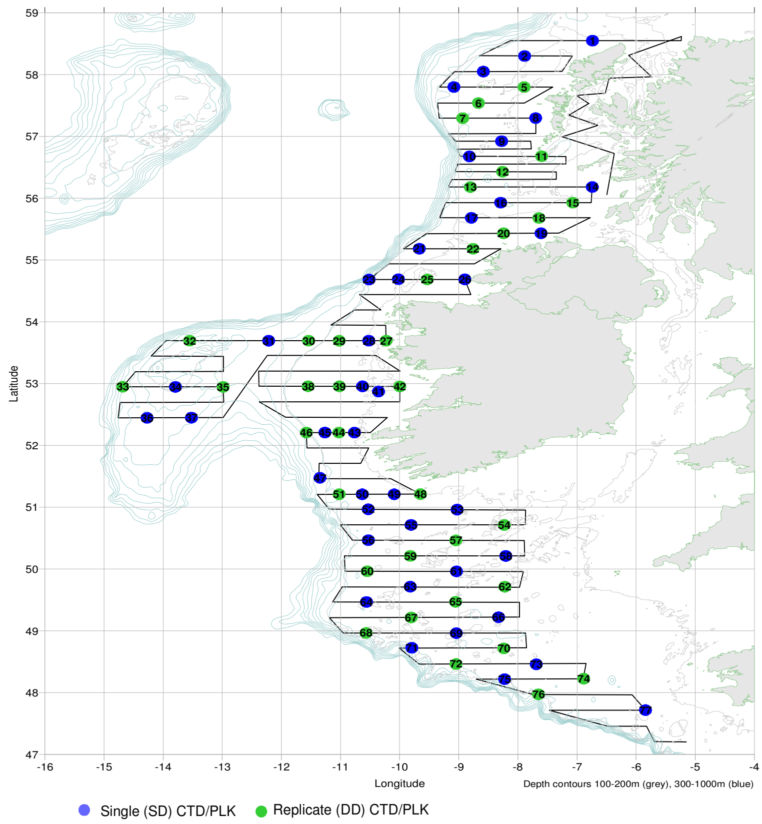


Figure 10. Position of hydrographic and plankton sampling stations (n=77).

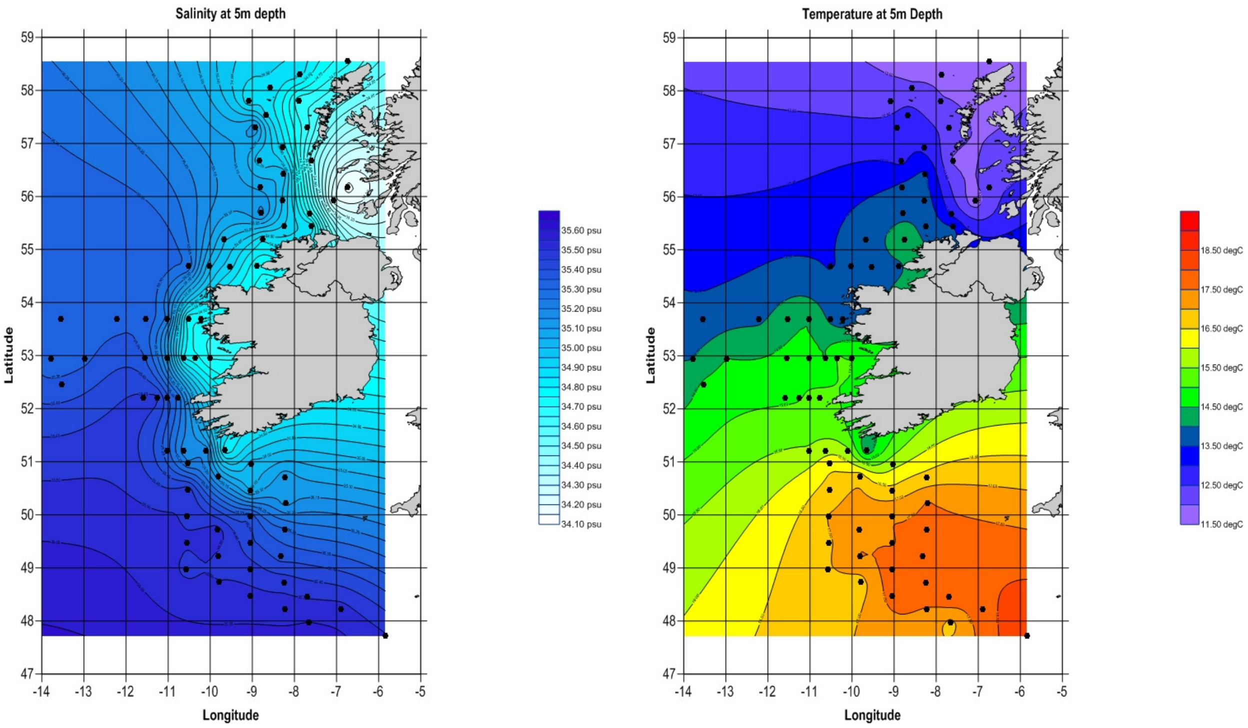


Figure 11. Surface (5m) plots of temperature and salinity compiled from CTD cast data. Station positions shown as block dots (n=77).

