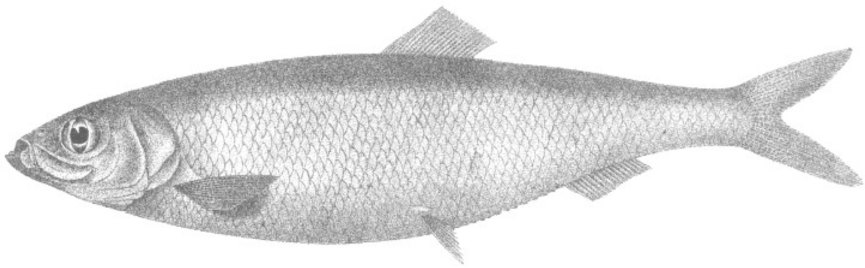
FSS Survey Series: 2023/04

RV Celtic Explorer

Celtic Sea Herring Acoustic Survey Cruise Report 2023

09 - 29 October, 2023



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Foras na Mara
Marine Institute

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1 Introduction

In the southwest of Ireland and the Celtic Sea (ICES Divisions VIIaS, g and j), herring are an important commercial species to the pelagic and polyvalent fleet. The local fleet is composed of dry hold polyvalent vessels and a smaller number of large purpose built refrigerated seawater vessels (RSW). The stock is composed of both autumn and winter spawning components with the latter dominating. The fishery targets pre-spawning and spawning aggregations in Q3-4. The Irish commercial fishery has historically taken place within 1-20nmi (nautical miles) of the coast. However, since the mid-2000s RSW fleet have actively targeted offshore aggregations migrating from summer feeding in the south Celtic Sea. In VIIj, the fishery is traditionally active from mid-November and is concentrated within several miles of the coast. The VIIaS fishery peaks towards the year end in December, but may be active from mid-October depending on location. In VIIg, along the south coast herring are targeted from October (offshore) to January at a number of known spawning sites and surrounding areas. Overall, the protracted spawning period of the two components extends from October through to February, with annual variation of up to 3 weeks. Spawning occurs in successive waves in a number of well known locations including large scale grounds and small discreet spawning beds. Since 2008 ICES division VIIaS (spawning box C) has been closed to fishing for vessels over 15m to protect first time spawners. For those vessels less than 15m a small allocation of the quota is given to this 'sentinel' fishery operating within the closed area.

The stock structure and discrimination of herring in this area has been researched. Hatfield et al. (2007) has shown the Celtic Sea stock to be fairly discrete. However, it is known that fish in the eastern Celtic Sea recruit from nursery areas in the Irish Sea, returning to the Celtic Sea as young adults (Brophy et al. 2002; Molloy et al., 1993). The stock identity of VIIj herring is less clear, though there is evidence that they have linkages with VIIb and VIaS (ICES, 1994; Grainger, 1978). Molloy (1968) identified possible linkages between young fish in VIIj and those of the Celtic Sea herring. Genetic studies are underway to determine stock identify and origin. For the purpose of stock assessment and management divisions VIIaS, VIIg and VIIj have been combined since 1982.

For a period in the 1970s and 1980s, larval surveys were conducted for herring in this area. However, since 1989, acoustic surveys have been carried out, and currently are the only tuning indices available for this stock. In the Celtic Sea and VIIj, herring acoustic surveys have been carried out since 1989. Since 2004 the survey has been fixed in October and carried out onboard the RV *Celtic Explorer.* This year, the survey was conducted onboard the RV Tom Crean.

Survey design and geographical coverage have been modified over the time series to adapt to changes in stock size and behaviour. Since 2016, the wider core distribution area has been surveyed by means of two independent surveys and supplemented with small high resolution adaptive surveys focusing on areas of high abundance.

2 Materials and Methods

2.1 Scientific Personnel

Leg	Leg 1	Date	Leg 2	Date
Start	Dublin	09.10.23	Cobh	19.10.23
End	Cobh	19.10.23	Galway	29.10.23

Organisation	Name	Name	Capacity
FEAS	Michael O'Malley	Michael O'Malley	Acou (Chief Sci)
FEAS	Turloch Smith	Cormac Nolan	Acou
FEAS	Dermot Fee	Eugene Mullins	Acou
Student	Georgina Vickery	Tobi Rapp	Acou
FEAS	Karl Bently	Sean O'Connor	Bio (Deck Sci)
FEAS	Artur Opanowski	Grainne Ryan	Bio
FEAS	Grainne Ni Conchuir	James Fahy	Bio
Student	Sibeal Alliot	Ciaran Fitzgerald	Bio
Student		Carla Deane	Bio
MMO	Lauren McBride	Lauren McBride	MMO
SBO	Niall Keogh	Niall Keogh	SBO
Industry Obs	John O'Regan	John O'Regan	IS&WFPO

SBO- Seabird observer, MMO- marine mammal observer, SmartSea student placement

2.2 Survey Plan

2.2.1 Survey objectives

The primary survey objectives are listed below:

- Carry out a two phase survey cruise track covering the core survey area
- Carry out additional adaptive surveys as required in areas of interest
- Collect biological samples from directed trawling on insonified fish echotraces
- Collect biological data on the age, length and maturity of herring and sprat
- Determine an age stratified estimate of relative abundance of herring within the survey area (ICES Divisions VIIj, VIIg and VIIaS)
- Determine an estimate of relative abundance of sprat, anchovy and sardine within the survey area (ICES Divisions VIIj, VIIg and VIIaS)
- Collect physical oceanography data from vertical profiles from a deployed sensor array
- Collect biological samples of sprat and herring for genetic analysis on stock origin studies.
- Visual surveys to determine the distribution and abundance of apex predators (marine mammals, tuna and seabirds)

2.2.2 Area of operation

The autumn 2023 survey covered the area from Mizen Head along the south coast to Carnsore Point and into the Celtic Sea (Divisions VIIj, VIIg and VIIaS), see Figure 1.

The survey was broken into two components. The first used a two survey approach to contain the stock within the core survey area (Pass 1 & Pass 2). The second adaptive component focused on high abundance areas of herring identified during the core surveys using higher intensity transect sampling effort.

2.2.3 Survey design

2.2.3.1 Core survey

In 2016, a change in survey design was implemented by consolidating all existing strata into a single core survey stratum. This broad scale survey composed of 8 nmi (nautical miles) spaced transects. A second pass was then carried out interlacing transects from the previous pass. Interlaced transects providing an effective coverage of 4 nmi resolution. Each pass represents an independent estimate of abundance.

A parallel transect design was applied with transects running perpendicular to the coastline and lines of bathymetry where possible. Offshore extension reached up to 90 nmi. Transect start points within each stratum are randomised each year within established baseline stratum bounds.

In total the core surveys accounted for 2,836 nmi of transects covering an area of over 17,273 nmi².

2.2.3.2 Adaptive survey

Adaptive surveys were carried out on areas of interest identified during the core survey.

Arears of specific interest are surveyed using adaptive techniques such as high intensity and/or replicate coverage. Offshore candidate areas were scouted to determine geographical extent of target aggregations where possible. A survey plan was then designed using parallel transects running perpendicular to the lines of bathymetry. Transect spacing is determined on an individual survey basis. The EK80 split beam data is supplemented with Omni sonar data (Simrad SU92) to provide increased spatial resolution on the extent of aggregations. Survey design followed methods described in Simmonds and MacLennan (2005) for adaptive surveys. Individual transects were run in parallel crossing the extent of the herring aggregation with the end point determined when no further herring were observed for 0.5 nmi.

Directed fishing trawls and in-trawl optics were used to determine echotrace identification as applied during routine surveying operations.

Four adaptive surveys were carried out accounting for 399 nmi of transects and an area coverage of 1,024 nmi².

2.3 Equipment and system details and specifications

2.3.1 Acoustic array

Equipment settings for the acoustic equipment were determined before the start of the survey program and were based on established settings employed by FEAS on previous surveys (O'Donnell et al*.,* 2004). The acoustic settings for the EK60 38 kHz transducer are shown in Table 1.

Acoustic data were collected using the Simrad EK60 scientific echosounder. The Simrad split-beam transducers are mounted within the vessel's drop keel and lowered to the working depth of 3.0 m below the vessel's hull or 8.8 m sub surface. Four operating frequencies were used during the survey (18, 38, 120 and 200) for trace recognition purposes and analysis, with data from the 38 kHz used to generate the abundance estimate.

While on survey track the vessel operates in silent mode (ICES 2002). During fishing operations normal two-engine operations were employed to provide sufficient back-up power to tow the net.

2.3.2 Calibration of acoustic equipment

A calibration of the EK60 was carried out in June Dunmanus Bay. The procedure followed methods described by Demer et al. (2015). Calibration results and settings (38 kHz) are provided in Table 1.

2.4 Survey protocols

2.4.1 Acoustic data acquisition

The "RAW files" were logged via a continuous Ethernet connection to the vessels server and the EK80 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® live viewer was used to display the echogram during data collection to allow the scientists to scroll through echograms noting the locations and depths of fish shoals. A member of the scientific crew monitored the equipment continually. Time and location (GPS position) data was recorded for each transect within each stratum. This log was used to monitor the time spent off track during fishing operations and hydrographic stations plus any other important observations.

2.4.2 Biological sampling

A single pelagic midwater trawl with the dimensions of 19 m in length (LOA) and 6 m at the wing ends and a fishing circle of 330 m was employed during the survey (Figure 18). Mesh size in the wings was 3.3 m through to 5 cm in the cod-end. The net was fished with a vertical mouth opening of approximately 13 m, which was observed using a cable linked Simrad FS70 netsonde. Spread between the trawl doors was monitored using Marport distance sensors.

All components of the catch from the trawl hauls were sorted and weighed; fish and other taxa were identified to species level. Fish samples were divided into species composition by weight. Species other than the herring were weighed as a component of the catch. Length frequency and length weight data were collected for each component of the catch. Length measurements of herring, sprat and pilchard were taken to the nearest 0.5 cm below. Age, length, weight, sex and maturity data were recorded for individual herring within a random 50 fish sample from each trawl haul, where possible. All herring were aged onboard. The appropriate raising factors were calculated and applied to provide length frequency compositions for the bulk of each haul.

