FSS Survey Series: 2019/03

Western European Shelf Pelagic Acoustic Survey (WESPAS)

13 June – 24 July, 2019

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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 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 42 days providing synoptic coverage of shelf waters from 47°30'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 2019. 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 2020.

2 Materials and Methods

2.1 Scientific Personnel

Leg	CE19010	CE19010
Dates	13-04 Jun/Jul	04-24 July
Days	22	20
Start	Falmouth	Galway
End	Galway	Galway
Acou (Chief Sci)	Ciaran O'Donnell	Michael O'Malley
Acou	Turloch Smith	Eugene Mullins
Acou	Ian Murphy	Michael Gras
Acou	Tobi Rapp	Hugo Maxwell
Bio (Deck Sci)	Dermot Fee	Marcin Blaszkowski
Bio	Sophia Wasserman	Sean O'Connor
Bio	Stephanie Linehan	Emma White
Bio	Stephan Brennan	Hayley Campbell
		Sharon Sugrue
MMO	John Power	Meadhbh Quinn
SBO	Paul Connaughton	Paul Connaughton
SBO	Sally O'Meara	Sibeal Regan
Zoo/Salps	Eoin Moorhouse	Laura Stenson
Zoo/Salps	Briana Casserly	Rachel Shaw
CDOM +	Monica Mullins	Catherine Jordan
CDOM +	Sarah Ayres	Daniel Waters
CDOM +	Mikey Reddin	Grainne Cronin O’Reilly

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 multiple 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 standing stocks

- Take morphometric and genetic samples of individual herring within ICES divisions 6a and 7b, c for stock identification analysis
- Use vertical CTD casts to determine hydrographic conditions and the extent of shelf front 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)
- Use multi-beam echosounders (Kongsberg EM2040) and Omni sonar (Simrad SU92) to collect data on the aggregation morphology and behaviour of target species
- Jellyfish species distribution from combined 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

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, 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 15 nmi (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 using established methods. 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 5,956 nmi using 58 transects relating to total area coverage of 60,183 nmi².

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 March 2019 in Killary Harbour. Calibration procedures followed methods laid out in Demer *et al.* (2015). The results of the 38 kHz calibration 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 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. Echoview® Echolog (Version 10) 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 stratum. 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 10) 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 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 mono-specific 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 23). Mesh size in the wings was 2.4 m through to 10 cm in the cod-end. The net was fished with a vertical mouth opening of approximately 25 m 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/boarfish/horse mackerel 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 applicable. 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 from the bottom to be taken in areas of clean ground.

2.4.1 Herring stock identification

When possible, a sample of 120 herring (>23 cm) were taken for morphometric and genetic analysis from herring in the Malin Shelf area (6a, 7b, c). These fish were 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 Coloured Dissolved Organic Matter (CDOM)

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 (5-6 m 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 Hydro-Bios® calibrated 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 Hydro-Bios® 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.

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 +/- 0.00016 g).

2.6.2 Jellyfish

The vertical ring net is a conventional method for broad scale sampling of zooplankton in coastal and oceanic waters. Jellyfish sampling was carried out alongside zooplankton sampling with the same deployment criteria as described. The volume filtered by the ring net was calculated using a Hydro-Bios® calibrated mechanical flow meter. 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, 87 ring net stations were successfully deployed along the cruise track line (Figure 12).

By-caught gelatinous fauna collected in the large pelagic net (Figure 23) 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 30 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. Almost 70 hours of visual 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 from the 14/06/19 to the 10/07/19 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 17.45 m above sea level, during all daylight hours, when weather conditions permitted. During periods of unfavourable weather conditions, observations were carried out from the bridge (10.63 m 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 100-400 mm 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 Cybertracker (http://www.cybertracker.org/) data collection software package (Version 3.501) 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 5 seconds.

Each line transect was assigned a unique transect number, and a new transect was started anytime the vessel activity changed (i.e. changing from on-transect to inter-transect). Each subsequent sighting was also assigned to this unique transect number.

Environmental data was time-stamped and recorded with GPS data at the beginning and end of each line transect. 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 Cybertracker and saved in the Access database.

The distance of each sighting from the ship was estimated using a fixed interval range finder (Heinemann, 1981), 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 Cybertracker 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

The seabird survey was conducted from the 14/06/19 to the 24/07/19 using a team of two seabird surveyors per survey leg. The lead seabird observer conducted visual survey effort, while the other seabird observer was responsible for data collection and recording. The observer's survey effort was maximized and optimized during periods of sea state less than or equal to sea state 6 and with visibility of greater than 300m. Additional visual point sampling (e.g., at oceanographic sampling stations or fishing stations) and incidental recording were also employed; however, line transect survey effort was prioritised by the observer. Seabird watches were conducted using a standard single platform line transect survey design while the vessel was travelling at a consistent speed and heading. Observations for seabirds were conducted from the monkey island (deck height 12 m above sea level) or the bridge (deck height 10 m above sea level). Observations were conducted from the monkey island preferably, however, as in previous surveys aboard the R.V. Celtic Explorer, access to the monkey island was dependent on weather conditions.

The data collection methodology was based on that originally proposed by Tasker *et al.* (1984) with later adaptations applied to allow correction factors to be applied for missed birds (Camphuysen *et al*., 2004). The method employed used a single platform line transect survey design with sub-bands to survey birds associated with the water, while flying birds were surveyed using a 'snapshot' technique. Observer effort was concentrated in a bow-beam arc of 90^{o} to one side (i.e., to port or starboard) of the vessel's track-line, however, all seabirds observed outside this area were also be recorded.

Survey effort for seabirds associating with the water were concentrated within a survey strip of 300m running parallel and adjacent to the vessels track-line and extending to the horizon. All birds surveyed within this region were be recorded as 'in-transect' and assigned to one of four distance sub-bands (A: 0-50 m, B: 50-100 m, C: 100-200 m, D: 200-300m) according to their perpendicular distance from the track-line. This approach allows for the evaluation of biases caused by specific differences in detection probability with increasing distance from the track line (Camphuysen *et al.* 2004). Seabirds occurring outside of this survey strip were recorded as 'off-transect' and assigned to separate sub-band (E: >300 m). The perpendicular distance to an animal was estimated using a fixed interval range finder (Heinemann, 1981), ensuring each animal is allocated to the correct distance sub-band.

Flying birds were surveyed using 'snapshots', where instantaneous counts of flying birds within a survey quadrant of 300 m x 300 m were conducted. The periodicity of these 'snapshots' was vessel speed dependent but timed to allow counts to occur as the vessel passes from one survey quadrant to the next. This method minimises biases in counts of flying birds relative to the movement of the vessel (Pollock *et al.,* 2000, Camphuysen *et al.* 2004).

Seabirds remaining with the vessel for more than 2 minutes were deemed to be associating with the vessel (Camphuysen *et al.* 2004) and were recorded as such. Seabirds seen associating with other vessels (i.e. fishing vessels) were also recorded as such.

Searching for seabirds was done with the naked eye, however, Leika Ultravid 8x42 HD binoculars were used to confirm parameters such as species identification, age, moult, group size and behaviour (Mackey *et al.* 2004). A Canon EOS 7D Mark II DSLR camera with a Canon EF 100-400 mm F4.5-5.6 IS II USM telephoto lens was used to visually document other information of scientific interest. Data was also collected on all migratory/ transient waterfowl and terrestrial birds encountered.

The Cybertracker (http://www.cybertracker.org/) data collection software package (Version 3.501) 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 5 seconds.

Each line transect was assigned a unique transect number, and a new transect was started anytime the vessel activity changed (i.e. changing from on-transect to inter-transect). Each subsequent sighting was also assigned to this unique transect number.

Environmental data was time-stamped and recorded with GPS data at the beginning and end of each line transect and also as soon as any change in environmental conditions occurred. Environmental data recorded included; wind speed, wind direction, sea state, swell, visibility, cloud cover and precipitation.

Each sighting was time-stamped and recorded with GPS data using Cybertracker. Sighting data such as; species identification, distance band, group size, composition, heading, age, moult, behaviour and any associations with cetaceans or other vessels were also recorded on the time stamped Cybertracker sighting record page. Where species identification could not be confirmed, sightings were recorded at an appropriate taxonomic level (i.e. large gull sp., Larus sp., Commic tern, etc.).

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

3 Results

3.1 Malin Shelf herring (6.a.S, 7.b, c and 6.a.N south of 58°30'N)

3.1.1 Biomass and abundance

Herring	Abund ('000)	Biomass (t)
TSB estimate	597,974	86,641
SSB estimate	426,663	68,607

The Malin Shelf Herring total stock biomass (TSB) was 86,641 t and total stock numbers (TSN) was 597,974,000 (Table 3). The spawning stock biomass (SSB) was 68,607 t and spawning stock numbers (SSN) was 426,663,000. The CV for the survey was 0.37.

The Malin Shelf survey area was divided into 6 strata representing a total area coverage of 32,162 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 Figure 4. The Malin Shelf survey time series is provided in Table 4.

3.1.2 Stock distribution

A total of 45 trawl hauls were carried out during the survey (Figure 1), with 1 haul containing >50% herring by weight of catch. Seven hauls in total contained herring within the Malin Shelf survey area (Table 2). A total of 115 echotraces were assigned to herring compared to 228 in 2018.

The area covered by the RV Celtic Explorer was similar to the 2018 survey. The area of 6.a.N to the north of 58°30'N was covered by RV Scotia in 2019; the overall estimate of the survey for the stock assessment of herring in 6.a will therefore be complete when both surveys are combined at WGIPS 2020. Herring were distributed in four out of the six strata (Table 5). There were no herring allocated to echotraces in the NW Coast strata or the Minch strata. A total of 58 EDSUs (1nmi. long) contained herring in the Malin Shelf survey area. This included a number of high NASC value EDSUs, with areas of high density occurring to the northwest of Tory Island, west of the Hebrides and north of St. Kilda (Figure 3). Herring were again found south of the 56 ˚N in 2019, similar to the historical distribution of herring found during this time series. There were adult herring distributed south of the 56°N in 2019 for the first time in a number of years. Herring schools were predominantly found in pillars in close proximity to the seabed (Figure 11g, 11h and 11j). Overall the stock was distributed throughout a similar area to 2018 (Figure 3). The distribution of herring during the survey period is usually 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 2019 largely followed this distribution.

3.1.3 Stock composition

A total of 304 herring were aged from survey samples with 1,568 length measurements and 505 length-weights recorded. Herring age samples ranged from 0-9 year olds (Table 3 & Figure 4). A further 276 herring were processed for morphometric and genetic analysis under SGHERWAY protocols (ICES 2010) in 2019; from hauls 35, 36 and 42.

The 2019 survey estimate was dominated by 2-wr (29% TSB and 35% TSN) and 3-wr (30% TSB and 29% TSN) (Table 3). The third most dominate age group was 4-wr herring contributing 17% to the TSB and 14% to TSN. Combined these three age classes represented 75% of TSB and 79% of TSN.

Maturity analysis of herring samples in 2019 indicated overall 79% of herring (TSB) were mature. In 2018, 71% of herring were mature. Maturity analysis by age class showed that 39% of 2-wr, 88% of 3-wr fish, and 100% of fish of 4-wr and older were mature (Table 3).

3.2 Boarfish

3.2.1 Biomass and abundance

Boarfish	Abund ('000)	Biomass (t)
TSB estimate	3,898,827	179,156
SSB estimate	2,701,057	169,216

Boarfish TSB (total stock biomass) and abundance (TSN) estimates were 179,156 t (CV 19.8%) and 3,898,827,000 individuals (CV 25.4 %) respectively.

The boarfish survey area was divided into five strata representing a total area coverage of 53,933 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 45 trawl hauls were carried out during the survey (Figure 1), with 11 hauls containing >50 % boarfish by weight (Table 2).

A total of 667 echotraces were assigned to boarfish as compared to 817 in 2018. Boarfish were observed in all survey strata (Table 7). The highest occurrence was in the Celtic Sea where over 61.8 % of the total survey biomass and 74.2% of total abundance was observed. This follows a similar pattern to previous years in containing the largest proportion of the stock. Within the Celtic Sea, the highest density of fish was observed in the southern survey area, south of 50°N following a similar pattern to the previous year (Figure 5). The southernmost transects were dominated by an area containing high density midwater clusters of juvenile boarfish (Figure 11a). The mid Celtic Sea saw aggregations of mature boarfish in the margins bordering the shelf edge (Figure 11b).

The west coast stratum ranked second and reported 21% of total biomass (14% abundance) in line with previous observations, although proportionally lower in 2019. The shelf area between 53-54°N, including the porcupine Bank, contained the highest abundance within these strata mirroring observations from 2018 (Figure 11c). The near absence of boarfish along the southwest coast of Ireland (51°-52°N) continued in 2019 from 2018 observations. The distribution of boarfish north of 55°N, to the north of Ireland and west of Scotland, was limited to the shelf edge margin (<180m) and continued towards the northern extreme of the survey (Figure 11i). The distribution of boarfish in the northern survey latitudes would indicate that the biotic and abiotic conditions continue to provide adequate feeding opportunities and spawning habitat to allow northward stock expansion.

3.2.3 Stock composition

A total of 808 boarfish were aged from survey samples in addition to 3,807 length measurements and 1,400 length-weights recorded. Boarfish age samples ranged from 1-15+ years (Table 6 & Figure 6). The age structure of the stock was determined using an established age length key.

The 15+ year age classes dominate the 2019 estimate contributing over 35.8% of TSB and 19.5% of TSN (Table 6). The 7-year-old (12.3% TSB and 11.4% TSN) and 10-year –old age classes (10% TSB and 7.4% of TSN) ranked second and third respectively. The ranked fourth was the 9-year-old (9.5% TSB and 7.4% TSN). Combined, the 15+, 7 and 10-year age classes represent 58.1% of TSB and 38.3% of TSN.

Maturity analysis of boarfish samples indicated 94.5% of observed biomass was mature (69.3% 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	333,501.0	79,026.0
SSB estimate	275,349.0	77,528.5

Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 79,026 t (CV 28.6%) and 333,501,000 individuals (CV 33.7%) respectively.

The horse mackerel survey area was composed of 7 strata relating to an area coverage of 60,183 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. The biomass of horse mackerel is 15% lower in terms of biomass and 13% in terms of abundance compared to 2018. Given the short time series the survey appears to be reporting working well, with the exception being the 2017 estimate resulting from the occurrence of a large single spawning aggregation in the northern area.

3.3.2 Stock distribution

A total of 45 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 120 echotraces were assigned to horse mackerel. Horse mackerel were most observed along the west coast of Ireland and Celtic Sea, where the bulk of the standing stock was located (Figure 7). Fewer schools were located to the northwest of Ireland or on the Porcupine Bank. Observations of horse mackerel along the west coast and Celtic Sea were comparable to 2018 in terms of distribution, but the number of schools (198 in 2018, 120 in 2019) and overall acoustic density were lower.

Of the 7 strata surveyed, four reported observations of horse mackerel. The Celtic Sea stratum contained the largest proportion of biomass observed (78.4% of TSB), followed by the west coast (19.2%), western Hebrides (2%) and Porcupine Bank (0.4%). Overall, the distribution of horse mackerel was considered patchy as compared to 2018, with only one area containing a mixture of medium and high density schools located off the southwest of Ireland (Figure 11d).

3.3.3 Stock composition

A total of 323 horse mackerel were aged from survey samples in addition to 463 length measurements and 341 length-weights recorded. Horse mackerel age samples ranged from 1-18 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 16-year age class dominated this year's survey estimate representing over 15.4% of TSB and 8.5% of TSN (Table 9). The 14-year age class ranked second representing over 11.8% of TSB and 6.9% of TSN (Table 9). Nine-year-old fish were ranked third contributing 11.43% to TSB and 7.9% to TSN. Combined these three age classes represented 38.7% of TSB and 23.4% of TSN.

Maturity analysis of horse mackerel samples indicated 98.1% of the total stock biomass was mature and over 82% of total abundance. Maturity analysis by age class showed that 25% of 1-year-old fish were mature, rising to 100% for fish two 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	682,177.0	43,462.0
Spawning stock	22,468.0	2,551.8

The estimate of Celtic Sea (CS) herring TSB (total stock biomass) and abundance (TSN) estimates were 43,462 t (CV 47.3%) and 682,177,000 individuals (CV 49%) respectively.

The herring survey area was composed of a single stratum in the Celtic Sea, representing an area of over 26,626 nmi² and was surveyed using the standard survey transect spacing of 15 nmi. No high intensity surveys were carried out for herring in 2019. 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

Ten echotraces were assigned to herring in the Celtic Sea and herring were sampled in four targeted hauls. Herring were observed in two areas; in the western and eastern Celtic Sea (Figure 11e-f and Figure 9).

3.4.3 Stock composition

A total of 165 CS herring were aged from survey samples in addition to 264 length measurements and 221 length-weights recorded. CS herring age samples ranged from 1-6 winter rings (wr) (Table 12 & 13 and Figure 10). Age structure of the stock was determined from survey aged otoliths.

One winter ring fish dominated the total estimate, representing over 65% of total biomass and over 72% of total abundance (Table 12). Two winter ring fish ranked second contributing 29.7% of the total biomass and 24.7% of total abundance. Combined these two immature ages classes represented over 95% of total biomass and over 97% of total abundance (Figure 10). Mature fish, accounted for the remaining 3% of the biomass and 1.5% of abundance. The strength of this emerging year class was first identified during the Celtic Sea herring acoustic survey in October 2018 and has tracked well through into 2019.

3.5 Hydrography and biogeochemical sampling

3.5.1 CTD sampling

In total, 87 CTD casts were carried out (Figure 12). Horizontal temperature and salinity maps for the survey area are provided for depths 5 m, 20 m, 50 m and at the seabed in Figures 13-16 respectively.

Surface waters, above the thermocline, showed a similar pattern of salinity in the 5 and 20 m depth profiles. Slightly lower salinity waters were found around coastal fringes and in the eastern Celtic Sea and are likely influenced by terrestrial run-off (Figures 13 &14). The temperature profile of surface waters showed the highest values in the south and in the eastern Celtic Sea as expected. Thermocline depth varied between sampling location ranging from of 35-45 m in the most part. Below the thermocline, (Figures 15 & 16), a pool of colder water is evident off the south coast of Ireland, forming a ribbon extending northwards along the coastal margin along the shelf. This water is likely from deeper Atlantic origin that has washed over the shelf sea. Salinity was relatively consistent with near surface observations. Temperature and salinity profiles would indicate the Irish shelf front boundary area occurring along the west coast of Ireland at approximately 11º W line of longitude and northwards of 52º N line of latitude.

Comparing hydrographic conditions with the acoustic observations of herring, it appears for all but one area in the southwest, the distribution of herring was closely aligned with the 10 ºC isotherm (Figure 17). Distribution appeared less influenced by salinity than temperature and is in agreement with previous years' observations during summer feeding phase.

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 87 hydrographic stations during the survey. Analysis of samples is underway.

3.5.3 Nutrient sampling

Samples were collected from all of the 87 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 87 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

The particulate absorption in seawater was 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. The correction of the pathlength amplification and the correction of the non-linear relationship between the optical density of samples on a Whatman GF/F filter and in suspension are discussed in (Mitchell, 1990). 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. This data is currently being quality checked and will be used for comparison to the hyperspectral surface reflectance data

For WESPAS 2018 we collected the first measurements of *in situ* reflectance from the Celtic Explorer using a pair of hyperspectral sensors which were mounted above the bridge of the Celtic Explorer. This data allows us to compare with satellite reflectance data used in ocean colour estimates of chlorophyll and primary productivity. Given that the satellite record along the west coast of Ireland is often impacted by clouds this approach also gives us valuable information along the WESPAS transect that can’t be gathered using remote sensing data. We were extremely lucky during WESPAS 2018 as there were several clear sunny days and during that time we were able to gather a reasonable dataset to compare with satellite ocean colour and this work continues on at present.

During WESPAS 2019, the hyperspectral array was supplemented with a 3rd sensor as shown in Figure 3 below. The use of a 3 sensor suite (Garaba et al., 2014; Garaba et al., 2015) incorporating an irradiance (measuring in the vertical) and two radiance sensors (pointing up - measuring the upwelling solar radiance and pointing down – measuring the sky leaving radiance) significantly improves our ability to more accurately determine the reflectance spectrum and remove solar glint (Garaba and Zielinski, 2013).

During WESPAS 2019 several thousand spectra were collected and the dataset is currently being quality assessed according to standard approaches (Garaba et al., 2015; Garaba and Zielinski, 2013) Ongoing work will compare shipboard reflectance chlorophyll estimates with the satellite and in situ observations and examine the influence of the particulate absorption (QFT-1 measurements) on the results. Further comparisons to the underway pCO_2 measurements and the discrete biogeochemical measurements will hopefully give more context to interpreting the spatial and temporal signals observed during WESPAS 2019.