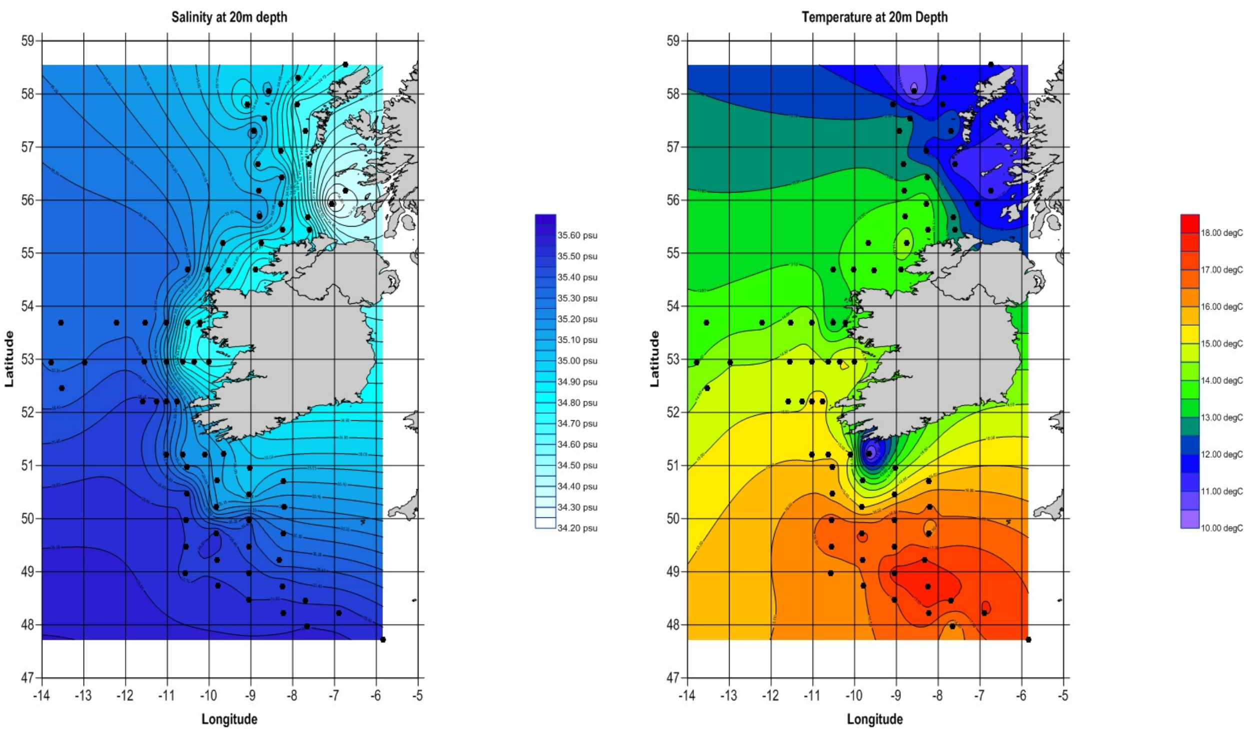


Figure 12. Plots of temperature and salinity compiled from CTD cast data at 20m depth. Station positions shown as block dots (n=77).