Decisions to fish on particular echo-traces were largely subjective and an attempt was made to target marks in all areas of concentration not just high density schools. No bottom trawl gear was used during this survey. However, the small size of the midwater gear used and its manoeuvrability in relation to the vessel power allowed samples at or below 1 m from the bottom to be taken in areas of clean ground.

2.4.3 Oceanographic data collection

Oceanographic stations were carried out during the survey at predetermined locations along the track. Data on temperature, depth and salinity were collected using a calibrated Seabird 911 sampler at 1 m subsurface and 3 m above the seabed.

2.4.4 Marine mammal and seabird observations

2.4.4.1 Marine Mammal sighting survey

During the survey, a single observer kept a daylight watch on marine mammals from the observation deck located 12.9 m above sea level).

During cetacean observations, watch effort was focused on an area dead ahead of the vessel and 45° to either side using a transect approach. Sightings in an area up to 90° either side of the vessel were recorded. The area was constantly scanned during these hours by eye and with binoculars. Ship's position, course and speed were recorded, environmental conditions were recorded every 15 minutes and included, sea state, visibility, cloud cover, swell height, precipitation, wind speed and wind direction. For each sighting the following data were recorded: time, location, species, distance, bearing and number of animals (adults, juveniles and calves) and behaviour. Relative abundance (RA) of cetaceans was calculated in terms of number of animals sighted per hour surveyed (aph). RA calculations for porpoise, dolphin species and minke whales were made using data collected in Beaufort Sea state ≤ 3. RA calculations for large whale species were made using data collected in Beaufort Sea state ≤ 5.

2.4.4.2 Seabird sighting survey

A single seabird surveyor worked each leg of the survey. A standardized line transect method with sub-bands to allow correction for species detection bias and 'snapshots' to account for flying birds was used (following recommendations of Tasker et al*.* 1984; Komdeur *et al.*1992; Camphuysen *et al*. 2004), as outlined below.

The seabird observer conducted visual survey effort while simultaneously recording all data. 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. All observations for seabirds were conducted from the observation deck located 12.9 m above sea level.

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 90º to one side (i.e., to port or starboard) of the vessel’s track-line, however, all seabirds observed outside this area were also 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: 0-50m, B: 50-100m, C: 100-200m, 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 trackline (Camphuysen et al. 2004). Seabirds occurring outside of this survey strip were recorded as ‘off-transect’ and assigned to a separate sub-band (E: >300m). 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 300m x 300m 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 100-400mm 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 3.514) 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 timestamped 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 timestamped 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., Common tern, etc.).

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

2.4.5 Zooplankton sampling

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.

Station samples were split in 50:50 for wet and dry processing for stations 1-44 (Celtic Sea and SW coast). 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 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).

2.5 Analysis methods

2.5.1 Echogram partitioning

Acoustic data was backed up every 24 hrs and scrutinised using Echoview® (V 13) post processing software.

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

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

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

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

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

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

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

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

2.5.2 Abundance estimate

Acoustic data were analysed using the StoX software package as adopted for all WGIPS coordinated surveys (ICES 2016). A description of StoX is provided by Johnsen *et al.* (2019). Estimation of abundance from acoustic surveys within StoX is carried out according to the stratified transect design model developed by Jolly and Hampton (1990).

3 Results

3.1 Celtic Sea herring stock

3.1.1 Herring biomass and abundance

Total herring biomass (TSB) and spawning stock biomass (SSB) by strata are provided in Table 3. The biomass presented below was determined using Pass 1 (core survey) as the largest geographical area surveyed.

Herring	Abund ('000)	Biomass (t)
Total stock	109,184.3	1,773.4
Spawning stock	-	-

3.1.2 Herring distribution

A total of 20 trawl hauls were carried out during the survey (Figure 1). Eleven hauls contained herring (Table 2).

Core Surveys

A total of 38 herring echotraces were identified (Pass 1: 17, Pass 2: 21). Within the core survey effort, herring catches were composed of immature individuals in mixed species catches containing other small pelagic fish. From mixed species catches, sprat represented the major component of the catch by weight and number. Mixed sprat and herring scattering layers were observed in coastal waters (<10 nmi of the coast) and in eastern and north-eastern survey area (Figure 2 & Figures 12 a-c).

Adaptive Surveys

Four adaptive surveys were conducted (Figure 3). The first was conducted offshore and focused on a high density aggregation of herring. Eight transects, each 8 nmi long were undertaken using a transect spacing of 2 nmi. This survey yielded the only high density aggregation of mature herring encountered from combined survey effort (Figure 3, Table 3). A second offshore adaptive survey yielded no herring.

An inshore adaptive survey was conducted inshore along the south coast from 1-10 nmi using 18 transects with a 4 nmi spacing. This survey yielded low numbers of immature herring in trawl catches and six individual echotraces identified as herring (Figure 3, Table 3).

The fourth adaptive survey took place in Dingle Bay and utilised a zig-zag transect design. This survey yielded low numbers of immature herring in trawl catches and three individual echotraces identified as herring (Figure 3, Table 3).

3.1.3 Herring stock composition

A total of 109 herring were aged from combined samples, in addition to 394 length-weights. Herring age samples ranged from 0-6 winter-rings (Figures 4 and 5, Tables 3 and 4). Biomass and abundance at length and age by Stratum is provided in Figures 1-5, Appendix 1.

Core survey

The Pass 1 survey estimate was made up entirely of immature fish. Of which, 0-wr fish made up of 97.6% of TSB & 99.1% of TSN and 1-wr fish accounted for 2.4% of TSB and 0.9% of TSN.

Pass 1 estimate was 1,773.4 t and a total abundance of 109,184.3 (‘000s) individuals (CV 0.61).

The Pass 2 estimate was made up entirely of immature fish. Of which, 0-wr fish made up of 97.8% of TSB & 98.9% of TSN and 1-wr fish accounted for 2.2% of TSB and 1.1% of TSN.

The Pass 2 survey estimate was 897.4 t and a total abundance of 3,423.9 (‘000s) individuals (CV 0.43).

Adaptive surveys

Of the four adaptive surveys carried out, three contained herring. One offshore survey contained mature herring and the two inshore surveys were composed entirely of immature fish. Estimates of biomass and abundance by strata are presented in Table 3 and Figure 4 respectively.

The Offshore adaptive survey estimate was made up entirely of mature fish (2-6 wr fish) observed in a single high density aggregation (Figure 12d). The Offshore adaptive survey TSB was 9,254.3 t and TSN of 70,633.5 (‘000s) individuals (CV 0.54).

Age composition was dominated by 4-wr, followed by 5-wr, 6-wr and 3-wr fish by weight. The dominant 4-wr fish contributed 45.9% to the TSB and 46.6% to TSN, followed by 5-wr fish (43.1% TSB & 41.5% TSN), then 6-wr fish (6.5% TSB & 5.7% TSN) and 3-wr fish (3.7% TSB & 4.6% TSN). All fish were found to be mature individuals.

The inshore adaptive survey estimate was made up entirely of immature fish (0 & 1 wr fish). The inshore adaptive survey TSB was 38.4 t and TSN of 2,293.5 (‘000s) individuals (CV 1.0).

The Dingle Bay adaptive survey estimate was made up entirely of immature fish (0 & 1 wr fish). The survey TSB was 66.4 t and TSN of 2,293.5 (‘000s) individuals (CV 0.89).

3.2 Other pelagic species

3.2.1 Sprat

Sprat	Abund ('000)	Biomass (t)
Total stock	2,727,228.5	11,342.0

Pass 1 represented a total biomass of 11,342 t of sprat and a total abundance of 2,727,229 (‘000s) individuals (CV 0.25). Sprat distribution and biomass and abundance by strata are presented in Figures 6 & 7 and Table 5.

Aggregations of sprat were found widely distributed across the survey area, both inshore and offshore (Figure 6). Inshore distribution is relatively consistent from year to year east of Cork Harbour, whereas offshore distribution shows a higher degree of inter-annual variability. The centre of gravity of fish offshore was located in the eastern area (east of the 7°W) extending outside of the survey area. The majority of the western offshore area returned sprat echotraces and is comparable to previous years. Higher abundance offshore in the eastern is not uncommon and is often accompanied by reports of higher sprat abundance during the co-occurring PELTIC survey (CEFAS, UK), as was the case in 2023 (J. Van Der Kooij, pers. comm., 2023).

In total, 2,427 individual length measurements and 1,519 length/weight measurements were recorded. Mean length was 9 cm and mean weight was 5.2g (8.8 cm and 5.5 g in 2022). Individuals ranged from 6 to 13.5 cm in length and 1 to 19 g in weight. Biomass and abundance by survey strata is presented in Table 5 and the survey time series in Table 6.

A total of 467 (401 in 2021) individual sprat echotraces were identified from combined survey effort (Figure 6). Aggregations were composed predominantly of mixed species scattering layers (Figure 12a-c).

3.2.2 Anchovy

Anchovy	Abund ('000)	Biomass (t)
Total stock	769,823.0	9,769.8

Pass 1 represented a total biomass of 9,770 t of anchovy and a total abundance of 769,823 (‘000s) individuals (CV 0.73). Anchovy distribution and biomass and abundance by strata are presented in Figures 8 & 9 and Table 8.

A total of 106 anchovy echotraces were identified offshore during the survey (26 in 2022). Anchovy distribution could be characterised as having an inshore and offshore distribution pattern during the 2023 survey. In both instances, anchovy was predominantly taken as part of mixed species scattering layers (Figure 12b). A small number of medium to high density monospecific aggregations were observed offshore (Figure 8f). The number of schools and distribution of anchovy shows a high degree of inter-annual variability. High abundance years are likely driven by hydrographic (temperature gradients) and associated feeding opportunities.

In total, 1,120 individual lengths and an additional 1,057 length/weight measurements were recorded. Mean length was 12 cm and mean weight was 10 g (16.5 cm and mean weight was 29.8 g in 2022). Individuals ranged from 10 to 18 cm in length and 5 to 36 g in weight.

3.2.3 Sardine

Sardine	Abund ('000)	Biomass (t)
Total stock	767,452.0	22,069.0

Pass 1 represented a total biomass of 22,069 t and a total abundance of 767,452 (‘000s) individuals (CV 0.93). Sardine distribution and biomass and abundance by strata are presented in Figures 10 & 11 and Table 7.