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). Unlike the previous year when the hot dry summer provided an unprecedented number of clear sky days, data before and during WESPAS 2019 were more limited, though the monthly composites give reasonable coverage over the North West European shelf.

The ocean colour images (above) show high chlorophyll levels along the shelf edge and porcupine mound with lower concentrations in the Celtic Sea. The peak of the spring bloom offshore was in May-June with lower levels encountered July when the bulk of the WESPAS 2019 survey was carried out. The remote sensing data acquired during 2019 and other years has allowed us to identify 4 main regions of interest. Work is ongoing into the physical and biogeochemical drivers of primary productivity in these regions.

1) Persistent low chlorophyll over the Porcupine Bank (White et al., 1998).
2) High Chlorophyll over Rockall Bank
3) Low chlorophyll in the Rockall Trough/High inshore at Shelf Edge
4) Low chlorophyll in the Celtic Sea/High offshore at Shelf Edge

3.6 Zooplankton biomass and jellyfish abundance

3.6.1 Zooplankton

Plankton samples were collected at 78 stations during the survey. Species composition analysis is currently underway using chemically fixed samples. Zooplankton biomass (dry weight) by station was similar during the period 2017-2019 and higher than 2016 (Figure 20). 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. The consistency of dry weight biomass from 2017 onwards compared to lower levels observed in 2016, given equal sampling effort, is difficult to ascertain without further detailed analysis. Further years may provide more insight into the utility of this sampling effort, such as the increase in numbers of immature fish (herring/boarfish/horse mackerel) of the 2017- 2018 year classes and the increased zooplankton biomass during the same period.

3.6.2 Jellyfish

Preliminary data for visual jellyfish observation surveys are provided below. On leg 1, The three most abundant species enumerated during visual surveys were identical to 2018 cruise which included the hydrozoan *Aqueora sp.*, the ctenophore *Beroe sp.* and the pleustonic hydrozoan *Velella velella*. On the second leg of 2019 the compositions of jellyfish differed from the year before. A total of 1,917 jellyfish were observed, down from the previous year of 2,577. The most abundant was the lion's mane jellyfish *C. capillata* (1421), followed by the cosmopolitan moon jellyfish (264) and the hydrozoan jellyfish *Aqueora victoria* (158). The most notable change in jellyfish composition from 2018 to 2019 in this region was the spike in observations of the lion's mane jellyfish (*Cyanea capillata*) which increased by 400% compared to the previous survey year. In the coming months, further data processing will allow the quantitative description of surface jellyfish abundance along the cruise track line which will allow more robust statistical comparisons of data years.

3.7 Marine mammals and seabirds

In total, 154 hours and 38 minutes of survey effort was conducted over the course of WESPAS 2019, 112 hours and 41 minutes of survey effort was conducted on Leg 1, while 41 hours and 57 minutes of survey effort was conducted on Leg 2 of the survey. In total, 144 hours and 27 minutes of survey effort were conducted using a line transect methodology, while 10 hours and 12 minutes of effort were conducted using the point sampling methodology.

A total of 128 sightings, were recorded throughout the survey. This includes 23 sightings recorded as auxiliary sightings and 30 sightings recorded as incidental sightings. From the total 128 sightings, marine mammals accounted for 105 sightings. The marine mammal sightings included; 3 whale species, 3 dolphin species, 1 porpoise species, and a number of sightings which could not be identified to species level. The remaining 23 sightings consisted of other marine megafauna.

Of the 128 sightings, 102 were recorded while conducting line transects, 7 were recorded while conducting point sampling, while the remaining 19 sightings were recorded off survey effort. A list of the species encountered can be seen in Table 14, and the distribution of the sightings can be seen in Figure 22.

Common dolphins (*Delphinus delphis*) were the most frequently encountered and most abundant species accounting for 63 sightings (49.2% of all sightings) and comprising of 1705 individuals in total (88% of all encountered individuals.)

Minke whales (*Balaenoptera* acutorostrata) were the second most frequently observed species. Minke whales were encountered on 16 occasions, accounting for 12.5% of all sightings. These sightings consisted of a total of 18 individuals (0.9% 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 17 separate occasions, accounting for 13.3% of all sightings. Each sighting consisted of a lone individual (0.9% of encountered individuals).

Other marine megafauna encountered included; blue fin tuna (*Thunnus thynnus*), blue shark (*Prionace glauca*), a probable sightings of a smooth hammerhead shark (*Sphyrna zygaena*) and a sighting of an unidentified shark species.

3.7.1 Marine mammal visual abundance survey

3.7.2 Seabird abundance and distribution

In total, 225 hours and 39 minutes of survey effort was conducted over the course of WESPAS 2019, 125 hours and 3 minutes of survey effort was conducted on Leg 1, while 100 hours and 36 minutes of survey effort was conducted on Leg 2 of the survey. In total, 187 hours and 36 minutes of survey effort were conducted using a line transect methodology, while 38 hours and 4 minutes of effort were conducted using the point sampling methodology.

A total of 4,529 seabird sightings were recorded throughout the survey, totalling 34,896 individuals (Table 15). In total, 7,333 seabirds were recorded as "in transect", while 27,562 were recorded "off transect". The species encountered included 28 species from 8 families. A further 23 sightings of terrestrial birds were also recorded, comprising of 56 individuals.

Fulmar (*Fulmarus glacialis*) were the second most frequently observed species accounting for 965 sightings (21.3% of all sightings), however, they were the most abundant species comprising of 8,159 individuals in total (32.8% of all encountered individuals.) Of these, 1,081 individuals were recorded as 'in transect'.

Gannets (*Sula bassana*) were the most frequently sighted and the second most abundant species accounting for 1,265 sightings (27.9% of all sightings) and comprising of 6,116 individuals in total (24.6% of all encountered individuals.) Of these, 865 individuals were recorded as 'in transect'.

Manx shearwaters (*Puffinus puffin*) were the third most frequently sighted and the fourth most abundant species accounting for 561 sightings (12.4% of all sightings) and comprising of 3,010 individuals in total (12.1% of all encountered individuals.) Of these, 989 individuals were recorded as 'in transect'.

European storm petrel (*Hydrobates pelagicus*) were the fourth most frequently observed species accounting for 524 sightings (11.6% of all sightings), however, they were the third most abundant species comprising of 3,425 individuals in total (13.8% of all encountered individuals.) Of these, 860 individuals were recorded as ‘in transect’.

On a number couple of occasions species including fulmar, Manx shearwaters, European storm petrel, and puffin became too numerous to accurately count. On these occasions surveying for these species was suspended.

The survey also recorded the first confirmed sighting of a south polar skua (*Stercorarius maccormicki*) in Irish waters.

A number of terrestrial species were also recorded during the survey including 7 sightings (totalling 12 individuals) of swifts (*Apus apus*) a spotted flycatcher (*Muscicapa striata*), and a pair of golden eagles (*Aquila chrysaetos*) which were seen in the Minch.

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 for the acoustic survey but 9 zooplankton stations were lost due to high winds.

Malin Shelf herring distribution was concentrated in an area to the north and west of Tory Island (south of 56˚N) in 6.a.S and to the west of the Hebrides in 6.a.N, particularly north of St. Kilda (Figure 3). However, there was a 47% decrease in overall the SSB in 2019 compared to 2018 in the survey area (O'Donnell et al 2018). The final estimate of herring in 6.a (combined 6.a.S, 7.b,c and 6.a.N) will be completed by including the biomass and abundance of herring from the survey of 6.a.N to the north of 58˚30N and west of 4˚W carried out by the RV Scotia. This final estimate will be worked up at WGIPS in 2020. There have been issues with stock identification and containment with this survey in the past, particularly in relation to the boundary of the North Sea stock at the 4˚W line, and the distribution of herring north and south of the 56˚N line (6.a.N/6.a.S), for example. Fish distributed either side of these boundary lines influence the survey estimates. There is work ongoing to try to split the survey into 6.a.N and 6.a.S components and it is hoped that this will be possible in the future.

There were good signs of 2-wr and 3-wr herring distributed in 6.a.S for the first time in a number of years. There were fewer 1-wr herring caught on the survey in 2019 compared to 2018, however, it is suspected that these fish may have been missed. A couple of hauls were attempted on fast moving midwater marks to the north of Lough Swilly and because there was no catch, it is unknown whether these marks were juvenile herring. These marks had the acoustical signatures of young herring and this was an area where young 1-wr herring were caught in 2018. This survey is not a good design for juvenile herring in any case. The age profile of survey samples in 2019 somewhat follows the cohorts from 2018; 2-wr and 3-wr herring dominate the survey (59% in terms of biomass, and 65% in terms of abundance). The survey was dominated by 1-wr, 2-wr and 4-wr herring in 2018. There is a small peak in 5-wr fish (corresponding to the 4-wr fish from the 2018 survey) in the western Hebrides strata (Figure 4), however, this is not evident in other areas. In 2016, there was a much more even distribution of year classes. No herring were found in the Minch in 2019. The CV estimate for the 2019 survey is higher than in 2018 (0.37 compared to 0.28); however, this is comparable to previous years in the time-series.

The distribution of boarfish was comparable to earlier years in the time series; with a high number of individual schools clustered towards the shelf edge in the southern Celtic Sea and a cluster of schools around the Porcupine Bank. Along the west coast, boarfish were distributed on the oceanic side of the Irish Shelf Front on the shelf sea and distribution extended northwards, constrained in a narrow ribbon along the shelf to 60º N. In 2019, across the distribution area mature fish dominated catch samples. However, an area of high abundance of immature fish was observed in the southern survey area, significantly larger and numerous than in previous years. The contribution of immature fish to the total estimate of abundance is the highest in the time series, (5.5% of total biomass and 30.7% of total abundance) indicating a potentially strong emerging year class within the stock.

Overall, the acoustic density and number of echotraces of boarfish was lower than observed in 2018, considering increased trawling effort (7%), acoustic sampling effort (17%) and area coverage (7% increase). Overall, total biomass and total abundance were comparable to 2018 with a 4% decrease in biomass and 8% decrease in abundance in 2019. Accurate age determination of the standing stock remains an issue due 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. This considered the oldest (15+ year) cohort remain the largest contributors to the stock biomass and abundance. In 2019, immature fish also contributed significantly, ranking highest in abundance and so providing an important future potential input to spawning stock biomass.

Horse mackerel were distributed along the Irish west coast, Porcupine Bank and Celtic Sea. Geographical distribution was comparable to previous surveys but the number and acoustic density of aggregations was lower than in 2018. Total stock biomass was 15% lower and total abundance was 13% lower compared to 2018. However, the survey time series is still and more surveys are still required to qualify the ability of this survey to provide a meaningful index of relative abundance. The age composition of the stock in 2019 was dominated by older age classes (16, 14, 9 & 18 years) contributing over 50% of the total stock biomass. Immature fish represented over 17% of total abundance (1.8% of biomass) which was higher than in the current time series (2016-2019).

Aggregations of Celtic Sea herring were encountered during the survey in what are considered historic feeding grounds. The high proportion of immature fish (96.7% TSN and 94.1% TSB) reflect observations made during the CSHAS 2018 that a strong year class is evident within the stock (O'Donnell et al., 2018). The 2019 CSHAS will quantify this year class as part of the annual time series.

The 2019 WESPAS survey reported higher than average numbers of immature fish and pre-recruiting Celtic Sea herring, boarfish and horse mackerel (1-2 years old). This would indicate favourable conditions for key life stages including, spawning, egg and larval survival and post larval development beginning in 2017. Given these species have similar, but not identical, ontogenic resource requirements this would indicate a favourable change in biotic and abiotic conditions bridging the requirements of more than one species. As this survey is not designed to track juveniles it is too early to judge how these year classes will contribute until they are fully recruited to the spawning stock in the coming year(s).

There were a large number of mackerel marks recorded throughout the Minch strata in the north of the survey area, and in the area to the southeast and southwest of Barra Head. These marks were often midwater (e.g. Figure 11l) in a range of depths down to 180m, and went on for many miles in places. There were also mackerel marks recorded on the surface in some areas. Mackerel were caught in some trawls targeting boarfish on the shelf edge (~200m). The marks throughout the survey area in the north were typical of mackerel marks reported in the literature (e.g. Korneliussen 2010) with very strong backscatter on the 120 and 200 kHz compared to the lower frequencies. There was mackerel in 23 out of 45 hauls throughout the survey area, most frequent in the northern part of the survey area.

Hydrographic conditions in surface waters were as to be expected during the summer months with warmer waters dominating more southern latitudes and well stratified water masses with a strong thermocline. Thermocline depth ranged from 35-45m in the main. Below the thermocline, and at seafloor, western Ireland was ringed by an area of cool water close to the coast with a district boundary front which continued in a ribbon northwards boarding the self-margin area. Herring were encountered predominantly within the cooler water (approximately 10ºC isotherm) ribbon to the west of Ireland, Scotland and in the Celtic Sea. Boarfish and horse mackerel distribution appeared to be more influenced by salinity, given they are more oceanic species, than herring and were primarily distributed in full seawater conditions regardless of temperature or latitude.

4.2 Conclusions

- Malin Shelf herring biomass was ~47% lower in 2019 compared to 2018 (SSB_{2019} = 69,000 t SSB_{2018} =130,000 t). The CV on the survey was higher in 2019 (0.37) when compared with 2017 (0.28); the CV in 2019 is comparable to previous years in the time series
- The Malin Shelf Herring total stock biomass (TSB) was 86,641 t and total stock numbers (TSN) was 597,974,000
- Herring were distributed further south in 2019 compared to 2018, with some adult herring south of 56°N. This is the second year in a row that herring were found in this area. For instance, there was very little herring distributed south of 56°N in both 2016 and 2017.
- The 2019 survey estimate was dominated by 2-wr (29% TSB and 35% TSN) and 3-wr (30% TSB and 29% TSN). This compares well with the 2018 survey, showing some cohort tracking; the dominant age classes in the 2018 survey were 1-wr and 2-wr fish.
- There were some 1-wr herring found in the survey this year, although numbers were much fewer than in 2018. It is suspected that young herring were missed on a number of hauls.
- Boarfish distribution showed a similar pattern to previous years. The number of schools was lower but mean acoustic density was comparable to 2018.
- Boarfish TSB (total stock biomass) and abundance (TSN) estimates were 179,156 t and 3,898,827,000 individuals (CV 25.4%) respectively.
- The contribution of immature boarfish to the 2019 estimate was significant given it is the highest in the time series representing 3% of total biomass and 20% of total abundance. Older fish (15+ year class) still dominate the stock (35.8% total biomass and 19.5% total abundance).
- An area containing numerous schools of immature boarfish was observed in the southern survey area to the west of France contributing to the increased number of immature fish observed overall. During previous year's, low numbers of immature fish have been observed with an inconsistent spatial pattern.
- Horse mackerel biomass is considered a reliable estimate of the standing stock in 2019 given comparable survey effort and area coverage with previous years. Improvements are required to ensure consistency of survey derived age sampling and reduce this source of error.
- Horse mackerel TSB (total stock biomass) and abundance (TSN) estimates were 79,026 t and 333,501,000 individuals (CV 33.7%) respectively.
- The positive signal of the 3-year class of horse mackerel notable in 2018 was tracked through into 2019, appearing as 4-year-old fish and ranking second most abundant (13.9%) after immature 1-year-old fish (19.1%).
- Aggregations of Celtic Sea herring were observed around traditional feeding areas in the west and eastern Celtic Sea. Catch samples were dominated by immature fish representing 96.7% of abundance and 94.1% of the biomass and indicating the strength of this, as yet to recruit, year class. Mature fish

were clearly underrepresented given the current state of the spawning stock biomass.

- Higher than average levels of immature fish for main target species observed during the survey. The potential of which will be monitored during subsequent surveys and as these fish become fully recruited to the respective spawning stocks.
- 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 and boarfish 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.
- There were a large number of mackerel marks recorded throughout the Minch strata in the north of the survey area, and in the area to the southeast and southwest of Barra Head. These marks were often midwater in a range of depths down to 180m, and went on for many miles in places. There were also mackerel marks recorded on the surface in some areas

5 Acknowledgements

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6 References

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7 Tables and Figures

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

Echo Sounder System Calibration Report

Vessel :	RV Celtic Explorer	Date :	26.03.19
Echo sounder :	Drop Keel	Locality :	Killary Harbour
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	-42.37 dB	Min. Distance	15.0m
TS Deviation	5 dB	Max. Distance	21.0m

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	6.98 deg	Along. Beam Angle	6.91 deg
Athw. Offset Angle	-0.04 deg	Along. Offset Angl	-0.05 deg
SaCorrection	-0.66 dB	Depth	8.80 m

Transceiver: GPT 38 kHz 009072033933 1 ES38B

Pulse Duration	1.024 ms	Sample Interval	0.191 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.	9.9 dB/km	Sound Velocity	1490.2 m/s

Beam Model results:

Transducer Gain =	25.85 dB	SaCorrection =	-0.64 dB
Athw. Beam Angle =	6.91 deg	Along. Beam Angle	6.87 deg
Athw. Offset Angle =	-0.02 deg	Along. Offset Angl	-0.05 deg

Data deviation from beam model:
RMS = 0.19 dB
Max = 0.66 dB No. = 196 Athw. = 4.1 deg Along = 2.6 deg
Min = -0.74 dB No. = 234 Athw. = 0.1 deg Along = 4.8 deg

Data deviation from polynomial model:
RMS = 0.16 dB
Max = 0.61 dB No. = 196 Athw. = 4.1 deg Along = 2.6 deg
Min = -0.54 dB No. = 197 Athw. = 4.0 deg Along = 2.7 deg

Comments :
WC 38.1mm, IBWSS 2019
Wind Force : **Wind Direction :**
Raw Data File: Z:\Acoustic Data\CE19005_BWAS_2019\Scientific\EK60\Data\Calibration\Calibration
Calibration File: Z:\Acoustic Data\CE19005_BWAS_2019\Scientific\EK60\Data\Calibration\Calibration

Calibration : Michael O'Malley

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	14.06.19	47.56	-6.14	16:11	151	135	223	76.3	0.3		18.0	5.3
2	15.06.19	47.81	-6.16	09:54	144	50	414	100.0				
3	16.06.19	47.06	-7.62	08:00	190	170	10	25.9			49.8	24.3
4	16.06.19	48.31	-8.85	17:40	177	0	67	82.4			1.9	15.7
5	17.06.19	48.56	-7.09	17:12	160	0	36	97.9			1.1	0.8
6	17.06.19	48.56	-7.41	20:29	155	120	4,000	99.9			0.1	
7	18.06.19	48.81	-8.98	07:11	144	25	324	85.4	14.5			0.1
8	20.06.19	49.06	9.72	11:14	153	15	0					
9	20.06.19	49.06	-10.91	18:40	176	30	54	5.8	0.8		89.6	3.8
10	21.06.19	49.31	-8.38	14:12	136	116	119	95.5	3.6		0.4	0.5
11	22.06.19	49.57	-8.99	07:46	141	71	2					100.0
12	23.06.19	49.82	-8.30	13:55	133	45	300					100.0
13	24.06.19	50.06	-10.08	12:32	118	10	500		100.0			
14	24.06.19	50.06	-10.65	17:10	152	122	225				61.3	38.7
15	25.06.19	50.31	-10.03	05:55	118	10	30	46.9			13.8	39.3
16	25.06.19	50.31	-9.53	09:35	133	0	38	1.6			43.7	54.7
17	25.06.19	50.31	-8.19	18:45	121	25	42					100.0
18	26.06.19	50.56	-8.35	08:25	121	0	275		0.5		18.3	81.2
19	27.06.19	50.81	-9.91	10:30	119	0	15	0.4	59.3	5.2	19.2	16.0
20	28.06.19	50.81	-7.64	07:20	100	0	28			30.1		69.9
21	28.06.19	50.81	-6.76	12:30	96	0	176		74.6	17.2	0.2	7.9
22	29.06.19	51.06	-10.11	10:22	124	0	40		82.6	9.9	1.4	6.1
23	29.06.19	51.60	-11.23	17:10	200	75	1,200	98.2			0.9	0.9
24	01.07.19	52.57	-11.16	11:30	127	0	29		80.7		6.7	12.6
25	01.07.19	52.58	-11.66	15:40	159	0	130		24.1		73.4	2.5
26	01.07.19	52.85	-11.35	23:25	130	0	38	2.1	85.1		8.2	4.6
27	02.07.19	53.10	-10.23	10:40	92	30						
28	02.07.19	53.10	-11.52	17:30	135	0	1		58.0			42.0
29	03.07.19	53.60	-10.79	11:12	107	0						
30	07.07.19	53.35	-13.88	12:47	154	75	2,000	97.7			2.3	
31	08.07.19	53.86	-11.20	12:30	207	90	0		100.0			
32	09.07.19	54.44	-9.85	08:48	97	30	46					100.0
33	10.07.19	55.11	-10.02	16:12	200	180	1,000	99.0				1.0
34	11.07.19	55.54	-8.08	18:23	81	60	7		99.0			1.0
35	13.07.19	55.86	-8.46	10:05	134	110	5,000			100.0		
36	13.07.19	55.86	-9.25	16:15	188	160	1,000	12.3	84.8	2.9		
37	14.07.19	56.33	-6.82	10:34	73	60	400		1.0	1.0		98.0
38	14.07.19	56.36	-7.53	16:04	160	140	200		45.0			55.0
39	15.07.19	56.87	-8.87	16:01	120	100	144					100.0
40	16.07.19	57.12	-7.81	06:18	90	15	150	63.0	3.0	1.0	5.0	28.0
41	17.07.19	57.87	-8.96	09:38	142	130	132		10.0	1.0		89.0
42	18.07.19	58.25	-8.52	11:51	164	140	335		46.0	29.0		25.0
43	18.07.19	58.25	-7.95	14:55	122	82	53		5.0	9.0		86.0
44	20.07.19	57.47	-6.89	08:02	180	30	91					100.0
45	21.07.19	55.40	-8.21	17:22	85	70	140		100.0			

