FSS Survey Series: 2018/03

Western European Shelf Pelagic Acoustic Survey (WESPAS)

10 June – 24 July, 2018

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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 and the boarfish acoustic survey. 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 to the north and west of Ireland from 54°N to 58°30'N. The boarfish survey was conducted from 2011 using a chartered fishing vessel and reported the abundance of spawning aggregations of boarfish from 47°N to 57°N. In 2016 both surveys were combined and since then have been carried out onboard the RV *Celtic Explorer* over a 42 day period providing synoptic coverage of shelf waters from 47°N northwards to 58°30'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 of boarfish and horse mackerel were submitted to the ICES assessment Working Group for Widely Distributed Stocks (WGWIDE) meeting in August 2018. Herring estimates are submitted to the Herring Assessment Working Group (HAWG) meeting in March every year. Survey performance will be reviewed at the ICES Planning Group meeting for International Pelagic Surveys (WGIPS) meeting in January 2019.

2 Materials and Methods

2.1 Scientific Personnel

Leg	CE18009	CE18010
Dates	09-28 June	04-24 July
Days	20	22
Start	Galway	Galway
End	Galway	Galway
Acou (Chief Sci)	Ciaran O'Donnell	Michael O'Malley
Acou	Turloch Smith	Brendan O'Hea
Acou	Deirdre Lynch	Eugene Mullins
Acou	David Tully	Tobi Rapp
Bio (Deck Sci)	Marcin Blaszkowski	Ian Murphy
Bio	Seán McLaughlin	Sean O'Connor
Bio	Hannah Koegh	Artur Opanowski
Bio	Michael Kineen	John Power
MMO	John Power	Catherine O'Sullivan
SBO	John Collins	Ashley Johnston
SBO	Dannielle Crowley	Sally O'Meara
Zoo/Salps	Aidan Long	Aidan Long
Zoo/Salps	Leigh Barnwal	Stephanie Linehan
CDOM –	Catherine Jordan	Monica Mullins
CDOM –	Mark Dwyer	John Phelan
CDOM –	Kevin McGookin	-

2.2 Survey Plan

2.2.1 Survey objectives

The primary survey objectives are listed below:

- Collect acoustic density measurements of boarfish, herring and horse mackerel within a pre-determined survey area using a split-beam echosounder (EK60) over multi frequencies
- Determine an age stratified estimate of biomass and abundance for the above target species from survey data
- Collect biological samples from directed trawling on fish echotraces to determine age structure and maturity state of target stocks
- Take morphometric and genetic samples of individual herring in 6a/7b,c for stock identification analysis
- 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.
- Use multi-beam echosounders (EM2040) collect data on the aggregation morphology and behaviour of small pelagics
- Visual survey for to determine the abundance and distribution of jellyfish. Combined with analysis of trawl and plankton net caught individuals.
- Analysis of water samples to determine the composition and spatial distribution of pico- and nano- plankton populations, bacteria and CDOM
- Determine a survey plan to be conducted by unmanned surface vessel (USV) collecting acoustic density measurements within a pre-defined area. Carry out an acoustic inter-calibration exercise with the USV for data comparison purposes.

2.2.2 Survey design and area coverage

Survey coverage began in the southern Celtic Sea at 47°30'N (northern Biscay) and worked northwards to 58°30'N (northern Hebrides), including the Porcupine Bank (Figure 1). Area coverage was based on the distribution of catches from the previous surveys (e.g. O'Donnell *et al.* 2007 and 2011).

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 15nmi (nautical miles) in open water areas and zigzag transects in the restricted Minch area. High intensity small scale surveys were carried out in specific areas of interest with a transect spacing of between 5-10nmi. Coverage extended from the 50 m contour to the shelf slope (250 m). An elementary distance sampling unit (EDSU) of 1nmi was used during the analysis of acoustic data during the main body of the survey area. In total the planned survey covered 5,096nmi using 66 transects relating to a total area coverage of 61,284nmi^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 analysis methods 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 were calibrated in Dunmanus Bay on June 11th at the start of the survey. A calibration was also conducted in Killary Harbour on July 22nd at the end of the survey. Calibration procedures 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. 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 8) 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 schools. 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 8) 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 using Target Strength (TS) to provide a species specific NASC value. This process was conducted within the StoX program.

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 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 boarfish is from Fassler et al (2013):

Boarfish	TS =	20logL – 66.2 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 a fishing circle of 420 m was employed during the survey (Figure 24). 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 and was observed using a cable linked Simrad FS70 netsonde. 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, boarfish, sprat and pilchard were taken to the nearest 0.5 cm below. Horse mackerel were taken to the nearest 1.0 cm below. Age, length, weight, sex and maturity data were recorded for individual herring, boarfish and horse mackerel 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 schools. 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.

2.4.1 Herring stock identification

When possible, a sample of 120 herring (>23cm) are taken for morphometric and genetic analysis from herring in the Malin Shelf area (6a/7b, c). These fish are processed according to SGHERWAY procedures (ICES 2010).

2.5 Hydrography and biogeochemical 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 Hydrography and water sampling

Seawater samples were collected from typically 6 depths on the up cast of the profile by triggering Niskin bottles at predetermined depths related to the hydrography observed during the down cast. The CTD data comprises continuous downcast and up casts records of the pressure, temperature, conductivity (salinity), dissolved oxygen, chlorophyll fluorescence and turbidity. These data are processed according to GO-SHIP guidelines and incorporated into ODV files for the continuous downcast data and the discrete bottle data collected during the up cast.

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 Niskin bottles into 1 ltr brown LDPE bottles. Sub samples were then obtained from the LDPEs.

2.5.2 CDOM measurements

Samples for the analysis of Colour Dissolved Organic Matter (CDOM) absorption were collected from the CTD cast directly from the Niskin bottles. They were then immediately filtered through a 0.2 µm syringe filter and part of the filtrate used for CDOM analysis onboard and the rest frozen at -20° C for later nutrient and FDOM analysis. CDOM measurements were performed using an Ocean Optics Maya spectrophotometer coupled to a 1m liquid wave guide capillary cell (LWCC), supplied by World Precision Instruments, and an Ocean Optics DH-mini light source.

The filtered samples frozen at -20° C will also be analysed, after thawing, back in the laboratory in Galway for nutrients and 3D EEM FDOM analysis (Horiba Aqualog). The 3D EEM FDOM dataset will be analysed using PARAFAC (Murphy et al., 2013) will allow the determination of independent fluorphore components in seawater which can be used to identify sources of FDOM from terrestrial or marine processes.

2.5.3 Nutrient sampling

Seawater samples are collected from the CTD and immediately filtered through 0.2 µm syringe filters. The filtrate is then frozen at -20 °C until analysis in the laboratory. For analysis in the laboratory samples are thawed overnight and then analysed for Nitrite, Nitrate, Phosphate and Silicate using specially adapted low volume methods based on standard green chemistry methods for nutrient analysis in seawater (García-Robledo et al., 2014; Koroleff, 1976; Murphy and Riley, 1962; Schnetger and Lehners, 2014).

2.5.4 Bacteria, Heterotrophic nanoflagellates, Pico and nanoplankton abundance

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. Unfiltered seawater samples collected directly from the CTD are run on an Accuri C6 flow cytometer while at sea according to established protocols (Marie et al., 1997; Marie et al., 2014). An untreated raw sample is used to identify the phytoplankton by size and fluorescence, *Synechococcus* species can be identified at this step by their unique combination of cell size and phycoerythrin fluorescence. A second raw sample is treated with Lysotracker Green to determine heterotrophic nanoplanktonic protists (Rose et al., 2004). While a third sample is fixed with glutaraldehyde and then treated with the DNA stain Syber Green to enumerate marine bacteria and phytoplankton via the combination of chlorophyll fluorescence (red) and the DNA stain (green).

2.5.5 Hyperspectral measurements

In order to more directly compare field data with satellite data, a pair of hyperspectral sensors were mounted above the bridge of the Celtic Explorer. The sensor pair incorporated an irradiance and radiance sensor for the purposes of determining the hyperspectral reflectance from the surface of the ocean for comparison to the reflectance measured by the ocean colour satellites.

Particulate absorption of fresh water and seawater can be determined by filtering a known amount of sample through a Glass Fiber Filter (GF/F) and measuring the particulate absorption coefficient $a_p(\lambda)$concentrated on the filter. This technique is called quantitative filter technique (QFT) and corrects for the pathlength amplification, an effect of scattering. Measurements were made shipboard using a QFT-1 filter holder (WPI) after filtering 200-1000 mL of seawater through a 25 mm GF/F filter. An Ocean Optics Maya spectrophotometer was coupled to the QFT-1 using 600 µm diameter fibre optical cable with a DH mini light source.

2.5.6 Chlorophyll measurements

Water samples from Niskin bottles collected at near surface (5-6m depth) were filtered. Filtered samples were labelled and frozen for analysis in the laboratory after the survey.

2.6 Zooplankton and jellyfish sampling

2.6.1 Zooplankton

Zooplankton sampling was carried out alongside CTD stations. A weighted 1 m diameter Hydro-bios ring net was used with a 200 µm mesh size and the net was fitted with a mechanical 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).

2.6.2 Jellyfish

Jellyfish samples recovered from the directed zooplankton vertical trawls were separated from the dry weight and fixed component samples for further analysis. Once recovered, the cod end was washed into a 30 L bucket. Considering the rapid degradation and underrepresentation of many ctenophore species in fixed samples, those that were visible to the naked eye were enumerated and recorded separately by passing fresh zooplankton samples through a 180 µm sieve. The sample was then fixed in 4% formalin solution for further analysis in a laboratory on land. In total, 86 ring net stations were successfully deployed along the cruise track line (Figure 12).

A multinet (type midi) was deployed opportunistically to sample plankton in different depth strata during the survey. The sampling equipment has a computer-controlled opening and closing mechanism and electronic flow meters. An integrated pressure sensor allows constant supervision of the operating depth which is indicated at the display of the deck command unit. The multinet had a 300 µm net mesh size and a net opening of 50 cm. For each station, the water column was broken into 5 vertical depth strata and sampled via an oblique tow. Sampling lasted approximately 7 minutes per stratum and a minimum water volume of 100 m^3 was filtered. Changes were made to the depth strata depending on the depth position of the migrating plankton layer at any one time, ensuring a single net bag filtered the diurnal plankton layer. The contents of the cod end buckets (x5) were placed in labelled 500 ml containers and fixed in 4% buffered formalin for taxonomic identification and enumeration back at the laboratory. Four multinet stations were undertaken. To evaluate the whether acoustic survey techniques can quantify abundances of gelatinous zooplankton in discrete depth strata, the multinet data will be compared with the single beam and multi-beam data that was collected during the multinet deployments.

By-caught gelatinous fauna collected in the pelagic survey trawl (Figure 24) were also recorded, weighed, measured and discarded after each haul. As the fishing was targeted and involved variable subsampling of catches, only qualitative data could be attained for gelatinous species using this large net. A total of 21 pelagic net hauls contained jellyfish taxa.

To quantify surface abundances of large jellyfish, surface counts of jellyfish from the bow of the Celtic Explorer were made during transits between sampling stations Observations were made from an elevated position from the bow of the ship, during day light hours (07:00–21:00 h). Jellyfish were identified to species level, and their numbers estimated per 5-min intervals using the following categories: 0, 1–10, 11–50, 51–100, 101–500, and >500 (jellyfish abundance estimates of much greater than 500 are impractical). Sample periods were 15 min long with 5 min breaks between successive samples. After three successive sample periods a 20 min break is taken, and after every 3–4 h a 1-h rest period is taken. Nearly 80 hours of visual surveys (933 surveys) were carried out over the duration of the research cruise.

2.7 Marine mammal and seabird surveys

2.7.1 Marine mammal abundance and distribution

The cetacean survey was conducted using a team of two marine mammal observers (MMOs), with one cetacean observer deployed per survey leg. To prevent MMO fatigue and optimise the validity of the data, survey effort was carried out in two-hour shifts, with a break of one hour between shifts.

Cetacean watches were conducted using a standard single platform line transect survey design while the vessel was travelling at a consistent speed and heading. When the vessel was stationary at oceanographic stations, cetacean watches were conducted using a standard single platform point sampling survey design. Visual watches were undertaken from the vessel's crow's nest, located 17.45m above sea level during all daylight hours, when weather conditions permitted. During periods of unfavourable weather conditions, observations were carried out from the bridge (10.63m above sea level).

Survey effort was concentrated in periods of sea state 6 or less, and in moderate or good visibility. Survey effort conducted outside of these parameters was conducted at the discretion of the observers. Survey effort for cetaceans was concentrated within an arc of 60^{o} either side (i.e., to port and to starboard) of the vessel's track-line but all sightings to 90^{o} both side of the track-line and further aft were also recorded. Searching for cetaceans was predominantly done with the naked eye, however, Nikon Prostaff 7 8x42 binoculars and a Canon EOS 7D DSLR camera with a Sigma 100-400mm zoom lens was used to confirm species identification and group size, and assess behaviour. Survey effort was also carried out during hauls and when at CTD stations.

The IFAW Logger 2000™ (IFAW, 2000) data collection software package was used to collect all positional, environmental and sightings data, and save it to a Microsoft Access database. Positional data was collected using a portable GPS receiver with a USB connection and recorded every 10 seconds.

Environmental data was recorded at least every 15-30 minutes, or sooner if there was a change in environmental conditions. Environmental data recorded included; wind speed, wind direction, sea state, swell, visibility, cloud cover and precipitation. All data entry was time stamped by Logger and saved in the Access database.

The distance of each sighting from the ship was estimated using a fixed interval range finder, while the bearing from the ship was estimated with an angle board. This data, along with data such as species identification, group size, composition, heading, sighting cues, surfacing interval, behaviour and any associations with birds or other cetaceans was also recorded on the time stamped Logger sighting record page. Where species identification could not be confirmed, sightings were recorded at an appropriate taxonomic/confidence level (i.e. probable, possible, unidentified whale, unidentified dolphin etc.). Auxiliary and incidental sightings were also recorded.

Ancillary data such as line changes, changes in survey activity (e.g. fishing/CTD cast) and fishing vessel activity were also recorded.

2.7.2 Seabird abundance and distribution

Surveys of seabirds at sea were conducted from the RV *Celtic Explorer* across 18 days between 10th and 27th June during Leg 1 and 19 days between 4th and 23rd July 2018 during Leg 2. 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 recommendations of Tasker et al. 1984; Komdeur et al. 1992; Camphuysen et al. 2004), as outlined below.

A single observer surveyed while the ship was travelling along transect lines during daylight hours, between 06:00 and 21:00 each day. Surveying ceased when the ship broke track (e.g. during fishing tows) or when stopped (e.g. during the deployment of the CTD and plankton nets). Environmental conditions, including wind force and direction, sea state, swell height, visibility, precipitation and cloud cover as well as the ship’s speed and heading were noted at the start of each survey period and when significant changes occurred thereafter. No surveys were conducted out on deck in conditions greater than sea state six, when high swell made working on deck unsafe. During such periods of inclement weather or heavy seas, surveying was conducted from inside the bridge. Survey effort was also stopped when visibility was reduced to less than 300m due to heavy rain or sea fog.

The seabird observation platform varied between the bridge deck and the monkey island, which are 10m and 12m above the waterline respectively and provide a good view of the survey area. The monkey island was used during periods of calm weather while the bridge deck was utilised during windier conditions as more shelter was afforded there. The survey area was defined as a 300m wide band operated on one side (in a 90˚ arc from the bow) and 300m ahead of the ship. This survey band was subdivided (A = 0-50m from the ship, B = 50-100m, C = 100-200m, D = 200-300m, E = >300m) 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 check distance estimates for birds sitting on the water or those flying birds which were recorded during ‘snapshot’ counts. The area was scanned by eye, with binoculars used only to confirm species identification or count the number of birds present in a flock. All birds seen within the survey area were counted, and those recorded sitting on the water in survey bands A to D 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 when the ship passed from one survey area to the next (every 300m). 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 one minute. Additional bird species observed outside the survey area or ad hoc counts of birds not occurring in the survey area were also recorded and added to the database for the research cruise, but are not included in abundance or density analysis.

During the 2018 survey, a series of point counts were made of seabirds associating with the vessel during fishing operations. These began as soon as the towed net began to appear near the surface of the water and finished once the fishing operation was complete, with the net back on board and any surplus fish cleared from the deck. Details such as date, time, location and details of the haul (gross tonnage, species present etc.) were noted for each of these point counts.

In this report, we present the daily total count data for each species along with the daily survey effort. It is envisaged that this data will be analysed such that 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 (2015).

3 Results

3.1 Malin Shelf herring (6aS, 7b, c and 6aN south of 58°30'N)

3.1.1 Biomass and abundance

Herring	Abund ('000)	Biomass (t)
Total stock (TSB)	1,698,261	183,186
Spawning stock (SSB)	750,614	129,740

The Malin Shelf Herring total stock biomass (TSB) was 183,186 t and total stock numbers (TSN) was 1,698,261,000 (Table 3). The spawning stock biomass (SSB) was 129,740 t and spawning stock numbers (SSN) was 750,614,000. The CV for the survey was 0.28.

The Malin Shelf survey area was divided into 6 strata representing a total area coverage of 29,847 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 42 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). A total of 228 echotraces were assigned to herring as compared to 161 in 2017.

Herring were distributed in five out of the six strata (Figure 2). There were no herring allocated to echotraces in the NW Coast Strata. A total of 117 EDSUs (1nmi. long) contained herring in the Malin Shelf survey area. This included a small number of high NASC value EDSUs, with areas of high density occurring to the southwest of St. Kilda and the southern Stanton Banks area (Figure 3). The area covered by the RV Celtic Explorer was similar to the 2017 survey. The area of 6aN to the north of 58°30'N was again covered by RV Scotia in 2018; the overall estimate of the survey for the stock assessment of herring in 6a will therefore be complete when both surveys are combined during WGIPS 2019. Herring were found further south than in 2017, with the distribution south of the 56 ˚N more similar to the historical distribution of herring found during this time series. Herring schools were predominantly located in pillars in close proximity to the seabed (Figure 11f and 11h), but there was evidence of 1-wr herring displaying more midwater behaviour (Figure 11g). Overall the stock was distributed throughout a slightly larger area compared to 2017 (Figure 3). Particularly encouraging was the distribution of 1- and 2-wr fish in the N Malin strata (South Stanton Bank). 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 and

Stanton Bank). The survey in 2018 largely followed these norms, with the added distribution of 0-group herring found in the Minch strata area (Figure 11j).

3.1.3 Stock composition

A total of 681 herring were aged from survey samples with 3,231 length measurements and 782 length-weights recorded. Herring age samples ranged from 0-11 year olds (Table 3 & Figure 4). A further 360 herring were processed for morphometric and genetic analysis under SGHERWAY protocols (ICES 2010) in 2018; from hauls 35, 37 and 39. Genetic samples were taken from herring in haul #32, these fish were mainly <23cm, therefore SGHERWAY morphometric samples were not taken from this haul.

4-wr herring dominated the 2018 survey estimate representing around 30% of TSB and 22% of TSN (Table 3). 2-wr herring were ranked second representing 19% of TSB and 24% of TSN. The third most dominate age group was 5-wr herring contributing 14% to the TSB and 10% to TSN. Combined these three age classes represented 63% of TSB and 55% of TSN.

Maturity analysis of herring samples indicated overall 71% of fish were mature. In 2017, 99% of fish were mature. Maturity analysis by age class showed that 23% of 2 year old fish, 85% of 3 year old fish, and 97% of 4 year olds were mature, rising to 100% of fish of 6-wr and older (Table 3).

3.2 Boarfish

3.2.1 Biomass and abundance

Boarfish	Abund ('000)	Biomass (t)
TSB estimate	3,221,110	186,252
SSB estimate	3,041,284	184,235

Boarfish TSB (total stock biomass) and abundance (TSN) estimates were 186,252 t and 3,221,110,000 individuals (CV 19.9 %) respectively.

The boarfish survey area was divided into 6 strata representing a total area coverage of 56,403 nmi^2 (Figure 2). A breakdown of boarfish stock abundance and biomass by age, maturity and stratum is detailed in Table 6 & 7 and Figures 5 & 6. The boarfish survey time series is provided in Table 8.

3.2.2 Stock distribution

A total of 42 trawl hauls were carried out during the survey (Figure 1), with 15 hauls containing >50% boarfish (Table 2).

A total of 817 echotraces were assigned to boarfish as compared to 394 in 2017. Boarfish were observed in all survey strata (Table 7). The highest occurrence was in the Celtic Sea where over 42% of the total survey biomass was observed. Within the Celtic Sea the highest density of fish was observed in the southern survey area, south of 50°N and characterised by an area containing a high density of schools (Figure 9a). This pattern of distribution is similar to previous years (Figure 5). The west coast stratum contained the second largest biomass of 27% and again followed the previously observed pattern of abundance. The shelf area between 53-54°N including the porcupine Bank was an area of high abundance. Interestingly the southwest (between 51-52°N) saw fewer schools than in previous years. The distribution of boarfish to the northwest and north of Ireland was mainly restricted to the shelf edge (<180m). This year for the first time boarfish aggregations were observed during the Scottish summer herring survey extending the latitudinal range to north of 59°N (Steven O'Connell *Pers communication)*. Previously boarfish have not been observed during this survey further north than 57°30N.

3.2.3 Stock composition

A total of 945 boarfish were aged from survey samples in addition to 4,807 length measurements and 2,234 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.

The 10 year age class dominates the 2018 estimate contributing over 20.4% of TSB and 19.4% of TSN (Table 6). The 11 group and 15+ year age class ranked second and third respectively representing over 12.9% of TSB and 9.3 and 10.5% of TSN each to the overall biomass. The fourth ranked group was the 12 year olds 10.8% to the TSB and 8.2% to TSN. Combined, the 10, 15+ and 11 year age classes represent 46.1% of TSB and 39.2% of TSN.

Maturity analysis of boarfish samples indicated 98.8% of observed biomass was composed of mature individuals (94.4% for abundance). Maturity analysis by age class showed that 33% of 3 year old fish were mature, rising to 100% for fish four years and older (Table 6).

3.3 Horse mackerel

3.3.1 Biomass and abundance

Horse mackerel	Abund ('000)	Biomass (t)
TSB estimate	540,422.0	92,931.9
SSB estimate	503,903.0	89,050.4

Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 92,931.9 t and 540,422,000 individuals (CV 36.8%) respectively.

The horse mackerel survey area was composed of 8 strata relating to an area coverage of 61,285 nmi^2 as shown in Figure 2. A breakdown of horse mackerel stock abundance and biomass by age, maturity and stratum is detailed in Tables 9 & 10 and Figures 7 & 8.

3.3.2 Stock distribution

A total of 42 trawl hauls were carried out during the survey (Figure 1), with 3 hauls containing >50% horse mackerel out of 20 containing horse mackerel overall (Table 2).