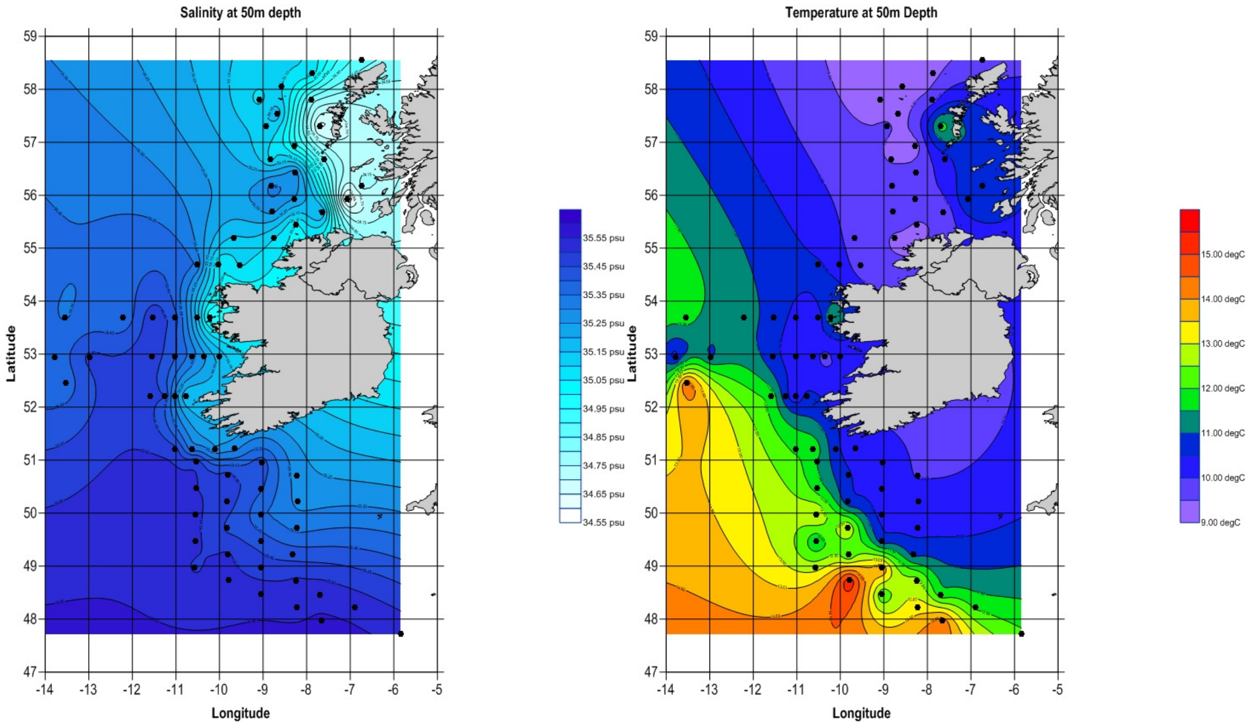


Figure 13. Plots of temperature and salinity compiled from CTD cast data at 50m depth. Station positions shown as block dots (n=77).

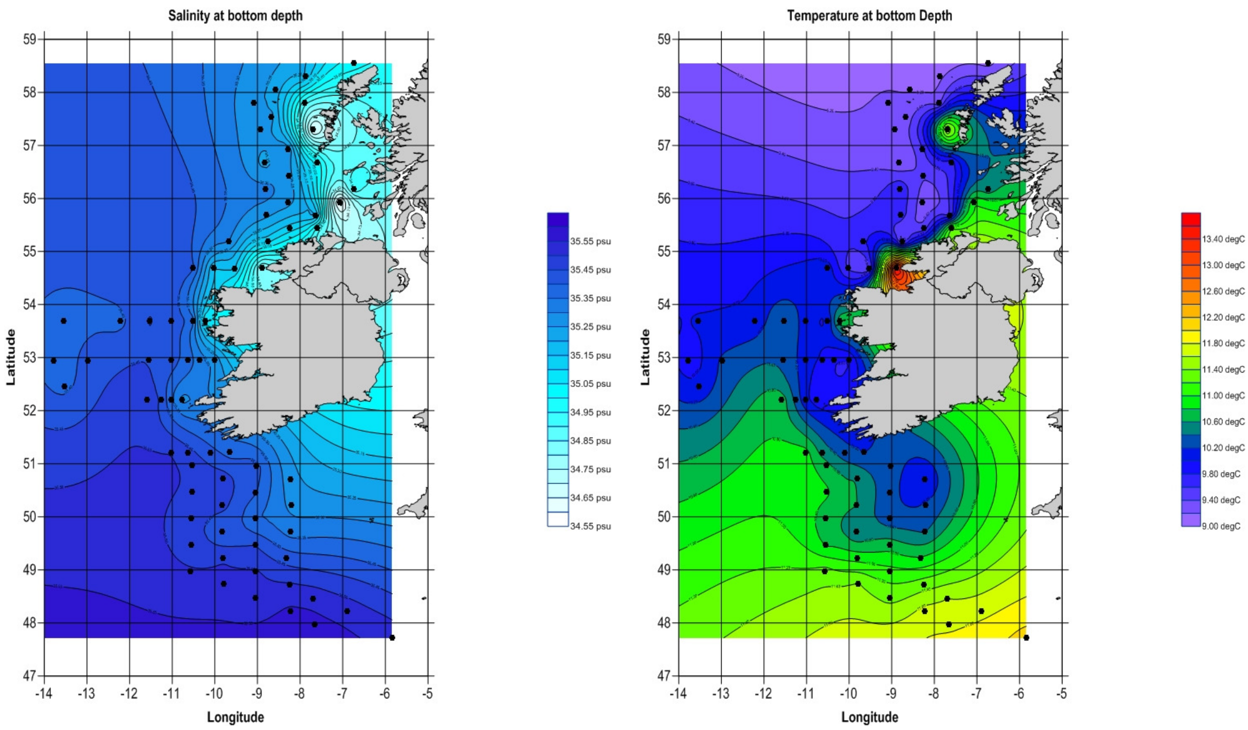


Figure 14. Plots of temperature and salinity compiled from CTD cast data at the seabed (+3-5m). Station positions shown as block dots (n=77).