Table 3. Malin Shelf herring stock estimate 2019 (6.a.S, 7.b,c and 6.a.N (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		-	-	-	-	-	-	-	-	-	-	-	-	0			0
6		-	-	-	-	-	-	-	-	-	-	-	-	0			0
6.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
7		-	-	-	-	-	-	-	-	-	-	-	-	0			0
7.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
8		-	-	-	-	-	-	-	-	-	-	-	-	0			0
8.5		-	-	-	-	-	-	-	-	-	-	-	-	0			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		-	-	-	-	-	-	-	-	-	-	-	-	0			0
16		-	-	-	-	-	-	-	-	-	-	-	-	0			0
16.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
17		-	-	-	-	-	-	-	-	-	-	-	-	0			0
17.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
18		-	-	-	-	-	-	-	-	-	-	-	-	0			0
18.5		-	-	-	-	-	-	-	-	-	-	-	-	0			0
19		10563	-	-	-	-	-	-	-	-	-	-	-	10563	633.8	60	0
19.5		-	-	-	-	-	-	-	-	-	-	-	-				
20		2224	-	-	-	-	-	-	-	-	-	-	-	2224	133.4	60	0
20.5		2780	-	-	-	-	-	-	-	-	-	-	-	2780	166.8	60	0
21		3336	-	-	-	-	-	-	-	-	-	-	-	3336	287.4	86.17	0
21.5		-	9009	-	-	-	-	-	-	-	-	-	-	9009	806.3	89.5	0
22		-	29250	-	-	-	-	-	-	-	-	-	-	29250	2875.2	98.3	0
22.5		2680	31388	-	-	-	-	-	-	-	-	-	-	34068	3612.2	106.03	22
23		-	48418	2010	-	-	-	-	-	-	-	-	-	50428	5723.8	113.51	34
23.5		-	43595	14397	-	-	-	-	-	-	-	-	-	57992	6966.1	120.12	53
24		-	29681	21749	-	-	-	-	-	-	-	-	-	51430	6650.9	129.32	62
24.5		-	15017	26478	3677	-	-	-	-	-	-	-	-	45172	6410.1	141.9	85
25		-	3348	28488	8715	3628	-	-	-	-	-	-	-	44179	6580.1	148.94	100
25.5		-	-	41970	11651	-	-	-	-	-	-	-	-	53621	8322.7	155.21	100
26		-	-	30846	20000	-	4020	-	-	-	-	-	-	54866	9169	167.12	100
26.5		-	2653	3579	13173	13972	6459	-	-	-	-	-	-	39836	6975.4	175.1	100
27		-	-	4971	15733	10552	7706	2680	-	-	-	-	-	41642	7620.2	182.99	100
27.5		-	-	-	12434	3322	5293	-	-	-	-	-	-	21049	4049	192.36	100
28		-	-	-	893	10372	670	-	-	-	-	-	-	11935	2369.7	198.54	100
28.5		-	-	-	-	9678	893	682	2478	-	-	-	-	13731	2786.4	202.92	100
29		-	-	-	-	3340	3350	-	4466	223	-	-	-	11379	2413.5	212.09	100
29.5		-	-	-	-	447	670	-	3350	2010	-	-	-	6477	1450.6	224	100
30		-	-	-	-	-	-	-	-	1558		-	-	1558	302.3	194	100
30.5		-	-	-	-	-	-	-	1449	-	-	-	-	1449	336.2	232	100
31		-	-	-	-	-	-	-	-	-	-	-	-	0			100
32		-	-	-	-	-	-	-	-	-	-	-	-	0			100
TSN (1000)	0	21583	212359	174488	86276	55311	29061	3362	11743	3791				597974			
TSB (t)		1498.1	24511.1	26283.7	14543.9	10451	5370.5	639.3	2554.6	788.9					86641.1		
Mean length (cm)		20.04	23.15	25.04	26.26	27.36	27.2	27.3	29.22	29.68							
Mean weight (g)		69.41	115.42	150.63	168.57	188.95	184.81	190.14	217.54	208.08						144.89	
SSB (t)		0	10536.6	23722.2	14543.9	10451	5370.5	639.3	2554.6	788.9					68607		
% mature		0	39	88	100	100	100	100	100	100							

Table 4. Malin Shelf herring survey time series 2008-2019. Survey coverage: - ^ 6.a.S & 7.b,c; * 6.a.S, 6.a.N & 7.b; ** 6.a & 7.b,c; ***6.a.S, 7.b,c & 6.a.N (south of 58°30’N).

Age	2008^	2009^	2010*	2011*	2012*	2013*	2014*	2015**	2016*	2017***	2018***	2019***
0	-	-	-	-	-	-	-	-	-	-	264.6	
1	6.1	416.4	524.8	82.1	608.3	-	1,115.4	4.9	-	-	395.8	21.6
2	75.9	81.3	504.3	202.5	451.5	96.2	214.7	162.1	9.7	11.0	339.2	212.4
3	64.7	11.4	133.3	752.0	444.6	254.3	166.3	291.7	102.3	273.4	112.5	174.5
4	38.4	15.1	107.4	381.0	516.1	265.8	380.0	580.7	91.4	111.0	314.1	86.3
5	22.3	7.7	103.0	110.8	180.3	78.7	352.1	487.3	91.4	71.6	137.5	55.3
6	26.2	7.1	83.7	124.0	115.4	26.9	125.0	513.4	58.2	94.4	43.7	29.1
7	9.1	7.5	57.6	118.4	116.9	18.5	18.9	143.9	46.5	28.0	59.5	3.4
8	5.0	0.4	35.3	70.7	83.8	10.8	9.7	33.4	2.7	9.9	16.8	11.7
9	3.7	0.9	17.5	41.6	56.3	4.1	4.7	-	0.5	2.6	8.2	3.8
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	598.0
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	86,641.1
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	68,607.0
CV	34.2	32.2	24.7	22.4	22.8	21.5	28.6	28.6	31.3	46.6	28.3	37.3

Table 5. Malin Shelf herring spawning stock biomass and abundance by strata 2019.

Strata name	Area (nmi²)	Transects	Abundance ('000)	Biomass (t)
Minch	3604	7	0	0
W Hebrides	7100	7	162,127	25,632
SW Hebrides	4867	4	9,713	1,360
NW Coast	2257	2	0	0
W Coast	11232	12	59,181	8,295
N Malin	3102	3	366,948	51,353
Total	**32,162**	**35**	**597,969**	**86,641**

Table 6. Total boarfish 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+	Unknown	(000's)	(t)	(g)	(%)
4																2291	2291	9.2	4	0
4.5	6583																6583	20.6	3.13	0
5	46543																46543	227.7	5	0
5.5	102249																102249	412.3	4	0
6	180430																180430	1076.7	6	0
6.5	148644																148644	999.1	7	0
7	203209	67465															270674	2354	9	0
7.5	92347	162432															254780	2534.6	10	0
8		149449															149449	1754.1	12	0
8.5		9766	10580														20346	269.4	13	0
9																15782	15782	282.3	18	100
9.5			24329														24329	477.7	20	100
10			46061														46061	971.5	21	100
10.5				52801													52801	1309.8	25	100
11				25479	38797				8675								72951	2126.4	29	100
11.5				14772	49441	32269	2158										98641	3271	33	100
12						43694	92790										136483	5371.2	39	100
12.5						8813	106673	60083									175569	7663.1	44	100
13							117803	17111	64933	17628		1002					218478	11200.4	51	100
13.5						21104	50019	55403	42623	80776	3548						253473	14044.9	55	100
14							64357	34213	87775	145531		28356		15253			375484	22944.6	61	100
14.5							11943	15811	66056	16034	38854	42794	9476	17078	110479		328526	21878.2	67	100
15									7215	2546	7074	120094	64838	18695	118539		339001	25923.3	76	100
15.5									10767	27581			4783	6208	191892		241231	19861.2	82	100
16															227165		227165	20674.1	91	100
16.5															69716		69716	7061	101	100
17															31659		31659	3404.7	108	100
17.5															9301		9301	1010.8	109	100
18																186	186	22.5	121	100
18.5																				
19																				
19.5																				
TSN (10^{-3})	780005	389112	80969	93052	88238	105880	445743	182622	288045	290096	49476	192247	79097	57234	758752	18259	3898827			
TSB (t)	5297.6	4212.5	1587.6	2565.1	2686.7	4255.7	22055	9854.1	16979.7	17989.5	3351.3	13676.3	6298.8	3904.8	64127.6	314		179156		
Mean length (cm)	6.4	7.63	9.65	10.8	11.28	12.19	12.91	13.3	13.81	13.98	14.5	14.73	14.97	14.64	15.6	8.46				
Mean weight (g)	6.79	10.83	19.61	27.57	30.45	40.19	49.48	53.96	58.95	62.01	67.74	71.14	79.63	68.22	84.52	17.2			45.95	
% mature*	0	0	33	100	100	100	100	100	100	100	100	100	100	100	100	100				
SSB	0.0	0.0	523.9	2565.1	2686.7	4255.7	22055.0	9854.1	16979.7	17989.5	3351.3	13676.3	6298.8	3904.8	64127.6	314.0		169216		

Table 7. Boarfish biomass and abundance by strata.

Strata name	Area (nmi²)	Transects	Abundance ('000)	Biomass (t)
W Hebrides	2,625.5	8	138432	8647.9
S Hebrides	2,164.4	5	175621	11623.4
W Coast	12,080.4	17	549919	36878.6
Porcupine Bank	4,965.4	6	141613	11110.2
Celtic Sea	32,097.3	16	2893242	110646
Total	53,933.0	52	3,898,827	178,906.1

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

Age (Yrs)	2011	2012	2013	2014	2015	2016	2017	2018	2019
0	-	-	-	-	-	-	-	-	-
1	5.0	21.5	-	-	198.5	4.6	110.9	76.7	782.3
2	11.6	10.8	78.0	-	319.2	35.7	126.7	31.2	389.1
3	57.8	174.1	1,842.9	15.0	16.6	45.5	344.6	115	96.8
4	187.4	64.8	696.4	98.2	34.3	43.6	367.3	68.3	93.1
5	436.7	95.0	381.6	102.3	80.0	6.0	156.0	106.7	88.2
6	1,165.9	736.1	253.8	104.9	112.0	10.0	209.0	165.9	105.9
7	1,184.2	973.8	1,056.6	414.6	437.4	169.0	493.1	320.7	445.7
8	703.6	758.9	879.4	343.8	362.9	112.6	468.3	197.7	182.6
9	1,094.5	848.6	800.9	341.9	353.5	117.6	397.2	293.4	288
10	1,031.5	955.9	703.8	332.3	360.0	96.6	285.8	624.7	290.1
11	332.9	650.9	263.7	129.9	131.7	17.0	120.9	339.2	49.5
12	653.3	1,099.7	202.9	104.9	113.0	32.0	82.1	264.1	192.2
13	336.0	857.2	296.6	166.4	174.0	48.7	74.4	198.4	79.1
14	385.0	655.8	169.8	88.5	108.0	18.3	220.4	116.5	57.2
15+	3,519.0	6,353.7	1,464.3	855.1	1,195.0	400.1	931.0	302.4	758.9
TSN (10^{-3})	11,104	14,257	9,091	3,098	3,996	1,157	4,387	3,221	3,899
TSB (t)	670,176	863,446	439,890	187,779	232,634	69,690	223,860	186,252	179,156
SSB (t)	669,392	861,544	423,158	187,654	226,659	69,103	218,810	184,235	169,216
CV	21.2	10.6	17.5	15.1	17.0	16.4	21.9	19.9	25.4

Table 9. Horse mackerel stock estimate.

Length (cm)	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Unknown	Numbers (000's)	Biomass (t)	Mn Wt (g)	Mature (%)
11																										0
12	21229																						21229	403.4	19	0
13	24767																						24767	569.6	23	20
14	10615																						10615	293.7	27.67	50
15	7076																						7076	214.1	30.25	33
16																						431	431	20.1	46.5	100
17																						216	216	11	51	100
18																						216	216	14.7	68	100
19		14282																					14282	946.7	66	100
20																						962	962	66.1	69	100
21			4406																				4406	392.1	89	100
22																										
23																										
24				746																			746	76	102	100
25			3213	1992																			5204	753.8	145	100
26			1573	11736																			13309	2258.9	170	100
27				17174	9343	3194	1919																31630	5978.7	189	100
28				12233	12946	5605	3390																34175	7136.9	209	100
29					3839	7871	11583	1600	4768														29662	6582	222	100
30				2476	4811		3453																10740	2649.2	247	100
31						283	2832	2832	283														6230	1665.1	267	100
32						1501	2401																3902	1165.6	299	100
33							855	360	9316														10531	3586.5	340.55	100
34							3387	968	1936		1452												7742	2675	345.5	100
35								415	1662	415	415		549	11164									14622	5630	385.03	100
36									8682					3167		6860							18710	7563.3	404.24	100
37														5004	10008	17666		5004					37682	16662.1	442.17	100
38												3892		3892		3892							11676	4970.1	425.67	100
39																		11676					11676	6145.5	526.33	100
40																		1061					1061	596	561.5	100
41																										
42																										
TSN (10^{-3})	63687	14282	9191	46357	30939	18455	29822	6175	26647	415	1867	3892	549	23228	10008	28419		17741				1825	333501			
TSB (t)	1480.7	946.7	1064.9	8692.7	6656.1	4034.2	7335.3	1696	9035.3	165.4	693.4	1471.2	210.4	9375.6	4438.5	12204.3		9413.6				112		79026		
Mean length (cm)	13.06	19	23.25	27.04	28.13	28.62	29.99	31.34	33.44	35	34.22	38	35	36.07	37	36.9		38.5				18				
Mean weight (g)	23.25	66.29	115.86	187.52	215.14	218.6	245.97	274.64	339.07	398	371.37	378	382.83	403.64	443.5	429.45		530.6				61			236.96	
% mature*	25	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100		100				0				
SSB	370	947	1,065	8,693	6,656	4,034	7,335	1,696	9,035	165	693	1,471	210	9,376	4,439	12,204		9,414				0	77803.8			

Table 10. Horse mackerel biomass and abundance by strata.

Strata name	Area (nmi²)	Transects	Abundance ('000)	Biomass (t)
W Hebrides	2884.1	8	11,997	1,595
S Hebrides	2027.0	4	0	0
N Stanton	2086.6	4	0	0
S Stanton	1880.3	4	0	0
W Coast	13655.6	17	65,951	15,175
Porc Bank	5552.1	6	804	303
Celtic Sea	32097.3	16	254,749	61,954
Total	60,183.0	59	333,501	79,027

Table 11. Horse mackerel survey time series.

Age (Yrs)	2016	2017	2018	2019
0	-	-	-	-
1	1.1	11.7	1.015	63.69
2	100.2	181.8	72.408	14.28
3	4.9	147	243.28	9.19
4	43.5	45.4	85.252	46.36
5	19.0	16.2	10.495	30.94
6	7.6	46	7.562	18.46
7	40.6	113	49.329	29.82
8	66.6	67.7	13.338	6.18
9	8.5	25.4	10.047	26.65
10	1.8	33.2	1.511	0.42
11	9.5	32.6	1.547	1.87
12	10.6	37.7	7.356	3.89
13	4.7	37.6	8.5	0.6
14	21.1	160.8	27.5	23.2
15	6.5	8.6	-	10.01
16	1.6	5.2	-	28.42
17	5.3	-	0.262	-
18	-	-	-	17.74
19	-	-	-	-
20	-	-	-	-
21	1.1	-	-	-
TSN (10^{-3})	354.5	969,655	540,422	333,501
TSB (t)	69,267	228,116	92,932	79,026
SSB (t)	65,194	227,395.6	89,050	77,529
CV	42.0	25.5	36.8	33.7

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												1512	1512	51.4	34	0
17	11386												11386	432.7	38	0
17.5	30255												30255	1236.4	41	0
18	52470												52470	2336.3	45	0
18.5	73130												73130	3742.6	51	0
19	67540	25215											92755	5216.8	56	0
19.5	139006												139006	8349.8	60	0
20	57366	2821											60187	4099.3	68	0
20.5	63663	6063											69726	5073.3	73	0
21		68818											68818	5073.7	74	92
21.5		22311											22311	1816.1	81	0
22		27147											27147	2352.6	87	0
22.5		6723	1793										8515	774.4	91	0
23	541	7574	541										8656	840.7	97	74
23.5		1924	1924										3848	378.4	98	100
24												2060	2060			
24.5			1742	871									2613	338.8	130	66
25																
25.5				1100									1100	159.5	145	100
26						1100							1100	177.1	161	100
26.5					412								412	74.1	180	100
27				2584									2584	447	173	100
27.5																
28					2584								2584	491	190	100
28.5																
29																
29.5																
30																
30.5																
31																
31.5																
TSN (10^{-3})	495358	168597	6000	4555	2996	1100						3572	682177			
TSB (t)	28429	12901.4	620.4	718.0	565.1	177.1						51.4		43462.2		
Mean length (cm)	19.14	21.1	23.5	26.2	27.8	26.0						20.82				
Mean weight (g)	57.39	76.5	103.4	157.6	188.6	161.0						34			63.9	
% mature*	0	8	20	75	100	100										
SSB (t)	0	1080	171	559	565	177							2551.0			

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

Strata name	Area (nmi²)	Transects	Abundance ('000)	Biomass (t)
Celtic Sea	32,097.3	16	682,177	43,462
Total	32,097.3	16	682,177	43,462

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
Bottlenose dolphin	*Tursiops truncatus*	3	57	14-28
Common Dolphin	*Delphinus delphis*	63	1705	1-800
Fin Whale	*Balaenoptera physalus*	4	15	1-6
Harbour Porpoise	*Phocoena phocoena*	1	4	4
Long-finned Pilot Whale	*Globicephala melas*	2	11	5-6
Minke Whale	*Balaenoptera acutorostrata*	16	18	1-2
Sperm Whale	*Physeter macrocephalus*	1	1	1
Unidentified Baleen Whale	*Mysticeti sp.*	5	8	1-2
Unidentified Dolphin	*Delphinidae sp.*	9	88	1-30
Unidentified Large Whale		1	1	1
	Total	**105**	**1,908**	
Blue shark	*Prionace glauca*	2	2	1
Bluefin Tuna	*Thunnus thynnus*	1	7	7
Ocean sunfish	*Mola mola*	17	17	1
Smooth Hammerhead Shark	*Sphyrna zygaena*	1	1	1
Unidentified Shark	*Selachimorpha sp.*	2	2	1
	Total	**23**	**29**	

Table 15. Totals for all seabird and terrestrial bird species recorded between 13th June and 24rd July 2019.