A total of 54 medium and high density echotraces were identified as sardine during the survey (45 in 2022). All sardine echotraces were encountered within 10 nmi of the coast within the Pass 1, Pass 2 and Inshore adaptive stratum (Figures 10) and is consistent with the recent time series. Individual sardines were observed as components of mixed catches dominated by sprat (weight and number) and as monospecific schools. One high density aggregation of sardine was located close inshore in the southeast during Pass 1 (Figure 12e).

In total, 797 individual length measurements and 649 length/weight measurements were recorded. Mean length was 16 cm and mean weight was 40 g (16.2 cm & 43 g in 2022). Individuals ranged from 9 to 23 cm in length and 5 to 103 g in weight.

3.3 Oceanography

A total of 38 CTD stations were carried out during the survey area. Surface plots of temperature and salinity are presented using 5 m and 20 m and as near bottom profiles are overlaid with acoustic density.

Horizontal plots of temperature and salinity at 5 and 20 m depths showed relatively uniform near surface conditions above the thermocline (Figures 13 and14). The water column was well stratified, as evident from the thermocline extending to c.50 m for offshore stations.

Near bottom temperature data indicated the dominance of cooler waters (10-11°C) extending from the western area and the presence of a warmer, and less saline, body of water in the north-eastern Celtic Sea (Figures 15 & 16). Offshore aggregations of mature herring were distributed in the 10-11°C isotherm, whereas immature fish were located inshore and to the east in the warmer mixed coastal waters (Figure 16). The centre of gravity of sprat aggregations were distributed within this body of warmer water and along boundary areas in the eastern survey area (Figure 15). Coastal aggregations of sprat were also observed in cooler, more saline waters in the southwest.

3.3.1 Zooplankton

No zooplankton sampling was undertaken during the survey.

3.4 Marine mammal and seabird observations

3.4.1 Marine mammal abundance and distribution survey

<u>Survey effort</u>

A total of 105 hours and 57 minutes of survey effort was conducted over the course of the 2023 survey. In total, 102 hours and 18 minutes of survey effort were conducted using a line transect methodology, while 3 hours and 39 minutes of effort were conducted using the point sampling methodology.

As there was only one observer deployed on the survey, the maximum recorded daily survey effort was 7 hours and 39 minutes while the average daily survey effort was 6 hours and 2 minutes.

Environment

Near calm conditions were recorded 11% of the time, where sea surface was smooth. Rough conditions were recorded during 8% of the survey and very rough was recorded for 9% of the survey. When conditions were considered as rough/very rough reduced watches were completed.

A swell height of 1 m was the most frequently recorded (63% of the survey). A swell height of 0.1-1 meters accounted for 16% of the time, and a swell of 3 m was recorded during a period of rough weather for 9% of the time.

Visibility was generally very good during cetacean survey effort. The most frequently recorded visibility was 11-15 km (65% of survey effort), while visibility of 6-10 km was the second most recorded (25% over survey effort). Poor visibility of >1 km was recorded 6% of the survey effort. During low visibility reduced watches were complete

Sightings report

A total of 69 sightings were recorded on the survey, reaching a total of 602 individuals across all sighting types and taxa. A summary of all sightings recorded on the survey is presented in Table 9 and Figure 17 and includes primary, auxiliary and incidental sightings of all megafaunal groups recorded during line transect and point sampling effort watches.

Of the 69 sightings, 63 cetacean sightings were recorded during the survey. The cetacean sightings included; 3 whale species, 2 dolphin species and a number of sightings which could not be identified to species level. Of the 69 sightings, 67 were recorded while conducting line transects, while 2 were recorded while conducting point sampling.

Common dolphins (Delphinus delphis) were the most frequently observed and most abundant species. Common dolphins were encountered on 51 occasions, accounting for 74% of all sightings. These sightings consisted of a total of 575 individuals.

Fin whales (Balaenoptera physalus) were the most frequently encountered baleen whale species accounting for 4 sightings (6% of all sightings) comprising of 5 individuals in total.

Minke whales (Balaenoptera acutorostrata) was the third most frequently encountered species. Consisting of 3 individuals (4% of all sightings). The ocean sunfish (Mola mola) were the most frequently encountered species of marine megafauna excluding marine mammals. Sunfish were spotted on 1 occasion. The sighting consisted of a lone individual (0.16% of encountered individuals).

Elasmobranch species were only encountered when observed in the haul and were not included in the sightings data.

Bluefin tuna were recorded on 5 occasions (7% of all sightings). The sightings coincided with bird, dolphin and whale interactions.

3.4.2 Seabird abundance and distribution survey

In total, 78 hours and 8 minutes of survey effort were conducted over the course of CSHAS 2023. In total, 69 hours and 25 minutes of survey effort were conducted using a line transect methodology, while 25 minutes of effort were conducted using the point sampling methodology. A further 9 hours and 17 minutes of effort were conducted as a casual watch.

A total of 2,459 seabird observations were recorded throughout the survey, totalling 13,756 individuals (Table 10). In total, 3,318 seabirds were recorded as “in transect”, while 10,438 were recorded “off transect”. The species encountered included 25 species from ten families. A further 48 observations of terrestrial migratory birds were also recorded, comprising of 152 individuals (Table 11).

Gannet (*Morus bassanus*) were the most frequently encountered species, recorded on 616 separate occasions, accounting for 25.1% of all records. Gannet records comprised of a total of 2,781 individuals (20.2% of all individual birds recorded) making gannet the most abundant species recorded on the survey. However, of these, only 538 birds were recorded as ‘in transect’.

Guillemot (*Uria aalge*) were both the second most frequently encountered and one of the most abundant species accounting for 409 records (16.6% of all encounters) and comprising of 1,434 individuals in total (10.4% of all encountered individuals.) Of these, 927 individuals were recorded as ‘in transect’.

Kittiwake (*Rissa tridactyla*) were the third most frequently observed species accounting for 344 sightings (14.0% of all sightings). Kittiwake were the second most abundant species comprising of 2,778 individuals in total (20.2% of all encountered individuals.) Of these, 496 birds were recorded as ‘in transect’.

A number of terrestrial/ migratory birds were encountered during the survey. A total of 48 observations of terrestrial/ migratory bird species were recorded during the survey (*Table 11*). These records comprised of 152 individuals from 20 species’. Species recorded included a merlin (*Falco columbarius*), a short-eared owl (*Asio flammeus*), a yellow wagtail (*Motacilla flava*) and fifty siskin (*Spinus spinus*).

4 Discussion and Conclusions

4.1 Discussion

The objectives of the survey were carried as planned with less than 12 hours of weather associated downtime.

Overall, geographical coverage and acoustic sampling effort was in line with previous years. Good trawl and hydrographic sampling was achieved. Core replicate surveys (Pass 1 & 2) were completed as planned. Adaptive surveys were carried out inshore (n=2) and offshore waters (n=2). Immature herring (0 and 1-wr) were well represented in the core survey area, albeit in low numbers, occurring as part of mixed species aggregations dominated by sprat and other small pelagic fish.

The 2023 TSB estimate (Pass 1: core stratum) was 1,773.4 t and 109 million individuals (CV 0.61) and was composed entirely of immature (0 and 1-wr fish). Since 2016, the survey estimate is reported from core stratum covering the largest geographical area.

Adaptive surveys carried out inshore (Dingle Bay and south coast) and showed agreement with observations from core survey effort; with low numbers of immature herring present in low density mixed species aggregations.

One adaptive survey was carried out on a discreet high density aggregation of herring. Herring in this area were in close proximity to the seabed and were typical of observations over recent years. This offshore adaptive survey yielded a TSB was 9,254.3 t and TSN of 70,633.5 (‘000s) individuals (CV 0.54). The age composition was dominated by 4-wr, followed by 5-wr, 6-wr and 3-wr fish by weight. The dominant 4-wr fish contributed 45.9% to the TSB and 46.6% to TSN, followed by 5-wr fish (43.1% TSB & 41.5% TSN), then 6-wr fish (6.5% TSB & 5.7% TSN) and 3-wr fish (3.7% TSB & 4.6% TSN). All fish were found to be mature individuals. The age profile of mature herring sampled during the adaptive survey was representative of those in landings data and from observations during the summer WESPAS survey (2023).

The biomass of sprat was lower than observed in 2022, with the centre of gravity of distribution in the eastern Celtic Sea extending outside the limits of the survey. Sprat were observed in close coastal waters along the south coast in line with previous years in low to medium densities. The highest density of sprat was observed offshore in the eastern survey area, located within a warmer body of water (12-16°C) than ambient conditions (10-11°). The distribution of sprat extended beyond survey coverage and was picked up by the co-occurring PELTIC survey conducted by CEFAS UK. The Pass 1 represented a total biomass of 11,342 t and a total abundance of 2,727,229 (‘000s) individuals (CV 0.25). Mean length and weight was comparable to observations in 2022.

Anchovy followed a similar pattern of distribution to sprat; with the highest occurrence associated with the warmer region to the east. Several medium to high density monospecific aggregations of anchovy were observed offshore with the remaining observations taken as components of mixed species aggregations dominated by sprat. Pass 1 represented a total biomass of 9,770 t and a total abundance of 769,823 (‘000s) individuals (CV 0.73). Annual estimates of anchovy show higher annual variability than other species reported during this survey.

Sardine were found almost entirely in inshore waters (<10nmi), following a similar pattern of distribution to 2022. Medium to high density monospecific aggregations were observed as well as by-catch from mixed species scattering layers. Pass 1 represented a total biomass of 22,069 t and a total abundance of 767,452 (‘000s) individuals (CV 0.93). Mean length and mean weight of sardine were comparable to 2022.