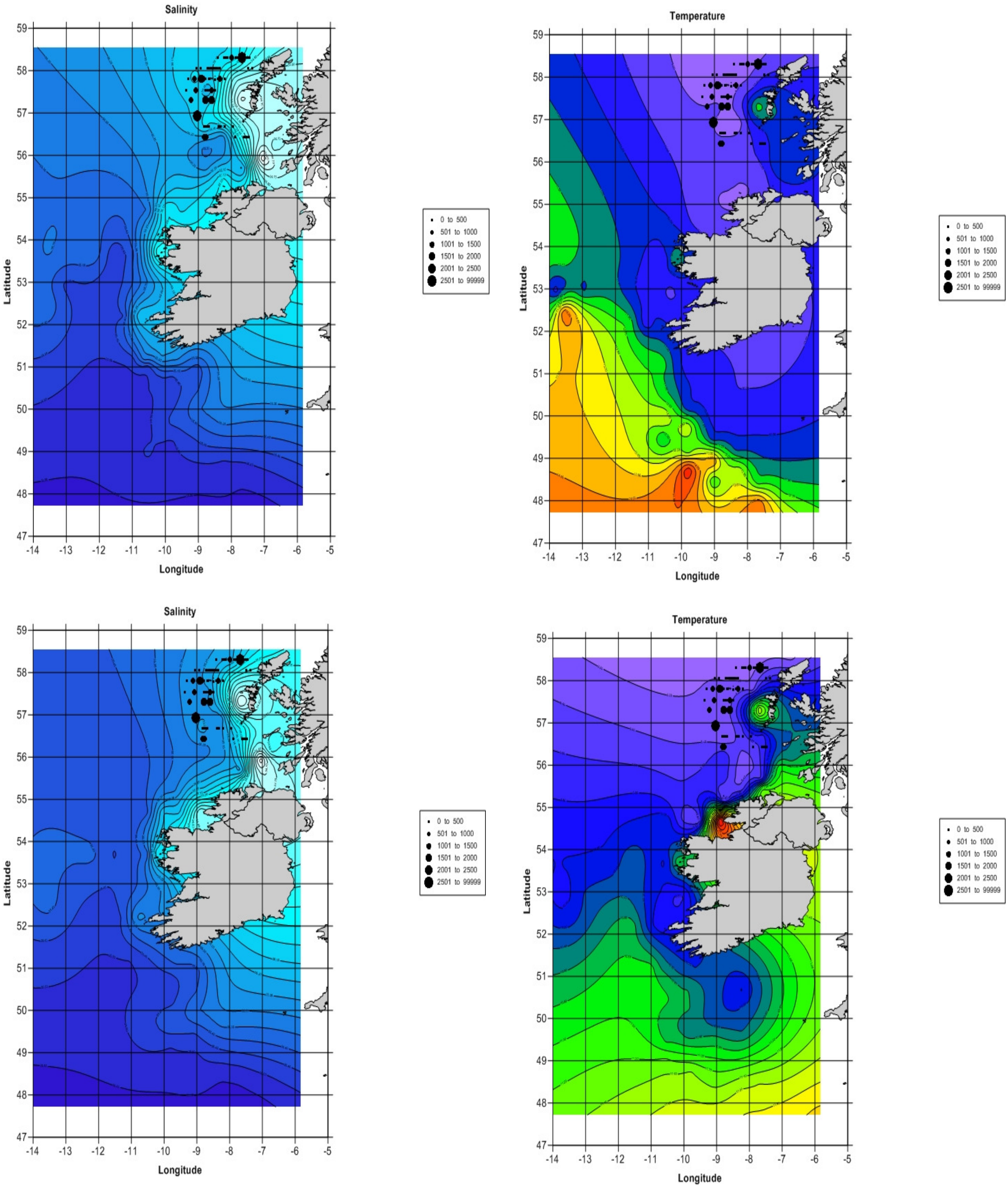


Figure 15. Habitat plots of temperature and salinity with herring distribution. Top panel at 50m and bottom panel bottom temp (+3-5m) values overlaid with herring NASC values (black circles).