Common Name	Species name	No. of Sightings	No. of Individuals	On Transect	Off Transect
Arctic Tern	*Sterna paradisaea*	13	20	9	11
Arctic Skua	*Stercoratius parasiticus*	2	2	0	2
Auk sp.	*Alcidae sp.*	13	371	212	159
Balearic Shearwater	*Puffinus mauretanicus*	1	1	0	1
Commic tern sp.	*Sterna hirundo / Sterna paradisaea*	1	15	0	15
Common Tern	*Sterna hirundo*	7	9	3	6
Fulmar	*Fulmarus glacialis*	965	8159	1081	7078
Gannet	*Sula bassana*	1265	6116	865	5251
Great Black-backed Gull	*Larus marinus*	31	43	7	36
Great Shearwater	*Puffinus graves*	1	1	0	1
Great Skua	*Stercoratius skua*	109	136	53	82
Guillemot	*Uria aalge*	299	1149	1051	98
Herring Gull	*Larus argentatus*	13	23	2	21
Kittiwake	*Rissa tridactyla*	225	1061	641	420
Leach's Petrel	*Oceanodroma leucorhoa*	3	3	2	1
Lesser Black-backed Gull	*Larus fuscus*	133	541	31	510
Little Tern	*Sterna albifrons*	1	3	3	0
Long-tailed Skua	*Stercoratius longicaudus*	1	1	0	1
Manx Shearwater	*Puffinus puffinus*	561	3010	1989	1021
Pomarine Skua	*Stercoratius pomarinus*	4	4	0	4
Puffin	*Fratercula arctica*	229	445	245	200
Razorbill	*Alea torda*	114	340	274	66
Shag	*Phalacrocorax aristotelis*	1	3	3	0
Sooty Shearwater	*Puffinus griseus*	8	8	1	7
South Polar Skua	*Stercorarius maccormicki*	1	1	0	1
Storm Petrel	*Hydrobates pelagicus*	524	3425	860	2565
Wilson's Petrel	*Oceanites oceanicus*	4	6	0	0
	Total	**4,529**	**24,896**	**7,332**	**27,556**
Collared Dove	*Streptopelia decaocto*	2	2		
common scoter	*Melanitta nigra*	3	21		
Dunlin	*Calidris alpina*	1	1		
Feral/ racing pigeon	*Columba livia domestica*	4	5		
Golden Eagle	*Aquila chrysaetos*	1	2		
Pied Wagtail	*Motacilla alba*	1	1		
Redshank	*Tringa totanus*	1	5		
Spotted Flycatcher	*Muscicapa striata*	1	1		
Swallow	*Hirundo rustica*	2	2		
Swift	*Apus apus*	7	12		
	Total	**23**	**52**		

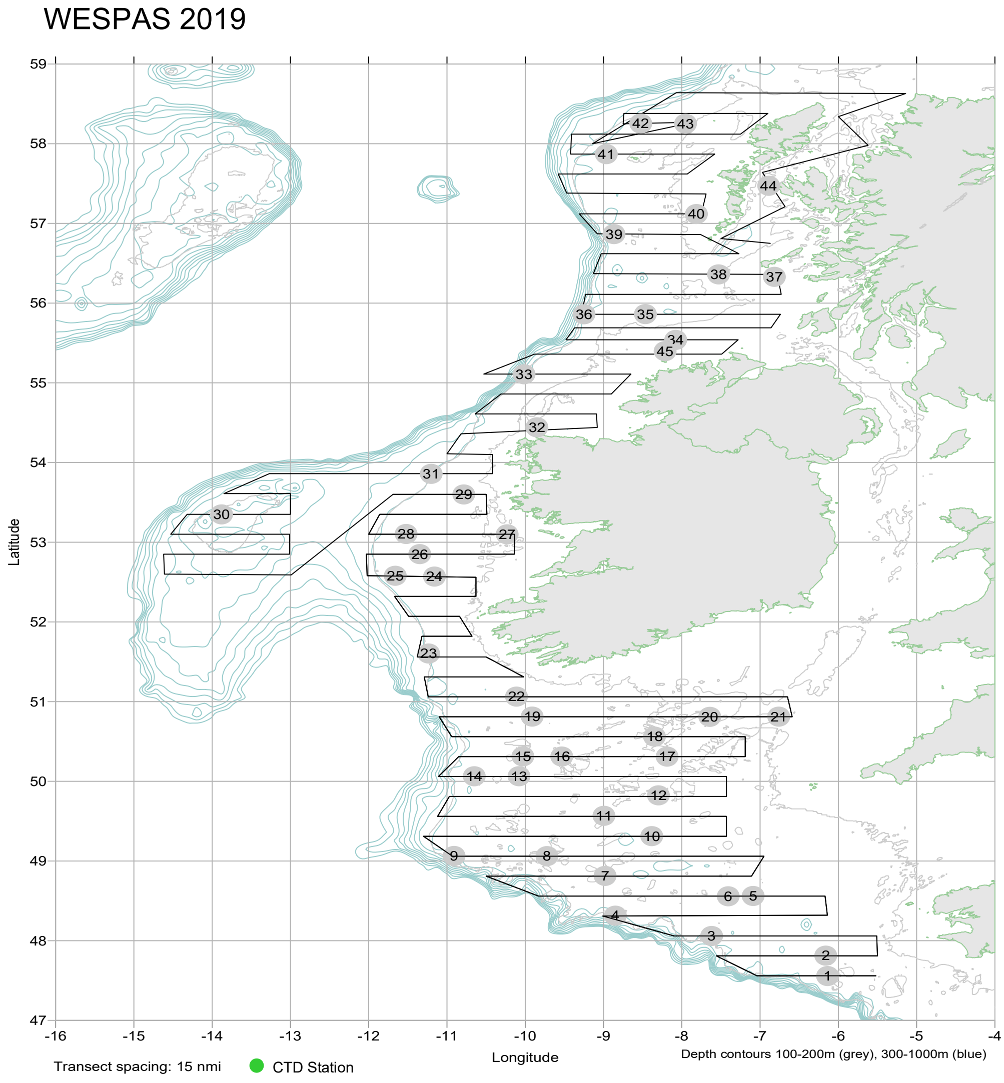


Figure 1. Survey cruise track (grey line) and numbered directed pelagic trawl stations. Corresponding catch details are provided in Table 2.

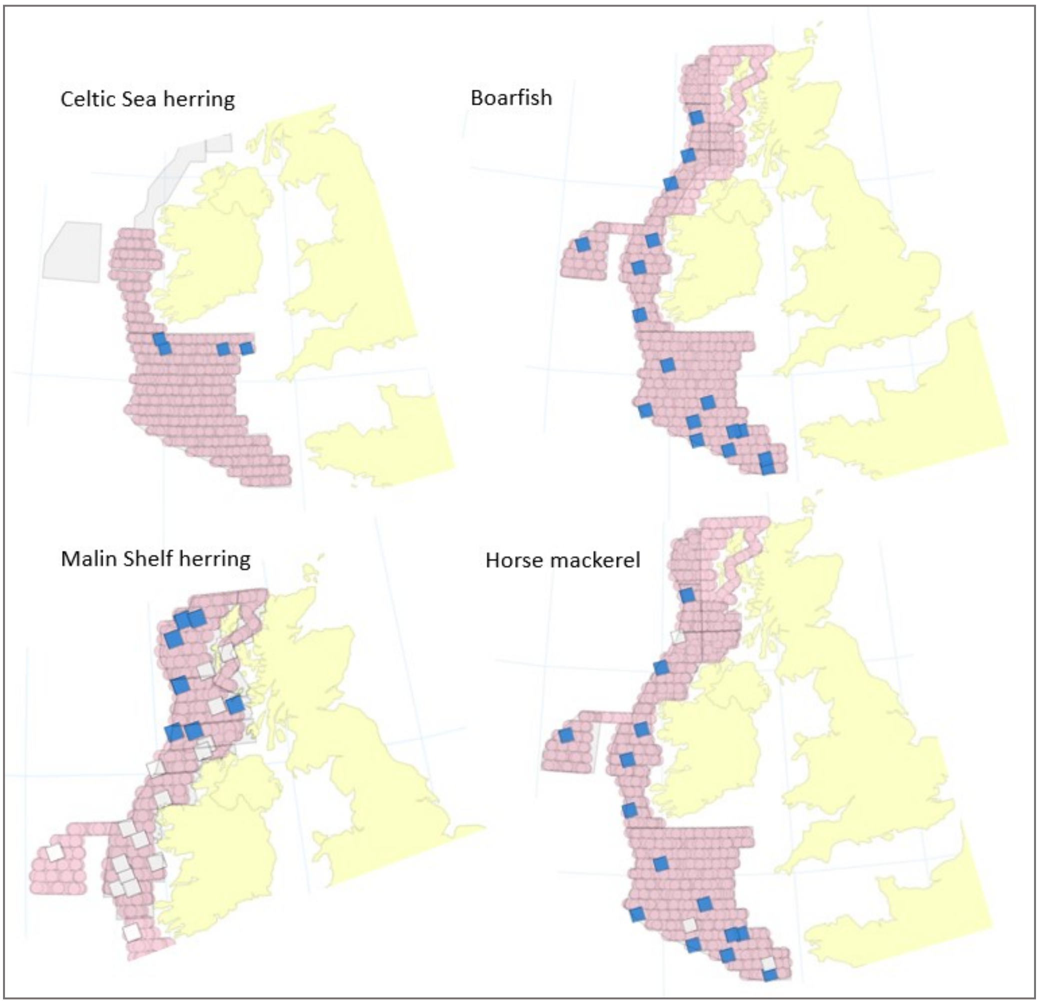


Figure 2. Species specific acoustic sampling stratification taken from StoX.

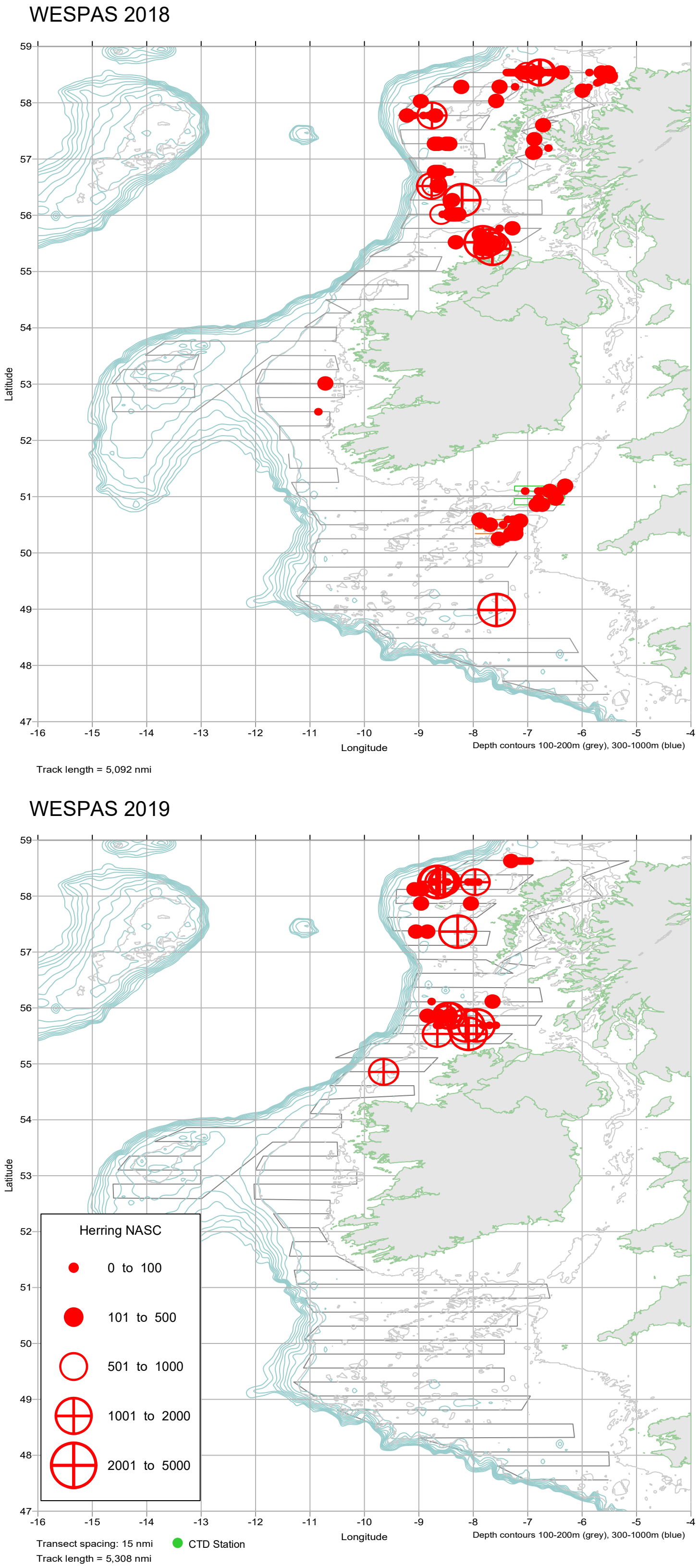


Figure 3. Malin Shelf (north of 54°N) herring distribution by weighted acoustic density. Top panel 2018, bottom panel 2019.

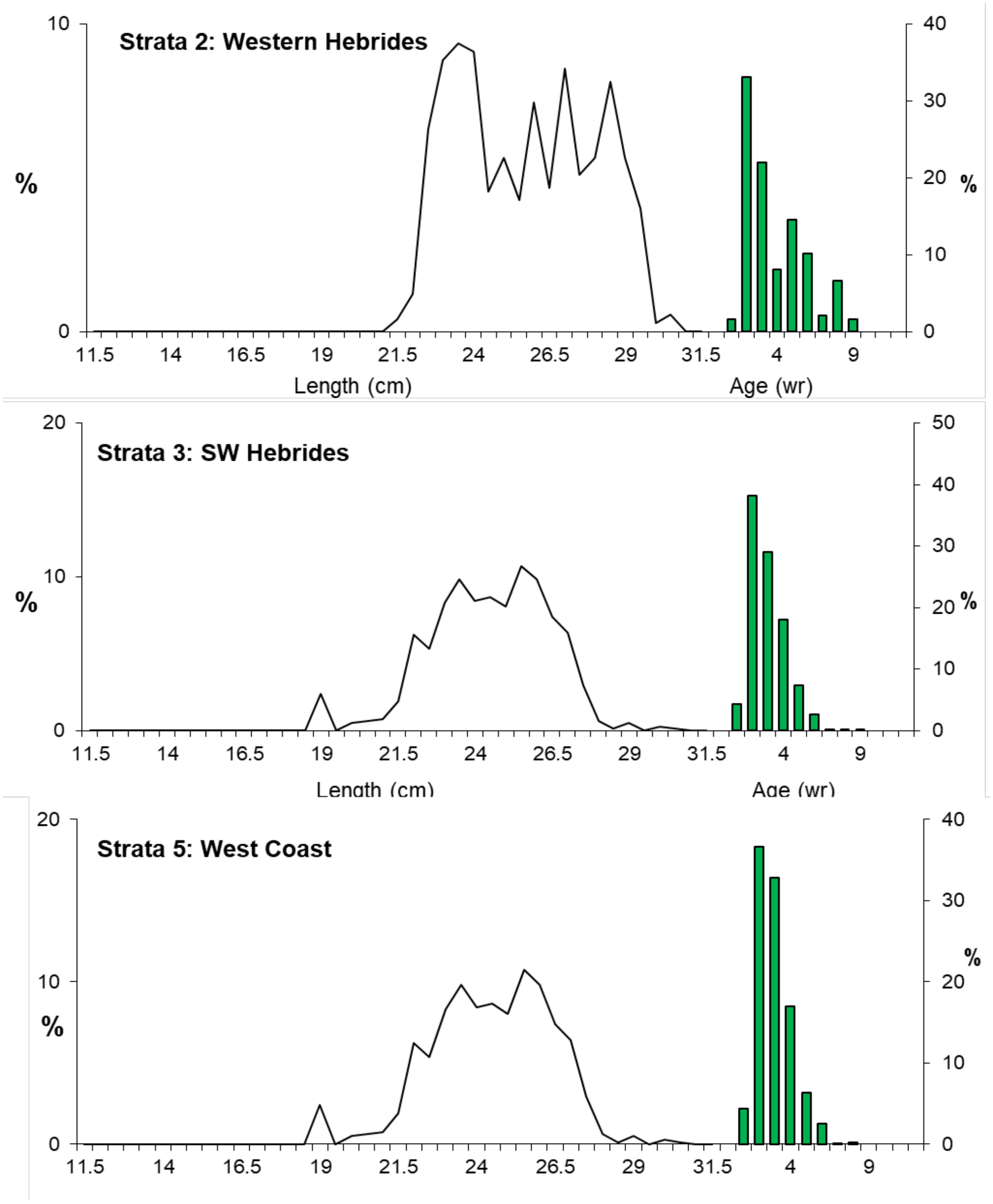


Figure 4. Length and age distribution of Malin Shelf herring by stratum and total survey area during WESPAS 2019.

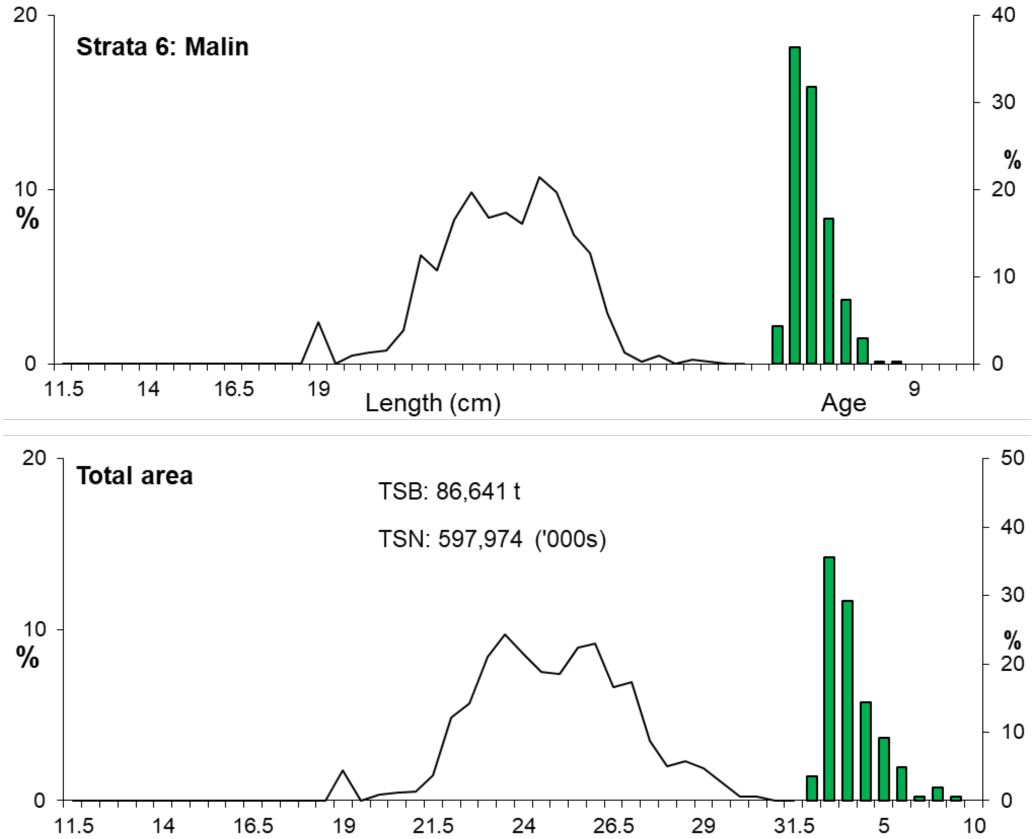


Figure 4. *Continued.* Length and age distribution of Malin Shelf herring by stratum and total survey area during WESPAS 2019.