4.2 Conclusions

- Overall, geographical coverage and acoustic sampling effort was in line with previous years. Good trawl and hydrographic sampling was achieved.
- The 2023 herring TSB estimate (Pass 1: core stratum) was 1,773.4 t and 109 million individuals (CV 0.61) and was composed entirely of immature (0 and 1-wr fish).
- The 2023 herring estimate represents a reduction from the 2022 estimate as no mature herring were encountered during core survey effort.
- Immature herring were widespread throughout the survey area, albeit in low numbers. Immature herring were encountered both offshore and in coastal waters in mixed species aggregations/layers dominated by sprat.
- Mature herring were located offshore in a discreet location and were surveyed using adaptive survey effort,
- Offshore adaptive survey yielded a TSB was 9,254.3 t and TSN of 70,633.5 (‘000s) individuals (CV 0.54). The age composition was dominated by 4-wr, followed by 5-wr, 6-wr and 3-wr fish by weight.
- The age profile of mature herring sampled during the adaptive survey was representative of those in landings data and from observations during the summer WESPAS survey (2023).
- The numbers of 0-wr and 1-wr fish remain low overall with no obvious signs of emerging strong year classes.
- The abundance of sprat observed this year was lower than that observed in 2022 and can be in part explained by the eastern distribution of aggregations extending outside of the survey area.
- Sprat total biomass estimate (Pass 1) was 11,342 t and a total abundance of 2,727,229 (‘000s) individuals (CV 0.25). The length profile of survey samples of sprat was comparable to the 2022 survey.
- Anchovy total biomass estimate (Pass 1) was 9,770 t and a total abundance of 769,823 (‘000s) individuals (CV 0.73). Annual estimates of anchovy show higher annual variability than other species reported during this survey.
- Sardine total biomass estimate (Pass 1) was 22,069 t and a total abundance of 767,452 (‘000s) individuals (CV 0.93). Mean length and mean weight of sardine were comparable to 2022. Sardine were found almost entirely in in-shore waters (<10nmi), following a similar pattern of distribution to 2022.

5 Acknowledgements

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6 References\Bibliography

Brophy, D., and B. S. Danilowicz (2002). Tracing populations of Atlantic herring (*Clupea harengus* L.) in the Irish and Celtic seas using otolith microstructure. ICES Journal of Marine Science, 59:1305-1313.

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

Camphuysen, C.J. and Webb, A. (1999). Multi-species feeding associations in North Sea seabirds: jointly exploiting a patchy environment. Ardea 87(2): 177-198.

Carwardine, M (2002). *Smithsonian Handbook of Whales, Dolphins and Porpoises.* Dorling Kindersley Limited, London and New York.

Cramp, S., Bourne, W.R.P. and Saunders, D. (1974). *The seabirds of Britain and Ireland*. Collins, London. 287 pp.

Cramp, S., et al. (1977-1994). *Handbook of the Birds of Europe the Middle East and North Africa - the Birds of the Western Palearctic*. Oxford University Press. [A 9 Vol multi-author work edited by Cramp and Cramp and Perrins.]

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

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

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

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N. and Simmonds, E.J. (1987). Calibration of acoustic instruments for fish density estimation: a practical guide. *Int. Coun. Explor. Sea. Coop. Res. Rep.* 144: 57 pp

Grainger, R. J. (1978). A study of herring stocks west of Ireland and their oceanographic conditions. Oceanography. Galway, University College Galway: 262.

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

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

ICES (2002) Underwater noise of research vessels. Review and recommendations. 2002. ICES No. 209

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

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

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

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

Johnsen, E., Totland, A., Skålevik, Å., Holmin, A.J., Dingsør, G.E., Fuglebakk, E. and Handegard, N.O., 2019. StoX: An open source software for marine survey analyses. Methods in Ecology and Evolution, 10(9), pp.1523-1528

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

Molloy, J., E. Barnwall, and J. Morrison. (1993). Herring Tagging Experiments around Ireland, 1991. Fishery Leaflet, 154: 7pp.

Molloy, J. (1968). "Herring investigations on the southwest coast of Ireland 1967." ICES CM 1968/H:14: 10 pp

Mackey, M., Ó Cadhla, O., Kelly, T.C., Aguilar de Soto, N. and Connolly, N. (2004). *Cetaceans and Seabirds of Ireland's Atlantic Margin. Volume 1 – Seabird distribution, density and abundance*. Report on research carried out under the Irish Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6 and 00/13, Porcupine Studies Group project P00/15 and Offshore Support Group (OSG) project 99/38. University College Cork.

Mitchell, P.I., Newton, S.F., Ratcliffe, N. and Dunn T.E. *Seabird Populations of Britain and Ireland. Results of the Seabird 2000 Census* (1998-2002). T. and A.D. Poyser.

O'Donnell, C., Griffin, K., Lynch D., Ullgren J., Goddijn L., Wall D. and Mackey M. (2004).Celtic Sea Herring Acoustic Survey Cruise Report, 2004.(http://catalog.marine.ie/geonetwork/srv/en/main.home)

O'Donnell, C., O'Malley, M., Smith, T., O'Brien, S., Mullins, E., Connaughton, P., Perez Tadeo, M., and Barile, C. (2020). Western European Shelf Pelagic Acoustic Survey (WESPAS), 03 June – 12 July, 2020. FEAS Survey Series: 2020/03. Marine Institute. http://hdl.handle.net/10793/1659

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

Shirihai H. and Jarrett B. (2006) *Whales, Dolphins and Seals. A Field Guide to the Marine Mammals of the World*. AandC Black, London.

Stone C.J., Webb A., Barton C., Ratcliffe N., Reed T.C., Tasker M.L, Camphuysen C.J and Pienkowski M.W. (1995). *An atlas of seabird distribution in north-west European waters*. Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough, PEI IJY United Kingdom.

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

Webb, A. and Durinck, J. (1992). Counting birds from ship. In J. Komdeur; J. Berelsen and G. Cracknell.

Wernham, C., Toms, M., Marchant, J., Clark, J., Siriwardena, G. and Baillie, S. (2002). *Migration Atlas: Movement of Birds in Britain and Ireland*. T. and A.D. Poyser.

7 Tables and Figures

Table 1. Calibration report: Simrad EK80 echosounder at 38 kHz.

Vessel : R/V Celtic Explorer		Date : 10.06.2023	
Echo sounder : EK60 PC		Locality : Dunmanus Bay	
Type of Sphere : WC-38,1	TS Sphere: -42.40 dB (Corrected for Soun vel)	Depth(btm) : 34 m	

Calibration Version 2.1.0.12

Comments:
WESPAS 2023_Dunmanus Bay- AutoCal

Reference Target:

TS	-42.41 dB	Min. Distance	15.60 m
TS Deviation	5.0 dB	Max. Distance	18.60 m

Transducer: ES38B Serial No. 30227

Frequency	38000 Hz	Beamtype	Split
Gain	25.82 dB	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	6.95 deg	Along. Beam Angle	6.86 deg
Athw. Offset Angle	0.02 deg	Along. Offset Angl	-0.07 deg
SaCorrection	-0.73 dB	Depth	8.80 m

Transceiver: GPT 38 kHz 009072033933 2-1 ES38B

Pulse Duration	1.024 ms	Sample Interval	0.193 m
Power	2000 W	Receiver Bandwidth	2.43 kHz

Sounder Type:
EK60 Version 2.4.3

TS Detection:

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

Environment:

Absorption Coeff.	8.8dB/km	Sound Velocity	1508.0 m/s

Beam Model results:

Transducer Gain =	2550 dB	SaCorrection =	-0.63 dB
Athw. Beam Angle =	6.92 deg	Along. Beam Angle =	6.89 deg
Athw. Offset Angle =	-0.05 deg	Along. Offset Angle=	-0.01 deg

Data deviation from beam model:
RMS = 0.09 dB
Max = 0.24 dB No. = 31 Athw. = 2.7 deg Along = 1.4 deg
Min = -0.28 dB No. = 147 Athw. = -3.3 deg Along = 0.2 deg

Data deviation from polynomial model:
RMS = 0.08 dB
Max = 0.21 dB No. = 31 Athw. = 2.7 deg Along = 1.4 deg
Min = -0.26 dB No. = 147 Athw. = -3.3 deg Along = 0.2 deg

Comments :
Dunmanus Bay
Wind Force : 5 kn **Wind Direction :** SW
Raw Data File: E:\CE23008_WESPAS2023\Calibration\38 kHz Cal\WESPAS2023-D20190705-T090459.raw
Calibration File: E:\CE22009_WESPAS2023\Calibration\38 kHz Cal\Cal 38 kHz.txt

Table 2. Catch table from directed trawl hauls.

No.	Date	Lat. N	Lon. W	Time	Bottom (m)	Target btm (m)	Bulk Catch (Kg)	Herring %	Mackerel %	Scad %	Sprat %	Sardine %	Others* %
1	10.10.23	51.48	-8.39	12:32	91	91	193.9	0.2	0.0	17.5	76.5		5.8
2	11.10.23	50.94	-7.74	21:36	100	100	2000.0	99.9					0.1
3	12.10.23	51.75	-7.76	08:14	74	60	161.2	0.4	2.0	0.9	18.3		78.3
4	13.10.23	52.07	-7.33	05:33	42	42	1500.0		0.3		33.5	64.3	2.0
5	13.10.23	51.91	-7.12	09:32	69	60	156.0	0.2	5.3	7.6	42.7		44.1
6	13.10.23	51.67	-7.12	09:55	76	76	185.5			0.6	64.7	0.0	34.7
7	14.10.23	51.58	-6.90	07:06	75	75	68.4		43.0		17.6		39.5
8	14.10.23	52.14	-6.77	12:43	28	28	1500.0		4.7			95.3	
9	15.10.23	51.69	-6.48	07:57	76	76	153.2	0.0	0.2	18.9	72.6	0.7	7.7
10	15.10.23	51.49	-6.26	15:22	110	90	116.8	6.0	1.4	25.6	63.1		3.9
11	15.10.23	51.07	-6.26	20:34	110	110	47.2			22.2	16.4		61.4
12	16.10.23	50.61	-5.94	02:31	86	86	68.8						100.0
13	16.10.23	50.95	-5.93	06:27	96	96	163.1	0.0	0.3	3.4	31.0		65.3
14	16.10.23	51.98	-5.77	15:55	102	60	66.0	1.6	1.1	0.2	90.1		7.1
15	18.10.23	51.67	-6.79	18:29	76	76	112.3	0.0	36.4	3.6	0.0	1.0	59.0
16	19.10.23	51.69	-8.29	17:11	40	30	350.0		1.6	0.2	1.0	96.3	1.0
17	20.10.23	52.00	-7.35	09:16	55	50	199.0	0.2	14.1	1.6	53.9	5.6	24.5
18	21.10.23	51.56	-7.01	11:43	76	70	12.0		4.0	0.9	37.4	1.2	57.7
19	23.10.23	51.38	-8.06	14:09	94	75	91.0		0.0	0.0			100.0
20	25.10.23	52.09	-10.27	11:11	43	28	50.5	2.2	12.3	0.7	73.5	2.8	8.5

Table 3. Herring biomass and abundance by strata. Pass 1 and adaptive survey (blue) presented as total stock biomass estimate for 2023.