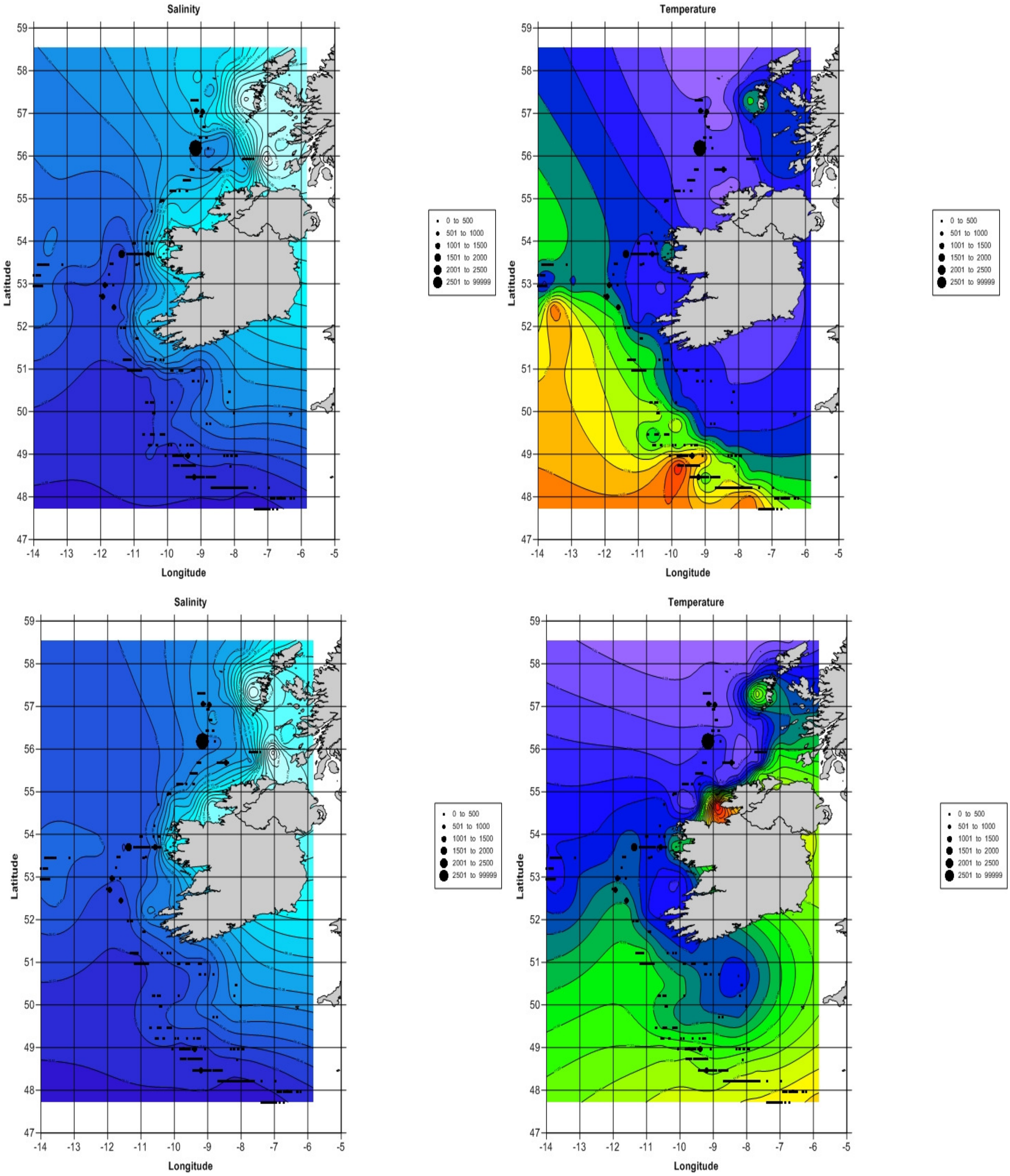


Figure 16. Habitat plots of temperature and salinity with boarfish distribution. Top panel at 50m and bottom panel bottom temp (+3-5m) values overlaid with NASC values (black circles).