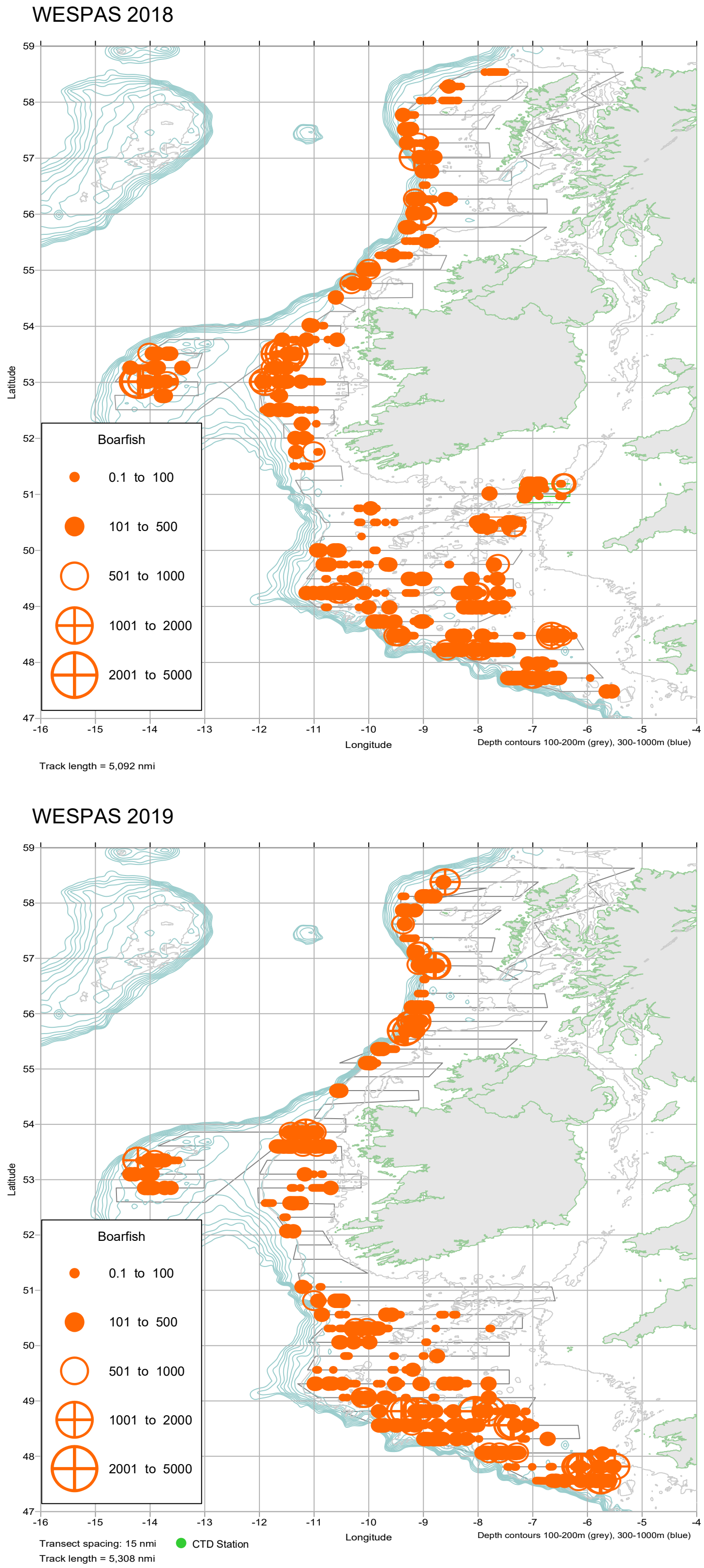


Figure 5. Boarfish distribution by weighted acoustic density. Top panel 2018, bottom panel 2019.

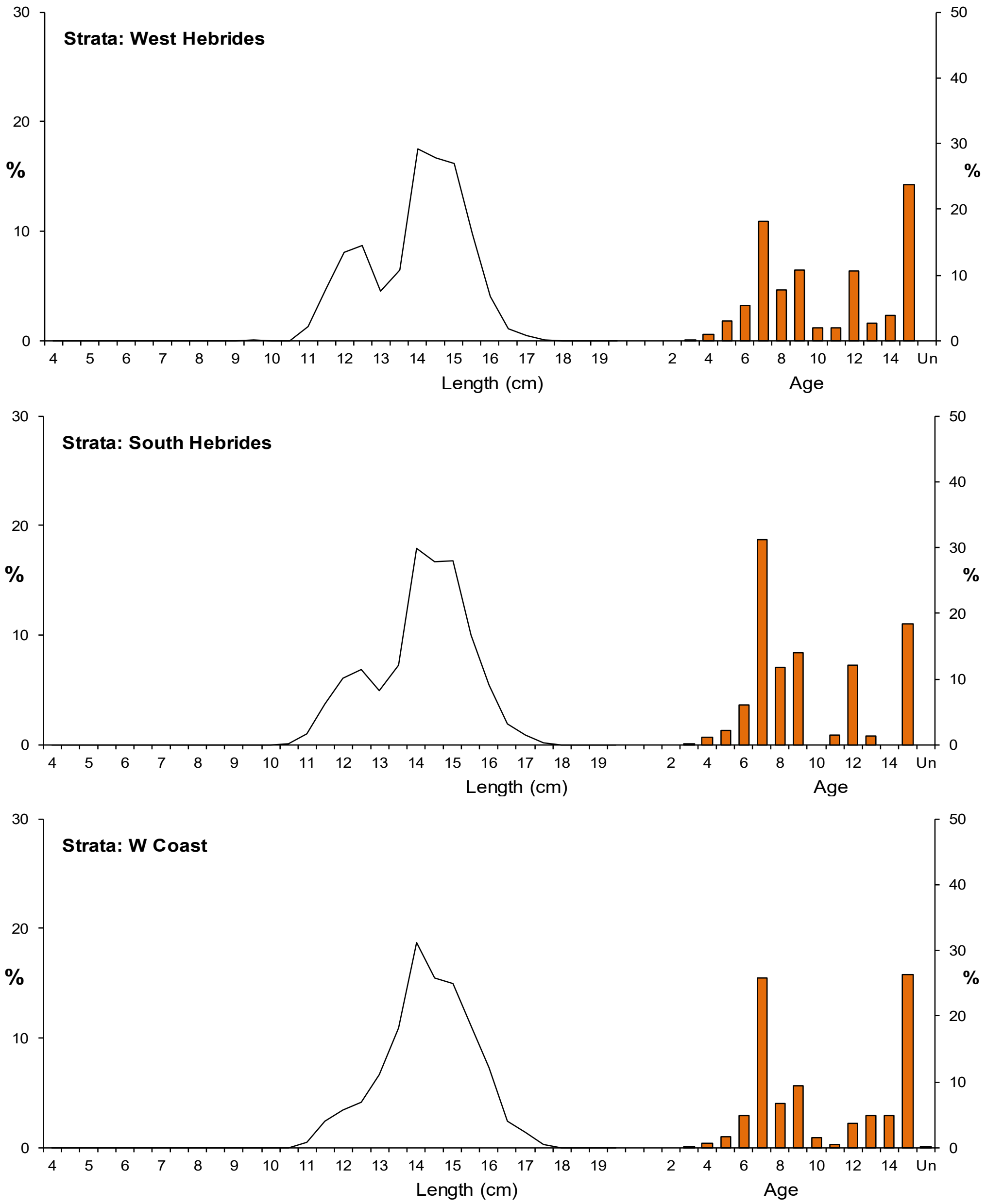


Figure 6. Abundance at length and age distribution of boarfish by stratum and total survey area.

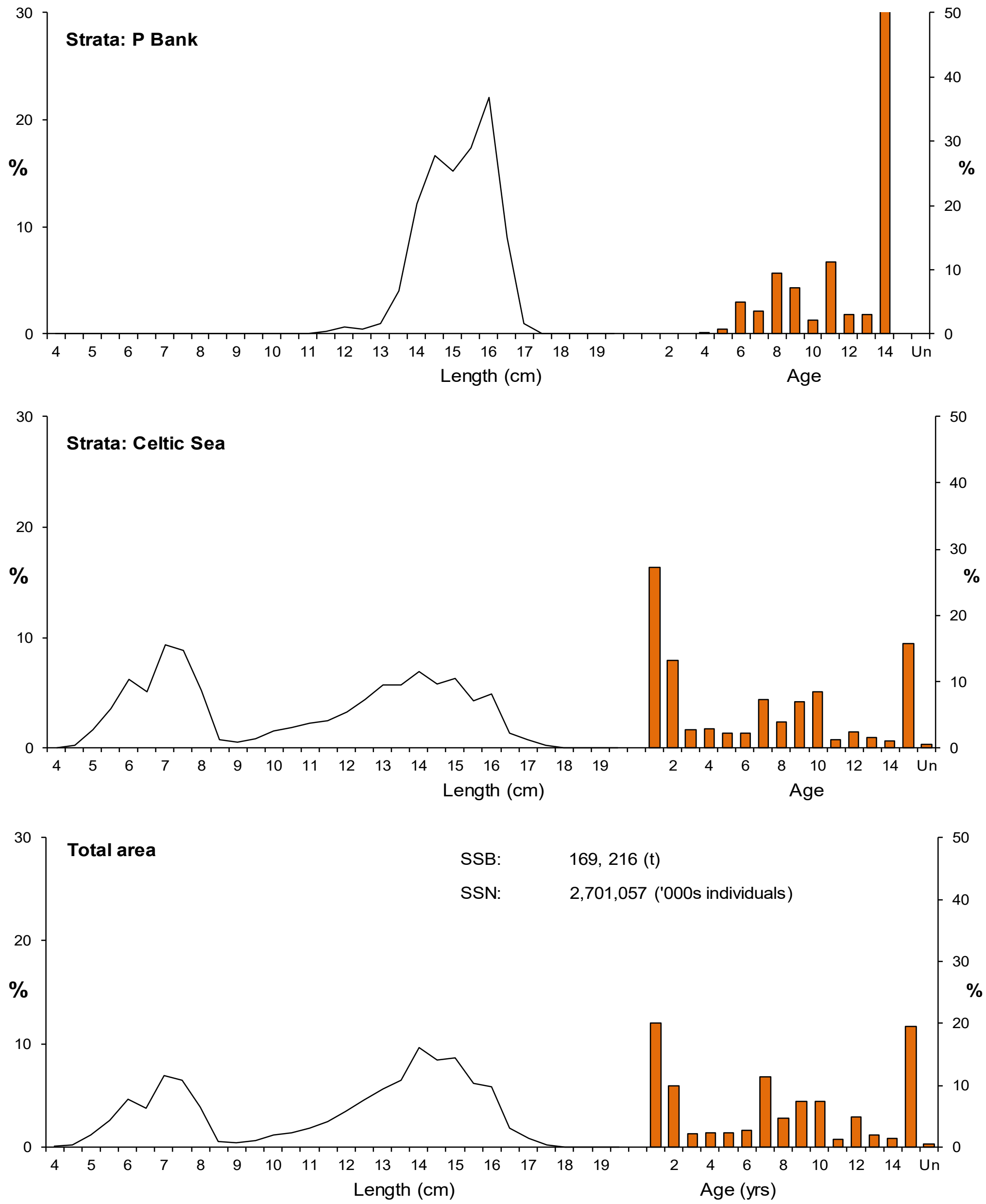


Figure 6. cont.

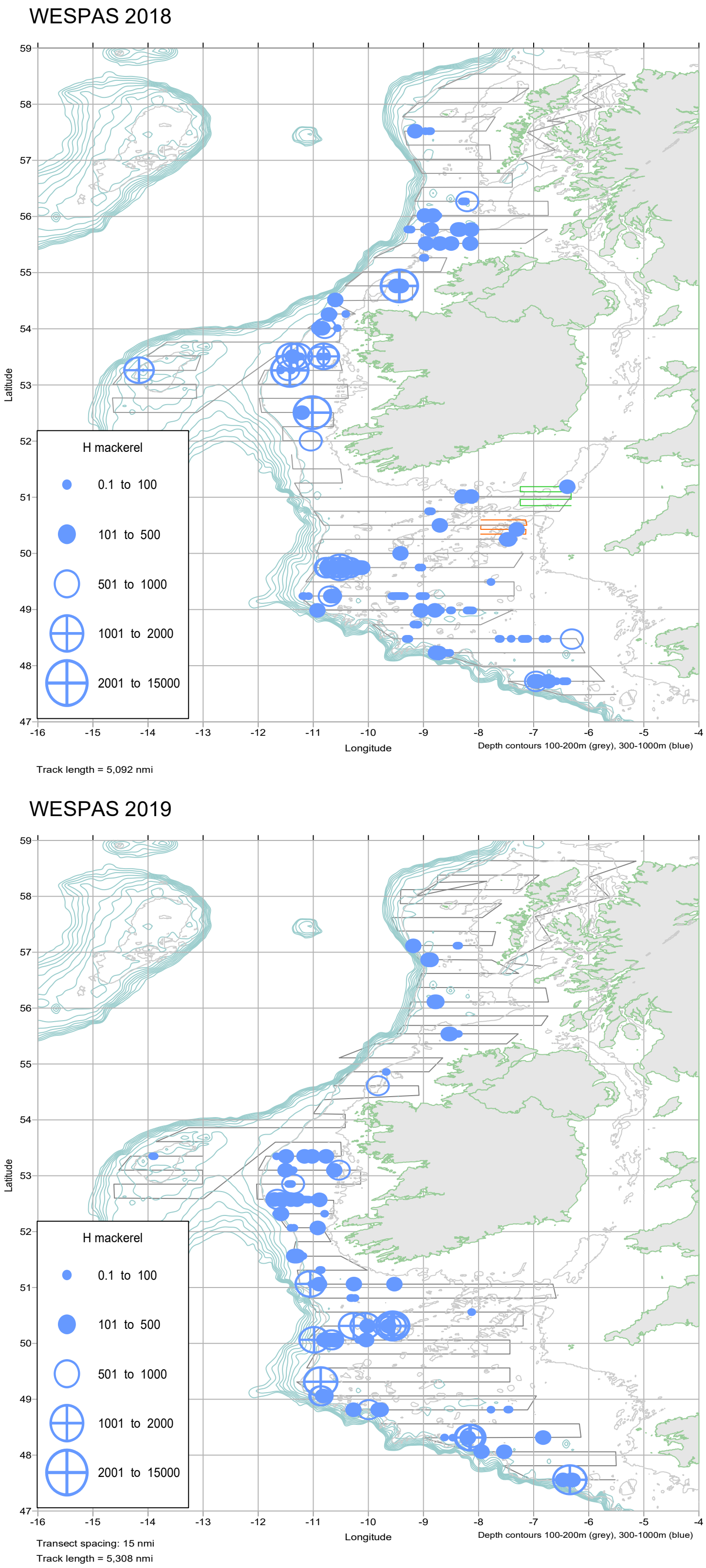


Figure 7. Horse mackerel distribution by weighted acoustic density. Top panel 2018, bottom panel 2019.

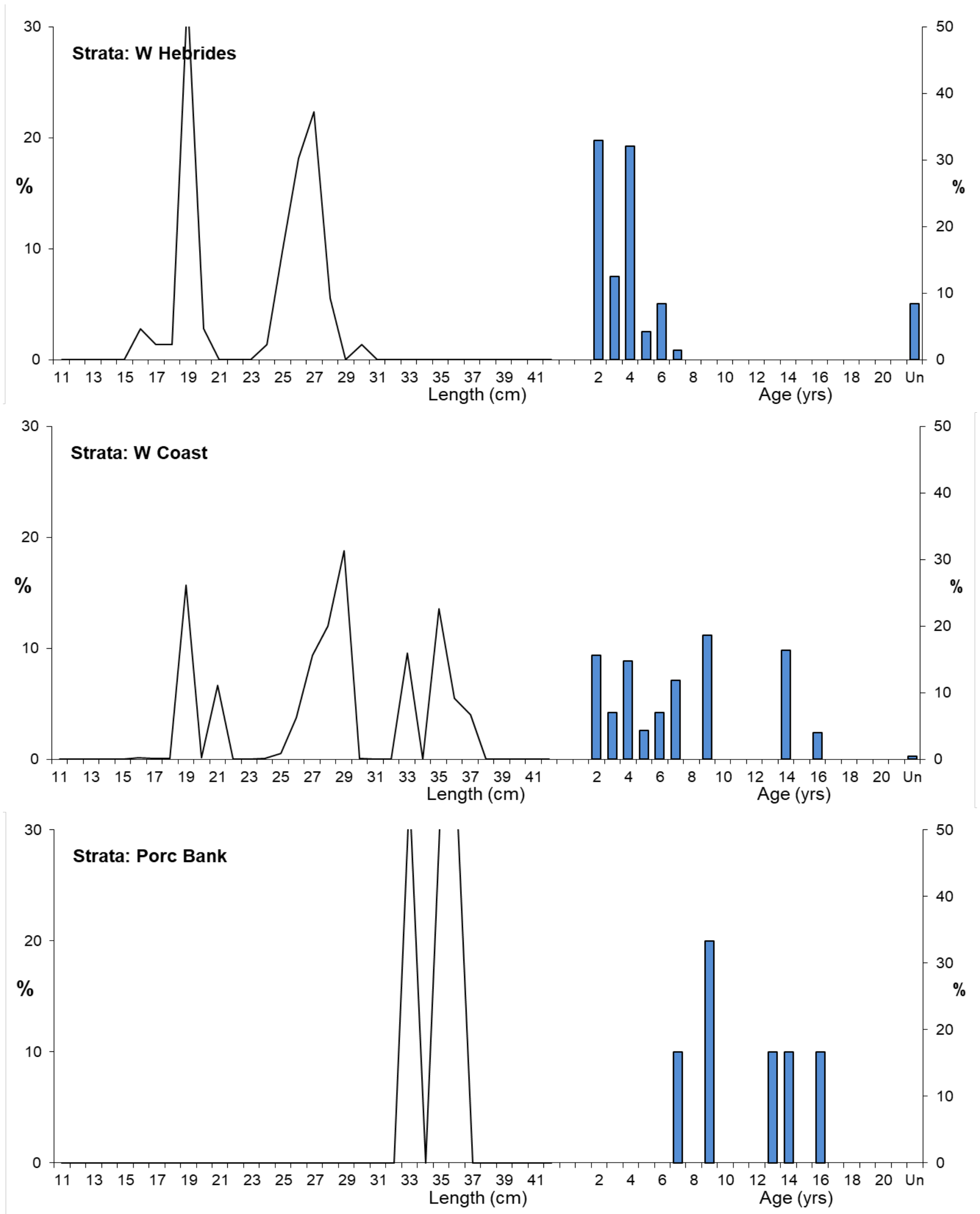


Figure 8. Length and age distribution of horse mackerel by stratum and total survey area.

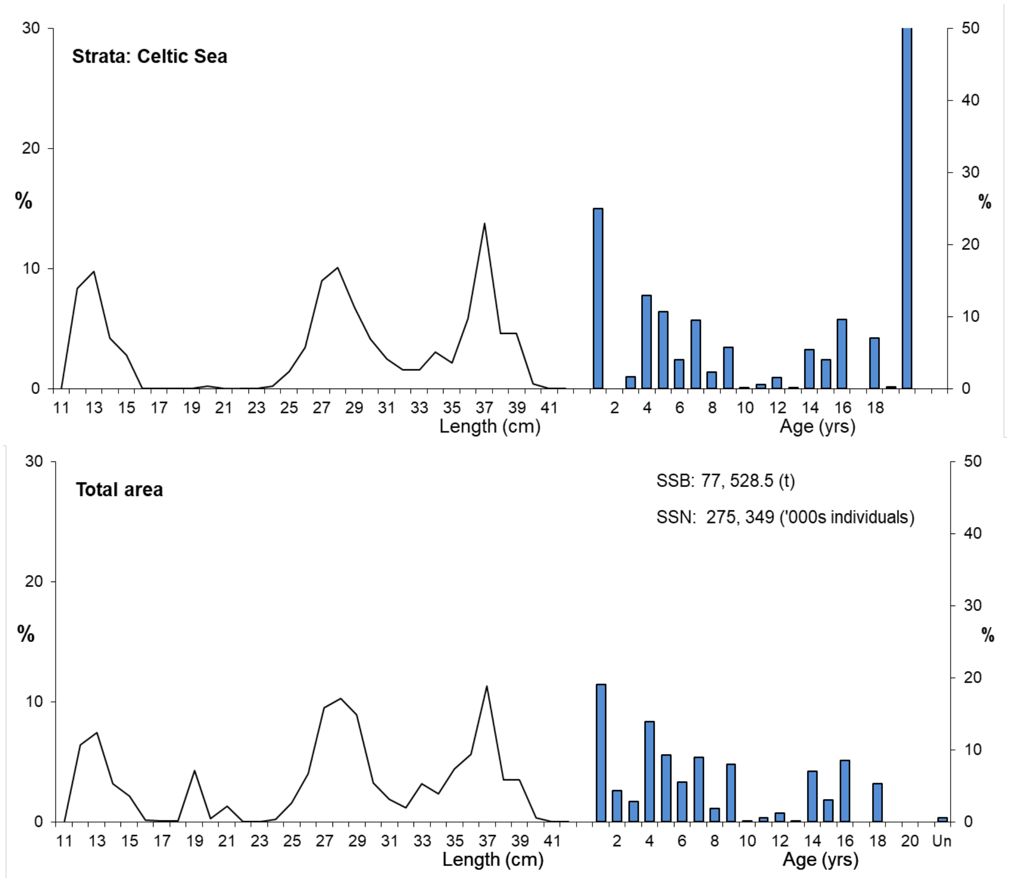


Figure 8. Continued. Length and age distribution of horse mackerel by stratum and total survey area.