Strata	Name	Type	Area (nmi²)	Transects	TSN ('000)	TSB (t)	SSN ('000)	SSB (t)	CV (Abun)
1	Pass 1	Core	9,173.5	13	109,184.3	1,773.4	-	-	0.61
2	Pass 2	Core	8,099.9	25	55,548.3	897.4	-	-	0.43
3	Inshore 1	Adaptive	854.5	17	2,293.5	38.4	-	-	1.00
4	Mini	Adaptive	85.2	8	70,633.5	9,254.3	70,633.5	9,254.3	0.54
5	Dingle Bay	Adaptive	84.4	zig zag	3,423.9	66.4	-	-	0.89
	Total		18,297.5	63					

Table 4. Celtic Sea herring survey time series.

Age (wr) Year	0	1	2	3	4	5	6	7	8	9	TSN (mils)	SSB ('000t)	Design	CV
2002	0	42	185	151	30	7	7	3	0	0	423	41	AR	0.49
2003	24	13	62	60	17	2	1	0	0	0	183	20	AR	0.34
2004	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	2	65	137	28	54	22	5	1	0	0	312	33	ARS	0.48
2006	0	21	211	48	14	11	1	0	0	0	305	36	ARS	0.35
2007	1	106	70	220	31	9	13	4	1	0	454	46	ARS	0.25
2008	2	63	295	111	162	27	6	5	0	0	671	93	ARS	0.20
2009	239	381	112	210	57	125	12	4	6	1	1147	91	ARS	0.24
2010	5	346	549	156	193	65	91	7	3	0	1414	122	ARS	0.20
2011	0.1	342	479	299	47	71	24	33	4	2	1300	122	ARS	0.28
2012	31	270	856	615	330	49	121	25	23	3	2322	246	ARS	0.25
2013	3.8	698	291.4	197.4	43.7	37.9	9.8	4.7	0	0.2	1286	71	ARS	0.28
2014	0	41	117	112	69	20	24	7	17	1	408	48	ARM	0.59
2015	0	0	40	48	41	38	7	6	5	0	184	25	ARM	0.18
2016	0	125	21	43	40	36	25	5	6	0	301	30	CRM	0.33
2017	0	0	6	3	7	5	4	0	1	0	27	4	CRM	NA
2018	109	56	16	27	6	0	0	0	0	0	213	8	CRM	0.50
2019	87	19.5	0.1	0	0	0	0	0	0	0	106.9	0.009	CRM	0.55
2020	1	27.7	32.2	5	1	0	0	0	0	0	67	3.1	CRM	0.51
2021	25.3	0	1.7	3.5	0.3	0.1	0	0.1	0	0	310	6.6	CRM	0.44
2022	11.3	0	0.79	57.3	39.1	3.36	0.9	0.52	0	0	113	12.3	CRM	1.24
2023	108	1	0.0	0.0	0	0	0	0	0	0	109	0	CRM	0.61

AR= Adaptive random, ARS= Adapt, random stratified, ARM= Adaptive random with mini surveys, CRM= Core random replicates with mini surveys

Table 5. Sprat biomass and abundance by strata.

Strata	Name	Type	Area (nmi²)	Transects	TSN ('000)	TSB (t)	CV (Abun)
1	Pass 1	Core	9,173.5	13	2,727,228.5	11,342	0.25
2	Pass 2	Core	8,099.9	25	2,129,130.7	9,184	0.31
3	Inshore 1	Adaptive	854.5	17	844,037.3	4,374	0.39
4	Mini	Adaptive	85.2	8	-	-	-
5	Dingle Bay	Adaptive	84.4	zig zag	24,503.7	165	0.57
	Total		18,298	63			

Table 6. Celtic Sea sprat survey time series.

	Pass1		Pass 2	
Year	**Abundance (Mils)**	**Biomass (t)**	**Abundance (Mils)**	**Biomass (t)**
2004	5,646	50,810		
2005	2,571	29,017		
2007	132	1,918		
2008	540	5,493		
2009	1,418	16,229		
2011	5,832	31,593		
2012	4,589	35,114		
2013	10,748	44,685		
2014	9,152	54,826		
2015	21,398	83,779		
2016	8,171	42,694	3,396	17,747
2017	4,189	13,442	13,285	52,473
2018	6,934	47,806	73,955	51,039
2019	10,344	60,608	74,282	42,787
2020	354	4,523	14,819	18,918
2021	3,018	12,376	7,255	28,081
2022	5,235	34,508	2,325	13,283
2023	2,727	11,342	2,129	9,184

Table 7. Sardine biomass and abundance by strata

Strata	Name	Type	Area (nmi²)	Transects	TSN ('000)	TSB (t)	CV (Abun)
1	Pass 1	Core	9,173.5	13	767,452	22,069.0	0.93
2	Pass 2	Core	8,099.9	25	565,910	16,272.7	0.63
3	Inshore 1	Adaptive	854.5	17	579,049	21,018.5	0.43
4	Mini	Adaptive	85.2	8	-	-	-
5	Dingle Bay	Adaptive	84.4	zig zag	17,929	194.8	0.47
	Total		18,298	63			

Table 8. Anchovy biomass and abundance by strata

Strata	Name	Type	Area (nmi²)	Transects	TSN ('000)	TSB (t)	CV (Abun)
1	Pass 1	Core	9,173.5	13	769,823	9,769.8	0.73
2	Pass 2	Core	8,099.9	25	318,308	3,969.0	0.49
3	Inshore 1	Adaptive	854.5	17	70,626	1,008.9	0.63
4	Mini	Adaptive	85.2	8	-	-	-
5	Dingle Bay	Adaptive	84.4	zig zag	3,639	80.0	0.85
	Total		18,298	63			

Table 9. Marine mammal sightings, counts and group size ranges for cetaceans sighted.

Common Name	Species name	No. of Sightings	No. of individuals	Group Size
Common dolphin	*Delphinus delphis*	53	575	2-120
Humpback whale	*Megaptera novaeangliae*	1	3	1-3
Fin whale	*Balaenoptera physalus*	3	5	1-2
Minke whale	*Balaenoptera acutorostrata*	3	3	1
Mix (Common dolphin & minke whale)	Mix (*D. delphinus & B. acutorostrata)*	1	20	1-20
Harbour Porpoise	*Phocoena phocoena*		1	1
Unid. Baleen Whale	*Mysticeti sp.*	1	1	1
Unid. Dolphin	Delphinid sp.	2	13	3-10
	Total	59	587	
Ocean sunfish	Mola mola	1	1	1
Tuna sp.	*Thunnus sp.*	5		
	Total	6	1	
	Grand total	65	588	

Table 10. Totals for all seabird species recorded.

Common Name	Scientific name	No. of Records	No. of Individuals	In Transect	Off Transect
Fulmar	*Fulmarus glacialis*	164	365	72	293
Cory's Shearwater	*Calonectris borealis*	91	325	180	145
Great Shearwater	*Ardenna gravis*	61	259	66	193
Sooty Shearwater	*Ardenna grisea*	121	818	341	477
Manx Shearwater	*Puffinus puffinus*	55	62	6	56
Storm Petrel	*Hydrobates pelagicus*	9	11	5	6
Gannet	*Morus bassanus*	616	2781	538	2243
Pomarine Skua	*Stercorarius pomarinus*	3	3	0	3
Arctic Skua	*Stercorarius parasiticus*	18	20	2	18
Pomarine/ Arctic Skua	*Stercorarius pomarinus/ parasiticus*	1	1	0	1
Long-tailed Skua	*Stercorarius longicaudus*	1	1	0	1
Great Skua	*Stercorarius skua*	14	15	0	15
Mediterranean gull	*Ichthyaetus melanocephalus*	2	2	0	2
Common Gull	*Larus canus*	24	316	37	279
Black-headed Gull	*Chroicocephalus ridibundus*	6	15	1	14
Lesser Black-backed Gull	*Larus fuscus*	93	1000	52	948
Herring Gull	*Larus argentatus*	59	756	75	681
Yellow-legged gull	*Larus michahellis*	4	4	0	4
Great Black-backed Gull	*Larus marinus*	65	341	16	325
Kittiwake	*Rissa tridactyla*	344	2778	496	2282
Large Gull sp.	*Laridae*	4	170	0	170
Common Tern	*Sterna hirundo*	3	3	0	3
Guillemot	*Uria aalge*	409	1434	927	507
Razorbill	*Alca torda*	227	1519	470	1049
Razorbill / Guillemot	*Alcidae*	34	717	10	707
Puffin	*Fratercula arctica*	13	19	14	5
Shag	*Gulosus aristotelis*	16	18	9	9
Great Northern Diver	*Gavia immer*	2	3	1	2
Total		**2459**	**13756**	**3318**	**10438**

Table 11. Totals of migrant terrestrial bird species recorded.