A total of 198 echotraces were assigned to horse mackerel. Horse mackerel were widely distributed along the west coast or Ireland, the Porcupine Bank and Celtic Sea where the bulk of the standing stock was located (Figure 7). Observations of horse mackerel along the west coast and Celtic Sea were comparable to 2016-17 in terms of distribution but the number and overall acoustic density was lower. The 2017 estimate of abundance was bolstered by a large single aggregation of spawning fish that contributed over 24% to the total biomass. No aggregations of this scale were observed this year. The west coast stratum remains a significant contributor to the TSB contributing 58% in 2018 followed by the Celtic Sea (35%). Schools of horse mackerel were frequently observed on the seabed and most often over a rocky substrate and along the west coast were often observed in areas containing boarfish (Figure 11b).

3.3.3 Stock composition

A total of 541 horse mackerel were aged from survey samples in addition to 1,466 length measurements and 750 length-weights recorded. Horse mackerel age samples ranged from 1-17 years (Table 9 & Figure 8). Age structure of the stock was determined using an age length key from constructed from the previous years aged survey samples.

The 3 year age class dominated this year's survey estimate representing over 32.2% of TSB and 45% of TSN (Table 9). The 7 year age class ranked second representing over 14.5% of TSB and 9.1% of TSN (Table 9). Fourteen year old fish were ranked third contributing 11.2% to TSB and 5.0% to TSN. Combined these three age classes represented 57.9% of TSB and 59.2% of TSN.

Maturity analysis of horse mackerel samples indicated 95.8% of the TSB was mature. Maturity analysis by age class showed that 99% of 5 year old fish were mature, rising to 100% for fish three years and older (Table 9).

3.4 Celtic Sea herring (7g and j)

3.4.1 Biomass and abundance

CS Herring	Abund ('000)	Biomass (t)
Total stock	132,419.0	22,745.5
Spawning stock	129,088.8	22,248.5

The estimate of Celtic Sea (CS) herring TSB (total stock biomass) and abundance (TSN) estimates were 22,745.5 t and 132,419,000 individuals (CV 74%) respectively.

The herring survey area was composed of two strata, one broad scale (Celtic Sea) and one high intensity (NW Bank and Celtic Deep). The former represented an area of over 26,626 nmi^2 and was surveyed using a transect spacing of 15 nmi, whereas the latter was surveyed using a higher intensity of 4-6 nmi and covered an area of 2,644 nmi. A breakdown of CS herring stock abundance and biomass by age, maturity and stratum is detailed in Tables 12 & 13 and Figures 9 & 10.

3.4.2 Stock distribution

CS herring were observed in two regions during the survey. A single high density school of herring was observed south of the Jones's Bank (Figure 11d). During the 2017 survey, a small number of individual herring were also observed around this area, occurring as a by-catch. Numbers were insufficient; both acoustically and biologically to produce a reliable estimate of abundance for the wider Celtic Sea stratum and this is reflected in the high CV value for the combined estimate (74%).

Herring were also observed on the Northwest Bank and in the western Celtic and were composed in the main of a higher number (n=41) of low density schools spread over a wide area (Figures 9 & 11e).The distribution of herring around this area is spatially consistent with observations from this survey in 2017. The Celtic Deep region was surveyed using the USV while the northwest Bank was survey by the Celtic Explorer.

Genetic samples were taken from both locations where herring were located and will be used in part of a larger project to determine the identity of stock components.

3.4.3 Stock composition

A total of 213 CS herring were aged from survey samples in addition to 337 length measurements and 122 length-weights recorded. CS Herring age samples ranged from 1-9 years (Table 12 & 13 and Figure 10). Age structure of the stock was determined from aged otoliths.

Five, four and six winter ring fish dominated the total estimate (Table 12). The age structure of fish was found to very between strata, with a wider range of age classes encountered around the Celtic Deep stratum (Figure 10).

3.5 Hydrography and biogeochemical sampling

3.5.1 CTD sampling

In total 86 CTD casts were carried out (Figure 12). Horizontal temperature and salinity maps for the survey area are provided for depths 5 m, 20, 40 and 60 m in Figures 13-16 respectively.

Surface waters were strongly influenced by the strong and persistent spell of clear and sunny weather experienced before during and after the survey. Thermocline depth varied by location but ranged between 20-45m across the spatial extent of the survey. Strong tidally mixed areas to the north of Ireland and those influenced by riverine inputs such as the River Shannon in the southwest of Ireland are visible as areas of cooler near surface conditions (Figure 14). At 50m depth cooler waters ring the Irish coastline and Celtic Sea (Figure 15) whereas warmer Atlantic origin water is visible to the west of Ireland and Scotland and denotes the boundary region of the Irish Shelf front. Seafloor temperatures show a similar pattern with a ring of cooler, less saline water ringing western Ireland and the Celtic Sea (Figure 16). Warmer, southern water masses in the Celtic Sea are clearly visible with near uniform seabed temperature along the west coast of Ireland and Scotland.

Comparing herring distribution with hydrographic conditions herring are observed in areas of cooler water (Figure 17). Salinity is variable for most areas where herring were located, but temperature was in the most part cooler than the surrounding area. The exception to this observation occurs in the southern Celtic Sea where a herring school was observed and identified (by trawling) in waters exceeding 11 °C at the seafloor.

For boarfish thermal preference appears as important as salinity (Figure 18). The greatest density of boarfish is aligned with full strength seawater and off the west coast this occurs on the oceanic side of the Irish Shelf Front. The pattern of distribution changes relative to temperature and depth along the west coast and Porcupine Bank where boarfish take a midwater position below the thermocline.

Horse mackerel (Figure 19) distribution appears to follow a similar pattern to that of boarfish in that full strength seawater is the preferred habitat with a variable temperature distribution profile from north to south.

3.5.2 CDOM measurements

CDOM sampling was undertaken at all of the 86 hydrographic stations during the survey. Analysis of samples is underway.

3.5.3 Nutrient sampling

Samples were collected from all of the 86 hydrographic stations during the survey. Analysis of samples is underway.

3.5.4 Pico/nano plankton sampling

Sampling of pico and nano plankton communities was carried out at all of the 86 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. Further analysis is currently on-going.

3.5.5 Hyperspectral analysis

3.5.6 Chlorophyll measurements

The frozen filters previously measured onboard for the QFT-1 measurements were analysed in the laboratory for chlorophyll a (b & c) concentrations after extraction with 90% acetone using a Telfon grinder and subsequent measurement of the solution absorbance using an Ocean Optics Flame spectrophotometer with a low volume 10 cm pathlength cell and DT-mini light source. The concentration of chlorophyll a was calculated using the trichromatic equation of Jeffrey and Humphrey (1975).

Generally good agreement was achieved between the satellite data collected data and data collected at sea (Figure 21). A more detailed analysis of this dataset will be conducted over the next few months.

3.6 Zooplankton biomass and jellyfish abundance

3.6.1 Zooplankton

Plankton samples were collected at 83 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) by station was higher overall than compared to the same time in 2016 (Figure 18). Zooplankton distribution, as determined from dry weight analysis, showed a relatively uniform distribution throughout the survey with little sign of the spatial patchiness observed in 2016. This defined difference between years is difficult to explain over such a short sampling time frame (2 successive years) but given the sampling effort and intensity this has the potential to provide important information on plankton distribution that was previous lacking.

3.6.2 Jellyfish

Preliminary data for this method are provided below. On leg 1, a total of 2,424 jellyfish were enumerated from visual surveys. The three most abundant species included the hydrozoan *Aqueora sp.* (1,235 observations), the ctenophore *Beroe sp.* (633 observations) and the pleustonic hydrozoan *Velella velella* (435 observations). The highly venomous lion's mane jellyfish *Cyanea capillata* was only spotted 19 times in the Celtic sea using this method. On the second leg, 2,577 jellyfish were observed in total. The most abundant was the cosmopolitan *Aurelia aurita* (1805 spotted), followed by the lion's mane jellyfish *C. capillata* (310) and the blue jellyfish *Cyanea lamarckii* (152 spotted). Further data processing will allow the quantitative description of surface jellyfish abundance along the cruise track line. Results are not available for other jellyfish methodologies as they require several months of laboratory analysis for taxonomic enumeration.

3.7 Marine mammals and seabirds

3.7.1 Visual abundance survey

In total, 272 hours and 18 minutes of survey effort was conducted over the course of the WESPAS 2018 survey, 132 hours and 45 minutes of survey effort was conducted on Leg 1, while 139 hours and 33 minutes of survey effort was conducted on Leg 2 of the survey. In total, 255 hours and 25 minutes of survey effort were conducted using a line transect methodology, while 16 hours and 52 minutes of effort were conducted using the point sampling methodology. Environmental data was collected a total of 1,698 times during the survey.

A total of 160 sightings, were recorded throughout the survey. This includes 47 sightings recorded as auxiliary sightings and 38 sightings recorded as incidental sightings. From the total 160 sightings, marine mammals accounted for 122 sightings. Decomposing marine mammal carcases were also sighted on two occasions. The remaining 36 sightings consisted of other marine megafauna. The marine mammal sightings included; 2 whale species, 6 dolphin species, 1 seal species, and a number of sightings which could not be identified to species level. Mixed species sightings were recorded on two separate occasions.

Of the 160 sightings, 159 were recorded while conducting line transects, while 1 was recorded while conducting point sampling. A list of the species encountered can be seen in Table 14, and the distribution of the sightings can be seen in Figures 22 & 23.

Minke whales (*Balaenoptera* acutorostrata) were the most frequently encountered species accounting for 39 sightings (24% of all sightings) comprising of 41 individuals in total.

Common dolphins (*Delphinus delphis*) were the second most frequently observed and most abundant species. Common Dolphins were encountered on 29 occasions, accounting for 18% of all sightings. These sightings consisted of a total of 436 individuals (46% of all encountered individuals).

The ocean sunfish (*Mola mola*) were the third most frequently encountered species, and the most frequently encountered species of marine megafauna excluding marine mammals. The sunfish were spotted on 25 separate occasions, accounting for 15% of all sightings. Each sighting consisted of a lone individual (3% of encountered individuals).

A number of elasmobranch species were encountered including; blue shark (*Prionace glauca*), porbeagle shark (*Lamna nasus*) and basking shark (*Cetorhinus maximus*). Leatherback turtles (*Dermochelys coriacea*) were encountered on two occasions.

3.7.2 Seabird abundance and distribution

The cumulative total of dedicated seabird survey effort during WESPAS 2018 comes to 156 hours and 16 minutes (9376 minutes) across 37 days. The cumulative total of individual seabirds recorded comes to 11151 of 26 species, of which 7,481 were noted as ‘off survey’ (outside of dedicated survey time or associating with the vessel, including during fishing operations point counts) and as such will be excluded from future analysis of abundance and density.

Leg 1: A total of 65 hours and 45 minutes (3,945 minutes) of dedicated seabird surveys was conducted across 18 days between 10th and 27th June 2018. A cumulative total of 4,434 individual seabirds of 18 species were recorded, of which 3,662 were noted as ‘off survey’ (Table 16).

Leg 2: A total of 90 hours and 31 minutes (5,431 minutes) of dedicated seabird surveys was conducted across 19 days between 4th and 23rd July 2018. A cumulative total of 6717 individual seabirds of 24 species were recorded, of which 3,819 were noted as ‘off survey’ (Table 16).

In addition, daily totals for six species of migrant terrestrial birds recorded on or around the vessel are also presented (Table 16).

4 Discussion and Conclusions

4.1 Discussion

The objectives of the survey were carried out successfully and as planned. Good weather conditions dominated during the survey allowing for extended marine mammal and seabird survey effort. No weather induced downtime was recorded.

Malin Shelf herring distribution was concentrated in an area to the west of the Hebrides in 6aN and in the southern and western Stanton Bank area in 6aS (Figure 3). There was an 18% increase in the SSB in 2018 compared to 2017 (O'Donnell et al 2017). There were good signs of young herring (1- and 2-wr fish) distributed in 6aS and in the area to the east and west of the Butt of Lewis in particular. 0-wr herring were found in the Minch, distributed near the surface in mixed schools that were dominated by 0-wr sprat. This was in contrast to 2016 and 2017 where there were relatively few herring observed south of 56°N in 6aS or 7b, c and no 0- and 1- wr fish. The age profile of survey samples in 2018 is encouraging in the context of cohort tracking for the assessment; 4 year old herring dominated the stock (30% in terms of biomass, and 22% in terms of abundance). The survey was dominated by 3-wr fish in 2017. In 2016, there was a much more even distribution of year classes. The CV estimate for the 2018 survey is lower than in 2017 (0.28 compared to 0.45); this is more comparable to previous years in the time-series.

The distribution of boarfish was comparable to 2017 and earlier years in the time series with the exception of the northern region. The northern distribution of the stock was observed to extend almost continuously, albeit it in low abundance, northward of 59°N north. Distribution was reported to continue up to 60°N as reported by the RV *Scotia*. Although important, these schools were not considered to be significant to the overall estimate. Overall, the acoustic density and number of echotraces of boarfish was lower than observed in 2017 for the same trawl and acoustic sampling effort. The age profile of dominant cohorts was different to 2017 and this is likely attributed to the use of an age length key to assign ages to biological samples rather than the aging of actual survey collected otoliths collected that year.

Horse mackerel were distributed in comparable regions along the Irish west coast, Porcupine Bank and Celtic Sea. Geographical distribution was thus comparable to previous surveys but the number and acoustic density of aggregations was lower than in 2017. That said the total stock estimate is more in line with 2016 than 2017. However, more years of survey effort are required for trends to emerge. The age composition of the stock in 2018 was strongly influenced by the 3 year old component, something not evident in 2017 as two year old fish. Seven and fourteen year class remain dominant.

Observations of Celtic Sea herring survey were continued in 2018. Combining RV and ASV platform effort allowed for a wider area to be covered. Acoustic inter-calibration of instruments from each platform allowed the data to be combined to produce an overall estimate of abundance. Containment issues still exist and thus limit the reliability of estimates of abundance for this stock. The stock identity of larger, older individuals in the southern survey area remains to be determined from genetic sampling. The presence of feeding herring around the Celtic Deep across years highlights the importance of this area to a portion of the stock throughout the summer and autumn period prior to the spawning migration.

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. The start of the survey coincided with the start of a prolonged period of hot and sunny weather. Thermocline depth ranged from 20-55m depending on location, with the lower limit observed areas with strong tidal mixing. Below the thermocline and at seafloor, Ireland appeared to be ringed by an area of cool water close to the coast with a district boundary front. Seafloor temperatures along the shelf area on the oceanic side of the front appeared almost uniform along the west coast of Ireland and Scotland with temperatures over 10 °C in the northernmost latitudes. Interestingly herring were encountered only within the cool water ribbon to the west of Scotland and not in the warmer regions. Boarfish and horse mackerel, as open ocean species, were primarily distributed in full seawater conditions and on the oceanic side of the Irish shelf front regardless of temperature or latitude.

4.2 Conclusions

- Malin Shelf herring biomass was ~18% higher in 2018 compared to 2017 (SSB_{2018} =130,000 t; SSB_{2017} = 107,000 t). The CV on the survey was lower in 2018 (0.28) when compared with 2017 (0.46); the CV in 2018 is comparable to previous years in the time series
- Malin Shelf herring TSB (total stock biomass) and abundance (TSN) estimates were 183,188 t and 1,698,300,000 individuals respectively
- Herring were distributed further south in 2018 compared to 2017, with some herring south of 56°N, particularly young fish (1- and 2-wr). There was very little herring distributed south of 56°N in both 2016 and 2017.
- The dominant age class of herring in the 2018 survey was 4-wr fish (30% TSB, and 22% TSN). This compares well with the 2017 survey, showing good cohort tracking; the dominant age class in the 2017 survey was 3-wr fish (43% TSB).
- The three most dominant year classes of herring were 2-, 4- and 5-wr fish and together represented over 63% of the TSB in 2018.The three most dominant year classes in 2017 were 3-, 4- and 6-wr fish, representing over 78% of the TSB.
- 1-wr herring were found in the survey for the first time since 2015. There were also 0-wr herring found mixed in surface schools of sprat in the Minch.
- Herring were found in very small numbers off the west coast of Ireland for the first time in many years on this survey.
- Boarfish distribution showed a similar pattern to previous years. The number of schools and acoustic density was lower than in 2017.
- Boarfish TSB (total stock biomass) and abundance (TSN) estimates were 186,252 t and 3,221,110,000 individuals (CV 19.9%) respectively.
- The northern distribution of boarfish continued north of the Hebrides outside of the core survey area and schools were observed the RV *Scotia*. However, it is important to note that the number and acoustic density were considered low.
- Horse mackerel biomass is considered a reliable estimate of the standing stock in 2018 given comparable survey effort and area coverage. Improvements are required to ensure greater containment in the southern boundary and western approaches to the Channel.
- Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 92,931 t and 540,422,000 individuals (CV 36.8%) respectively.
- The positive influence of the 3 year class of horse mackerel is notable.
- Celtic Sea herring were observed around the banks in the eastern Celtic Sea as well as in the mid Celtic Sea. The size and age of schools observed, although low in number were notably different. Containment remains an issue for reliable estimates abundance during this survey. However, it is intended that this will be further developed to provide an additional measure of this stock.

5 Recommendations

- Continuation of the south to north work flow to align with surveys in the south (PELGAS- France) and north (HERAS- Scotland) and provide synoptic estimates of abundance for a multiple species.

- Real time aging of horse mackerel survey samples to provide within year age estimates of survey data.

- Research the possibility of egg counts from plankton samples (WP2) as a means to track spawning, and peak spawning events by geographic region for boarfish and horse mackerel.

- To further develop this survey more ship-time is required. As the survey is observing not only target species for the focal component but also the distribution of other species that are also surveyed during the year, specifically Celtic Sea herring.

- Westward extension of some transects in the northwest of the survey area to ensure boarfish stock containment. This may also require some extra survey days.

6 Acknowledgements

We would like to thank Captains Denis Rowan and Anthony Hobin and the crew of the Celtic Explorer for their help and professionalism during the survey. Many thanks also to the seabird and marine mammal survey teams, who worked tirelessly during the survey in all weathers and with great enthusiasm.

7 References

Camphuysen, K. J., Fox, A. D., Leopold, M. F. and Petersen, I. K. 2004. Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the U.K.: a comparison of ship and aerial sampling methods for marine birds, and their applicability to offshore wind farm assessments, NIOZ report to COWRIE (BAM – 02-2002), Texel, 37pp.

Dalen, J. and Nakken, O. 1983. “On the application of the echo integration method” ICES CM 1983/B:19

Demer, D. A., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., Domokos, R., *et al*. 2015. Calibration of acoustic instruments. ICES Cooperative Research Report No. 326.

Fässler, S. M. M., O'Donnell, C. and Jech, J. M. 2013; Boarfish (*Capros aper*) target strength modelled from magnetic resonance imaging (MRI) scans of its swimbladder, *ICES Journal of Marine Science*, 70(7):1451–1459.

Foote, K.G. 1987. Fish target strengths for use in echo integrator surveys. *J. Acoust. Soc. Am.* 82: 981-987

García-Robledo, E., Corzo, A. and Papaspyrou, S., 2014. A fast and direct spectrophotometric method for the sequential determination of nitrate and nitrite at low concentrations in small volumes. Marine Chemistry, 162(0): 30-36.

Hall, M.E., O’Connor, I., Breen, D., McGeehan, A., Hunt, J., Borawska, A., Meade, R., Groth, L., & Tierney, D. (in press) Distribution of seabirds at sea during the Cetacean on the Frontier scientific cruises August 2009 and February 2010. Irish Wildlife Manuals, National Parks and Wildlife Service, Department of Arts Heritage and the Gaeltacht, Dublin, Ireland.

Heinemann, D. 1981. A Range Finder for Pelagic Bird Censusing. Journal of Wildlife Management 45(2): 489-493.

ICES 1994. Report of the Study Group on Herring Assessment and Biology in the Irish Sea and Adjacent Waters. ICES CM 1994/H :5. 67pp.

ICES 2010. Report of the Study Group on the evaluation of assessment and management strategies of the western herring stocks (SGHERWAY). ICES CM 2010\SSGSUE:08, 194 pp.

ICES. 2015. Manual for International Pelagic Surveys (IPS). Series of ICES Survey Protocols SISP 9 – IPS. 92 pp.

ICES 2016. First Interim Report of the Working Group of International Pelagic Surveys WGIPS). ICES CM SSGIEOM/05, 433 pp.8

IFAW 2000. Logger 2000 software. International Fund for Animal Welfare, London.

Irish Rare Bird Committee (2012) The Irish Bird List. www.irbc.ie/topbar/IrishList/IRBC_IrishList(31122012).pdf (accessed October 2014).

IWDG 2009. Irish Whale and Dolphin Group sightings database (Republic of Ireland and Northern Ireland). www.iwdg.ie/Iscope (accessed April 2013).

Jolly, G. M., and I. Hampton. 1990. A stratified random transect design for acoustic surveys of fish stocks. Canadian Journal of Fisheries and Aquatic Sciences 47(7): 1282-1291.

Komdeur, J., Bertelsen, J. & Cracknell, G. (ed.) 1992. *Manual for Aeroplane and Ship surveys of Waterfowl and Seabirds*. IWRB Special Publication No. 19, Ministry of the Environment, National Environmental Research Institute, Department of Wildlife Ecology, Kalø, Denmark.

Koroleff, I., 1976. Analysis of micronutrients. In: K. Grashoff (Editor), Methods of Sea-water Analysis. Verlag-Chimie, New York.

Mackey, M., Ó Cadhla, O., Kelly, T.C., Aguilar de Soto, N. and Connolly, N. 2004. *Cetaceans and Seabirds of Ireland"s Atlantic Margin. Volume 1 – Seabird distribution, density and abundance*. Report on research carried out under the Irish Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6 and 00/13, Porucpine Studies Group project P00/15 and Offshore Support Group (OSG) project 99/38. University College Cork.

Marie, D., Partensky, F., Jacquet, S. and Vaulot, D., 1997. Enumeration and Cell Cycle Analysis of Natural Populations of Marine Picoplankton by Flow Cytometry Using the Nucleic Acid Stain SYBR Green I. Applied and Environmental Microbiology.

Marie, D., Rigaut-Jalabert, F. and Vaulot, D., 2014. An improved protocol for flow cytometry analysis of phytoplankton cultures and natural samples. Cytometry Part A, 85(11): 962-968.

Mitchell, B.G., 1990. Algorithms for determining the absorption coefficient for aquatic particulates using the quantitative filter technique, pp. 137-148.

Murphy, J. and Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta, 27: 31-36.