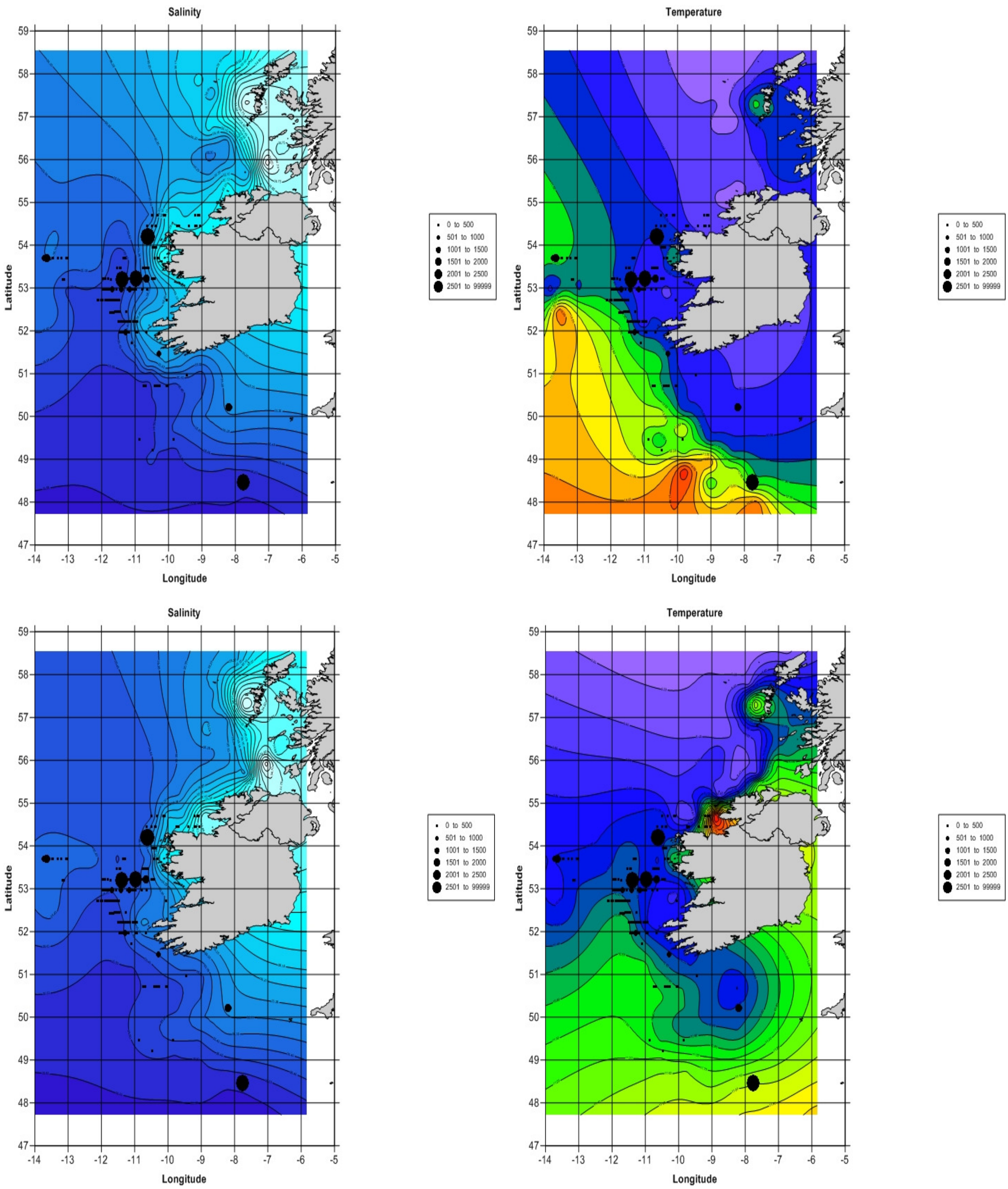


Figure 17. Habitat plots of temperature and salinity with horse mackerel distribution. Top panel at 50m and bottom panel bottom temp (+3-5m) values overlaid with NASC values (black circles).

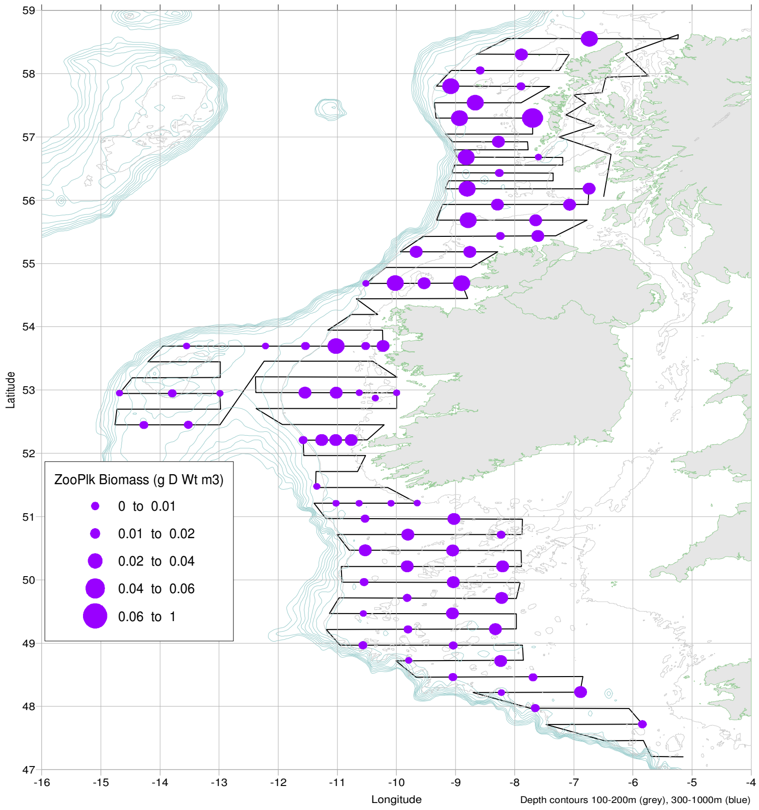


Figure 18. Zooplankton biomass by station (g dry wt m^3).

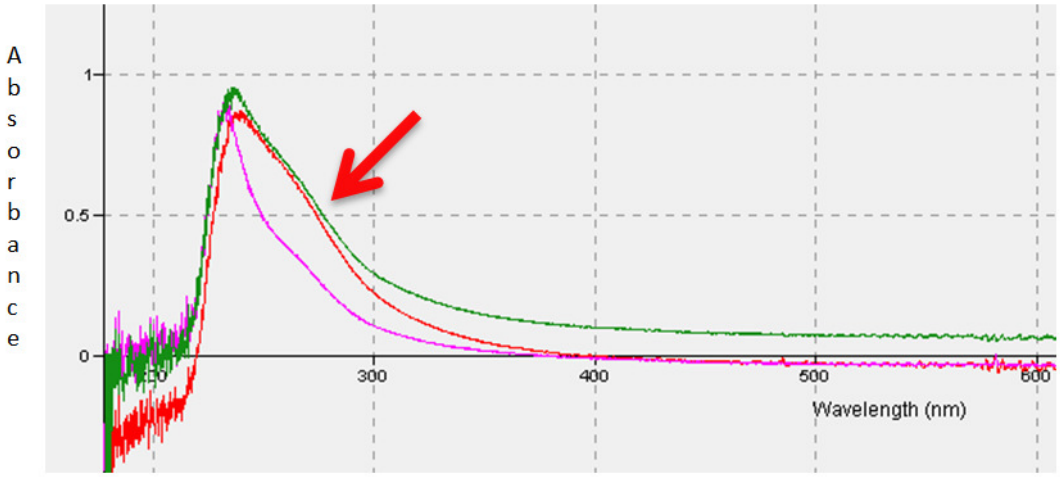


Figure 19. CDOM absorption spectrums of water samples from different depths at the same station. Arrow indicates subtle variations of the spectral slope of depth dependent samples.