Common Name	Scientific name	No. of Individuals	No. of Sightings
Eurasian Blackcap	*Sylvia atricapilla*	1	1
Common Chiffchaff	*Phylloscopus collybita*	2	3
Eurasian Collared Dove	*Streptopelia decaocto*	1	1
Goldcrest	*Regulus regulus*	2	2
European Golden Plover	*Pluvialis apricaria*	4	36
European Goldfinch	*Carduelis carduelis*	1	2
Northern Lapwing	*Vanellus vanellus*	1	2
Meadow Pipit	*Anthus pratensis*	15	22
Merlin	*Falco columbarius*	1	1
Pied/ White wagtail	*Motacilla alba*	2	2
Redwing	*Turdus iliacus*	3	3
Short-eared Owl	*Asio flammeus*	1	1
Eurasian Siskin	*Spinus spinus*	1	50
Eurasian Skylark	*Alauda arvensis*	2	3
Common snipe	*Gallinago gallinago*	2	2
Common Starling	*Sturnus vulgaris*	2	3
Barn Swallow	*Hirundo rustica*	4	12
Ruddy Turnstone	*Arenaria interpres*	1	1
Whooper Swan	*Cygnus cygnus*	1	4
Western Yellow Wagtail	*Motacilla flava*	1	1
Total		**48**	**152**

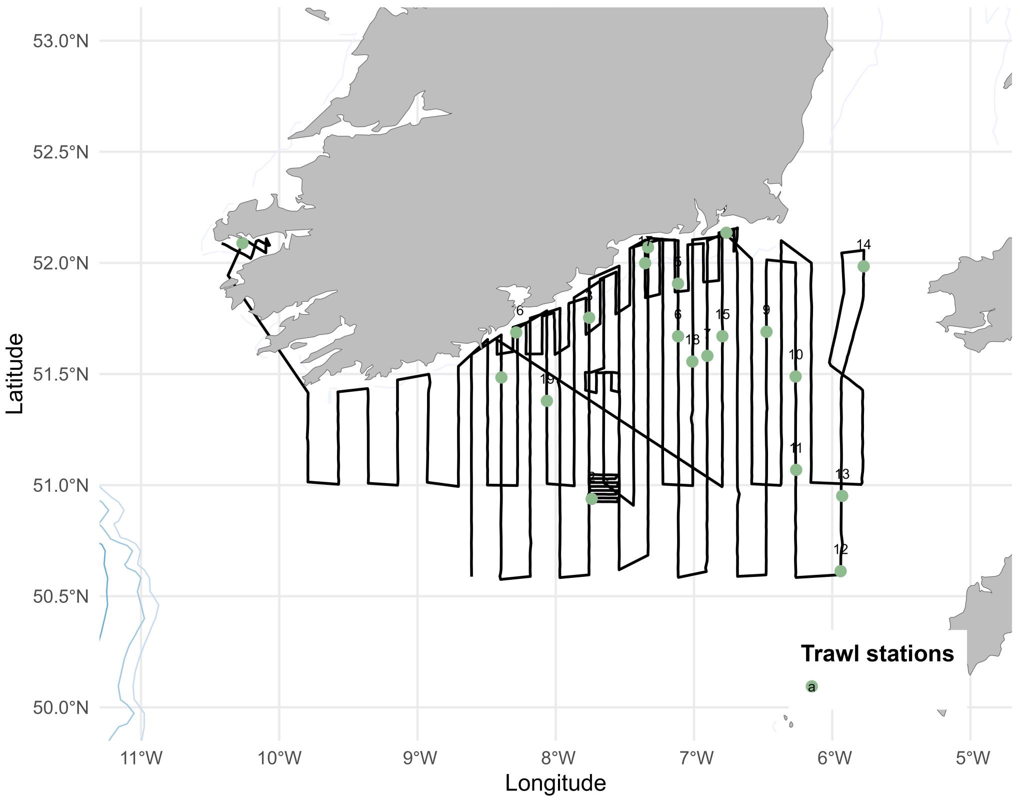


Figure 1. Cruise track effort (Core and Adaptive) and numbered trawl stations.

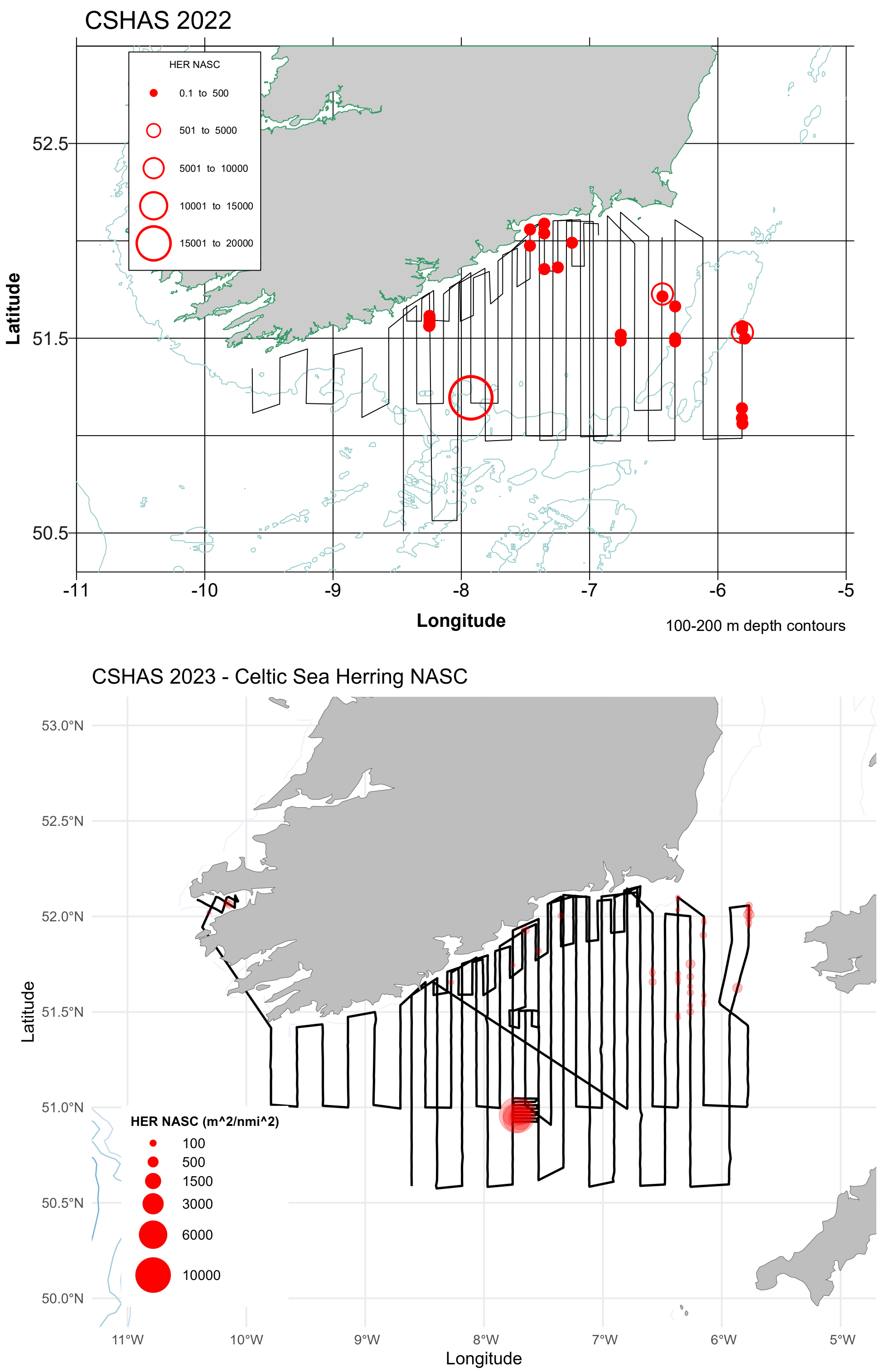


Figure 2. Herring NASC (Nautical area scattering coefficient) plot of herring distribution 2022 and 2023 from combined survey effort.

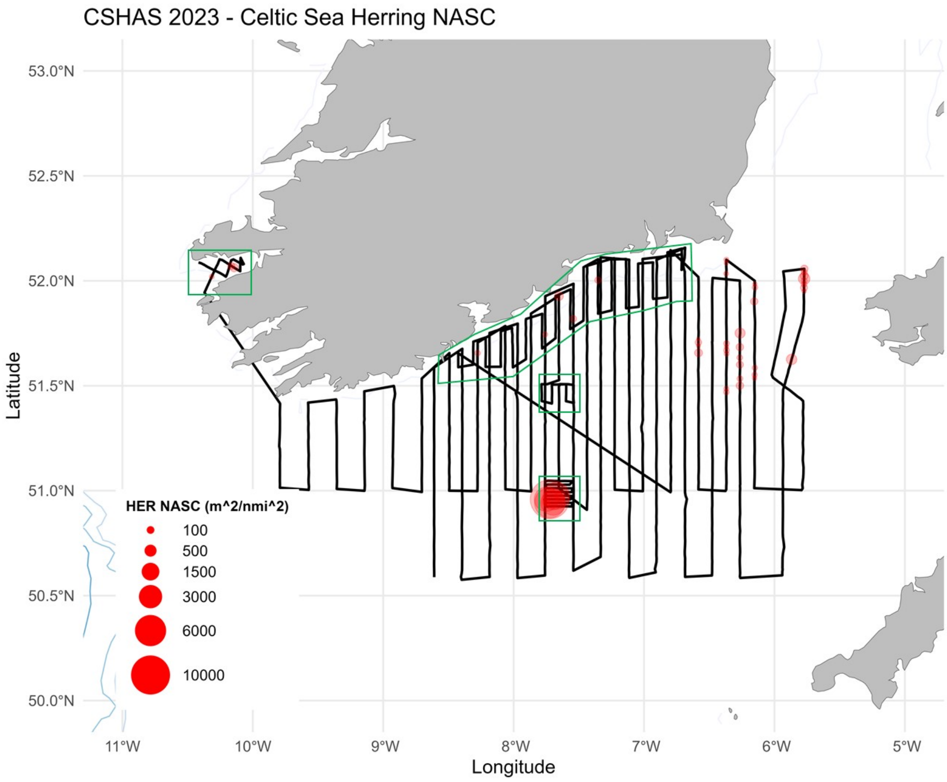


Figure 3. Herring NASC (Nautical area scattering coefficient) plot of the distribution from adaptive survey effort (green boxes).

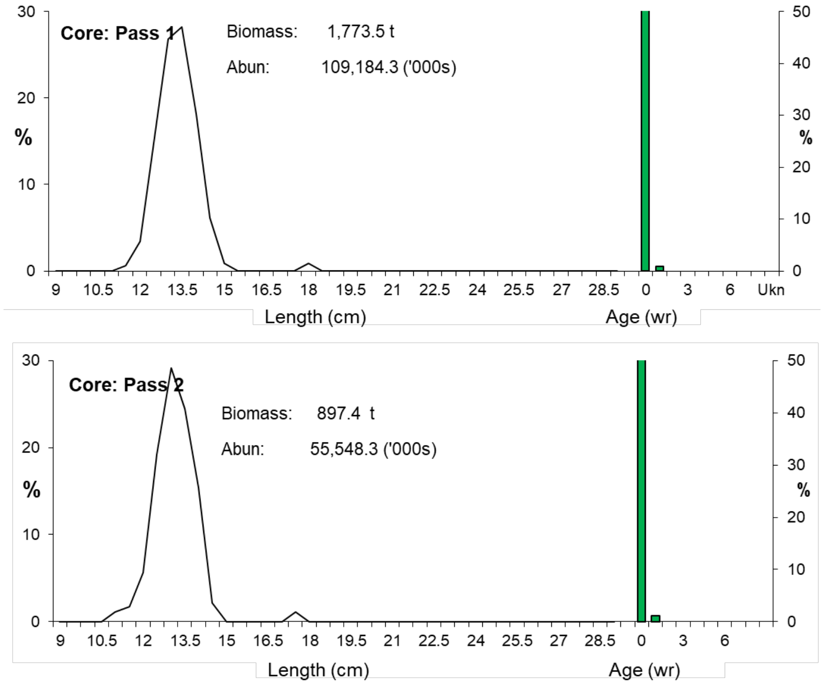


Figure 4. Age and length composition of herring from core survey strata in 2023.