O'Donnell, C., Griffin, K., Lynch D., Ullgren J., Goddijn L., Wall D. & Mackey M. (2004).Celtic Sea Herring Acoustic Survey Cruise Report, 2004. http://hdl.handle.net/10793/679

O'Donnell, C., Egan, A., Lynch, D., Boyd, J., Wall, D. & Goddjin, L., "Northwest Herring Acoustic Survey Cruise Report and Abundance Estimate, 2007", FSS Survey Series, Marine Institute 2007. http://hdl.handle.net/10793/295

O'Donnell, C., Farrell, E., Saunders, R. & Campbell, A. "Boarfish Acoustic Survey Report 07 July – 28 July, 2011", Marine Institute 2011. http://hdl.handle.net/10793/675

O'Donnell, C., O'Malley, M., Mullins, E., Lynch, D., Keogh, N., and O'Sullivan, C. (2017). Western European Shelf Pelagic Acoustic Survey (WESPAS) 06 June - 21 July, 2017. FEAS Survey Series: 2017/03. Marine Institute. http://hdl.handle.net/10793/1326

Pollock, C.M., Reid, J.R., Webb, A., and Tasker, M.L. 1997. *The distribution of seabirds and cetaceans in the waters around Ireland*. JNCC Report No. 267

Rose, J.M., Caron, D.A., Sieracki, M.E. and Poulton, N., 2004. Counting heterotrophic nanoplanktonic protists in cultures and aquatic communities by flow cytometry. Aquatic Microbial Ecology, 34(3): 263-277.

Schnetger, B. and Lehners, C., 2014. Determination of nitrate plus nitrite in small volume marine water samples using vanadium(III)chloride as a reduction agent. Marine Chemistry, 160: 91-98.

Tasker, M.L., Jones, P.H., Dixon, T., & Blake, B.F. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardised approach. Auk 101: 567-577.

8 Tables and Figures

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

Echo Sounder System Calibration Report

Vessel :	RV Celtic Explorer		Date :	10.06.18	
Echo sounder :	Drop Keel		Locality :	Dunmanus Bay	
Type of Sphere :	WC 38.1	TS_{Sphere}: -42.2 dB	Depth(Sea floor) :	36 m	

Calibration Version 2.1.0.12

Comments:
Dunmanus Bay Survey Start

Reference Target:

TS	-42.2 dB	Min. Distance	18.0m
TS Deviation	5 dB	Max. Distance	22.0m

Transducer: ES38B Serial No.

Frequency	38000 Hz	Beamtype	Split
Gain	26.65 dB	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	7.09 deg	Along. Beam Angle	7.03 deg
Athw. Offset Angle	-0.01 deg	Along. Offset Angl	-0.05 deg
SaCorrection	-0.58 dB	Depth	8.80 m

Transceiver: GPT 38 kHz 009072033933 1 ES38B

Pulse Duration	1.024 ms	Sample Interval	0.190 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	Max. Echolength	180%

Environment:

Absorption Coeff.	10.2 dB/km	Sound Velocity	1481.5 m/s

Beam Model results:

Transducer Gain =	25.29 dB	SaCorrection =	-0.60 dB
Athw. Beam Angle =	7.04 deg	Along. Beam Angle	6.97 deg
Athw. Offset Angle =	-0.02 deg	Along. Offset Angl	-0.06 deg

Data deviation from beam model:
RMS = 0.23 dB
Max = 0.79 dB No. = 237 Athw. = 2.8 deg Along = 3.3 deg
Min = -0.74 dB No. = 212 Athw. = -3.7 deg Along = -0.4 deg

Data deviation from polynomial model:
RMS = 0.22 dB
Max = 0.74 dB No. = 211 Athw. = -4.8 deg Along = -0.6 deg
Min = -0.70 dB No. = 212 Athw. = -3.7 deg Along = -0.4 deg

Comments :
SE wind F3, strong tide
Wind Force : F4 **Wind Direction :** N
Raw Data File: C:\Program files\Simrad\Scientific\EK60\Data\Calibration\WESPAS 2018\Drop Keel
Calibration File: C:\Program files\Simrad\Scientific\EK60\Data\Calibration\WESPAS 2018\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	11.06.18	50.34	-7.25	10:58	104	104	450	4.5	1.8	13.9	0.2	79.6
2	13.06.18	47.72	-6.60	10:01	170	150	109	2.3			51.9	45.8
3	14.06.18	48.23	-8.57	13:50	174	174	235	39.4	3.3			57.3
4	14.06.18	48.23	-7.91	19:14	180	180-155	193	86.5			13.0	0.5
5	15.06.18	48.47	-6.27	11:04	130	130	225		14.5		71.4	14.1
6	16.06.18	48.48	-9.50	08:36	184	184-160	600	84.7			2.3	13.0
7	16.06.18	48.73	-8.98	17:51	160	160-120	160	99.6			0.2	0.3
8	17.06.18	48.99	7.58	05:27	146	125-100	27		30.1	5.4	53.3	11.2
9	17.06.18	49.00	-7.49	07:28	134	134-110	172	94.7	0.5	0.5		4.3
10	18.06.18	49.24	-10.98	10:00	173	173-153	85	79.7			0.4	19.9
11	18.06.18	49.24	-10.48	13:57	143	125-100	700	99.1	0.7		0.3	0.0
12	19.06.18	49.49	-8.90	18:01	124	85-60	79	99.7				0.3
13	20.06.18	49.75	-10.46	13:26	139	30-50	400		83.9		16.1	0.0
14	21.06.18	50.00	-8.53	15:50	131	131-115	235		0.3			99.7
15	22.06.18	50.25	-10.46	09:47	143	100-75	300	87.5	2.0		9.8	0.8
16	22.06.18	50.25	-9.29	16:51	132	132	3,000		3.6			96.4
17	23.06.18	50.50	-7.73	10:05	107	90	145		1.9	11.2		86.9
18	24.06.18	50.75	-9.75	09:58	115	85-65	3		6.7			93.3
19	25.06.18	50.86	-6.53	15:55	93	80-60	650					100.0
20	27.06.18	51.76	-10.98	11:20	158	75	7		43.4		24.6	32.0
21	04.07.18	52.51	-10.89	11:06	127	100-127	80	0.3		1.6		98.1
22	05.07.18	53.01	-10.74	05:23	130	125-130	51	0.6		0.2		99.2
23	05.07.18	53.26	-11.43	17:06	146	125-145	7	37.1	53.0		6.5	3.4
24	06.07.18	53.51	-11.41	06:17	175	50-100	1,000	91.0	0.2		8.8	0.0
25	08.07.18	53.51	-13.72	05:40	210	60-90	1,000	93.8	6.0			0.2
26	09.07.18	54.01	-10.82	08:20	183	75-100	1,500	95.6		0.6	3.5	0.3
27	09.07.18	54.26	-10.36	15:33	100	75-100	500		0.1			99.9
28	10.07.18	54.76	-10.31	11:51	125	100-125	171	73.0	17.6	0.1	0.1	9.2
29	10.07.18	55.02	-10.01	16:59	115	75-115	1,500	95.9	0.5		1.3	2.2
30	11.07.18	55.52	-9.01	13:30	100	80-100	182	10.4	0.3	0.1	9.4	79.7
31	11.07.18	55.52	-7.71	20:07	65	40-65	12					100.0
32	12.07.18	55.54	-7.77	04:46	69	20-40	4,000			99.0		1.0
33	13.07.18	55.77	-9.14	09:15	134	110-134	160	59.8	8.1		29.2	2.8
34	13.07.18	56.02	-8.58	14:32	145	125-145	29		8.8	23.7		67.6
35	14.07.18	56.52	-8.66	19:34	140	120-140	306		35.4	64.5		0.1
36	15.07.18	56.77	-8.71	12:56	122	115-122	8					100.0
37	16.07.18	57.27	-8.52	07:42	144	115-140	117		7.7	90.3		2.1
38	16.07.18	57.52	-9.23	16:16	180	90-110	139	99.5			0.3	0.2
39	17.07.18	57.77	-8.89	11:20	152	110-152	1,250		0.9	97.5		1.6
40	19.07.18	58.54	-7.25	06:21	97	50-100	320		55.7	35.5		8.8
41	19.07.18	58.54	-5.64	12:36	140	120-140	500			0.8		99.2
42	20.07.18	57.30	-6.30	15:51	81	0-40	84			7.2		92.8

Table 3. Malin Shelf herring stock estimate 2018 (6aS, 7bc and 6aN (south of 58°30'N).

	Age (years)													Numbers	Biomass	Mn Wt	Mature
Length	0	1	2	3	4	5	6	7	8	9	10	11	12+	(*10-3)	(t)	(g)	(%)
5.5	9586	-	-	-	-	-	-	-	-	-	-	-	-	9586			0
6	61349	-	-	-	-	-	-	-	-	-	-	-	-	61349			0
6.5	115030	-	-	-	-	-	-	-	-	-	-	-	-	115030			0
7	49846	-	-	-	-	-	-	-	-	-	-	-	-	49846			0
7.5	24923	-	-	-	-	-	-	-	-	-	-	-	-	24923			0
8	-	-	-	-	-	-	-	-	-	-	-	-	-	0			0
8.5	3834	-	-	-	-	-	-	-	-	-	-	-	-	3834			0
9	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
9.5	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
10	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
10.5	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
11	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
11.5	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
12	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
12.5	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
13	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
13.5	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
14	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
14.5	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
15	|	-	-	-	-	-	-	-	-	-	-	-	-	0			0
15.5	|	1284	-	-	-	-	-	-	-	-	-	-	-	1284			0
16	|	8068	-	-	-	-	-	-	-	-	-	-	-	8068	291.9	36.18	0
16.5	|	26772	-	-	-	-	-	-	-	-	-	-	-	26772	1086.5	40.58	0
17	|	53633	-	-	-	-	-	-	-	-	-	-	-	53633	2226.4	41.51	0
17.5	|	53062	-	-	-	-	-	-	-	-	-	-	-	53062	2444.5	46.07	0
18	|	54239	-	-	-	-	-	-	-	-	-	-	-	54239	2786.7	51.38	0
18.5	|	65759	-	-	-	-	-	-	-	-	-	-	-	65759	3659.5	55.65	0
19	|	42590	2462	-	-	-	-	-	-	-	-	-	-	45052	2719.2	60.36	0
19.5	|	34646	-	-	-	-	-	-	-	-	-	-	-	34646	2239.5	64.64	0
20	|	36564	6611	-	-	-	-	-	-	-	-	-	-	43175	3106.6	71.95	0
20.5	|	6091	30269	-	-	-	-	-	-	-	-	-	-	36360	2738.8	75.33	0
21	|	11286	17917	-	-	-	-	-	-	-	-	-	-	29203	2446.8	83.79	19
21.5	|	1774	31122	-	-	-	-	-	-	-	-	-	-	32896	3113.3	94.64	9
22	|	-	35701	-	-	-	-	-	-	-	-	-	-	35701	3589.5	100.54	0
22.5	|	-	47818	-	-	-	-	-	-	-	-	-	-	47818	4918.8	102.87	5
23	|	-	68001	2450	-	-	-	-	-	-	-	-	-	70451	7887.3	111.96	29
23.5	|	-	50475	9823	-	-	-	-	-	-	-	-	-	60298	7085.4	117.51	17
24	|	-	27927	6372	1398	1774	-	-	-	-	-	-	-	37471	4856.1	129.6	87
24.5	|	-	7759	12698	7142	-	-	-	-	-	-	-	-	27599	3666.9	132.86	75
25	|	-	10460	9250	22271	-	-	-	-	-	-	-	-	41981	5858.5	139.55	83
25.5	|	-	2647	21656	28277	5083	-	-	-	-	-	-	-	57663	8625.1	149.58	93
26	|	-	-	27383	48058	6585	820	-	-	-	-	-	-	82846	13087.2	157.97	100
26.5	|	-	-	13555	47902	19485	-	-	-	-	-	-	-	80942	14073.8	173.88	99
27	|	-	-	3188	60333	37803	1074	-	-	-	-	-	-	102398	18567.3	181.32	98
27.5	|	-	-	3189	48507	24002	-	9136	-	-	-	-	-	84834	15988.6	188.47	100
28	|	-	-	2891	29339	24105	11430	10544	3147	-	-	-	-	81456	16328.3	200.45	100
28.5	|	-	-	-	12064	12537	13657	11194	3259	2015	-	-	-	54726	11331.5	207.06	100
29	|	-	-	-	6211	6164	6759	15670	3431	1229	1282	-	-	40746	8887.9	218.13	100
29.5	|	-	-	-	2632	-	9982	8982	5535	-	-	-	-	27131	6081	224.13	100
30	|	-	-	-	-	-	-	3998	1414	4920	-	-	-	10332	2291.8	221.84	100
30.5	|	-	-	-	-	-	-	-	-	-	-	3511	-	3511	793.6	226	100
31	|	-	-	-	-	-	-	-	-	-	-	602	-	602	133	221	100
32	|	-	-	-	-	-	-	-	-	-	-	1038	-	1038	276.2	266	100
TSN (1000)	264568	395768	339168	112454	314133	137539	43721	59524	16786	8164	1282	5151		1698261			
TSB (t)		21464.2	35763	17223.8	54787.7	25648.5	9149.3	12289	3591.5	1786.1	281.4	1202.8			183187.5		
Mean length (cm)		18.3	22.54	25.44	26.71	27.28	28.59	28.64	28.96	29.48	29	32					
Mean weight (g)		54.41	105.44	153.16	174.41	186.48	209.27	206.46	213.96	218.78	219.6	266				127.89	
SSB (t)		307.03563	7789.5909	14571.6424	53387.77	25216	9149.49	12289	3591.5	1786.1	281.53	1370.2			129740		
% mature		1	22	85	97	98	100	100	100	100	100	100					

Table 4. Malin Shelf herring survey time series 2008-2018. Survey coverage: - ^ 6aS & 7bc; * 6aS, 6aN & 7b; ** 6a & 7bc; ***6aS, 7bc & 6aN (south of 58°30'N).

Age	2008^	2009^	2010*	2011*	2012*	2013*	2014*	2015**	2016*	2017***	2018***
0	-	-	-	-	-	-	-	-	-	-	264.6
1	6.1	416.4	524.8	82.1	608.3	-	1,115.4	4.9	-	-	395.8
2	75.9	81.3	504.3	202.5	451.5	96.2	214.7	162.1	9.7	11.0	339.2
3	64.7	11.4	133.3	752.0	444.6	254.3	166.3	291.7	102.3	273.4	112.5
4	38.4	15.1	107.4	381.0	516.1	265.8	380.0	580.7	91.4	111.0	314.1
5	22.3	7.7	103.0	110.8	180.3	78.7	352.1	487.3	91.4	71.6	137.5
6	26.2	7.1	83.7	124.0	115.4	26.9	125.0	513.4	58.2	94.4	43.7
7	9.1	7.5	57.6	118.4	116.9	18.5	18.9	143.9	46.5	28.0	59.5
8	5.0	0.4	35.3	70.7	83.8	10.8	9.7	33.4	2.7	9.9	16.8
9	3.7	0.9	17.5	41.6	56.3	4.1	4.7	-	0.5	2.6	8.2
10+	-	-	-	25.6	42.0	1.2	-	8.3	-	-	6.4
TSN (mil)	251.4	547.7	1,566.9	1,908.7	2,615.0	756.6	2,386.8	2,225.5	402.8	601.8	1,698.3
TSB (t)	44,611.0	46,460.0	192,979.0	313,305.0	397,797.0	118,946.0	294,200.0	449,343.0	70,745.0	107,900.0	183,187.5
SSB (t)	43,006.0	20,906.0	170,154.0	284,632.0	325,835.0	92,700.0	200,200.0	425,392.0	69,269.5	106,657.0	129,740.0
CV	34.2	32.2	24.7	22.4	22.8	21.5	28.6	28.6	31.3	46.6	28.3

Table 5. Malin Shelf herring spawning stock biomass and abundance by strata 2018

Strata	Name	Area (nmi^2)	Transects	Abundance ('000)	Bio (t)
1	Minches	3105	9	318989	2,494
2	W Hebrides	6148	7	657518	108,588
3	SW Hebrides	5030	4	233196	36,301
4	NW Coast	2251	2	0	0
5	W Coast	10212	12	9731	750
6	N Malin	3102	2	477546	35053.9
	Total	29,847	36	1,696,980	183,186

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+	Unknown	Numbers (000's)	Biomass (t)	Mn Wt (g)	Mature (%)
5	25.2																12612	25.2	2	0
5.5	18.9																6306	18.9	3	0
6																				
6.5	113.5																18918	113.5	6	0
7	253.8																32514	253.8	8	0
7.5	50.4																6306	50.4	8	0
8		239.3															20016	239.3	12	0
8.5		72.4	438.9														36738	511.3	14	0
9			543.8														34446	543.8	16	0
9.5			400.2														21652	400.2	18	0
10		96.7	287.8														18384	384.5	21	100
10.5			381.2	275.7													25384	656.9	26	100
11				1515.1	863.7												82695	2378.8	29	100
11.5				210.3	1465	3350.5											153631	5025.9	33	100
12					770.4	1107	3344.9	73.8									143938	5296.1	37	100
12.5					442.7	754.7	3167.9	1876.2									148018	6241.5	42	100
13						603	4236	3415.3	568.5	215.3							185259	9038.1	49	100
13.5							3788.2	3950.8	7993.9	75.8							301310	15808.7	52	100
14								87.2	7087.2	17155.4	106.4				76.6		425790	24512.7	58	100
14.5								260.5	370.7	20311.9	2791.8	3049.2	1439.7	1135.9	1945.8		485278	31305.4	65	100
15										302.2	21042.2	536.9	2878.6	2785.5	5245.7		458932	32791.1	71	100
15.5												16500.5			7485.5		305973	23986	78	100
16													11599.3		4459.8		187800	16059.1	86	100
16.5														5610.4	1932.8		80135	7543.2	94	100
17															2617.7		25313	2617.7	103	100
17.5																275.2	2572	275.2	107	100
18																				
18.5																				
19																				
19.5															19.6		297	19.6	66	100
20																				
20.5															155.3		892	155.3	174	100
TSN (10^{-3})	76655	31222	115019	68265	106679	165920	320741	197749	293448	624683	339214	264184	198415	116492	299850	2572	3221110			
TSB (t)	461.9	408.4	2051.9	2001.1	3541.8	5815.2	14537	9663.8	16020.2	38060.6	23940.5	20086.5	15917.6	9531.8	23938.8	275.2		186252		
Mean length (cm)	6.47	8.4	9.28	10.97	11.54	11.83	12.72	13.11	13.71	14.25	14.93	15.31	15.63	15.7	15.57	17.5				
Mean weight (g)	6.03	13.08	17.84	29.31	33.2	35.05	45.32	48.87	54.59	60.93	70.58	76.03	80.22	81.82	79.84	107			57.82	
% mature*	0	24	33	100	100	100	100	100	100	100	100	100	100	100	100	100				
SSB	0.0	96.7	669.0	2001.1	3541.8	5815.2	14537.0	9663.8	16020.3	38060.6	23940.4	20086.6	15917.6	9531.8	23938.8	275.2	184235.0			

Table 7. Boarfish biomass and abundance by strata.

Name	Area (nmi^2)	Transects	Abun ('000)	Bio (t)
W Hebrides	4,690.8	8	274,422	17,407
S Hebrides	1,980.8	4	146,345	7,361
W Coast	14,726.6	20	908,062	50,201
Porcupine Bk	5,734.6	6	365,017	27,824
Celtic Sea	26,626.7	16	1,422,426	78,530
Celtic Deep	2,644.2	8	104,837	4,929
Total	56,403.7	62	3,221,109	186,252.2

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

Age (Yrs)	2011	2012	2013	2014	2015	2016	2017	2018
0	-	-	-	-	-	-	-	-
1	5.0	21.5	-	-	198.5	4.6	110.9	76.7
2	11.6	10.8	78.0	-	319.2	35.7	126.7	31.2
3	57.8	174.1	1,842.9	15.0	16.6	45.5	344.6	115
4	187.4	64.8	696.4	98.2	34.3	43.6	367.3	68.3
5	436.7	95.0	381.6	102.3	80.0	6.0	156.0	106.7
6	1,165.9	736.1	253.8	104.9	112.0	10.0	209.0	165.9
7	1,184.2	973.8	1,056.6	414.6	437.4	169.0	493.1	320.7
8	703.6	758.9	879.4	343.8	362.9	112.6	468.3	197.7
9	1,094.5	848.6	800.9	341.9	353.5	117.6	397.2	293.4
10	1,031.5	955.9	703.8	332.3	360.0	96.6	285.8	624.7
11	332.9	650.9	263.7	129.9	131.7	17.0	120.9	339.2
12	653.3	1,099.7	202.9	104.9	113.0	32.0	82.1	264.1
13	336.0	857.2	296.6	166.4	174.0	48.7	74.4	198.4
14	385.0	655.8	169.8	88.5	108.0	18.3	220.4	116.5
15+	3,519.0	6,353.7	1,464.3	855.1	1,195.0	400.1	931.0	302.4
TSN (10^{-3})	11,104	14,257	9,091	3,098	3,996	1,157	4,387	3,221
TSB (t)	670,176	863,446	439,890	187,779	232,634	69,690	223,860	186,252
SSB (t)	669,392	861,544	423,158	187,654	226,659	69,103	218,810	184,235
CV	21.2	10.6	17.5	15.1	17.0	16.4	21.9	19.9

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	Unknown	(000's)	(t)	(g)	(%)
11																							125			0
12																										
13																						5.5	262	5.5	21	0
14																						7.3	262	7.3	28	0
15																										
16																										
17		49.4																					1048	49.4	47.11	0
18																						22.9	441	22.9	52	0
19	63.2	113.1																					2830	176.3	62	0
20		351.9																					4363	351.9	81	100
21		1441.8																					16587	1441.8	87	50
22		4289	422.5																				46985	4711.5	100	81
23		592.9	10029	70.4																			95236	10692.6	112	91
24		51.6	10579	768.4	222.3																		93979	11621	124	98
25			8366.6	1201.8	50.8	75.2																	70202	9694.4	138	93
26			291.7	5889.6	356.1																		41741	6537.4	157	98
27			48.6	5199.5	490.7	517.4	223.1	69.7															36858	6549	178	100
28			257.2	477.9	258.4	276.5	1349.5																13507	2619.5	194	100
29					338.7	271.9	782.1	99.8															6695	1492.4	223	100
30					171.9	168.8	2488.5																11400	2829.3	248	100
31						59.8	1798.1																7110	1857.9	261	100
32						187.3	2457.4	487.3				170.6											11246	3302.5	294	100
33							921.6	851.5	53.5		166.5	209.9		383.8									8166	2586.8	316.78	100
34							2605.3	2868.1	1543.8			2008.2	2145	2277.7									39210	13448.1	342.98	100
35							818				305.3			639.8									4682	1763.1	376.56	100
36										610.5		132	30.3	4422.4									13878	5195.1	374.33	100
37									2186.2		77.4		855.9	2202.9									12325	5322.4	431.84	100
38														83.5									203	83.5	411	100
39														196.9									394	196.9	499.95	100
40														209.8									425	209.8	494	100
41																	164						262	163.5	624	100
42																										
TSN (10^{-3})	1015	72408	243280	85252	10495	7562	49329	13338	10047	1511	1547	7356	8462	27469			262					1090	540422			
TSB (t)	63.2	6889.6	29995	13608	1888.9	1556.9	13444	4376.4	3783.5	610.5	549.1	2520.6	3031.2	10417			164					35.8		92931.9		
Mean length (cm)	19	21.59	23.89	26.14	26.82	28.17	31.07	33.18	35.57	36	34.56	33.84	34.69	35.62			41					15				
Mean weight (g)	62.29	95.15	123.29	159.61	179.98	205.88	272.53	328.1	376.59	404	355.09	342.69	358.22	379.23			624					37			172	
% mature*	0	75	94	98	99	100	100	100	100	100	100	100	100	100			100					0				
SSB	0	5,137	28,209	13,384	1,874	1,552	13,444	4,376	3,784	611	549	2,521	3,031	10,417			164					0	89050.4			

Table 10. Horse mackerel biomass and abundance by strata.