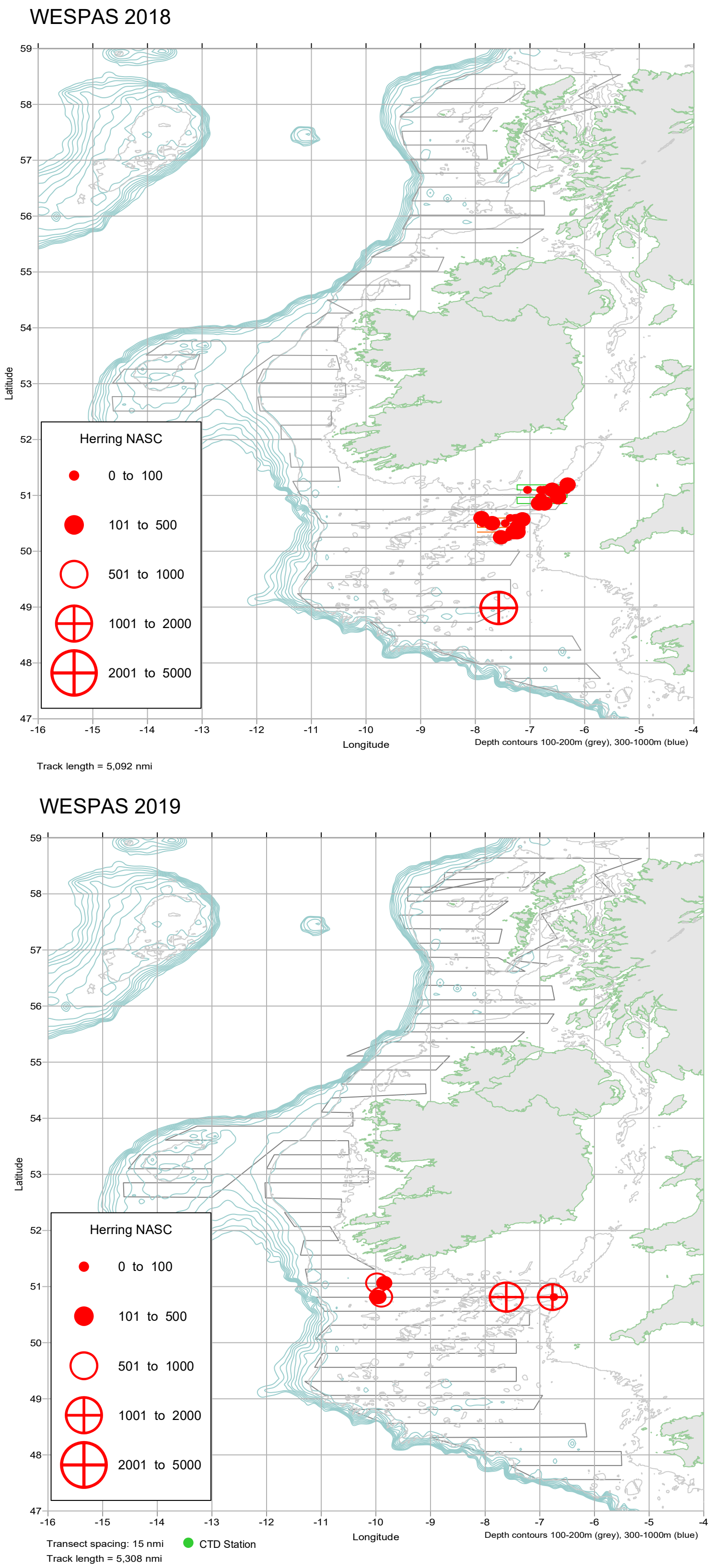


Figure 9. Celtic Sea herring distribution by weighted acoustic density.

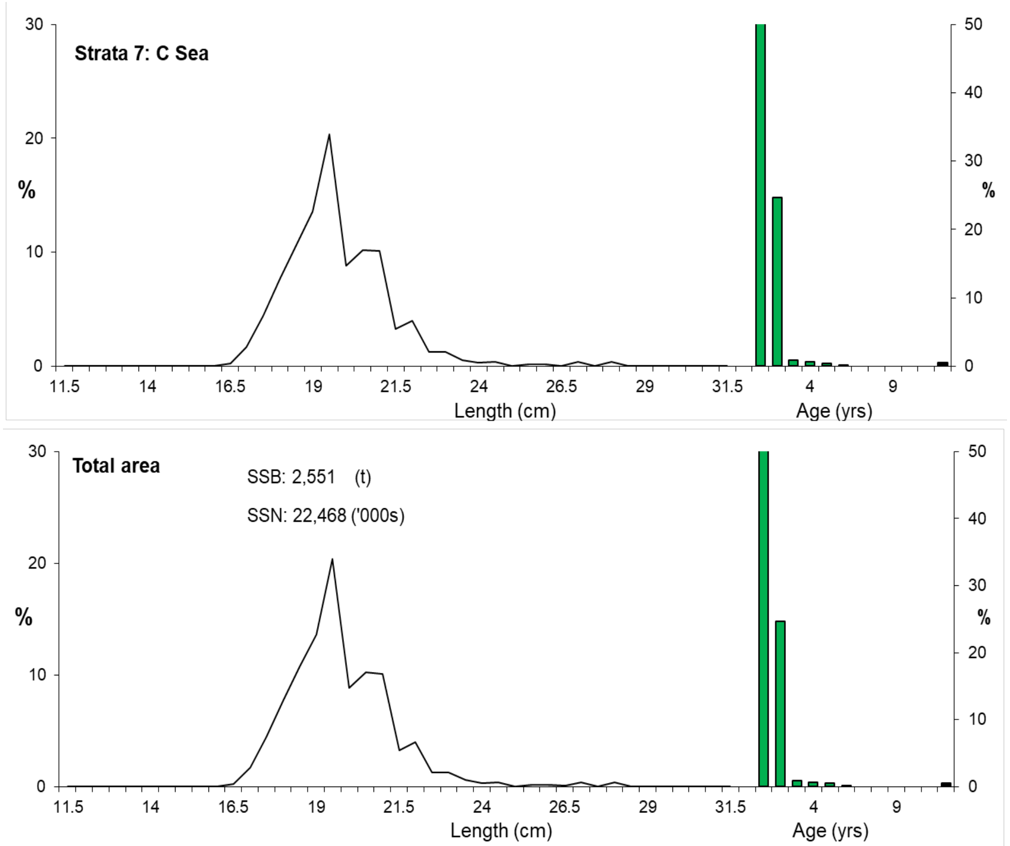
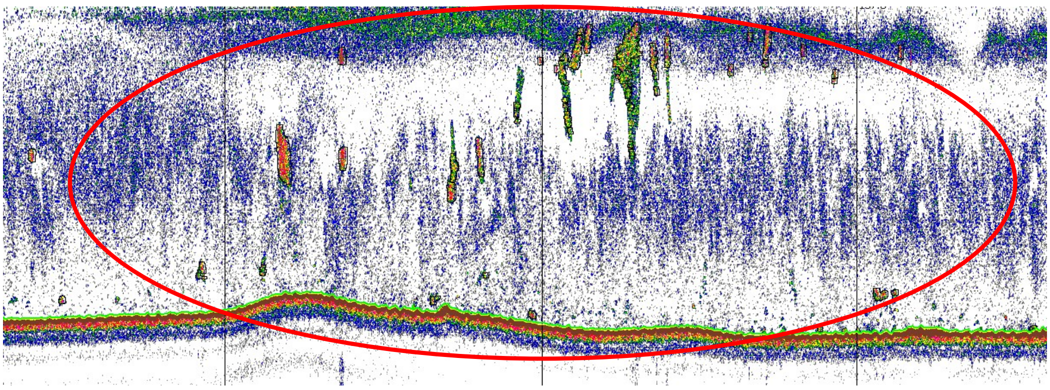
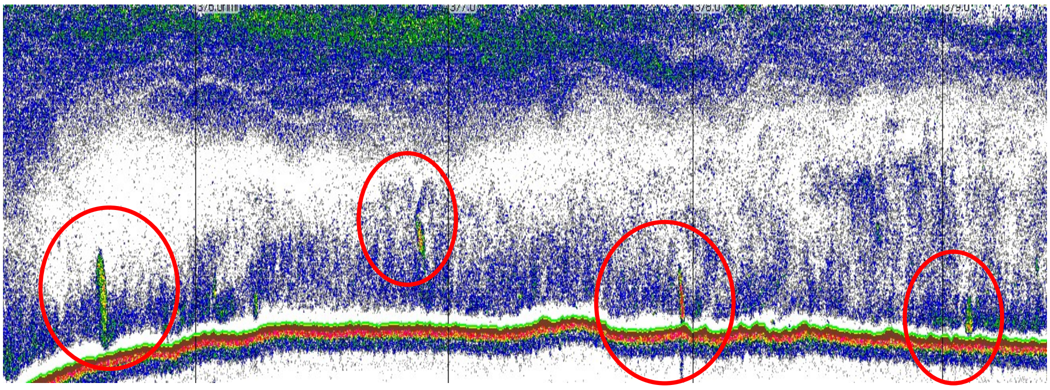


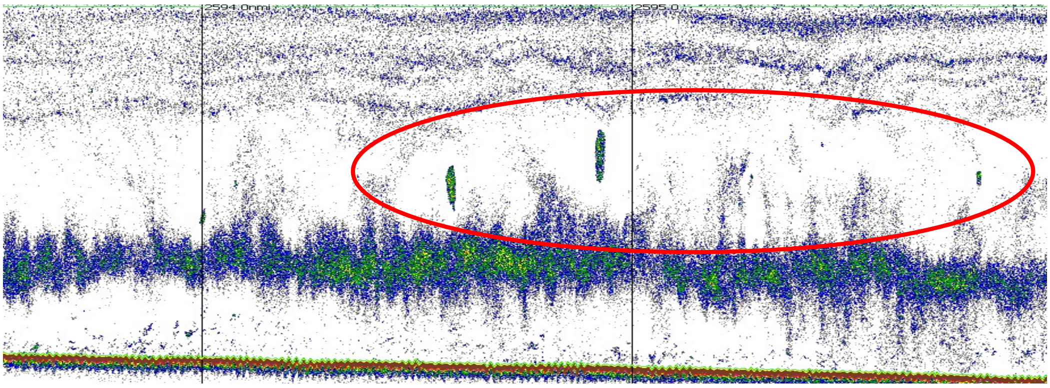
Figure 10. Length and age distribution of Celtic Sea herring by stratum and total survey area.



a). *Haul 2 Southern Celtic Sea. Pelagic schools of immature boarfish (circled red) close to the shelf edge. Water depth 144 m.*

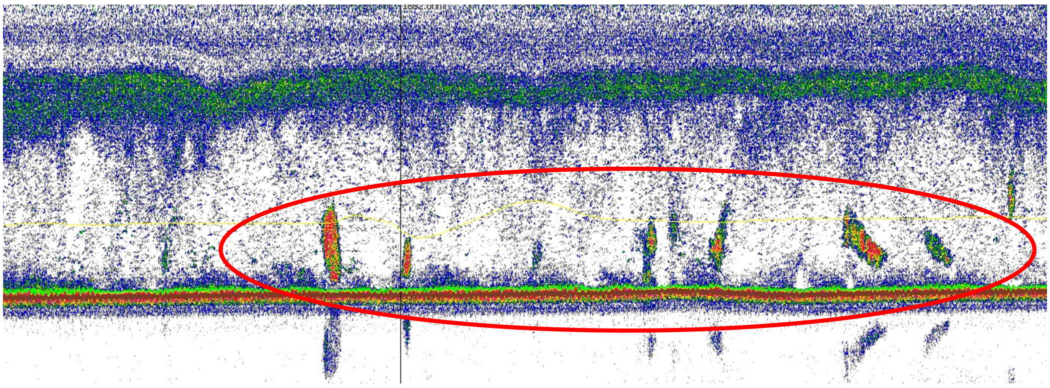


b). *Haul 04, Southern Celtic Sea. Medium density boarfish schools at the shelf edge. Water depth 177 m.*

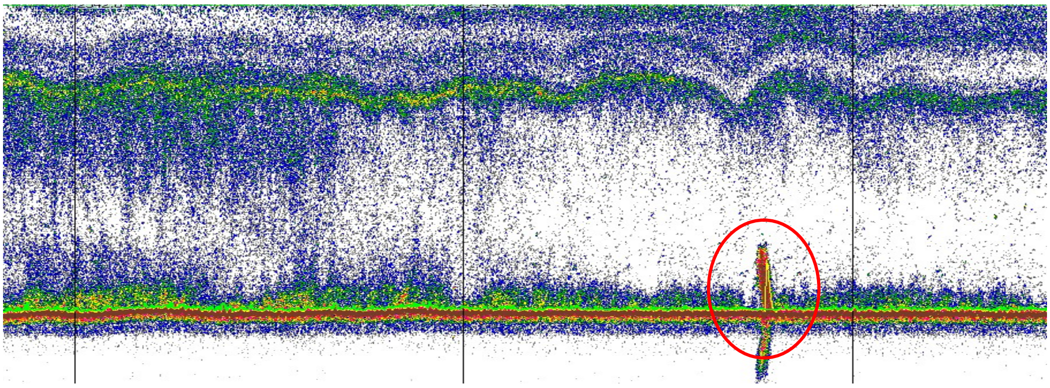


c). *Haul 23. Medium density midwater schools of mature boarfish encountered off the southwest Irish coast. Water depth 200 m.*

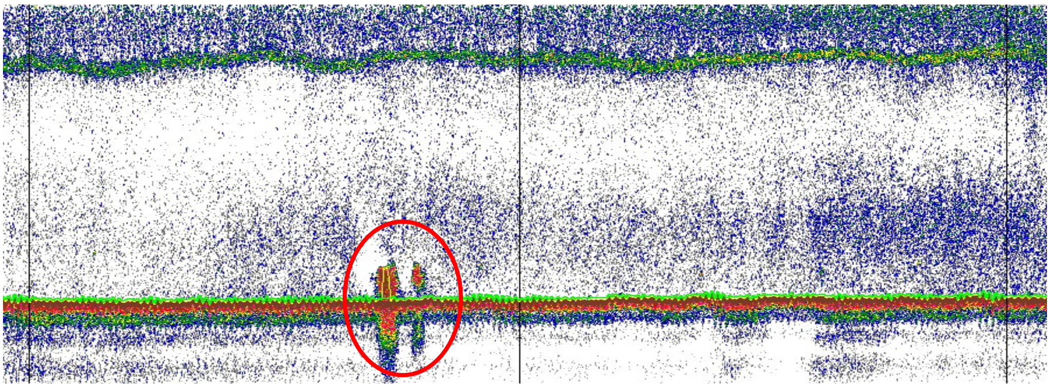
Figures 11a-l. Echotraces recorded on an EK60 echosounder (38 kHz) with images captured from Echoview. Note: Vertical bands on echogram represent 1nmi (nautical mile) intervals.



d). *Haul 16. Mid Celtic Sea. High density schools of horse mackerel encountered in the mid Celtic Sea. Water depth 133 m.*



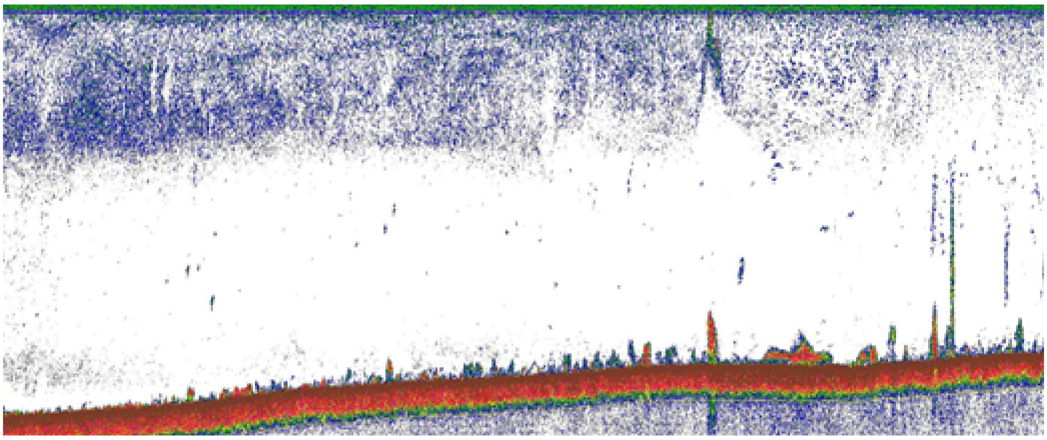
e). *Haul 22. High density single herring school located off the southwest coast in the western Celtic Sea, water depth 124 m.*



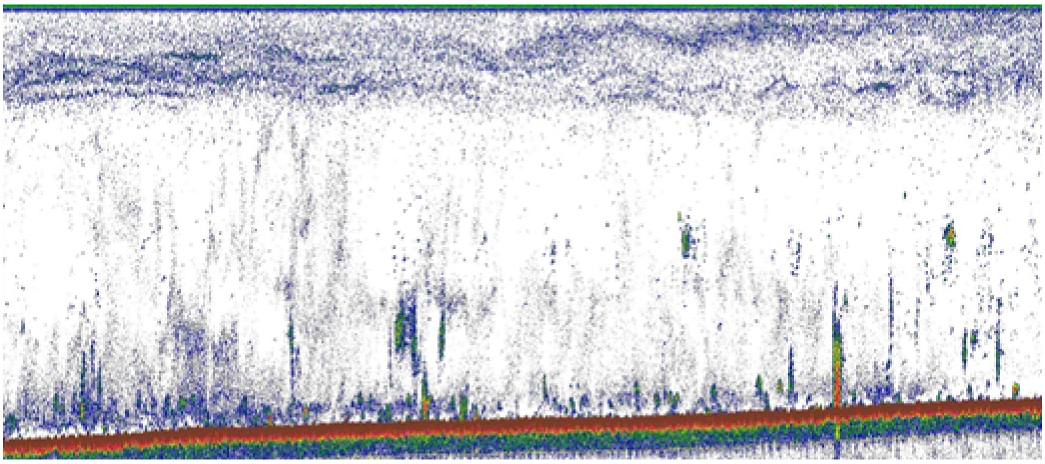
f). *Haul 20. High density herring schools in the Celtic Deep region, eastern Celtic Sea, water depth 100 m.*

Figures 11a-l. continued

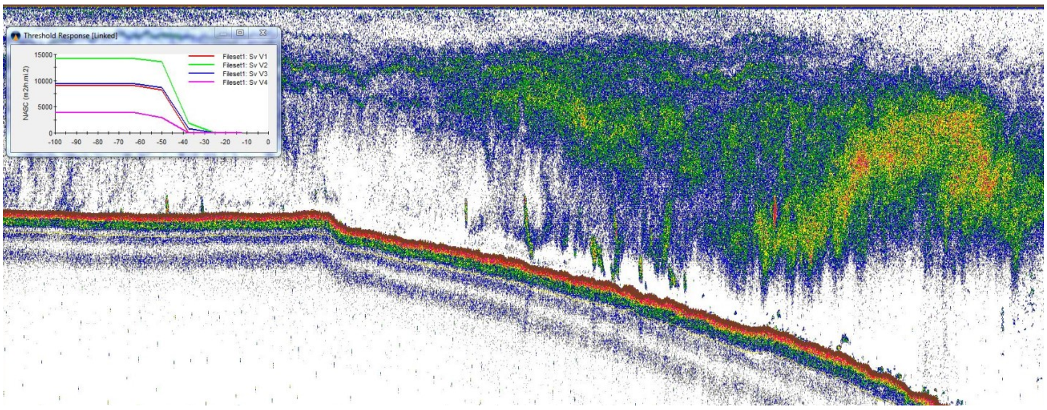
Figures11a-l. continued.



g). *Haul 35. Northwest of Tory Island, herring marks (18 kHz shown for clarity) along bottom, water depth 134 m.*