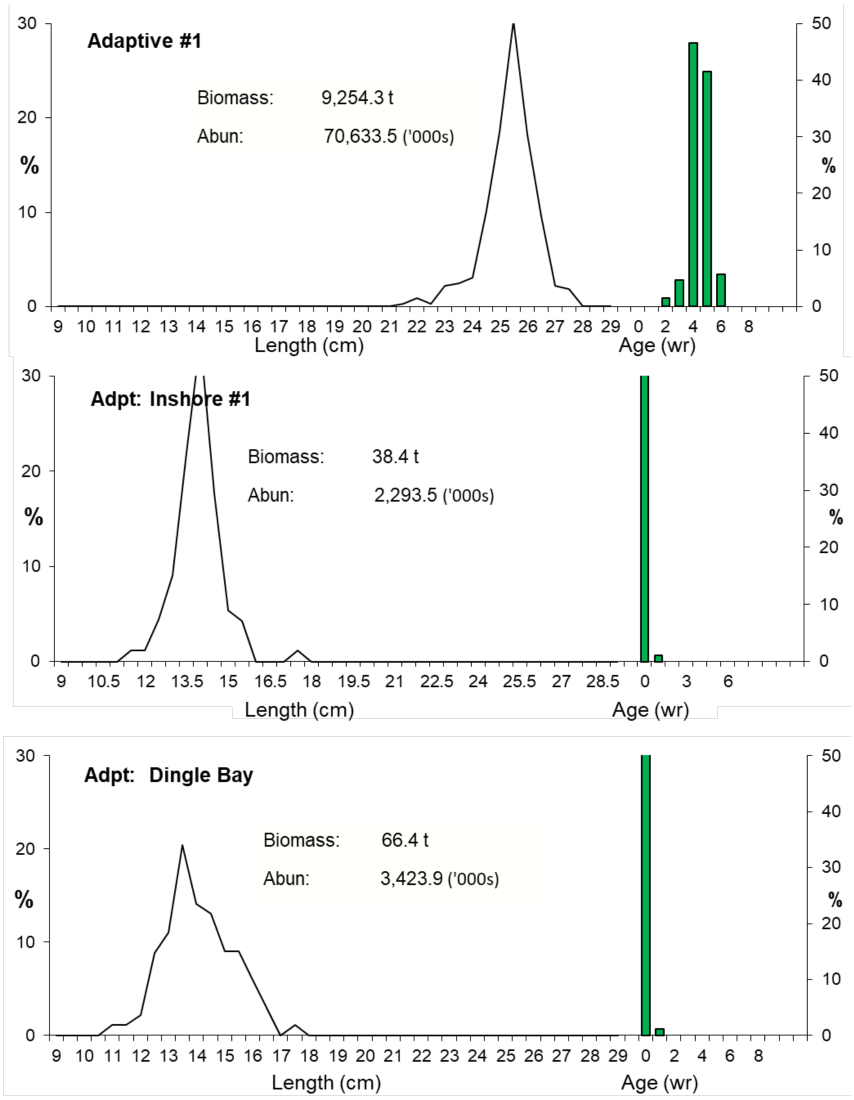


Figure 5. Age and length composition of herring from adaptive survey strata in 2023.

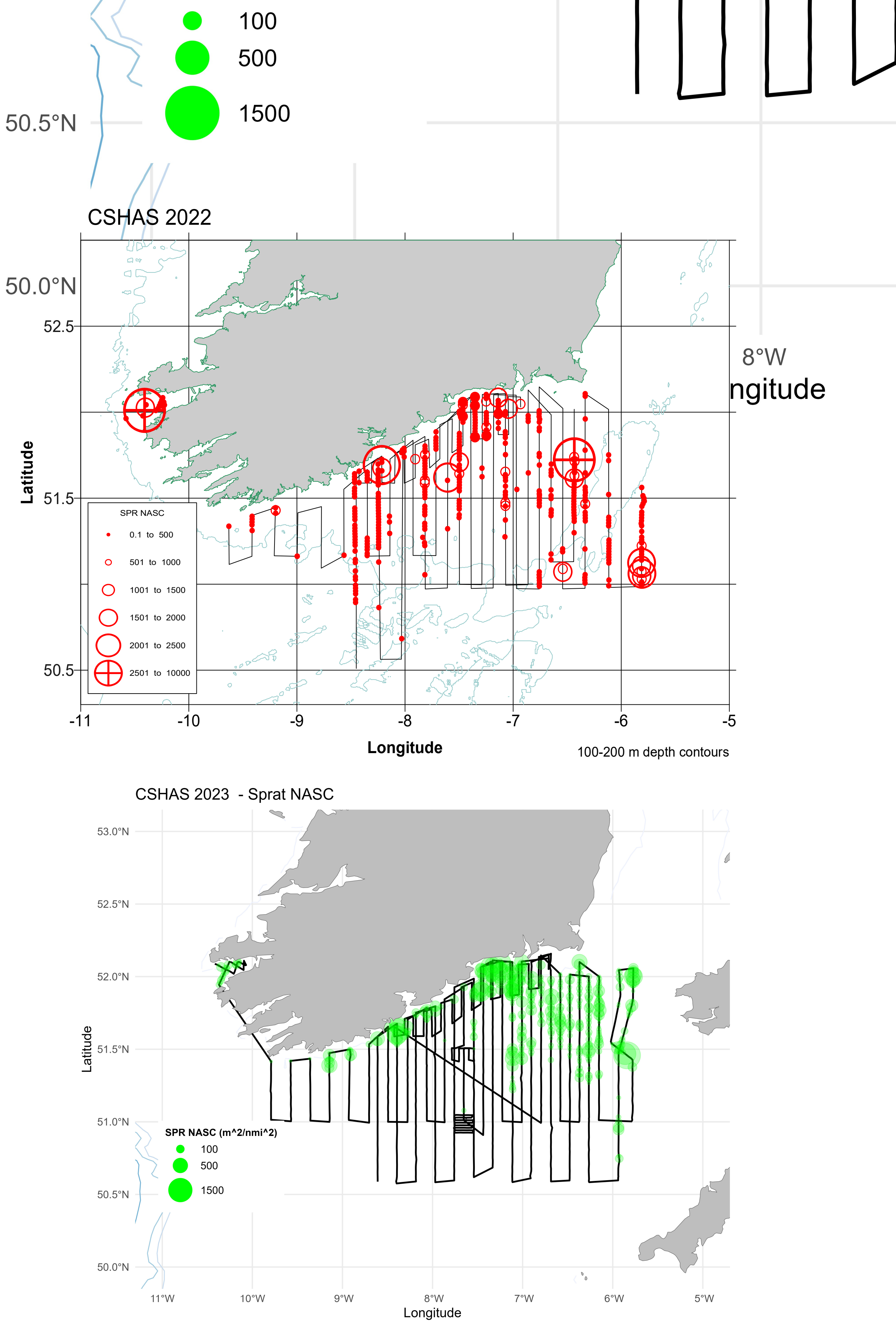


Figure 6. Sprat NASC (Nautical area scattering coefficient) plot of the distribution from combined survey effort, top 2022, bottom 2023.

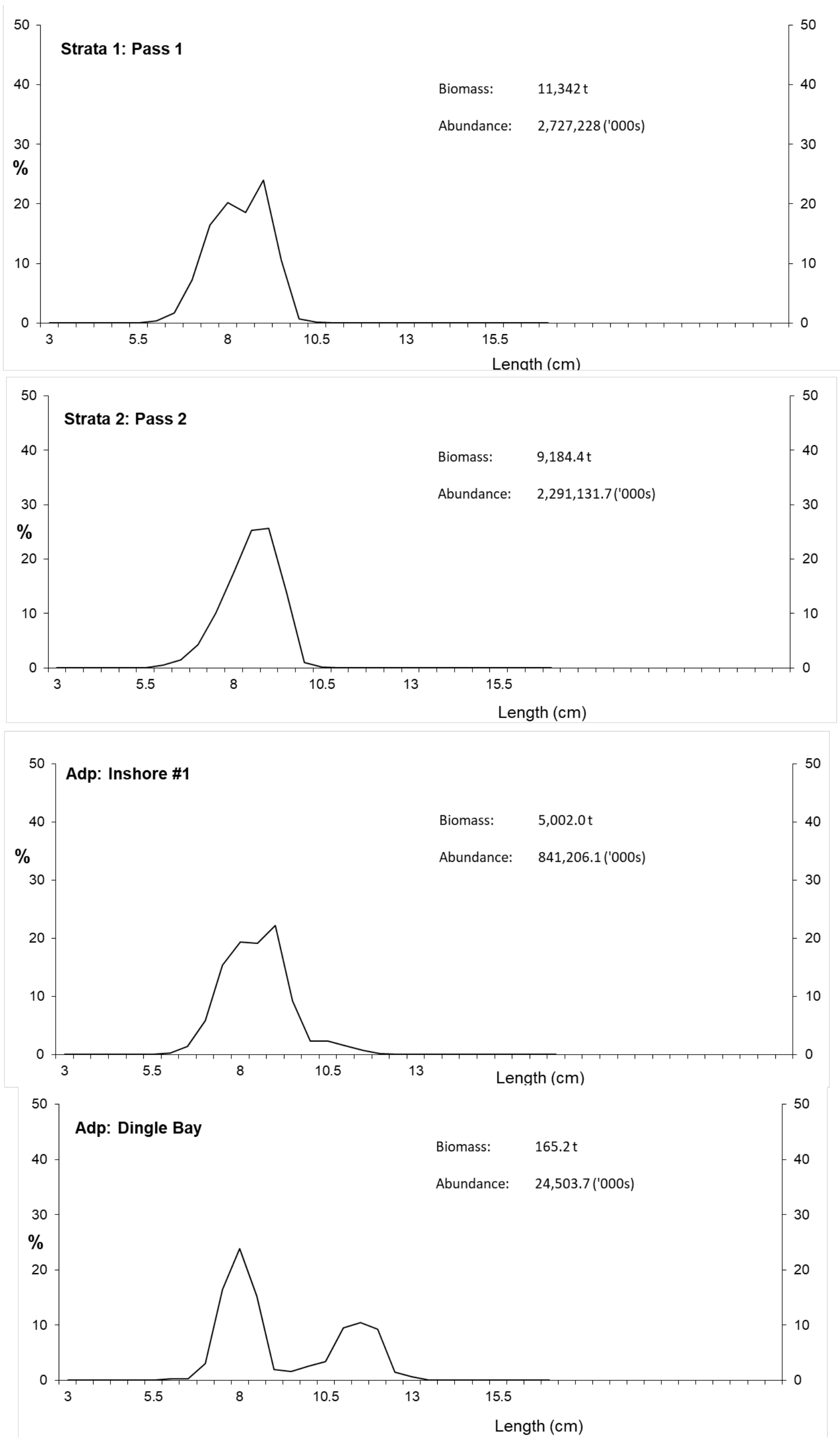


Figure 7. Length composition of sprat by strata and combined survey effort in 2023.