Name	Area (nmi²)	Transects	Abun ('000)	Bio (t)
W Hebrides	4,690.8	8	2,800	356
S Hebrides	1,980.8	4	1,116	141.8
N Stanton	1,522.3	3	9,552	1212.9
S Stanton	2,323.8	5	7,917	1003.1
W Coast	14,726.6	20	323,584	53,733
Porc Bank	5,734.6	6	14,689	3,043
Celtic Sea	26,626.7	17	176,882	32,727
Celtic Deep	2,121.5	8	3,884	715
Minch	1,557.6	9	-	-
Total	61,284.8	80	540,424	92,932

Table 11. Horse mackerel survey time series.

Age (Yrs)	2016	2017	2018
0	-	-	-
1	1.1	11.7	1.015
2	100.2	181.8	72.408
3	4.9	147	243.28
4	43.5	45.4	85.252
5	19.0	16.2	10.495
6	7.6	46	7.562
7	40.6	113	49.329
8	66.6	67.7	13.338
9	8.5	25.4	10.047
10	1.8	33.2	1.511
11	9.5	32.6	1.547
12	10.6	37.7	7.356
13	4.7	37.6	8.5
14	21.1	160.8	27.5
15	6.5	8.6	-
16	1.6	5.2	-
17	5.3	-	0.262
18	-	-	-
19	-	-	-
20	-	-	-
21	1.1	-	-
TSN (10^{-3})	354.5	969,655	540,422
TSB (t)	69,267	228,116	92,931.90
SSB (t)	65,194	227,395.6	89,050.40
CV	42.0	25.5	36.8

Table 12. Celtic Sea herring stock estimate.

Length (cm)	Age (years) 1	2	3	4	5	6	7	8	9	10	11	Unknown	Numbers (10^{-3})	Biomass (t)	Mn Wt (g)	Mature (%)
11.5																
12																
12.5																
13																
13.5																
14																
14.5																
15																
15.5																
16																
16.5																
17																
17.5																
18																
18.5																
19																
19.5																
20																
20.5																
21																
21.5												10.6	125	10.6	85	0
22			63.4										689	63.4	92	0
22.5			43.2	46.4									961	89.6	93	0
23		12.6	108.7		19.6								1377	140.9	102	66
23.5			102.5	120.6	13.9								2321	237	102	69
24			83.5	201.3	25.5								2701	310.4	115	81.25
24.5			136.1	165.8	222.5								4198	524.4	125	85
25				193.4	133.7								2517	327.1	130	85.72
25.5			34.7	142.7	170.7	163.7							3661	511.9	140	95
26			928.8	6.8	271.8	62.3	48.9	27.7					9020	1346.4	149	100
26.5				56.7	3441.4	164.8	109.5	104.3	82.4				24521	3959	161	100
27				768	3871	57.3	277.3	105.4	24.3				29398	5103.3	174	100
27.5					1757.9	1634.3	258.2	45.7	15.7				20481	3711.8	181	100
28					1218.6		102.1	45.4	43.6				7375	1409.6	191	100
28.5						1253	91.3						6656	1344.3	202	100
29							1334						6234	1334	214	100
29.5				2292.2									10059	2292.2	228	100
30									29.6				125	29.6	236	100
30.5																
31																
31.5																
TSN (10^{-3})		125.0	11556.0	22209.0	65532.0	18550.0	11243.0	1971.0	1107.0			125	132419			
TSB (t)		12.6	1501.0	3993.8	11146.8	3335.3	2221.3	328.5	195.5			10.6		22745.5		
Mean length (cm)		23.0	24.8	27.2	26.8	27.6	28.2	27.0	27.3			21.5				
Mean weight (g)		101.0	129.9	179.8	170.1	179.8	197.6	166.7	176.6			85			171.77	
% mature*		66	86	95	99	100	100	100	100							
SSB ('000 t)		8.3	1287.3	3811.7	11069.3	3326.4	2221.3	328.5	195.6				22248.5			

Table 13. Celtic Sea herring total stock biomass and total abundance by strata.

Name	Area (nmi²)	Transects	Abun ('000)	Bio (t)
Celtic Sea	26,626.7	15	99,738	18,175
C Deep/NW Bank	2,644.2	11	32,681	4,570
Total	29,270.9	26	132,419	22,745.5

Table 14. Marine mammal and megafauna sightings, counts and group size ranges for cetaceans sighted during the survey (includes on and off effort).

Common Name	Species name	No. of Sightings	No. of individuals	Group Size
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	1	3	3
Bottlenose dolphin	*Tursiops truncatus*	5	105	8-45
Common dolphin	*Delphinus delphis*	28	336	2-50
Common/ striped dolphin	*D. delphinus/ S. coeruleoalba*	1	1	1
Humpback whale	*Megaptera novaeangliae*	1	1	1
Long finned pilot whale	*Globicephala melas*	3	20	4-11
Minke whale	*Balaenoptera acutorostrata*	38	39	1-2
Mix (Bottlenose dolphin & pilot whale)	*Mix (T. truncatus & G. melas)*	1	(20 & 20)	40
Mix (Common dolphin & minke whale)	*Mix (D. delphinus & B. acutorostrata)*	1	(100 & 2)	102
Risso's dolphin	*Grampus griseus*	5	47	6-15
White beaked dolphin	*Lagenorhynchus albirostris*	4	10	2-3
Unid Baleen Whale	*Mysticeti sp*	4	4	1
Unid Cetacean	*Cetacea sp*	2	2	1
Unid Dolphin	*Delphinid sp*	20	192	1-70
Unid Large Whale		2	2	1
Unid Small Whale		1	1	1
	Total	**160**	**950**	
Grey Seal	*Halichoerus grypus*	3	4	1-2
	Unidentified Seal	2	2	1
	Total	**5**	**6**	
Decomposing Carcass	Unid. marine mammal	2	2	1
	Total	**2**	**2**	
Basking shark	*Cetorhinus maximus*	1	1	1
Blue shark	*Prionace glauca*	4	4	1
Leatherback turtle	*Dermochelys coriacea*	2	2	1
Ocean sunfish	*Mola mola*	25	25	1
Porbeagle shark	*Lamna nasus*	1	1	1
Tuna Sp	*Thunnus sp*	1	1	1
Unidentified Fish	*Teleost sp*	1	2	2
Unidentified Shark	*Selachii sp*	1	1	1
	Total	**36**	**37**	

Table 15. Totals for all seabird species recorded between 10th June and 23rd July 2018.

Leg 1:

Vernacular Name	Scientific Name	On Survey	Off Survey	Total
Wilson's storm-petrel	*Oceanites oceanicus*	0	1	1
European storm-petrel	*Hydrobates pelagicus*	38	277	315
Fulmar	*Fulmarus glacialis*	61	356	417
Sooty shearwater	*Ardenna griseus*	1	4	5
Great shearwater	*Ardenna gravis*	3	1	4
Manx shearwater	*Puffinus puffinus*	89	92	181
Gannet	*Morus bassanus*	248	2334	2582
Kittiwake	*Rissa tridactyla*	5	10	15
Sabine's gull	*Xema sabini*	2	0	2
Great black-backed gull	*Larus marinus*	4	23	27
Herring gull	*Larus argentatus*	0	21	21
Lesser black-backed gull	*Larus fuscus graellsii*	176	446	622
Unidentified gull sp.	*Larus sp.*	0	2	2
Common tern	*Sterna hirundo*	0	6	6
Great skua	*Stercorarius skua*	4	19	23
Arctic Skua	*Stercorarius parasiticus*	0	1	1
Guillemot	*Uria aalge*	38	9	47
Razorbill	*Alca torda*	5	1	6
Puffin	*Fratercula arctica*	98	59	157
Total		772	3662	4434

Leg 2:

Vernacular Name	Scientific Name	On Survey	Off Survey	Total
Great Northern Diver	Gavia immer	1	0	1
European storm-petrel	*Hydrobates pelagicus*	22	19	41
Unidentified storm-petrel		1	6	7
Fulmar	*Fulmarus glacialis*	275	667	942
Cory's shearwater	*Calonectris borealis*	4	2	6
Sooty shearwater	*Ardenna griseus*	2	6	8
Great shearwater	*Ardenna gravis*	0	2	2
Manx shearwater	*Puffinus puffinus*	285	302	587
Unidentified shearwater sp.		1	0	1
Gannet	*Morus bassanus*	784	1208	1992
Shag	*Phalacrocorax aristotelis*	0	5	5
Cormorant	*Phalacrocorax carbo*	0	4	4
Kittiwake	*Rissa tridactyla*	25	44	69
Common gull	*Larus canus*	2	10	12
Great black-backed gull	*Larus marinus*	2	12	14
Herring gull	*Larus argentatus*	2	11	13
Lesser black-backed gull	*Larus fuscus graellsii*	62	141	203
Unidentified large gull sp.	*Larus sp.*	21	4	25
Common tern	*Sterna hirundo*	0	1	1
Arctic tern	*Sterna paradisaea*	0	3	3
Unidentified *Sterna* tern sp.	*Sterna sp.*	0	17	17
Great skua	*Stercorarius skua*	17	24	41
Pomarine skua	*Stercorarius pomarinus*	0	1	1
Arctic skua	*Stercorarius parasiticus*	1	1	2
Guillemot	*Uria aalge*	393	243	636
Razorbill	*Alca torda*	227	88	315
Unidentified Guillemot/Razorbill		552	651	1203
Puffin	*Fratercula arctica*	219	346	565
Black Guillemot	*Cepphus grylle*	0	1	1
Total		2898	3819	6717

Table 16. Totals of migrant terrestrial bird species recorded between 10th June and 23rd July 2018.

Leg 1:

Vernacular Name	Scientific Name	Total
Unidentified passerine sp.		1
Racing pigeon	*Columba livia* domest.	7
Swift	*Apus apus*	1
Collared dove	*Streptopelia dedaocto*	6
Total		15

Leg 2:

Vernacular Name	Scientific Name	Total
Dunlin	*Calidris alpina*	25
Total		25

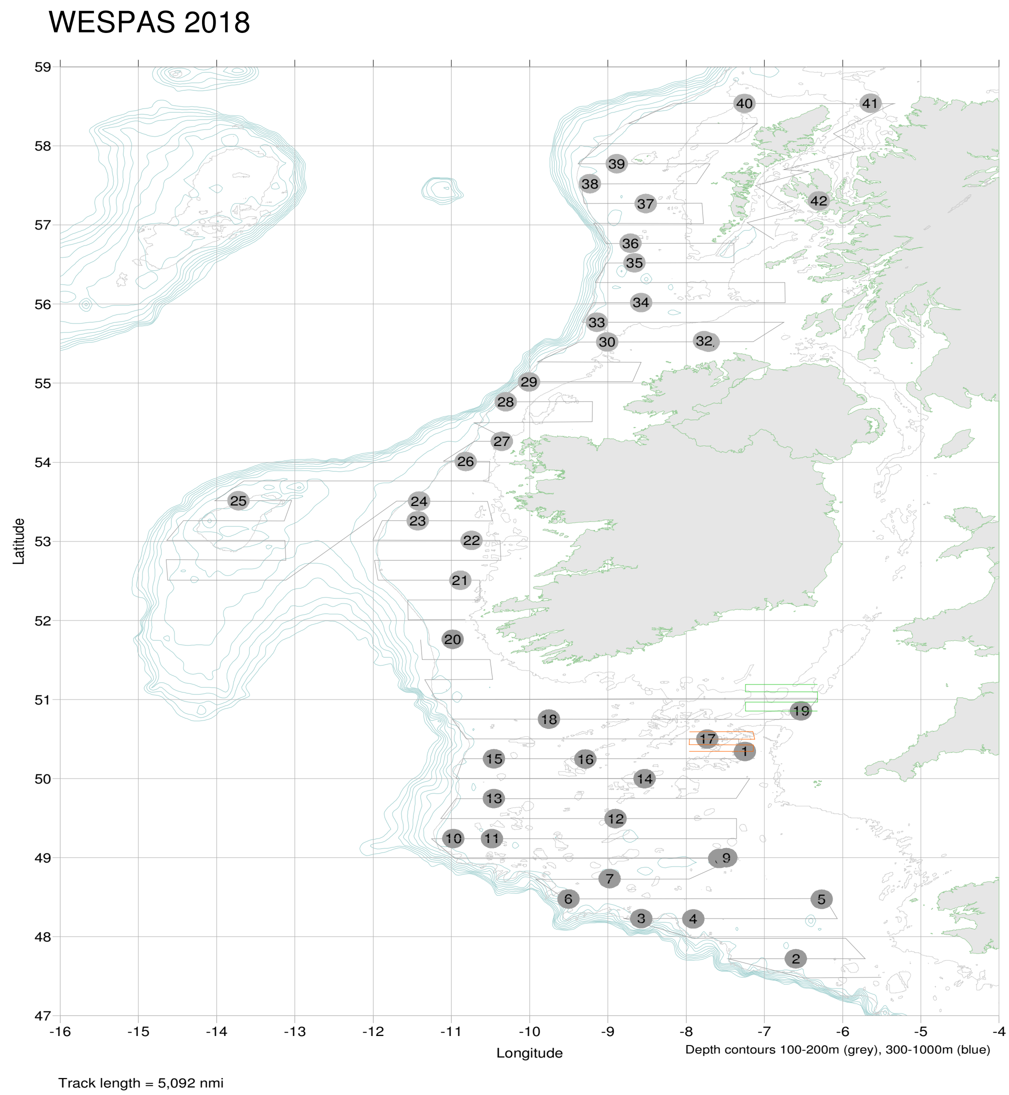


Figure 1. Survey cruise track (grey line) and numbered directed pelagic trawl stations. Corresponding catch details are provided in Table 2. Green line indicates transect survey conducted by autonomous vehicle in the western Celtic Deep and orange line indicates survey carried out by the *C. Explorer* on the Northwest bank.

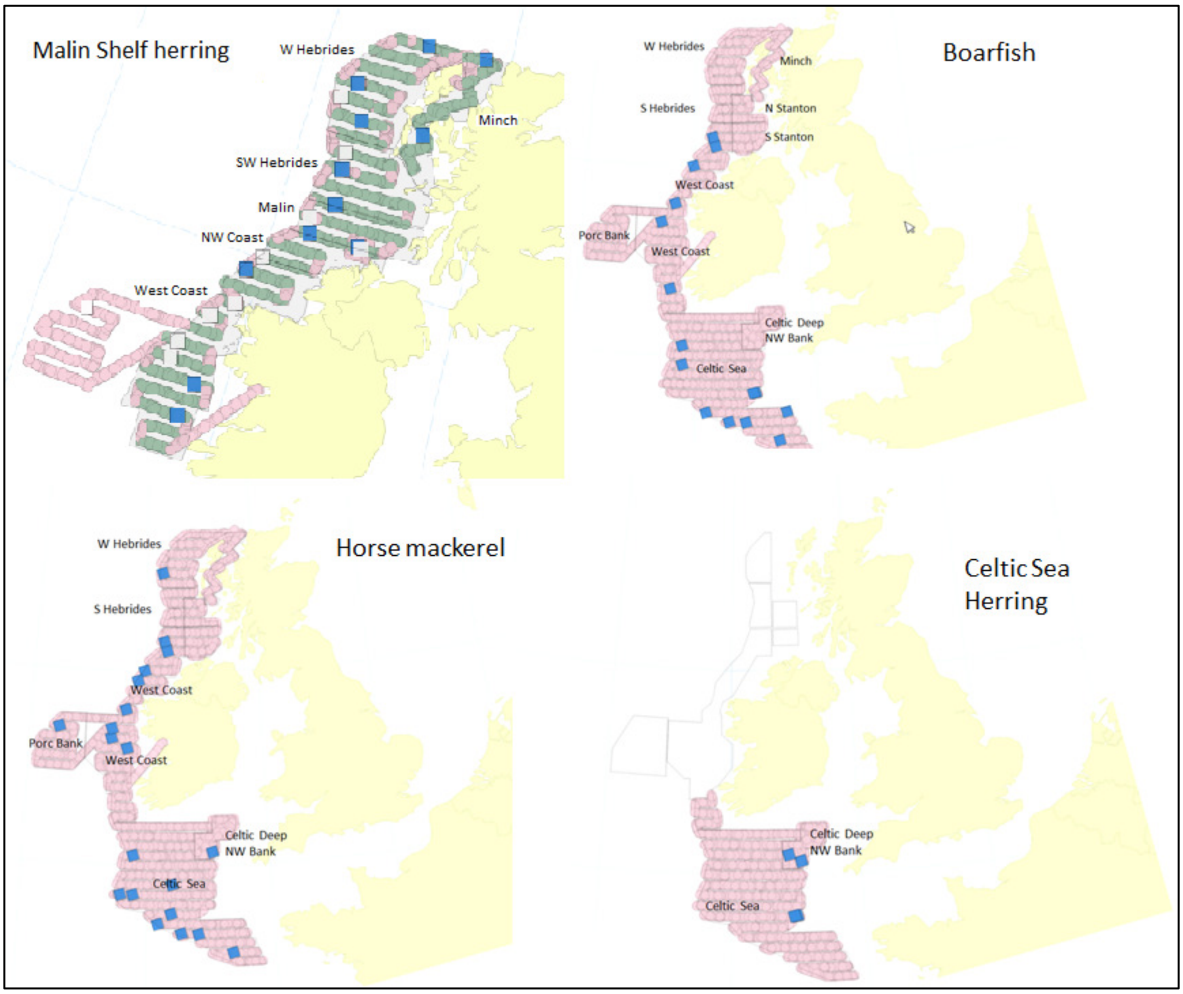
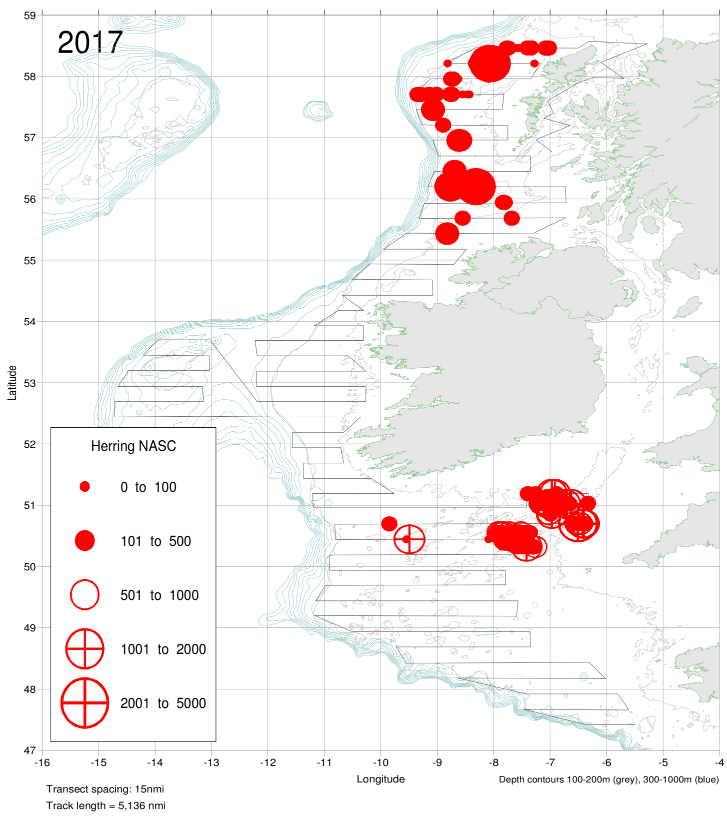


Figure 2. Acoustic sampling area stratification as applied during the calculation of species specific acoustic abundance.



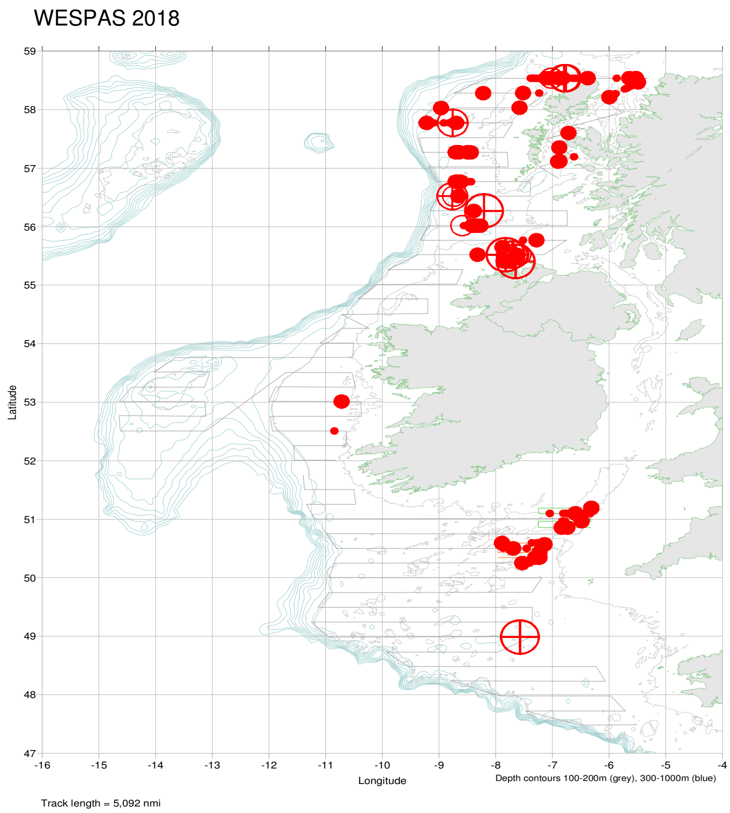


Figure 3. Malin Shelf (north of 54°N) and Celtic Sea (south of 52°N) herring distribution by weighted acoustic density and Celtic Sea her. Top panel 2017, bottom panel 2018.