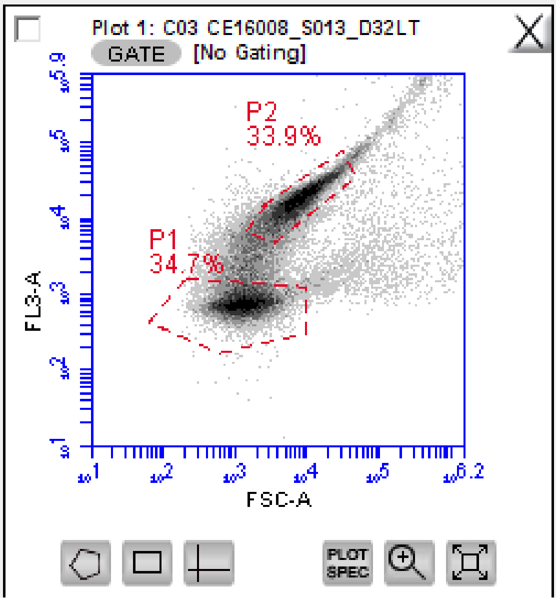


Figure 20. Forward scattering of light against chlorophyll a fluorescence (FL3-A). Here there are two distinctly different organisms. In this instance both are of reasonably similar size, overlapping on the X-axis, with very different fluorescence yields. Both employing chlorophyll a as their photosynthetic pigment.

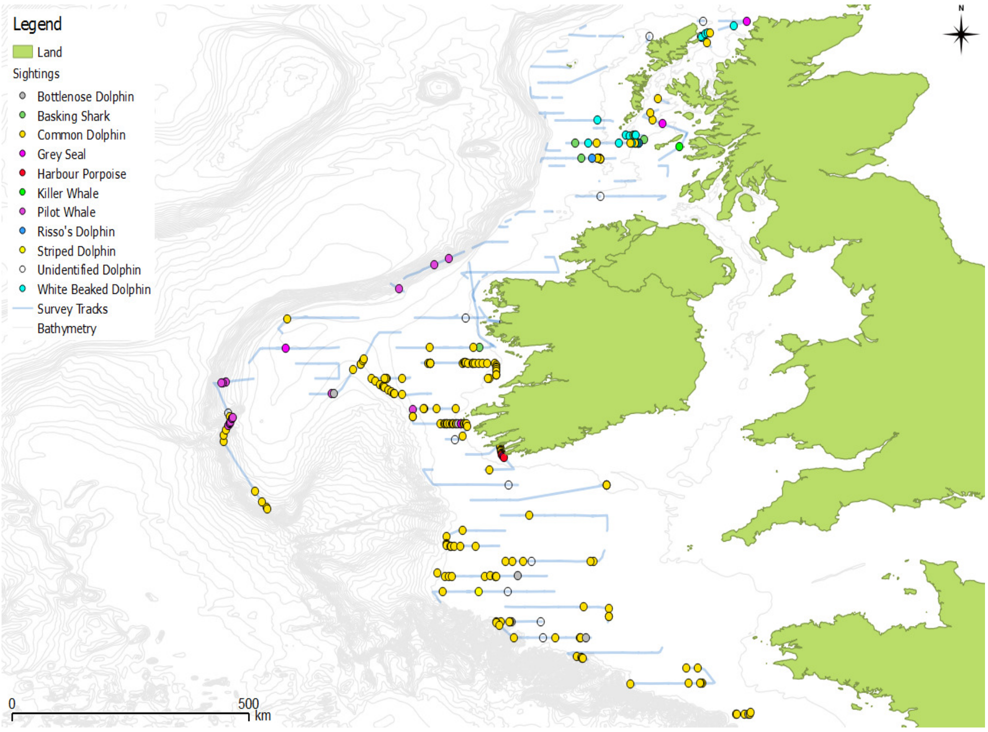


Figure 21. Distribution of dolphin, seal and basking shark sightings during the survey profiled with observer effort.