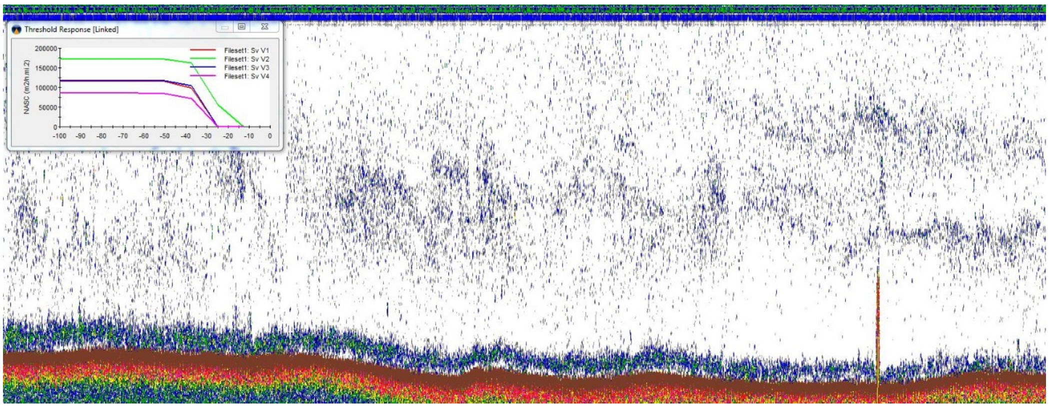


h). *Haul 42. North of St. Kilda, herring marks (18 kHz shown for clarity) along bottom, water depth 164 m.*

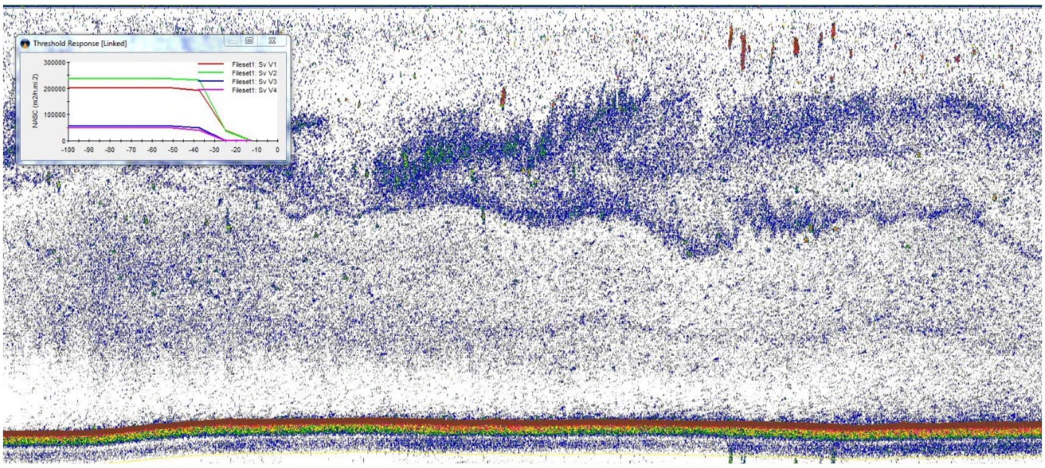


i). *Haul 33. West of Aranmore. Boarfish marks close to the shelf edge. Water depth ~200 m.*

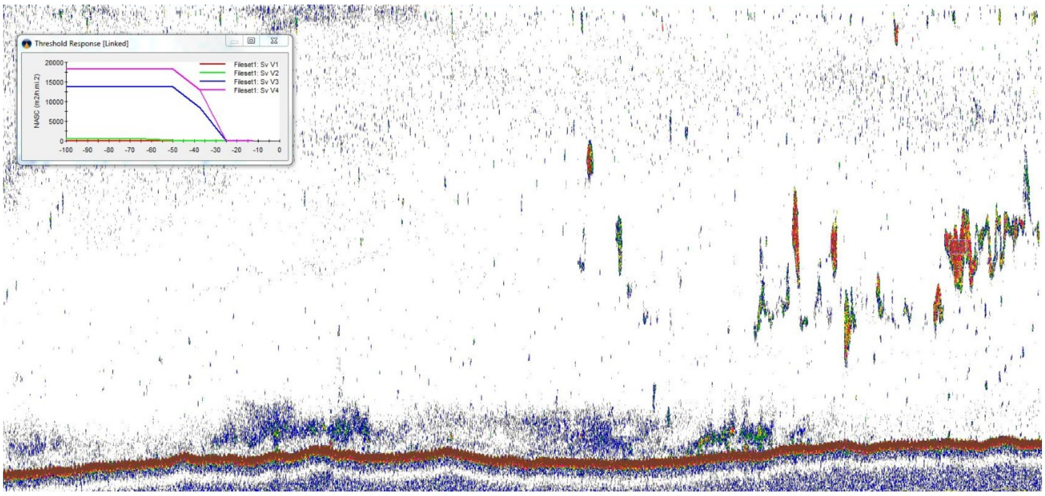
Figures11-l. continued.



J). *Haul 34. Suspected herring mark (missed) north of Lough Swilly. Water depth ~80 m.*



k). *Haul 44. Surface marks of sprat in the Minch. Water depth ~180 m.*



l). *Midwater marks of mackerel (on 200 kHz) in the south Minch area east of Barra. Backscatter was strong on 120 and 200 kHz, much weaker on the 18 and 38 kHz. Water depth ~120 m.*

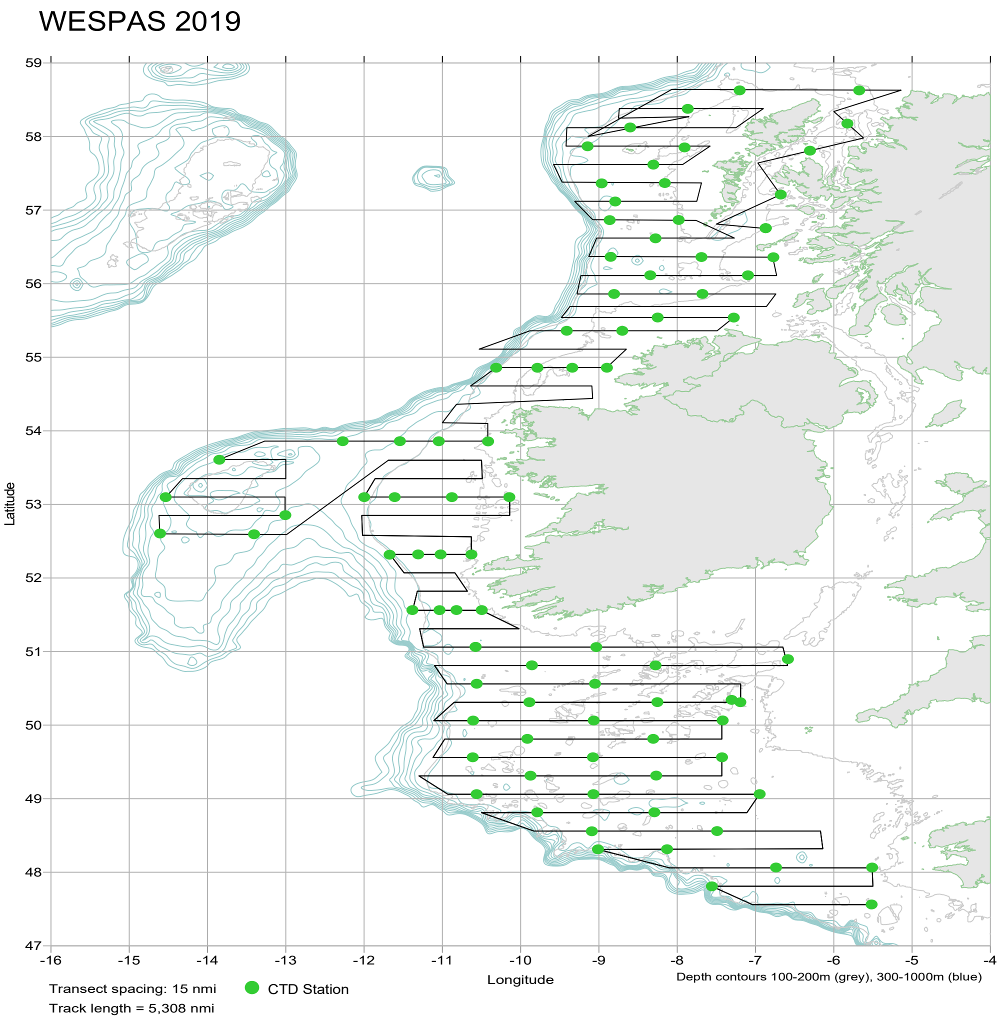


Figure 12. Position of hydrographic and co-occurring zooplankton sampling stations (n=87).

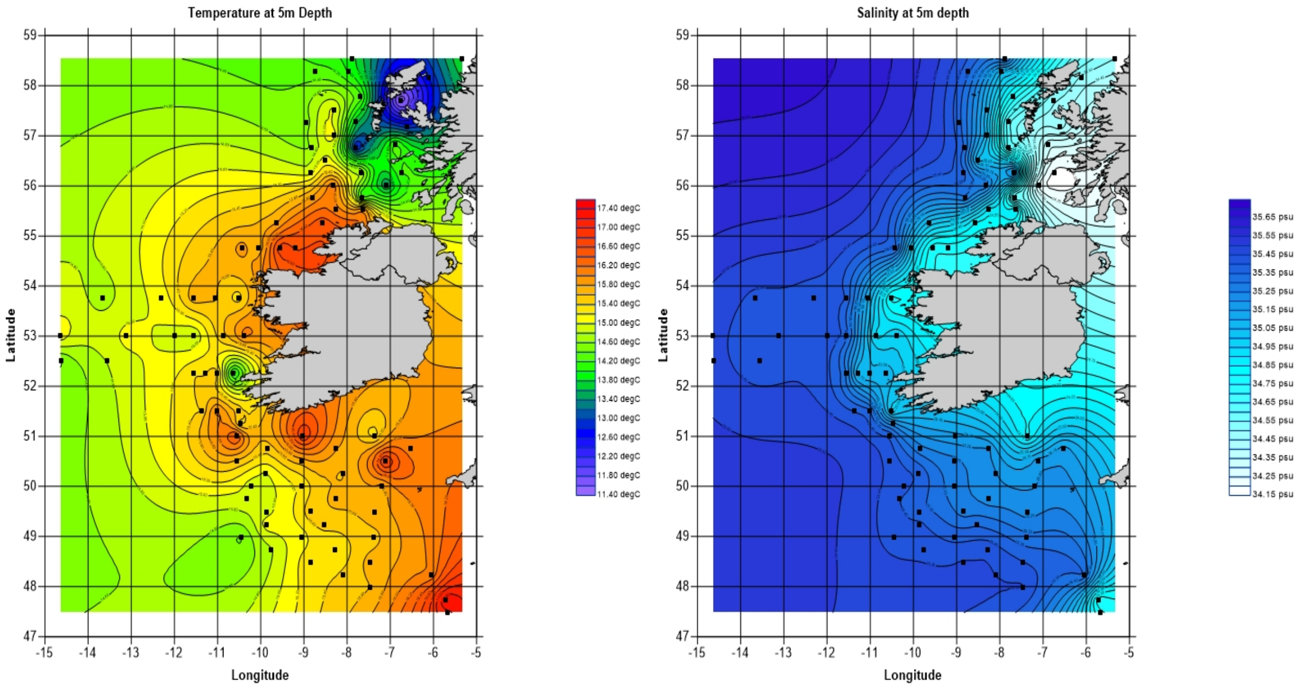


Figure 13. Surface (5m) plots of temperature and salinity compiled from CTD cast data. Station positions with valid data shown as block dots (n=87).

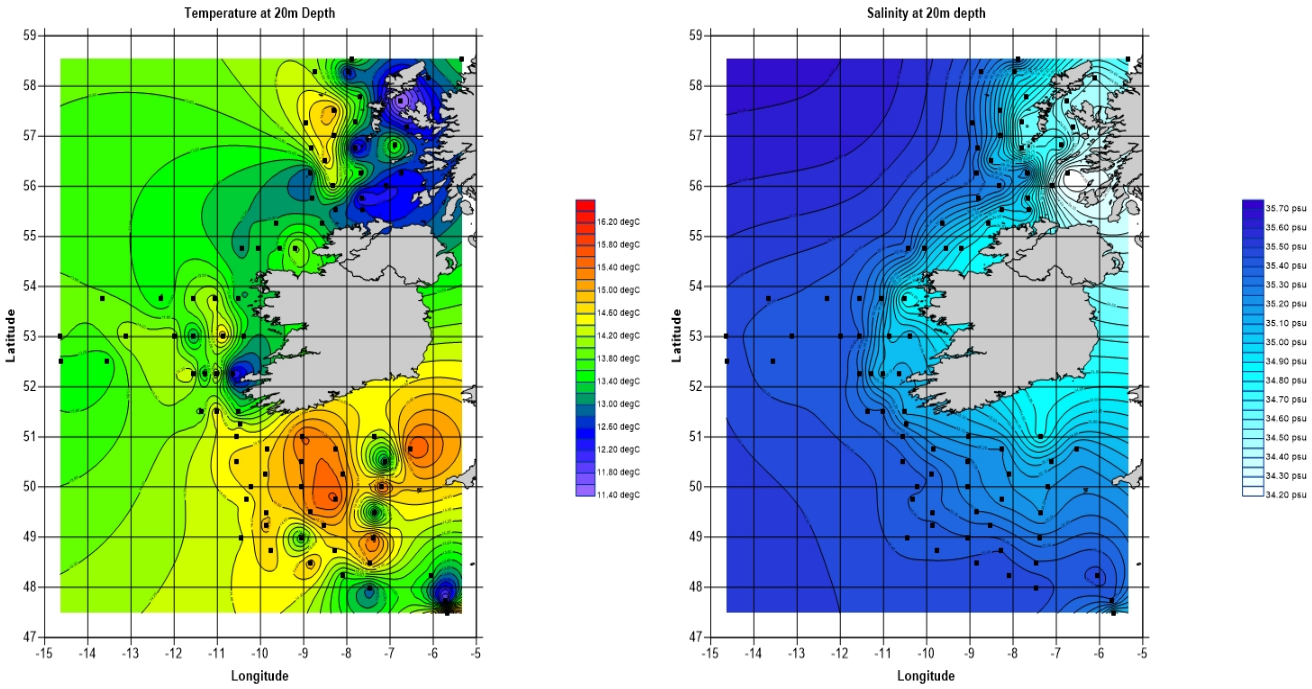


Figure 14. Plots of temperature and salinity compiled from CTD cast data at 20m depth. Station positions with valid data shown as block dots (n=87).

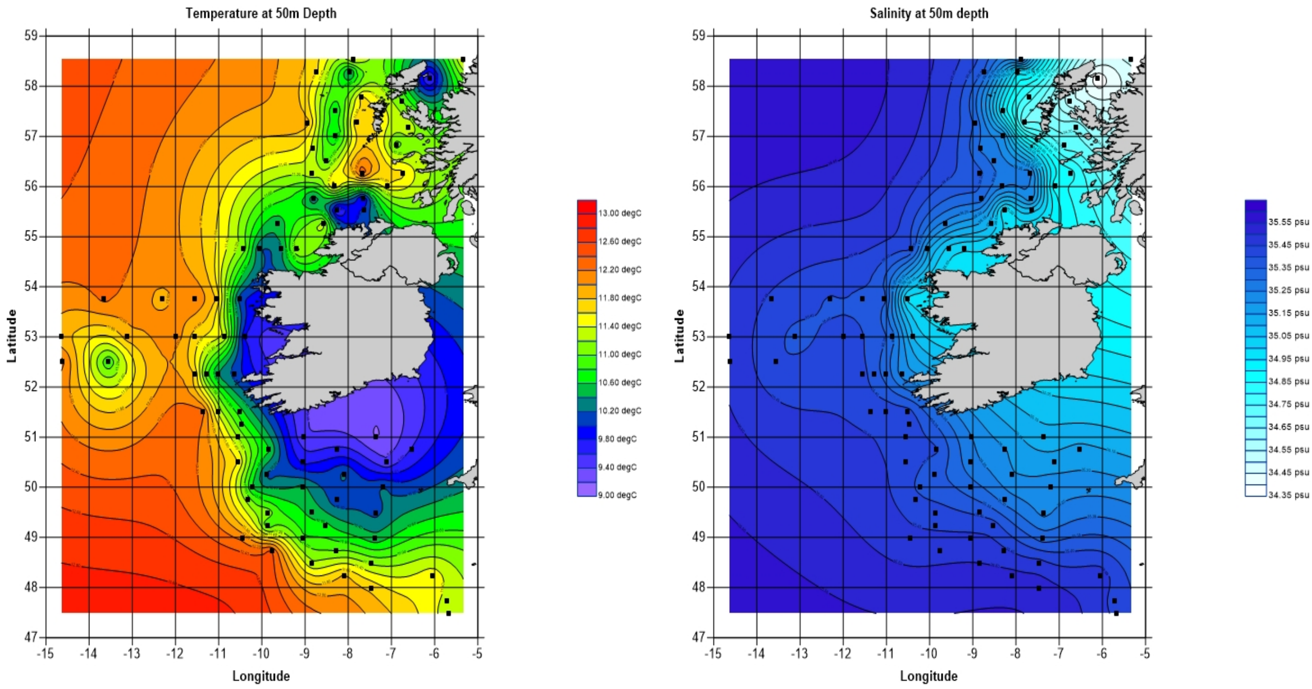


Figure 15. Plots of temperature and salinity compiled from CTD cast data at 50m depth. Station positions with valid data shown as block dots (n=87).

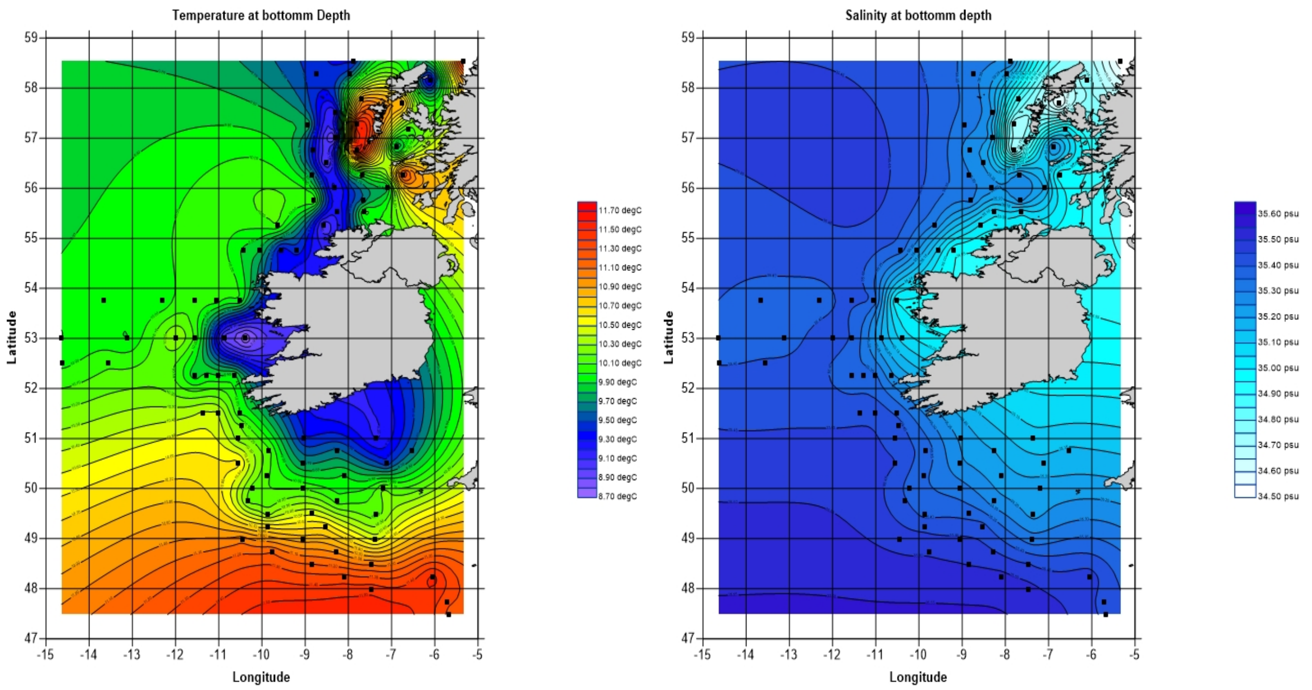


Figure 16. Plots of temperature and salinity compiled from CTD cast data at the seabed (+3-5m). Station positions with valid data shown as block dots (n=87).