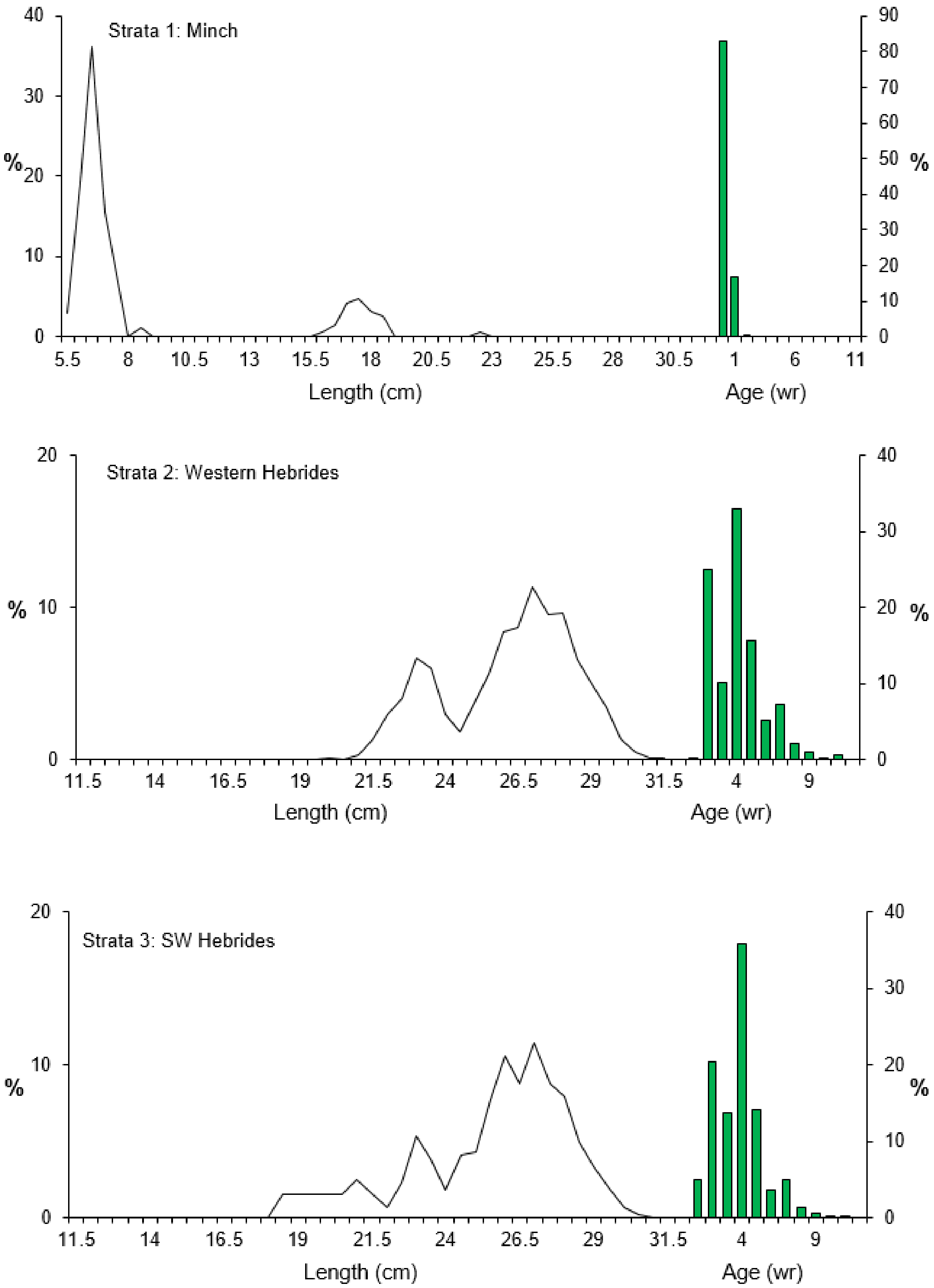


Figure 4. Length and age distribution of Malin Shelf herring by stratum and total survey area during WESPAS 2018.

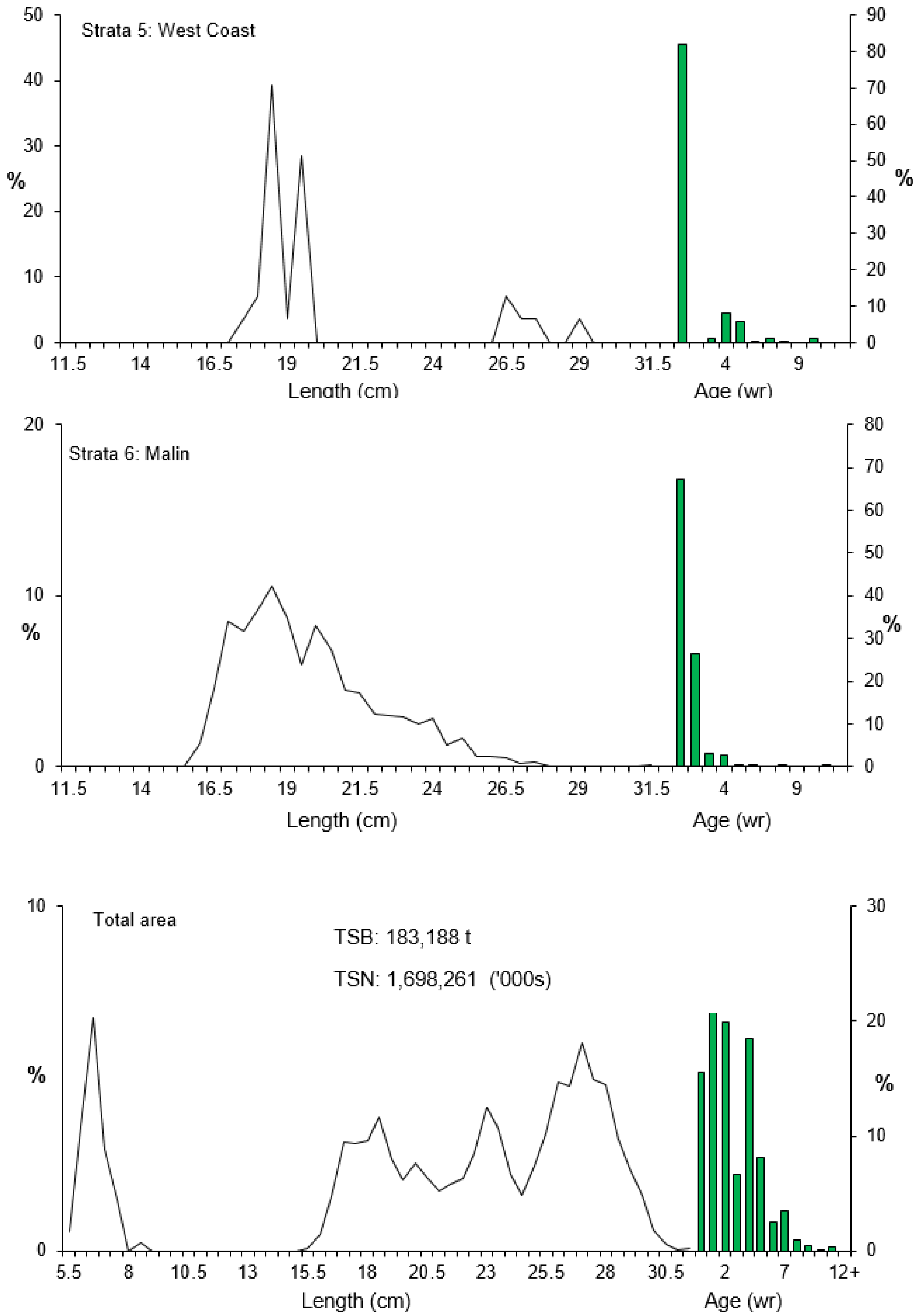


Figure 4. Cont.

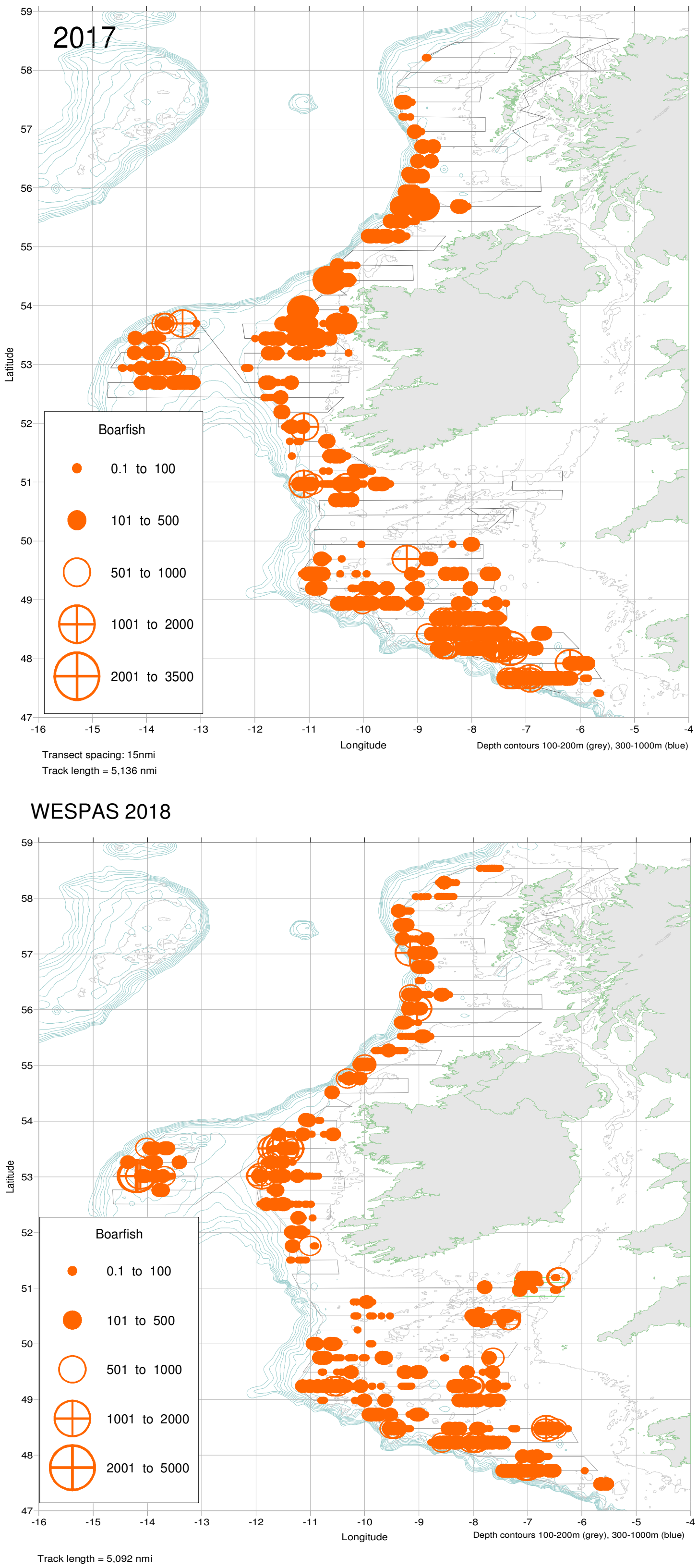


Figure 5. Boarfish distribution by weighted acoustic density. Top panel 2017, bottom panel 2018.

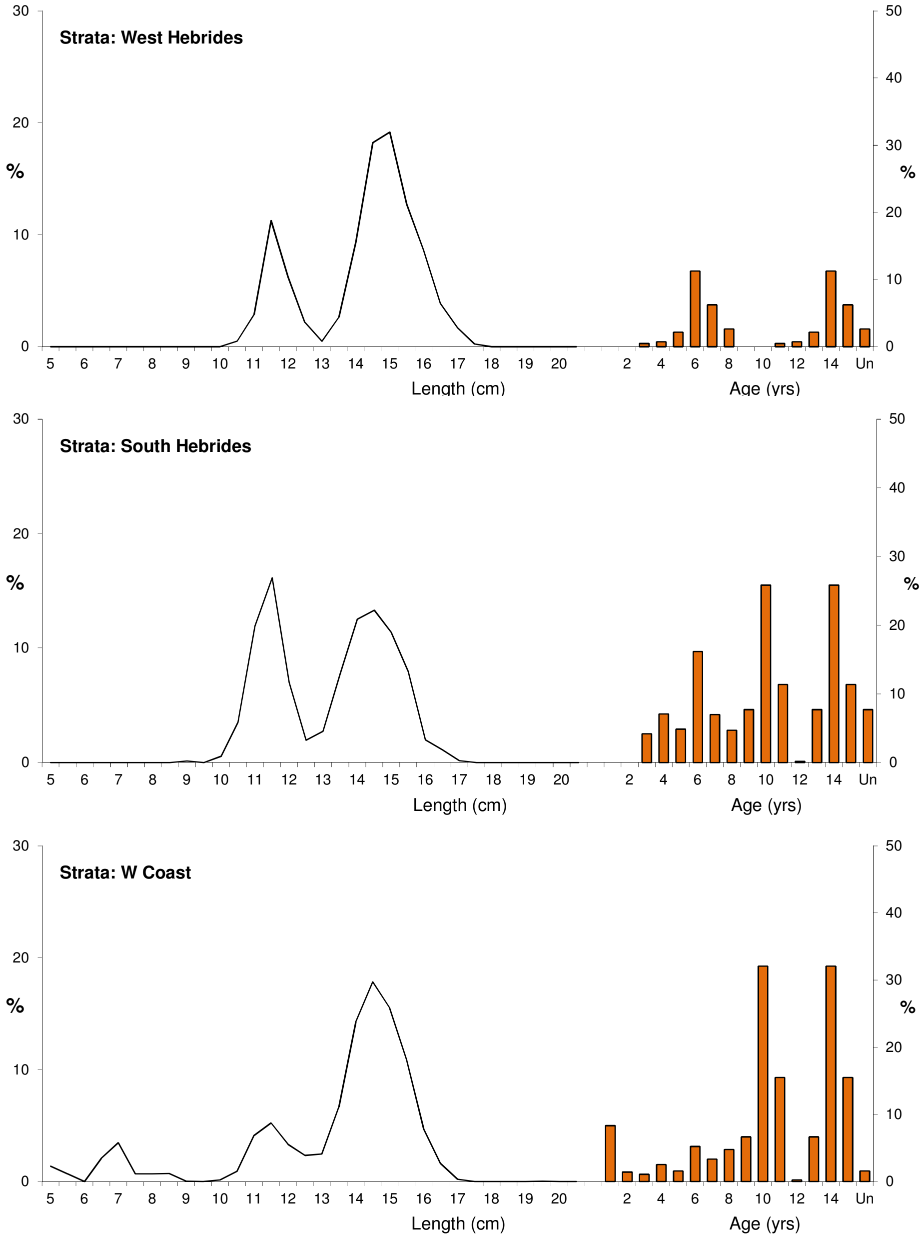


Figure 6. Length and age distribution of boarfish by stratum and total survey area.

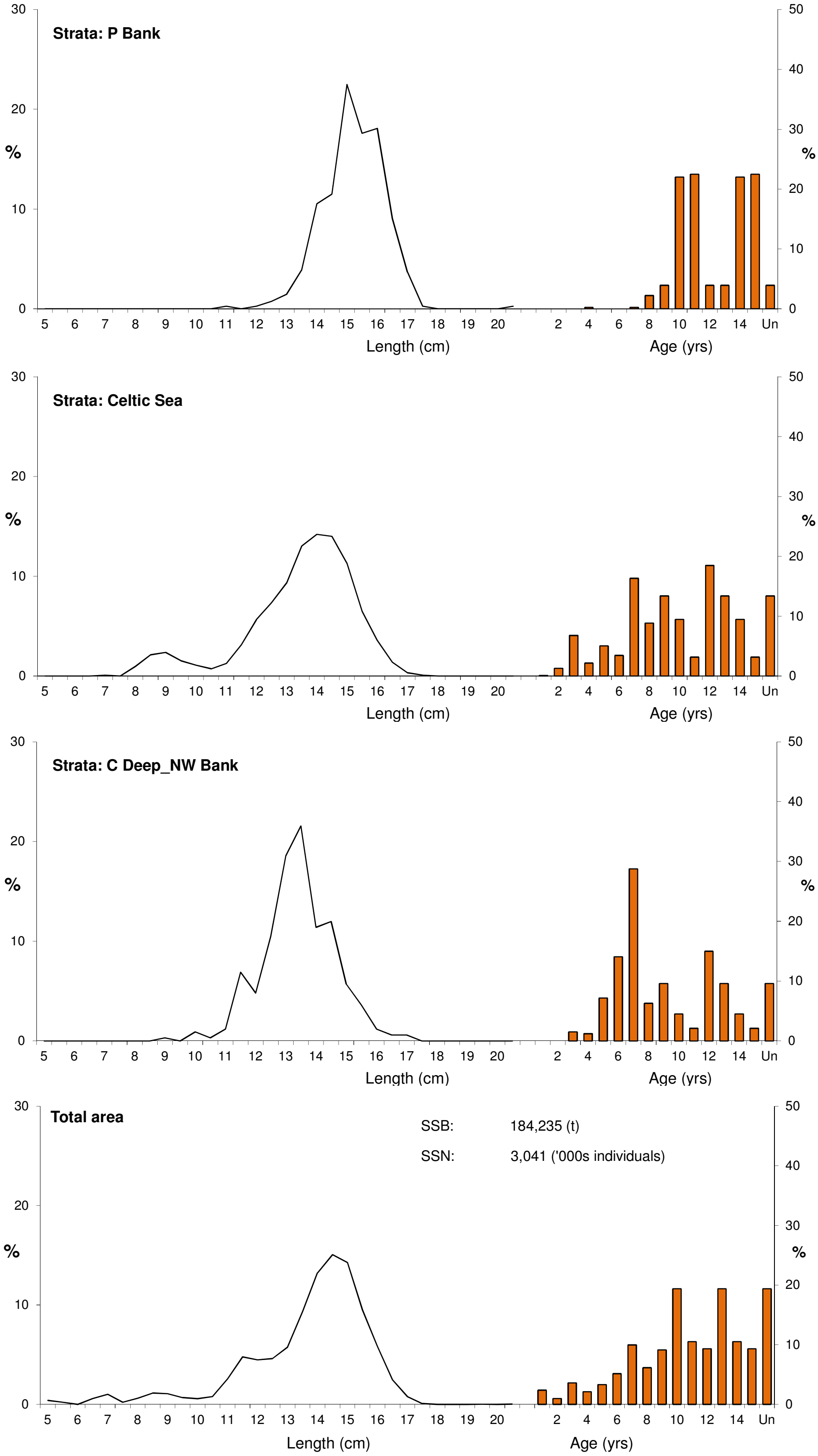


Figure 6. cont.

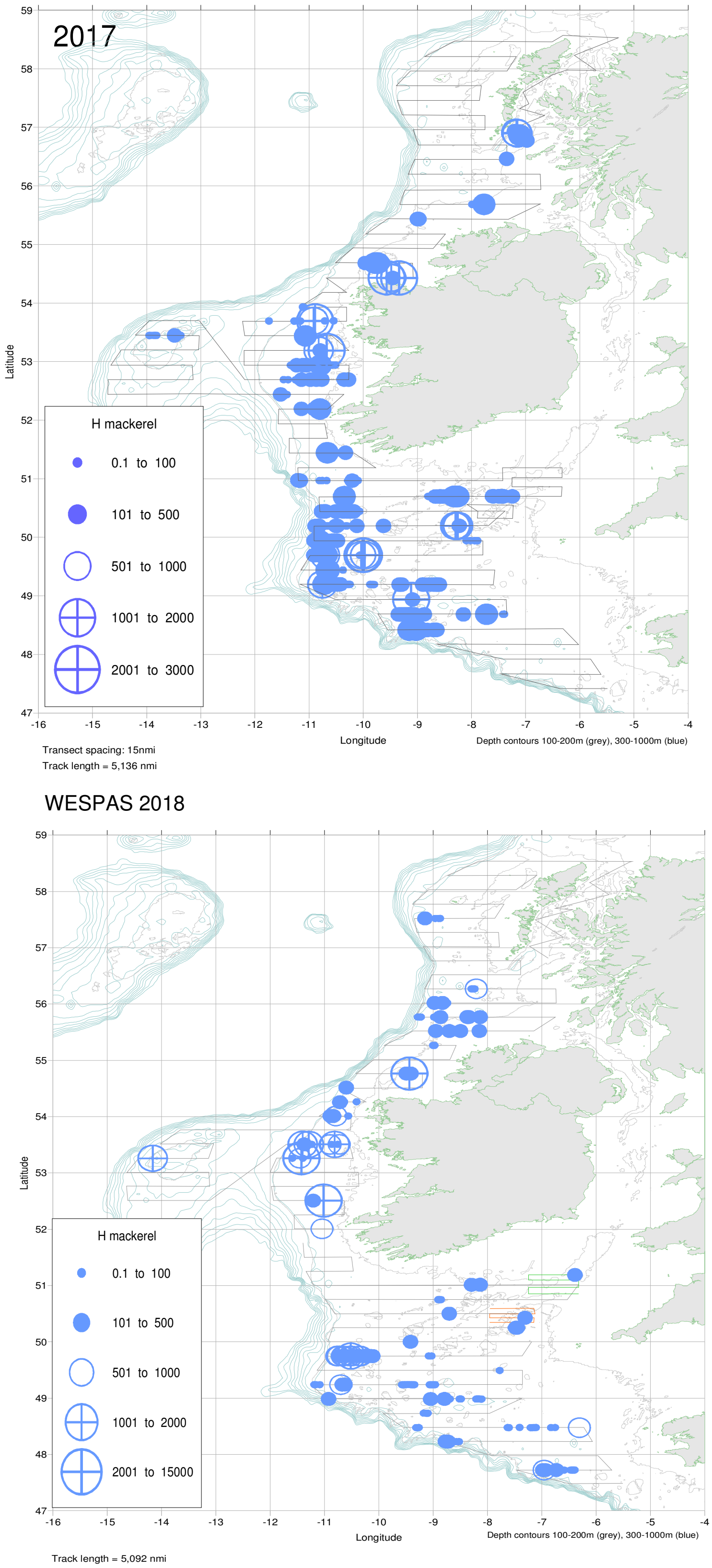


Figure 7. Horse mackerel distribution by weighted acoustic density. Top panel 2017, bottom panel 2018.