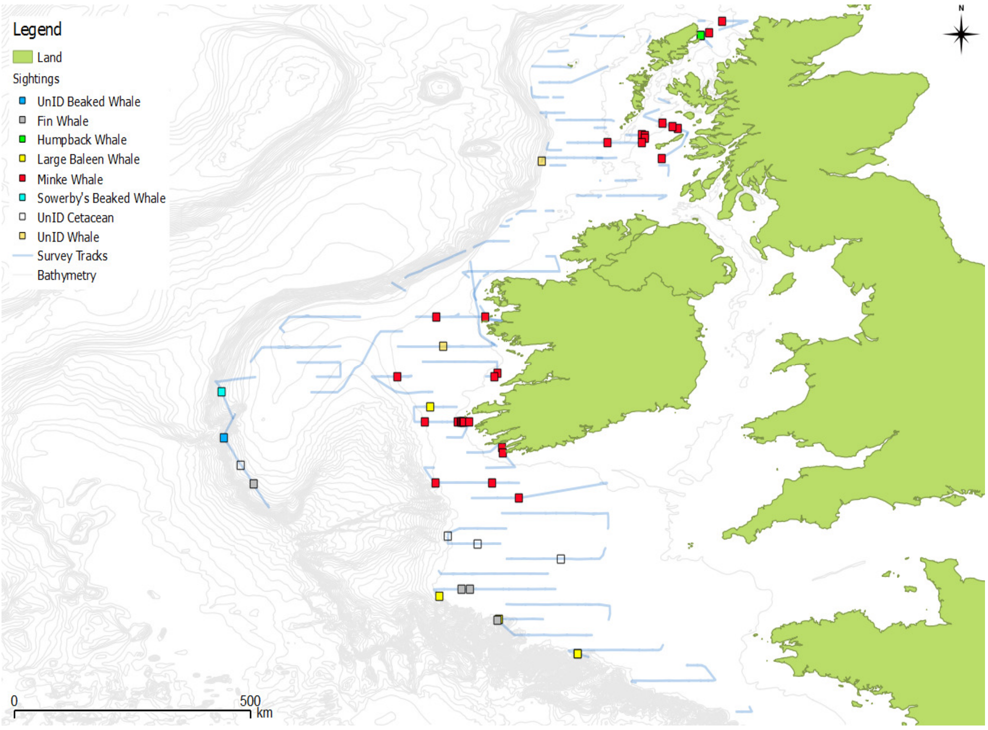


Figure 22. Distribution of cetacean sightings during the survey profiled with observer effort.

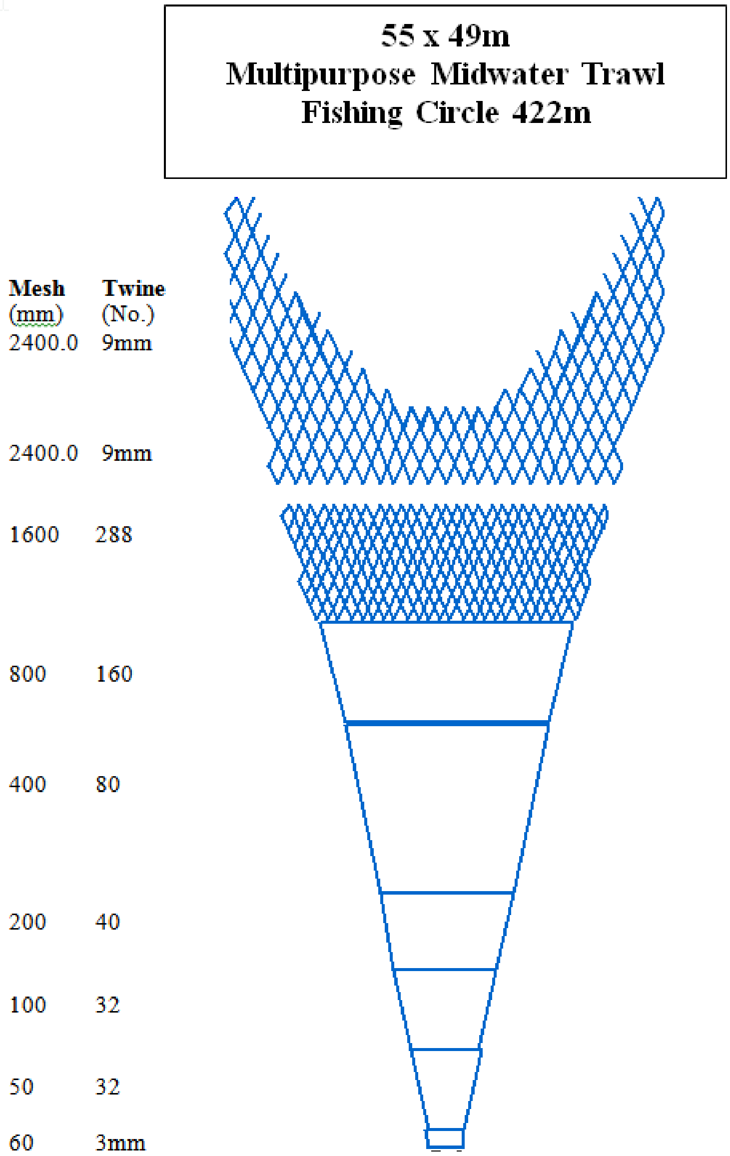


Figure 23. Single multipurpose midwater trawl net plan and layout.

Note: All mesh sizes given in half meshes; schematic does not include 32m brailer.