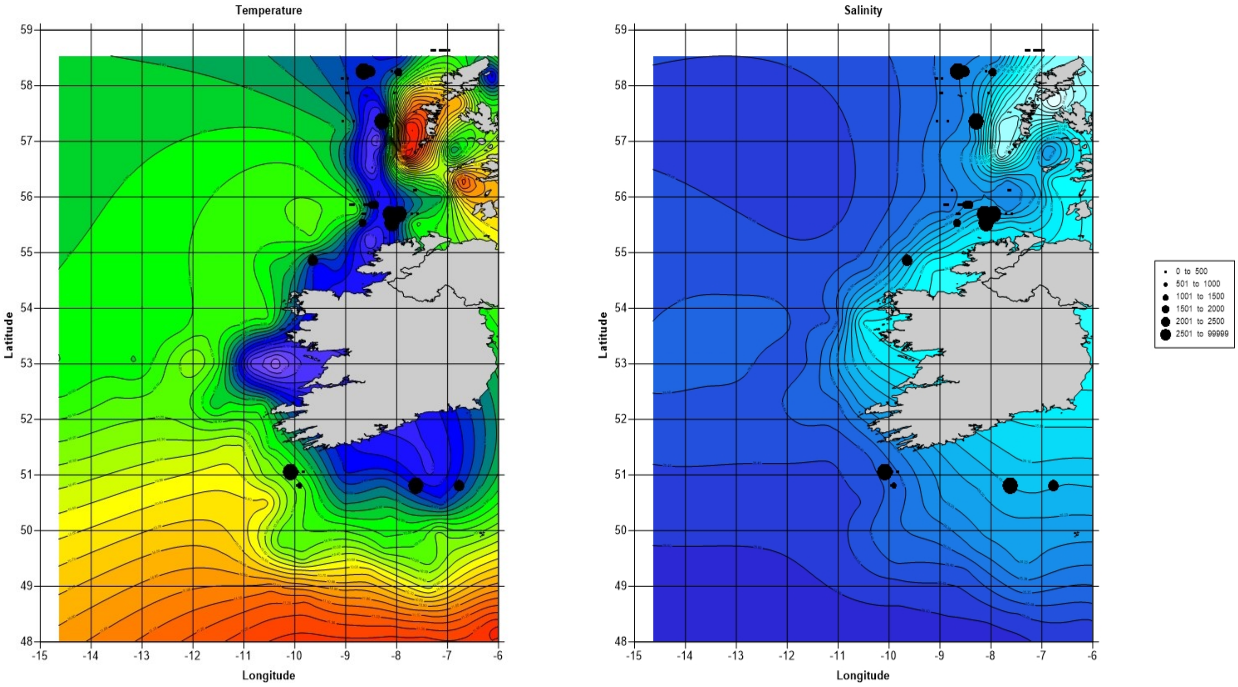


Figure 17. Habitat plots of temperature and salinity with herring distribution. Sea floor values overlaid with herring NASC values (black circles).

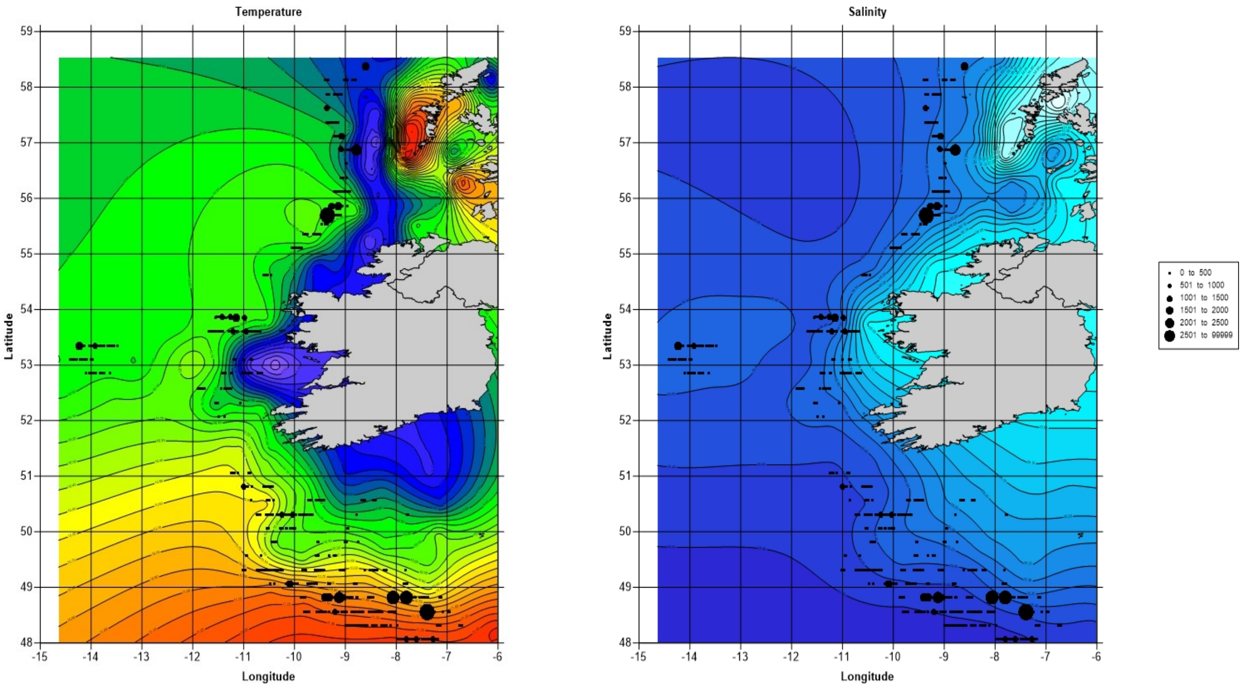


Figure 18. Habitat plots of temperature and salinity with boarfish distribution. Sea floor values overlaid with boarfish NASC values (black circles).

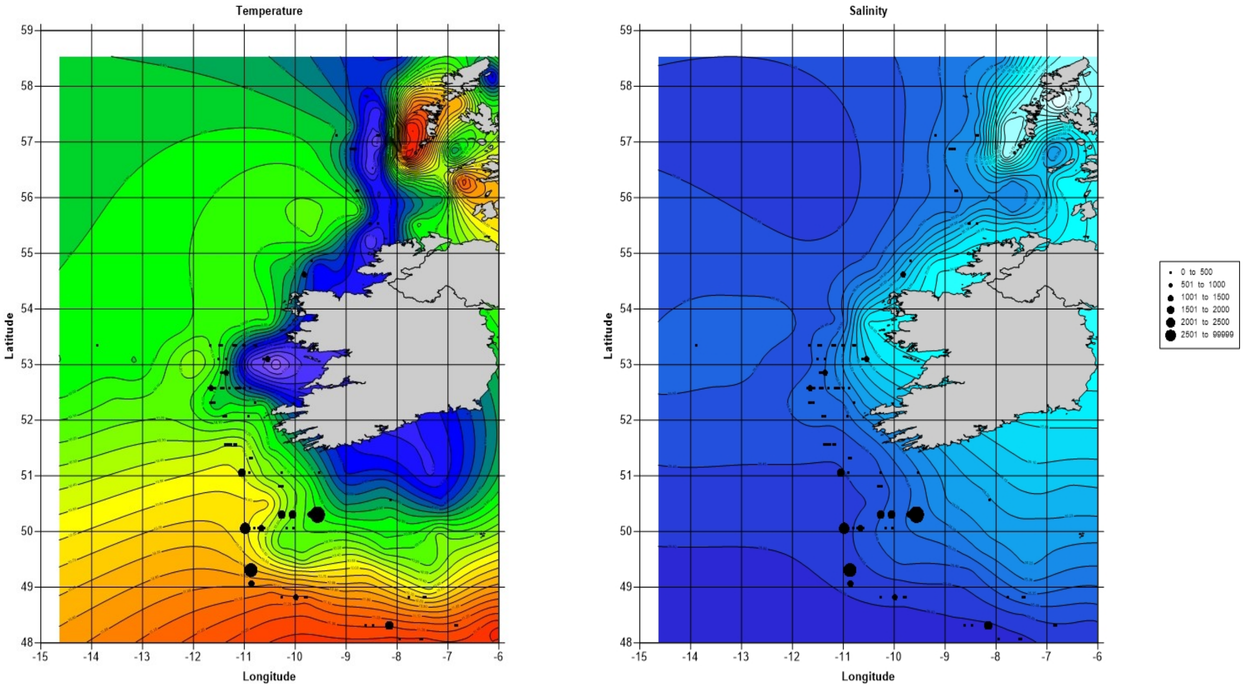


Figure 19. Habitat plots of temperature and salinity with horse mackerel distribution. Sea floor values overlaid with horse mackerel NASC values (black circles).

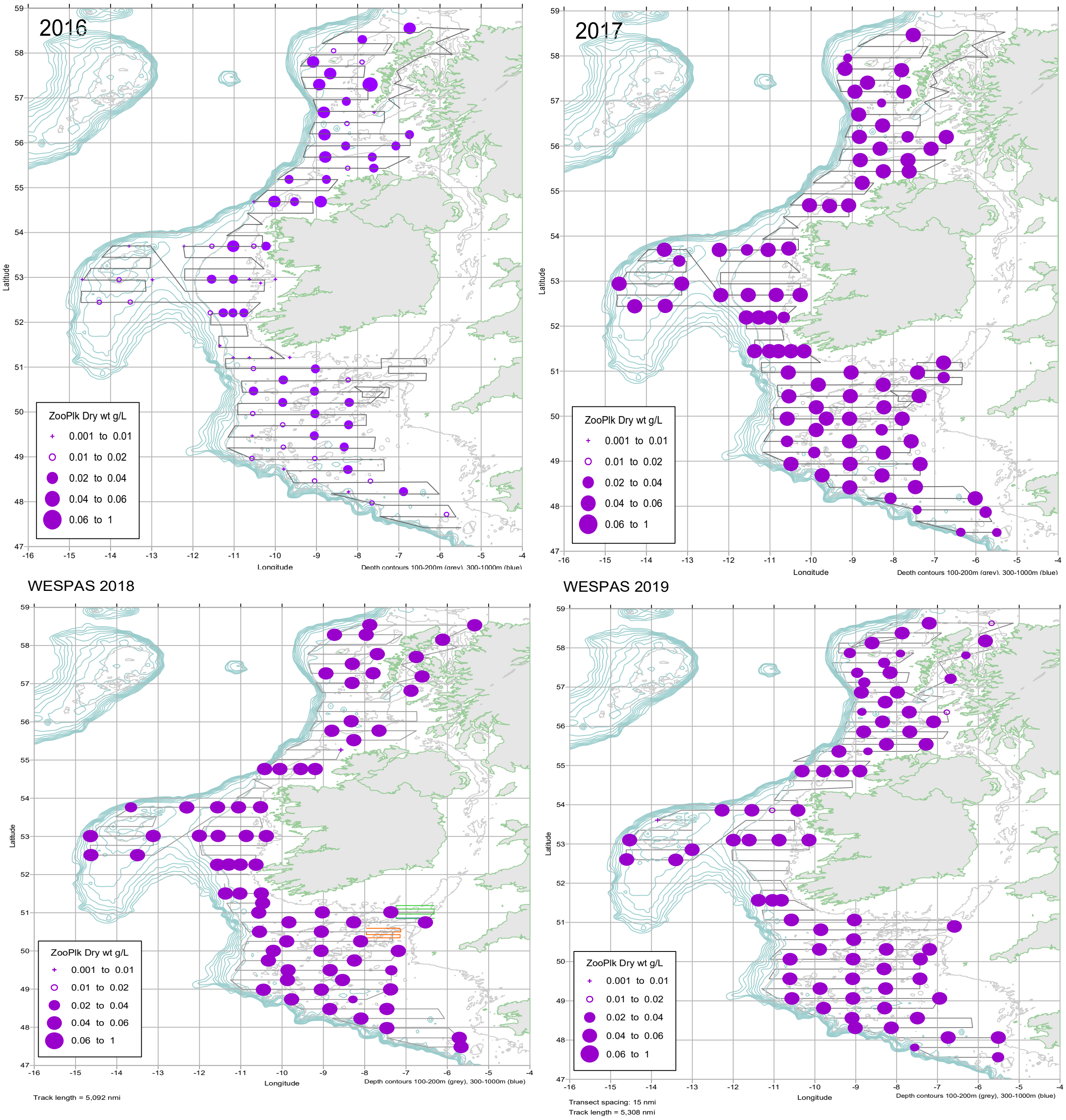


Figure 20. Zooplankton dry weight biomass by station (g dry Wt. m3) 2016-2019.

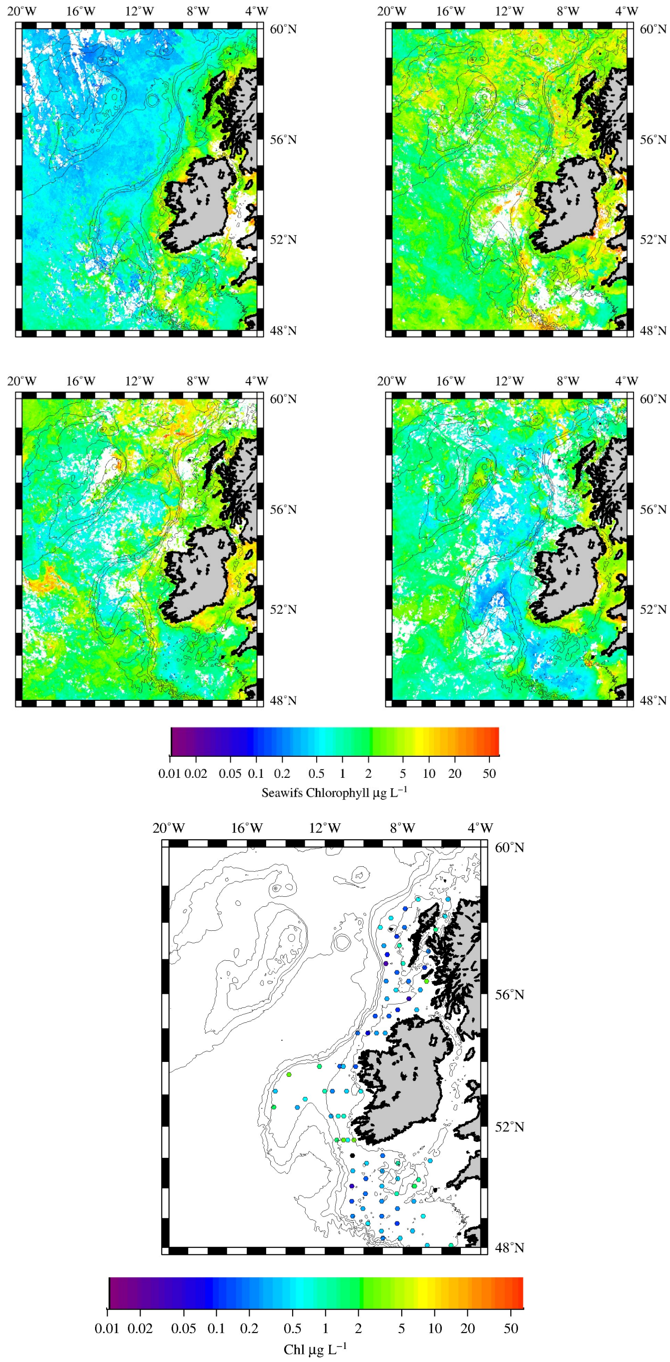


Figure 21. Top panel: OC5CI Chlorophyll monthly composite images for April (top left), May (top right), June (bottom left) and July 2019 (bottom right) (Source: CMEMS). Bottom panel: Near surface mixed layer chlorophyll measurements during WESPAS 2019.

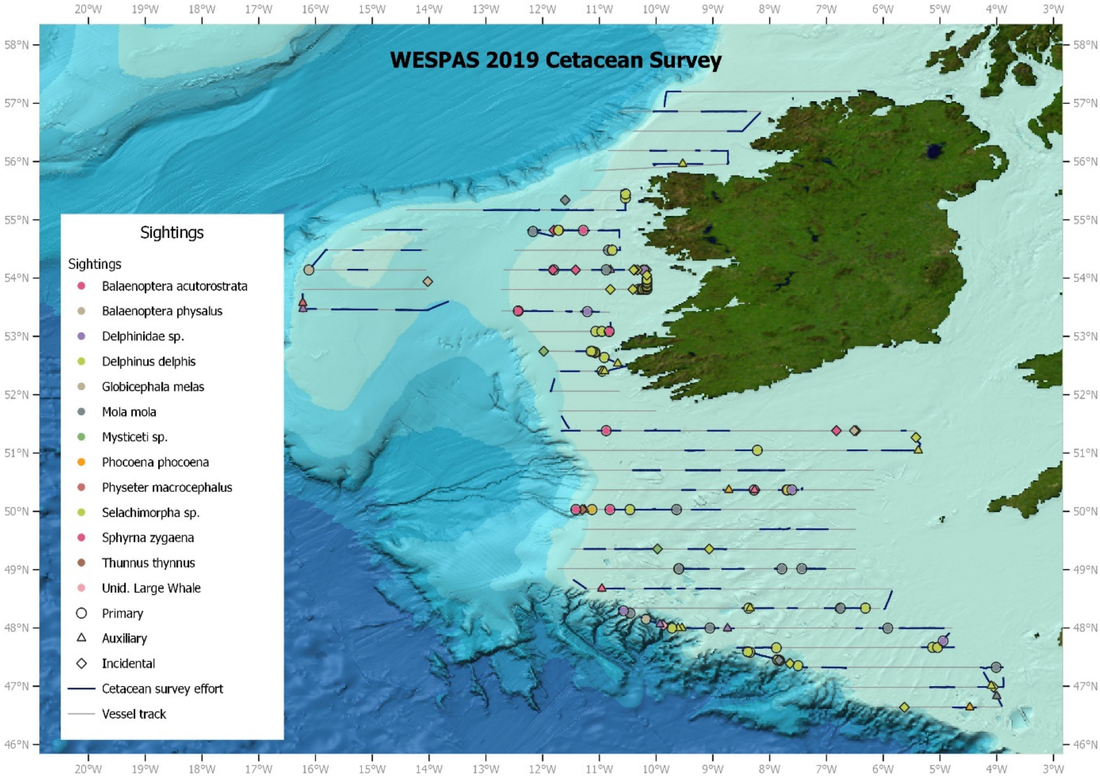


Figure 22. Distribution of marine mammal sightings while on-effort profiled with observer effort.

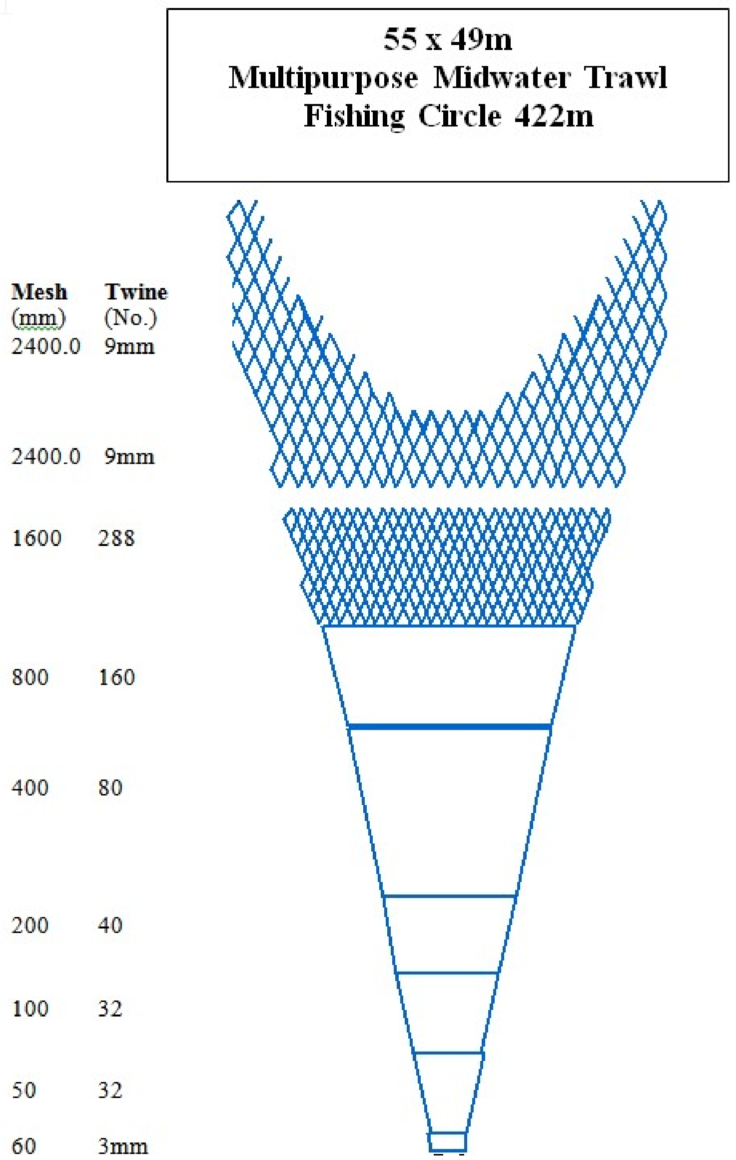


Figure 23. Single multipurpose midwater trawl net plan and layout.

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