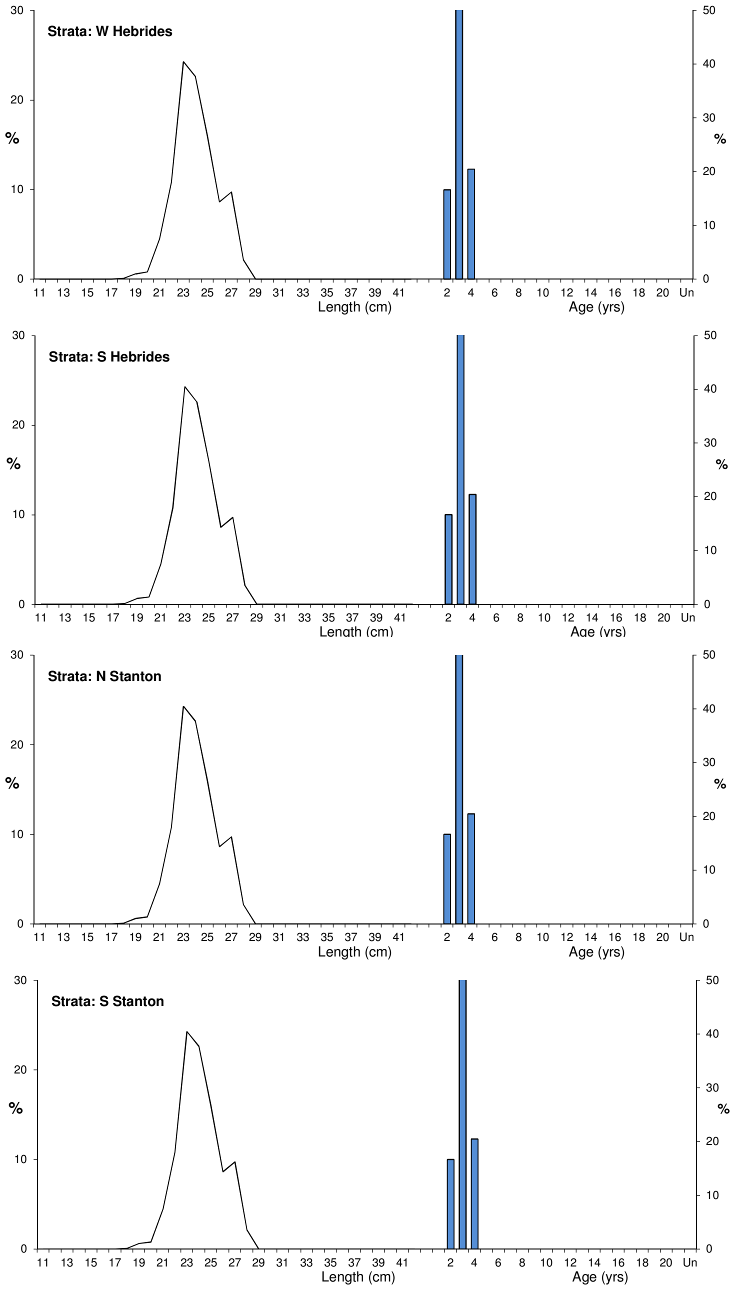


Figure 8. Length and age distribution of horse mackerel by stratum and total survey area.

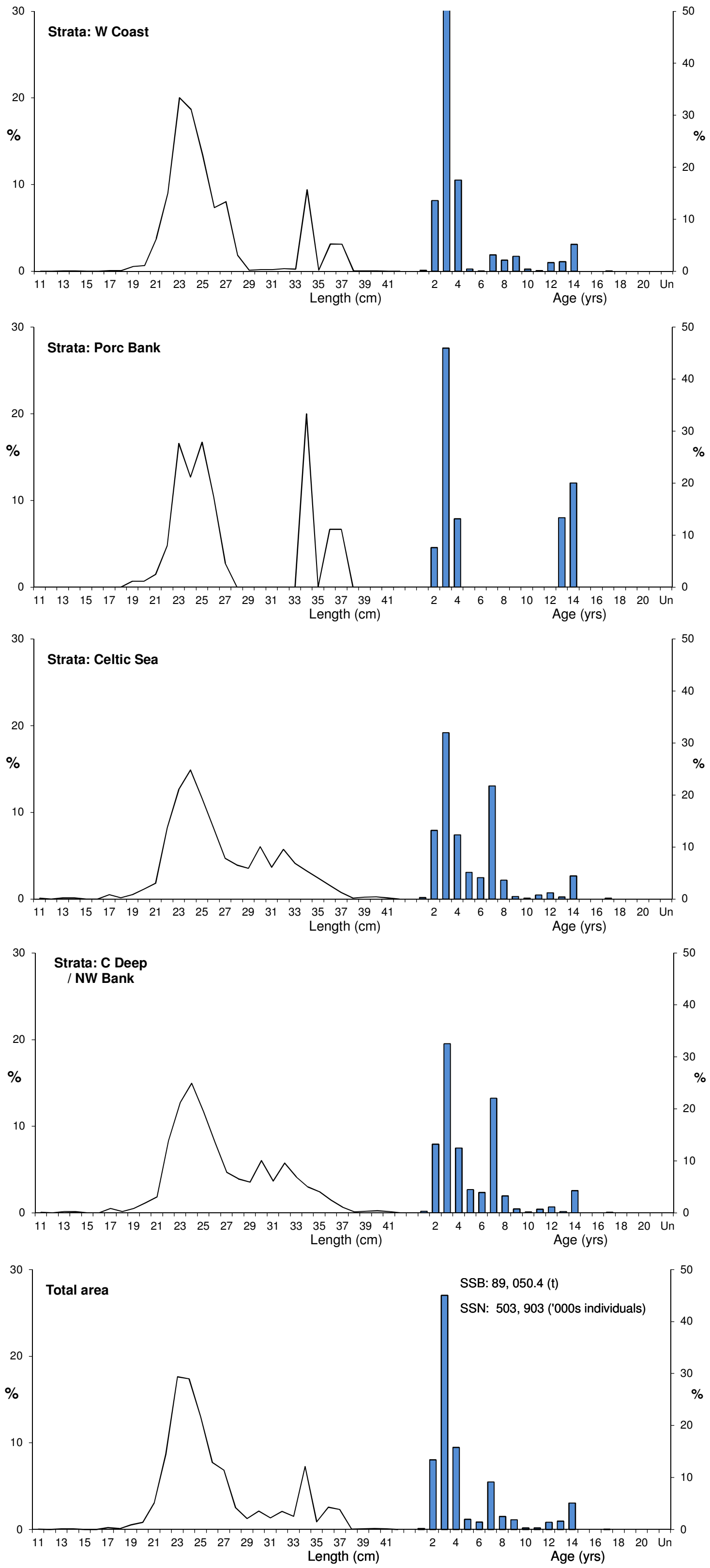


Figure 8. continue

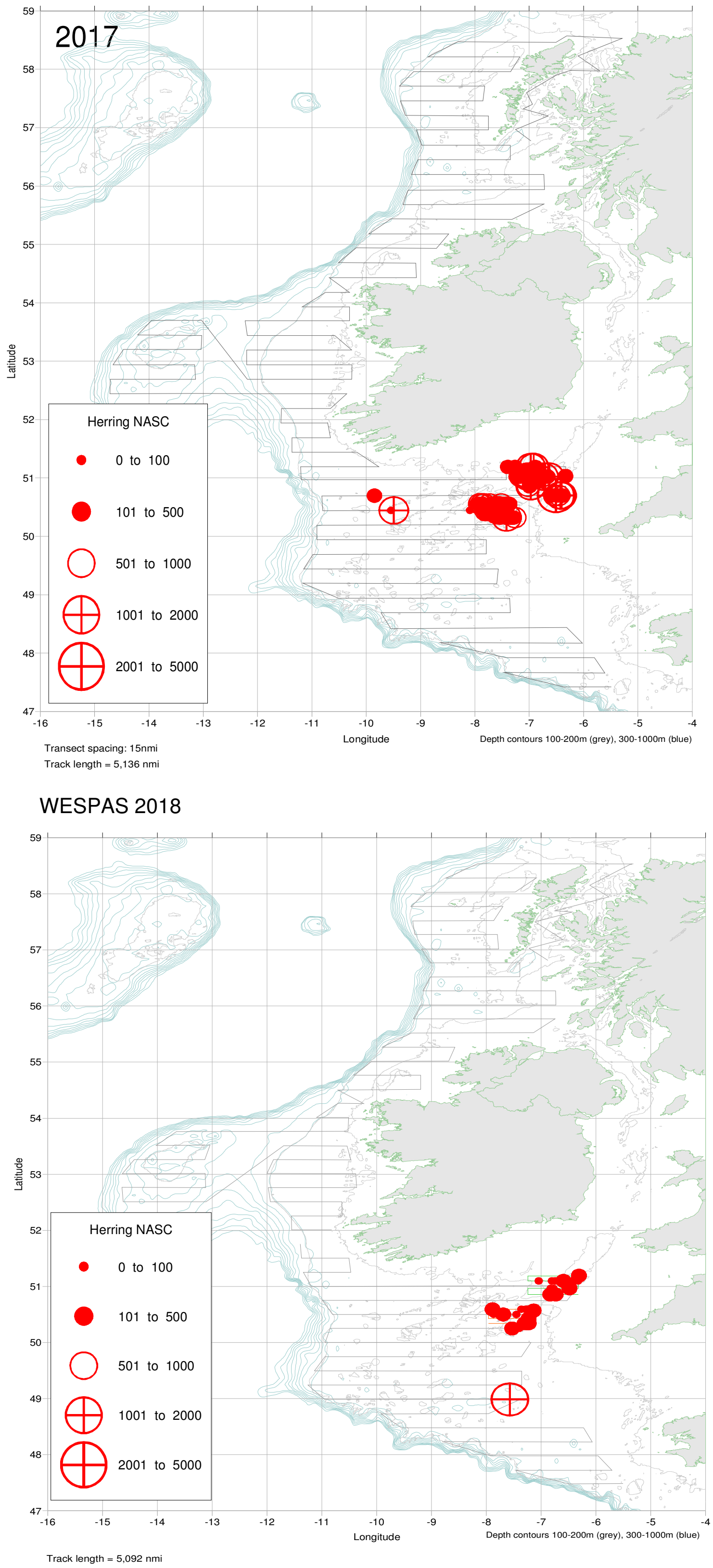


Figure 9. Celtic Sea herring distribution by NASC (Nautical area scattering coefficient)

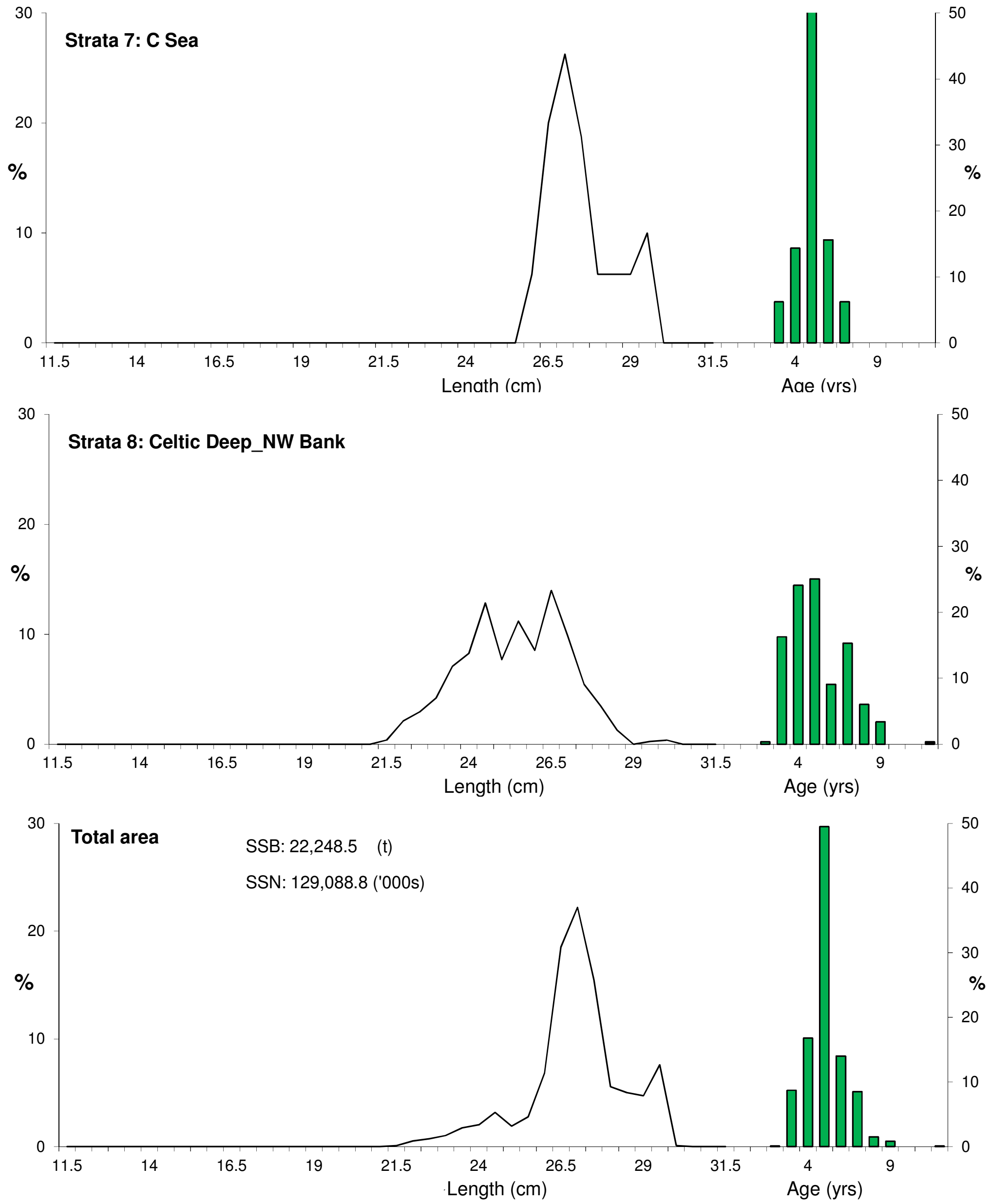
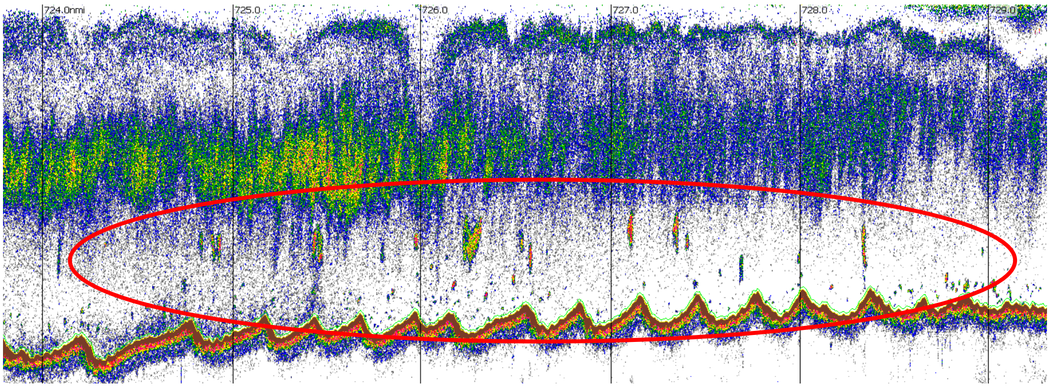
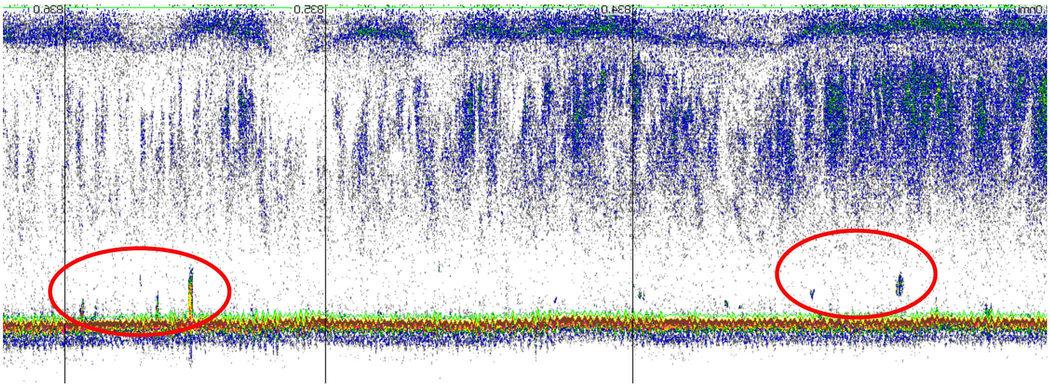


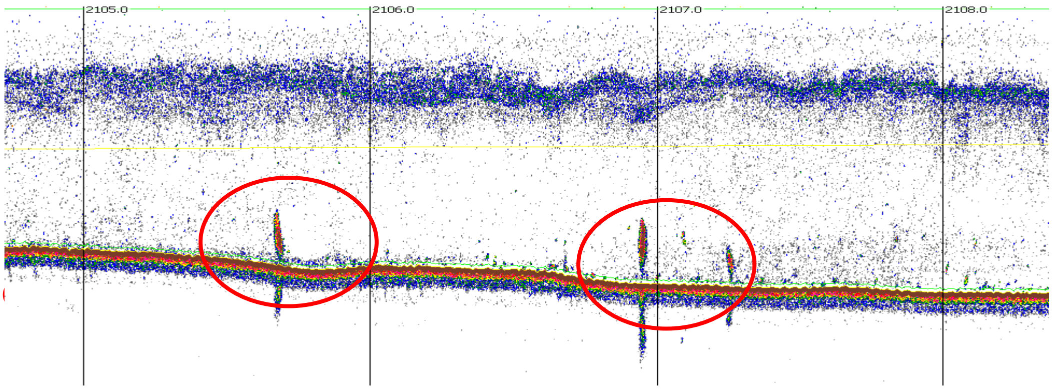
Figure 10. Length and age distribution of Celtic Sea herring by stratum and total survey area.



a). *Haul 04, Southern Celtic Sea. Pelagic schools of mature boarfish (circled red) close to the shelf edge. Water depth 180 m.*

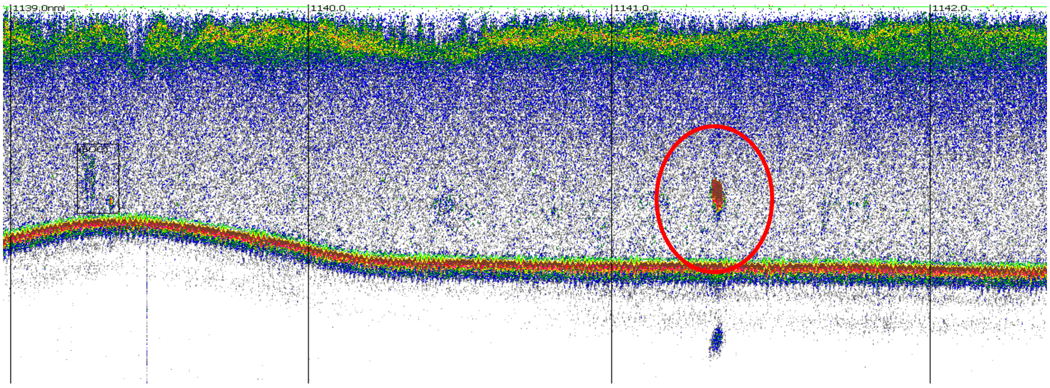


b). *Haul 05, Southern Celtic Sea. Medium density horse mackerel schools in the eastern survey area off the French coast. Water depth 130 m.*

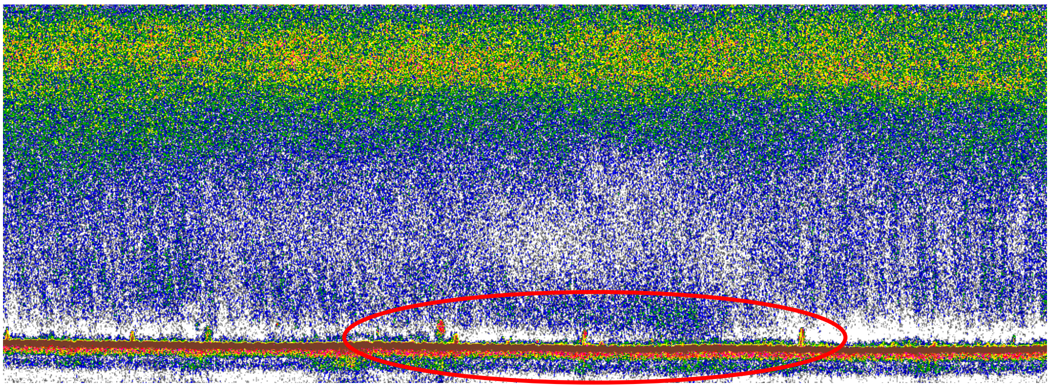


c). *Haul 16. Mid Celtic Sea. Example of high density schools of juvenile (0-group) blue whiting commonly encountered in the mid Celtic Sea. Water depth 132 m.*

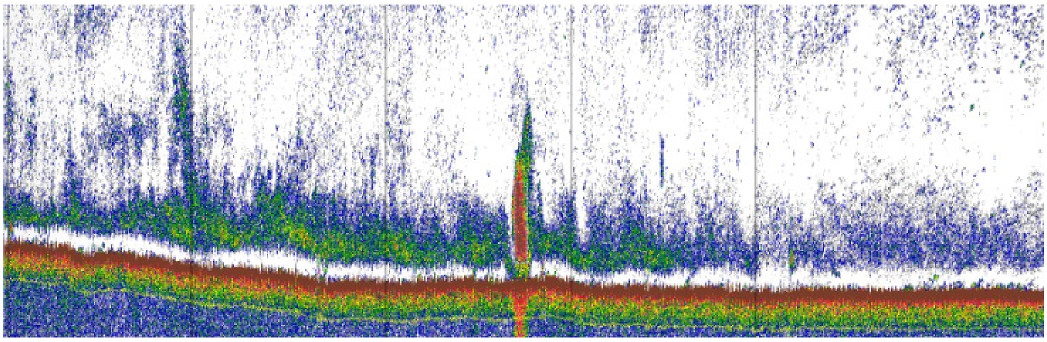
Figures 11a-j. Echotraces recorded on an EK60 echosounder (38 kHz) with images captured from Echoview. Note: Vertical bands on echogram represent 1nmi (nautical mile) intervals.



d). *Haul 08. High density single herring school located close to Jones Bank, water depth 146 m.*

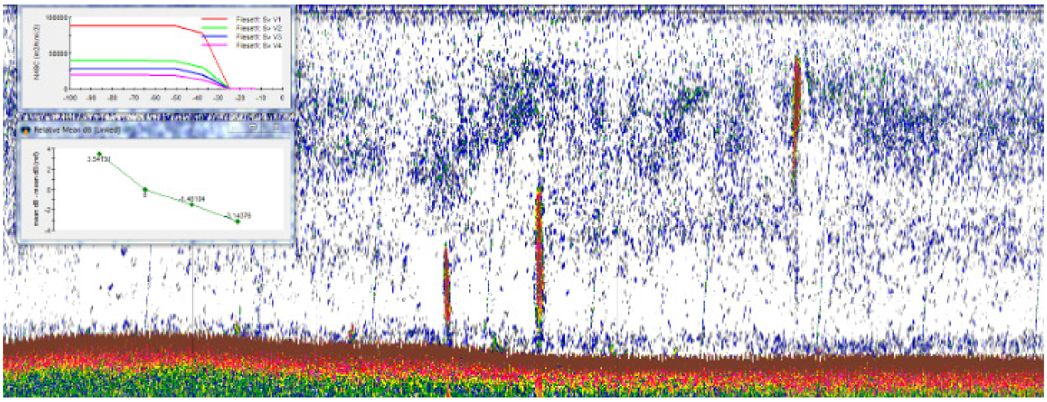


e). *Haul 01. Northwest Bank. Small, medium density schools of herring located on the bottom. Water depth 104 m.*

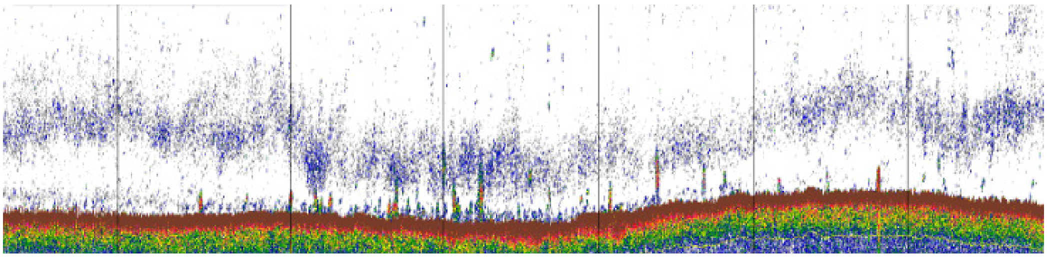


f). *Haul 39. SW of St. Kilda, high density herring school, water depth 152 m.*

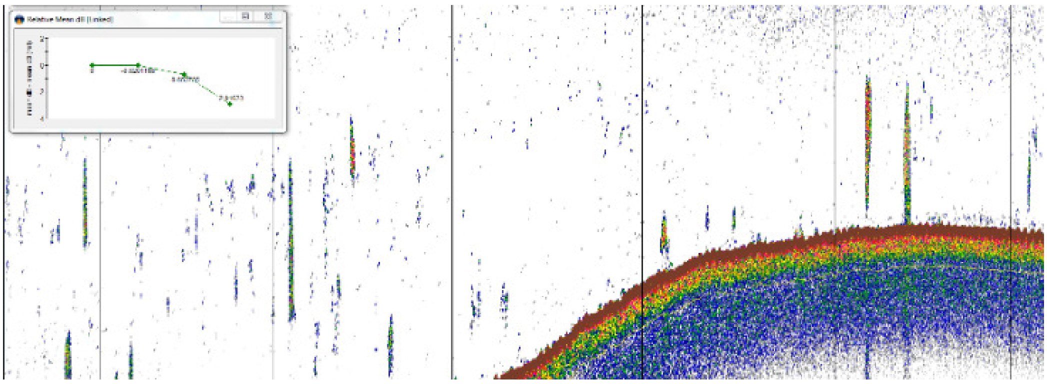
Figures 11a-i. continued



g). *Haul 32. SE Stanton Bank, mid-water herring schools (mainly 1- and 2-wr) depth 69 m.*

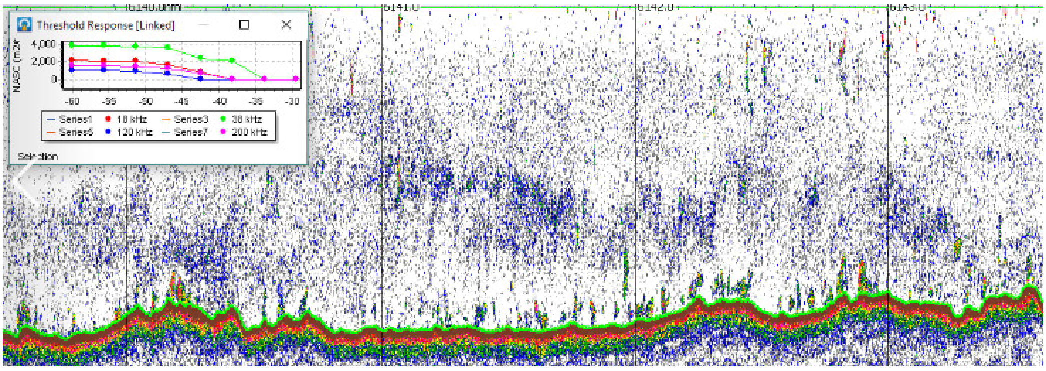


h). *Haul 35. W Stanton Bank, herring marks along bottom on hard ground, water depth 140 m.*

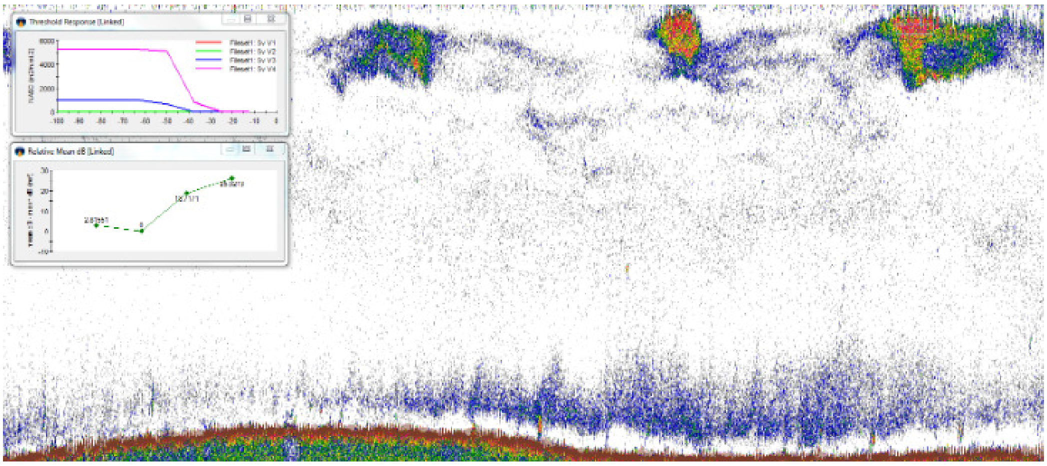


i). *Haul 29. West of Aranmore. High density marks of boarfish close to the shelf edge. Water depth 115-200 m.*

Figures11-i. continued.



J). *Surface marks of 0-group sprat and herring (with mixed gadoids on the bottom) in the Minch*



k). *Surface marks of mackerel as observed on the 200 kHz west of the Hebrides; common throughout the Malin Shelf area.*

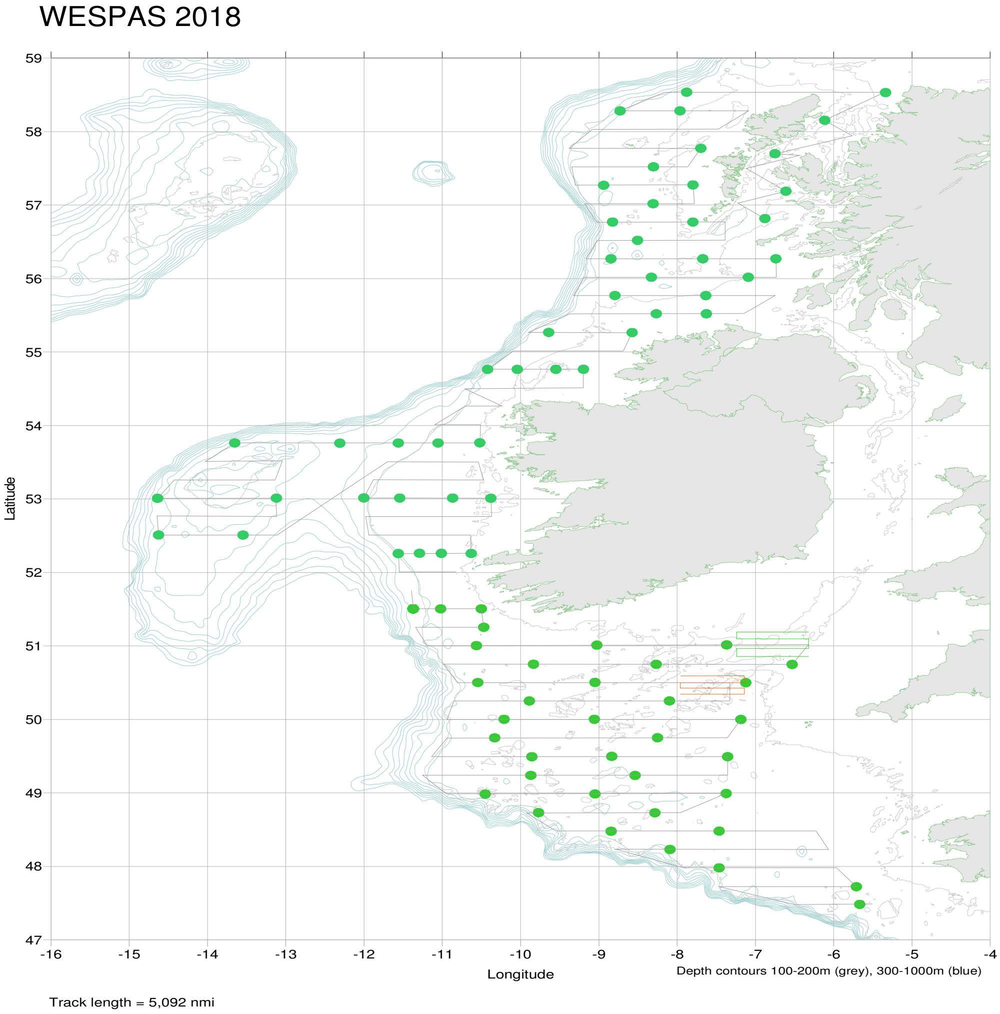


Figure 12. Position of hydrographic and co-occurring zooplankton sampling stations (n=86).

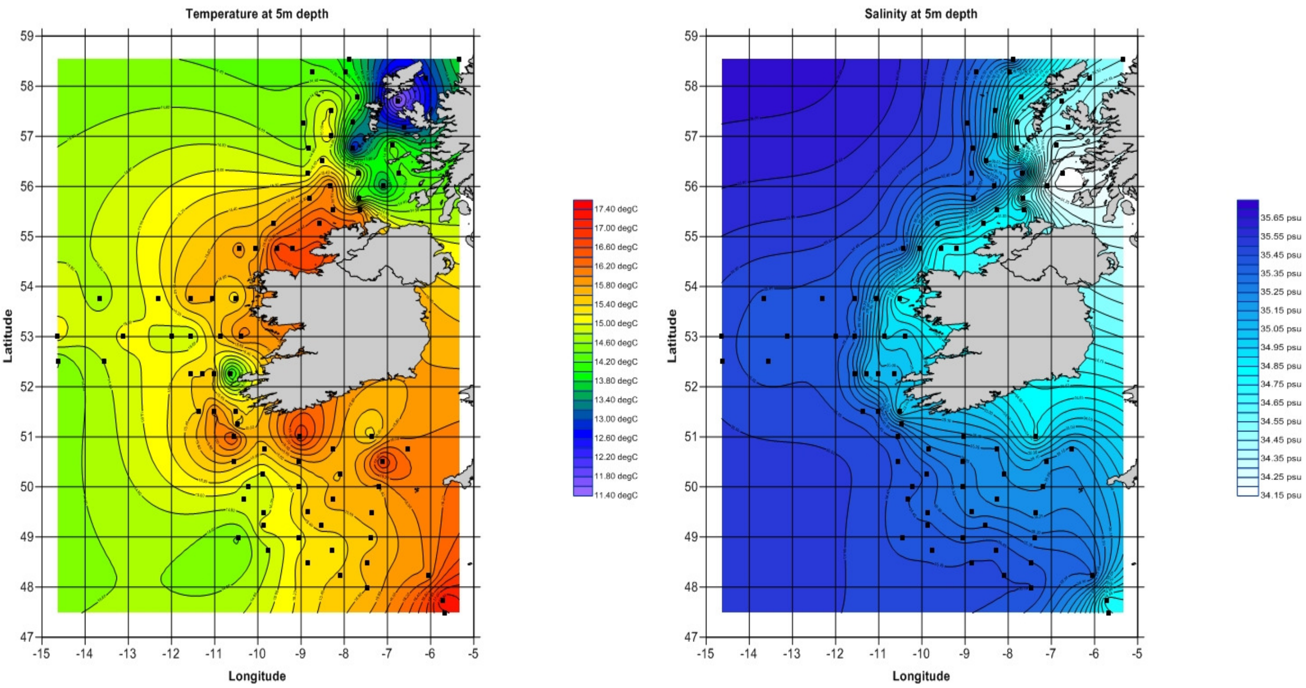


Figure 13. Surface (5m) plots of temperature and salinity compiled from CTD cast data. Station positions with valid data shown as block dots (n=86).

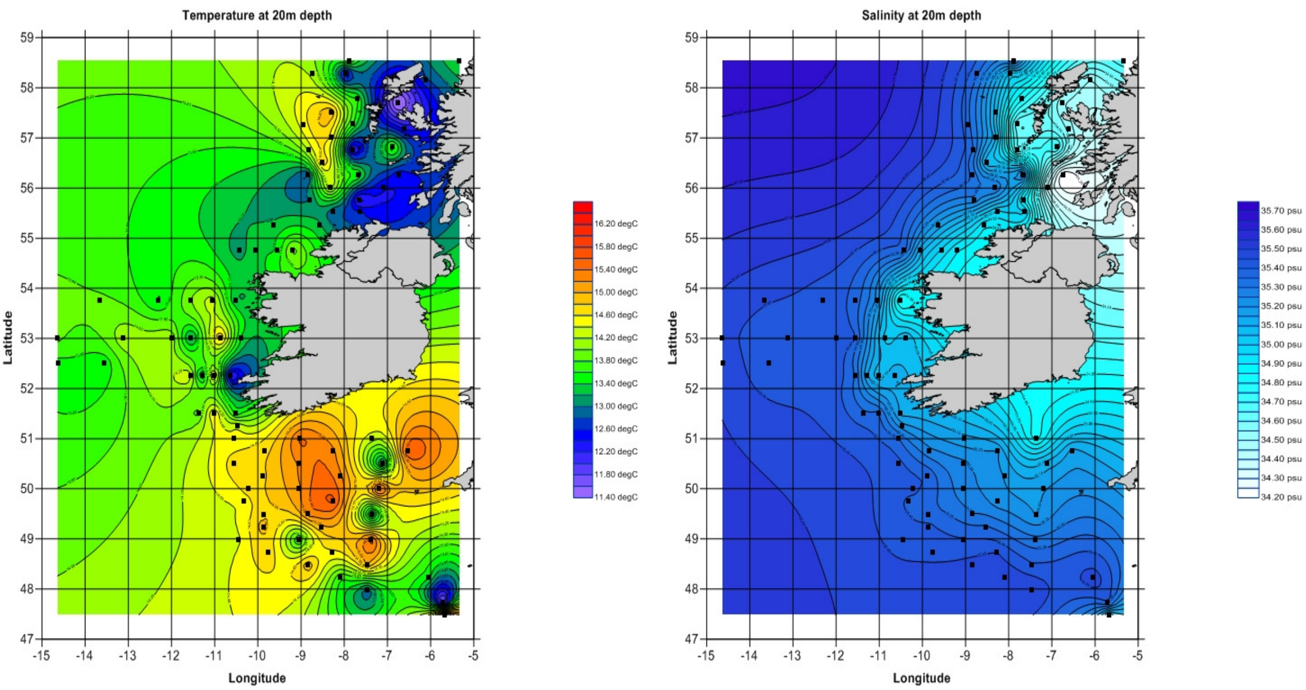


Figure 14. Plots of temperature and salinity compiled from CTD cast data at 20m depth. Station positions with valid data shown as block dots (n=86).

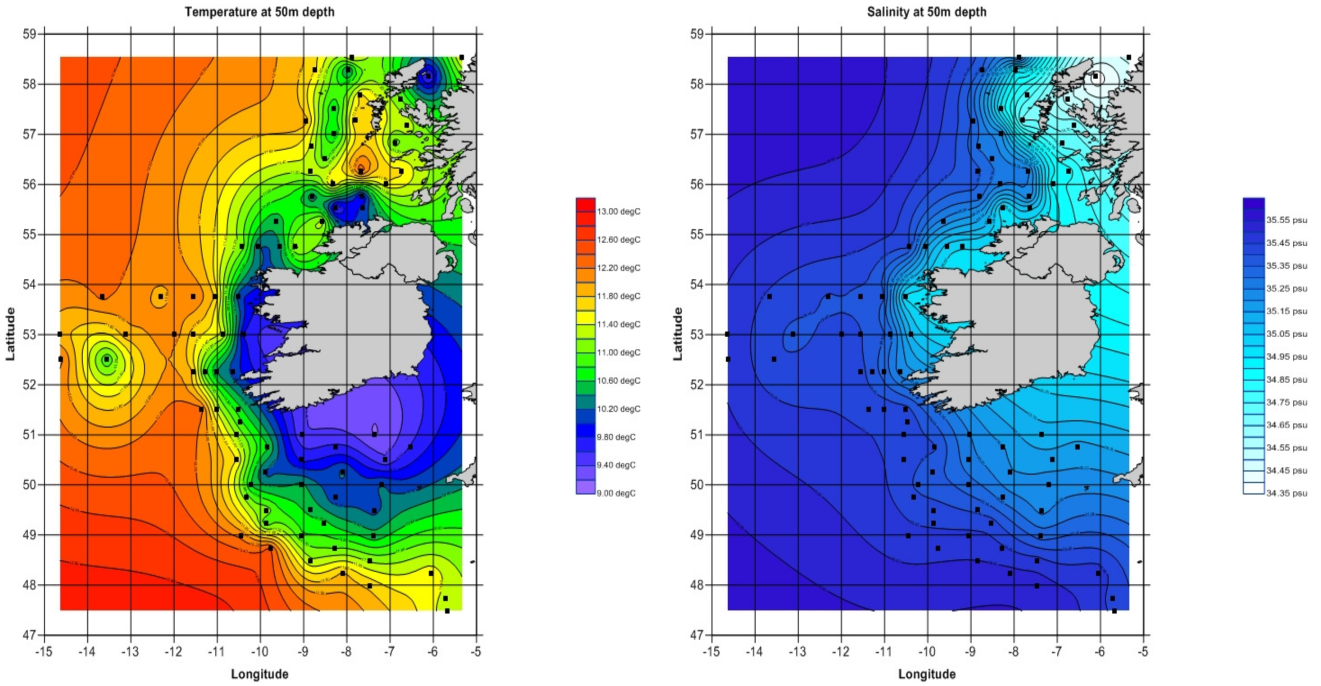


Figure 15. Plots of temperature and salinity compiled from CTD cast data at 50m depth. Station positions with valid data shown as block dots (n=86).

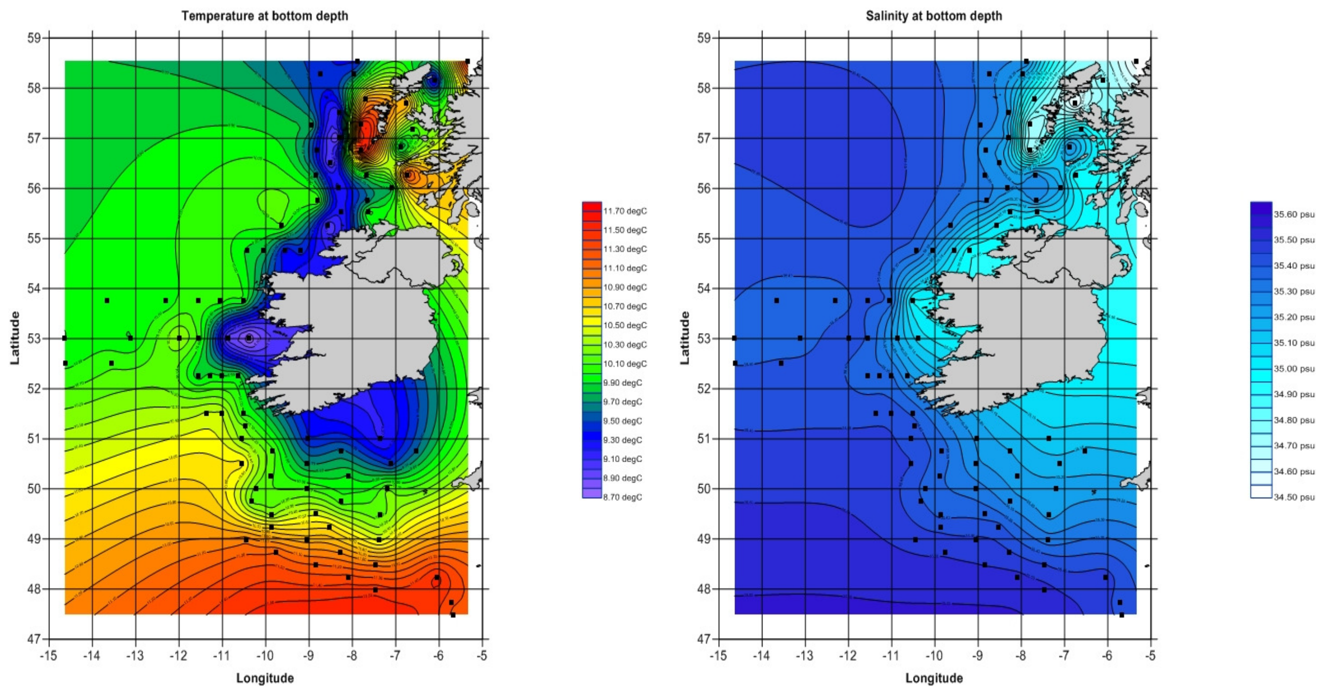


Figure 16. Plots of temperature and salinity compiled from CTD cast data at the seabed (+3-5m). Station positions with valid data shown as block dots (n=86).

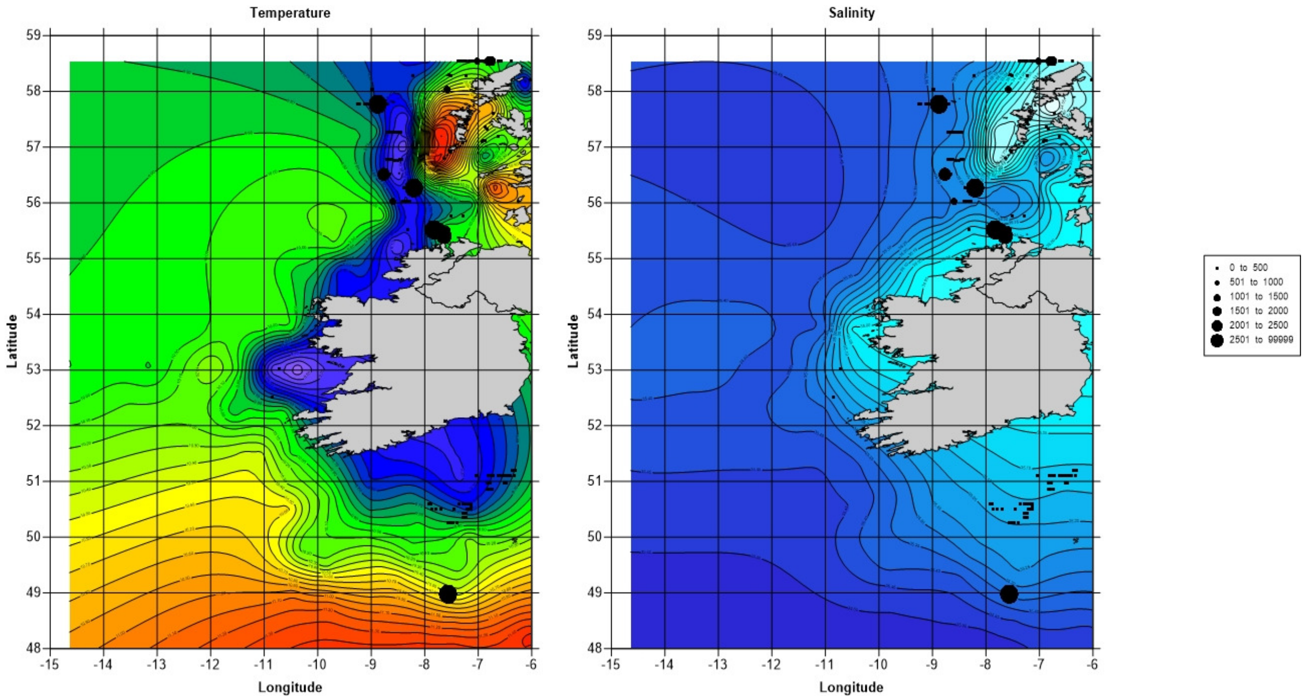


Figure 17. Habitat plots of temperature and salinity with herring distribution. Sea floor values overlaid with herring NASC values (black circles).

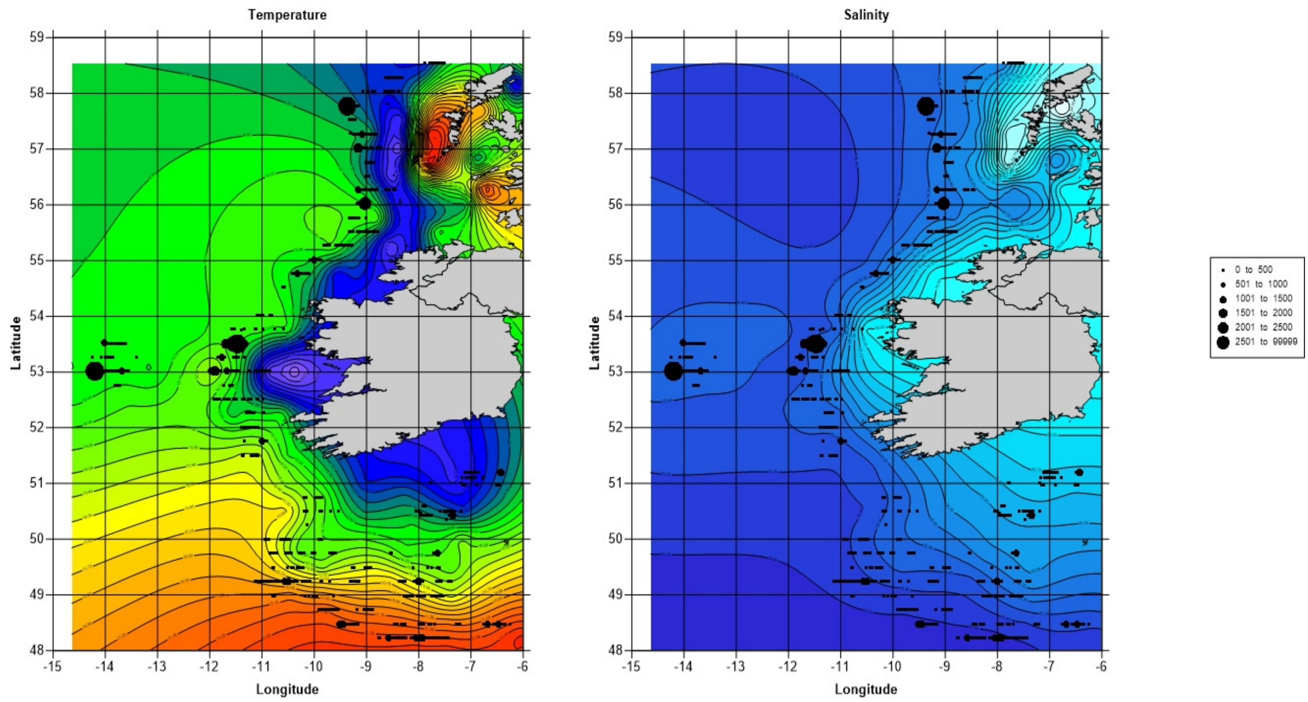


Figure 18. Habitat plots of temperature and salinity with boarfish distribution. Sea floor values overlaid with boarfish NASC values (black circles).

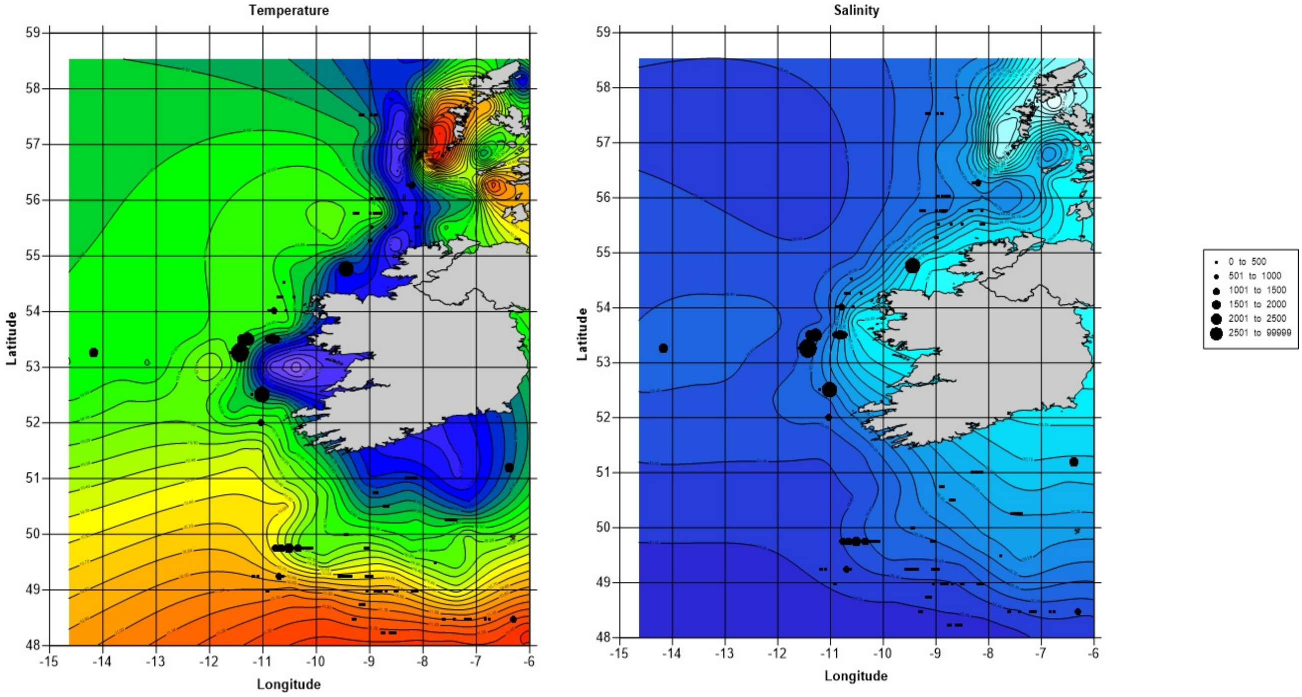


Figure 19. Habitat plots of temperature and salinity with horse mackerel distribution. Sea floor values overlaid with horse mackerel NASC values (black circles).

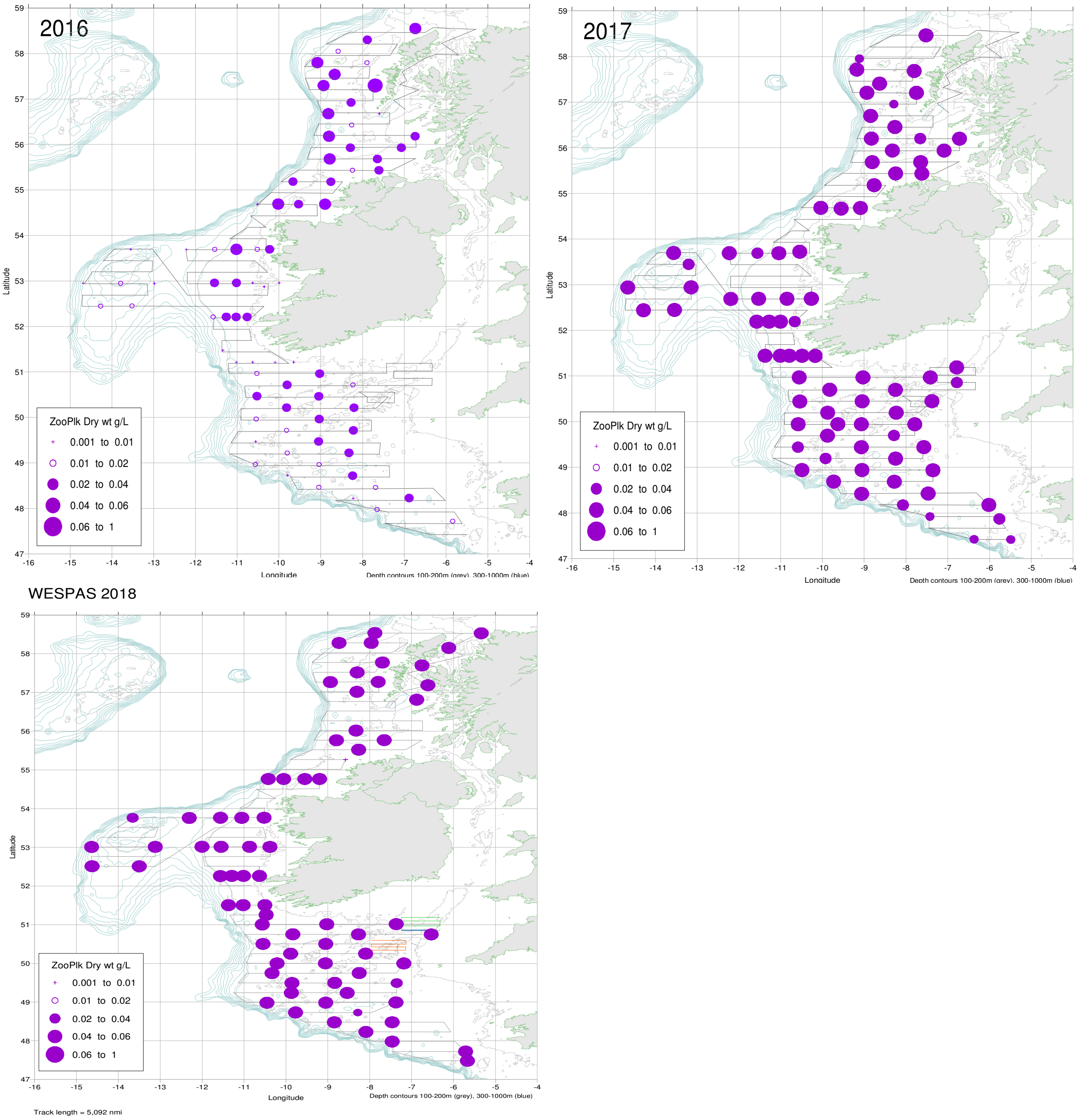


Figure 20. Zooplankton dry weight biomass by station (g dry Wt. m^3) 2016-2018.

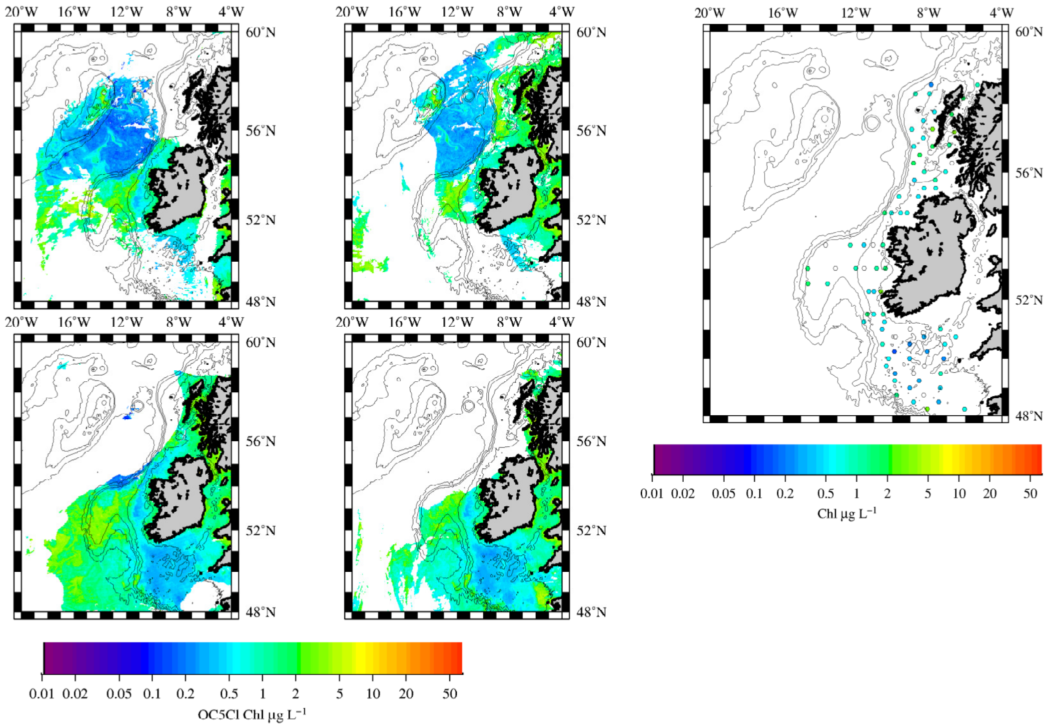


Figure 20. Left panel: OC5CI Chlorophyll images from June 27, 28, 29 and 30 (Source: CMEMS). Right panel: Near surface mixed layer chlorophyll measurements during WESPAS 2018

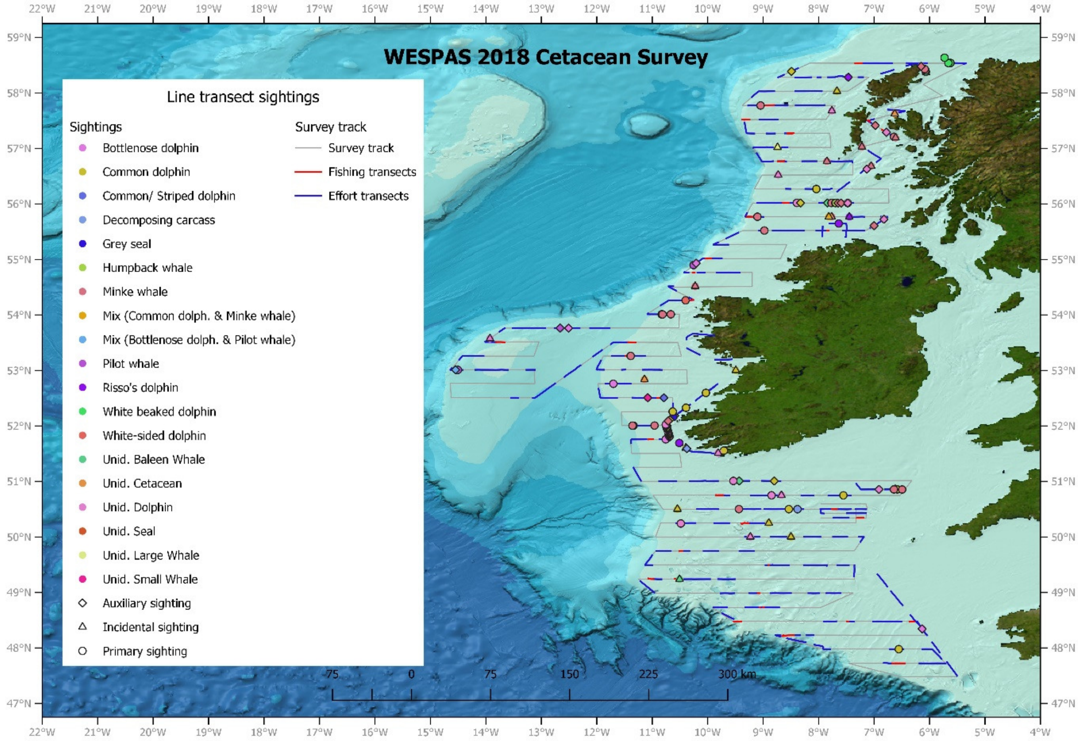


Figure 22. Distribution of marine mammal sightings while on-effort profiled with observer effort.

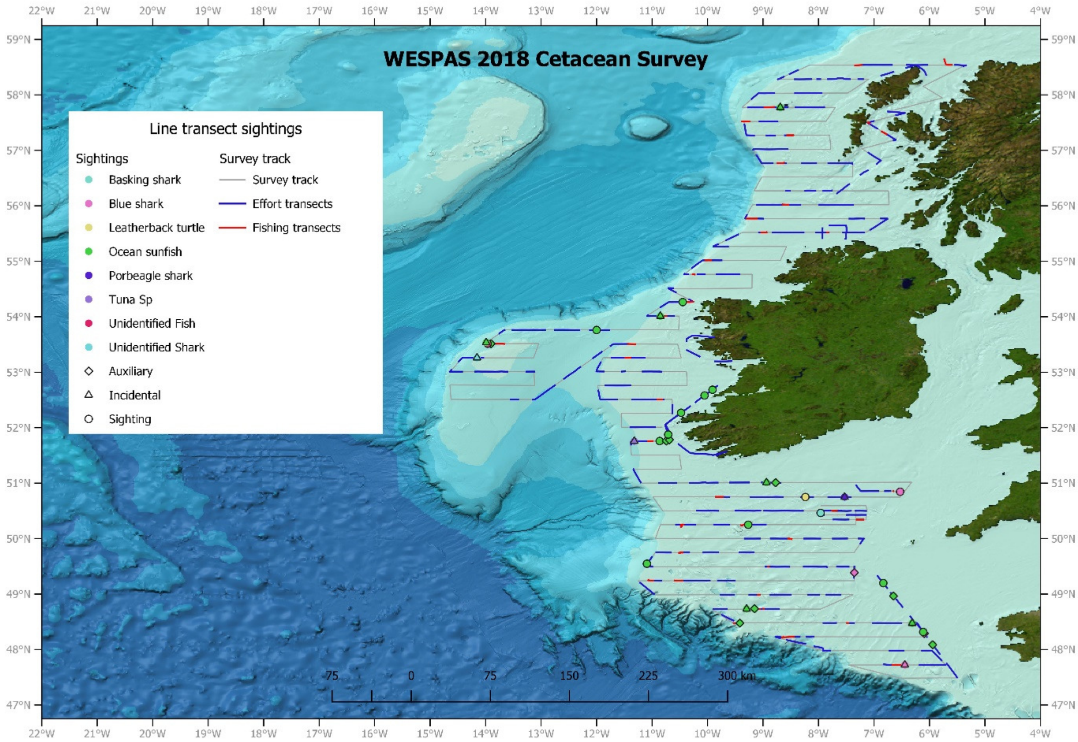


Figure 23. Distribution of marine megafauna sightings during the survey profiled with observer effort.

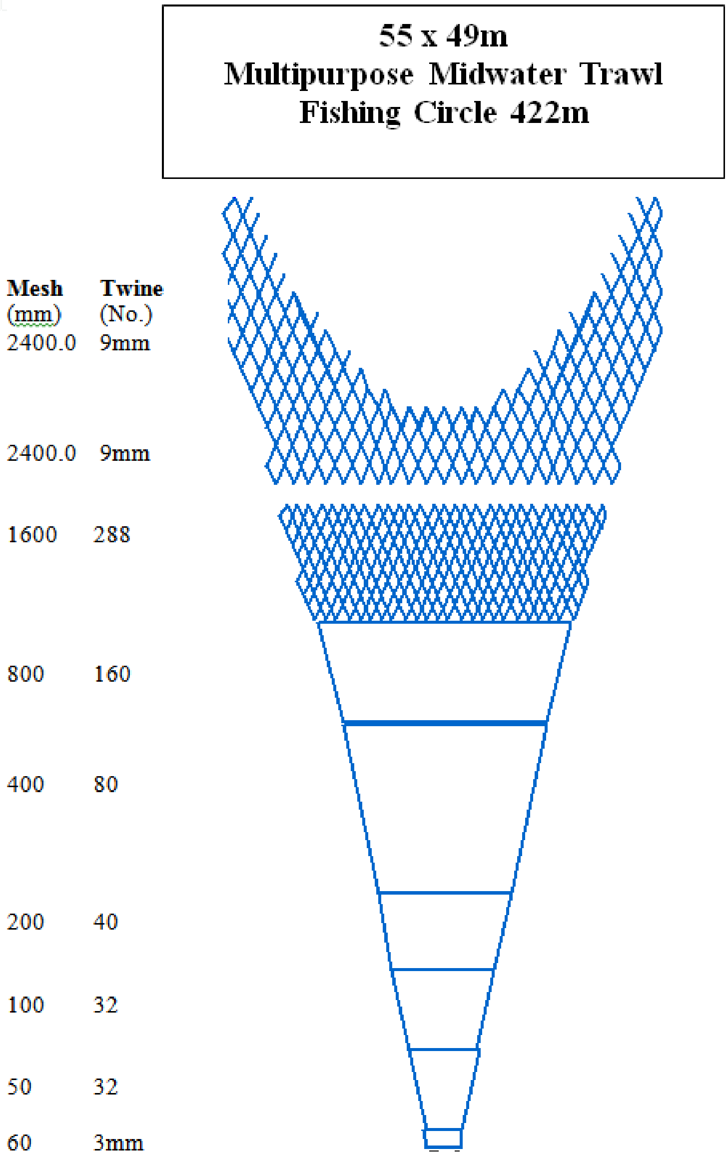


Figure 24. Single multipurpose midwater trawl net plan and layout.

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