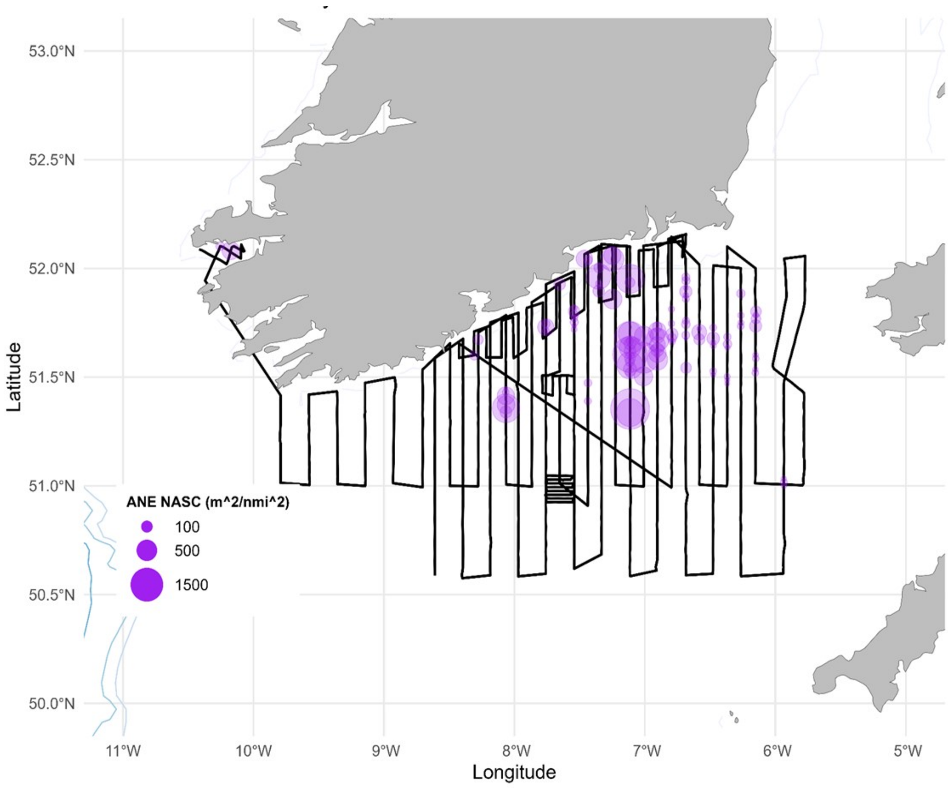


Figure 8. Anchovy NASC (Nautical area scattering coefficient) plot of the distribution from combined survey 2023.

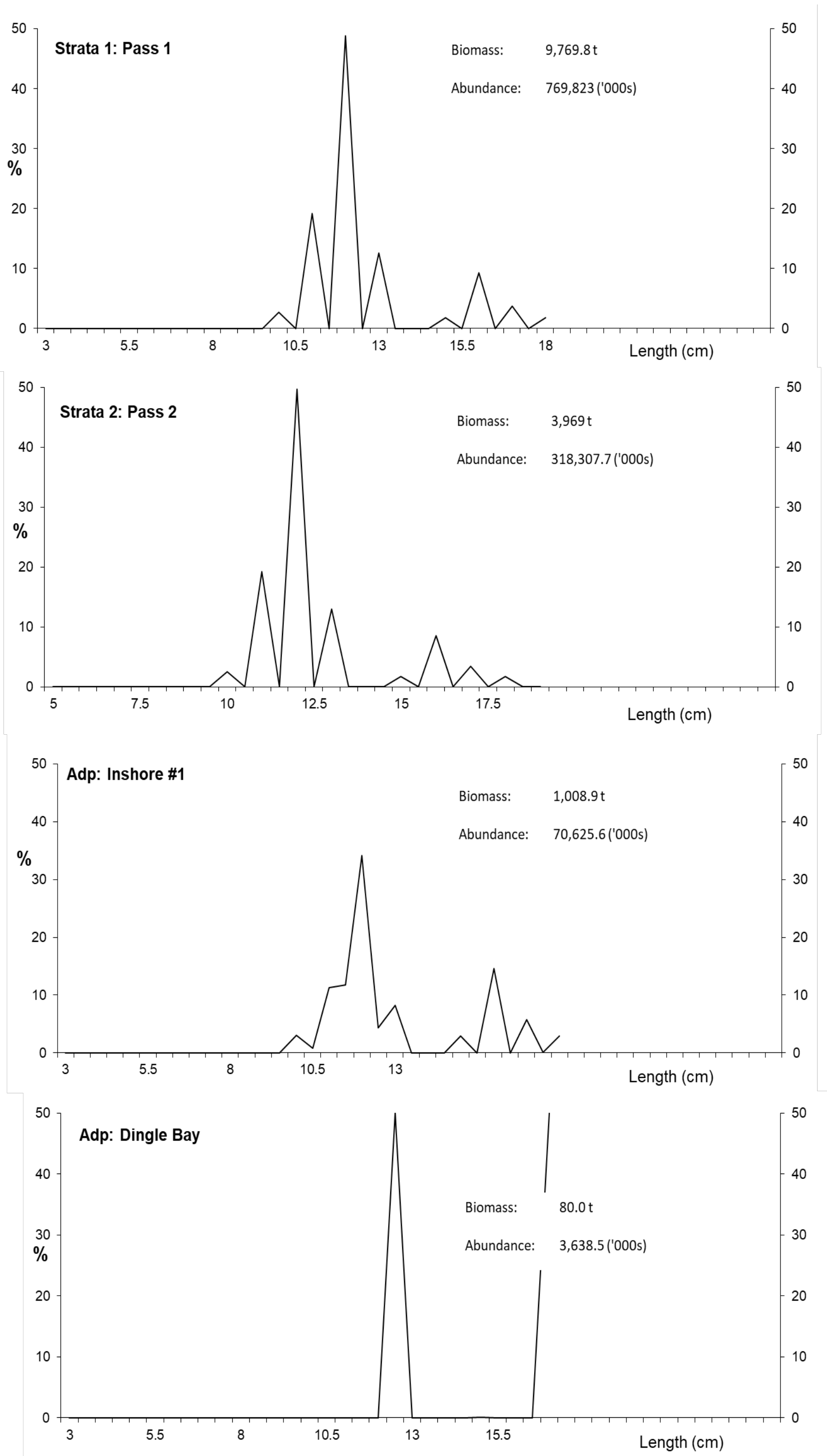


Figure 9. Length composition of anchovy by strata 2023.

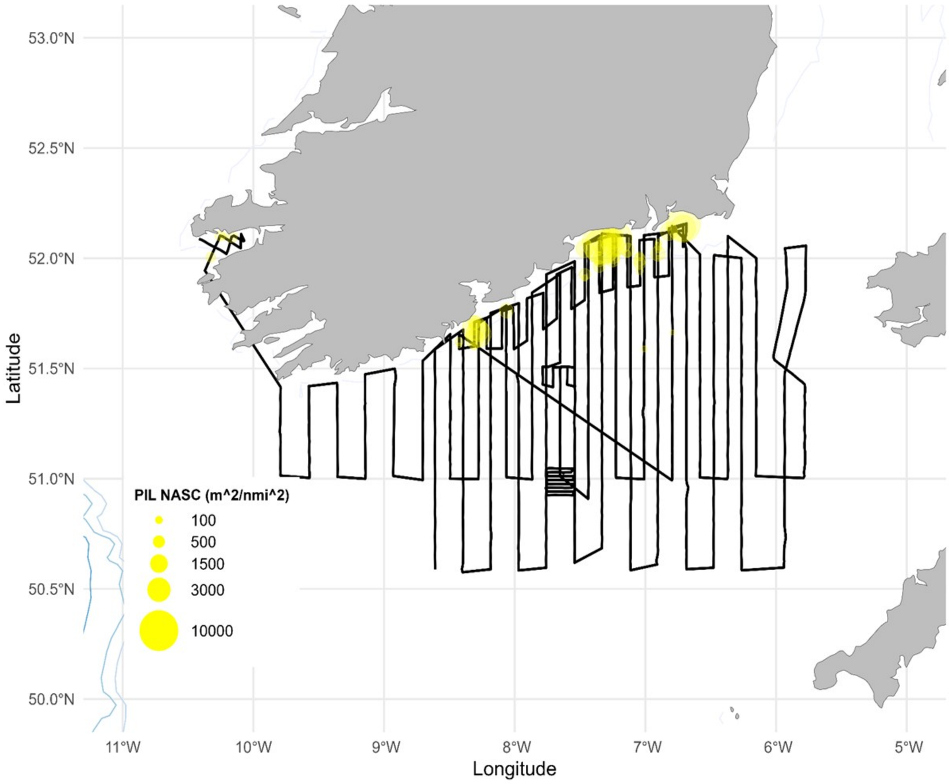


Figure 10. Sardine NASC (Nautical area scattering coefficient) plot of the distribution from combined survey 2023.

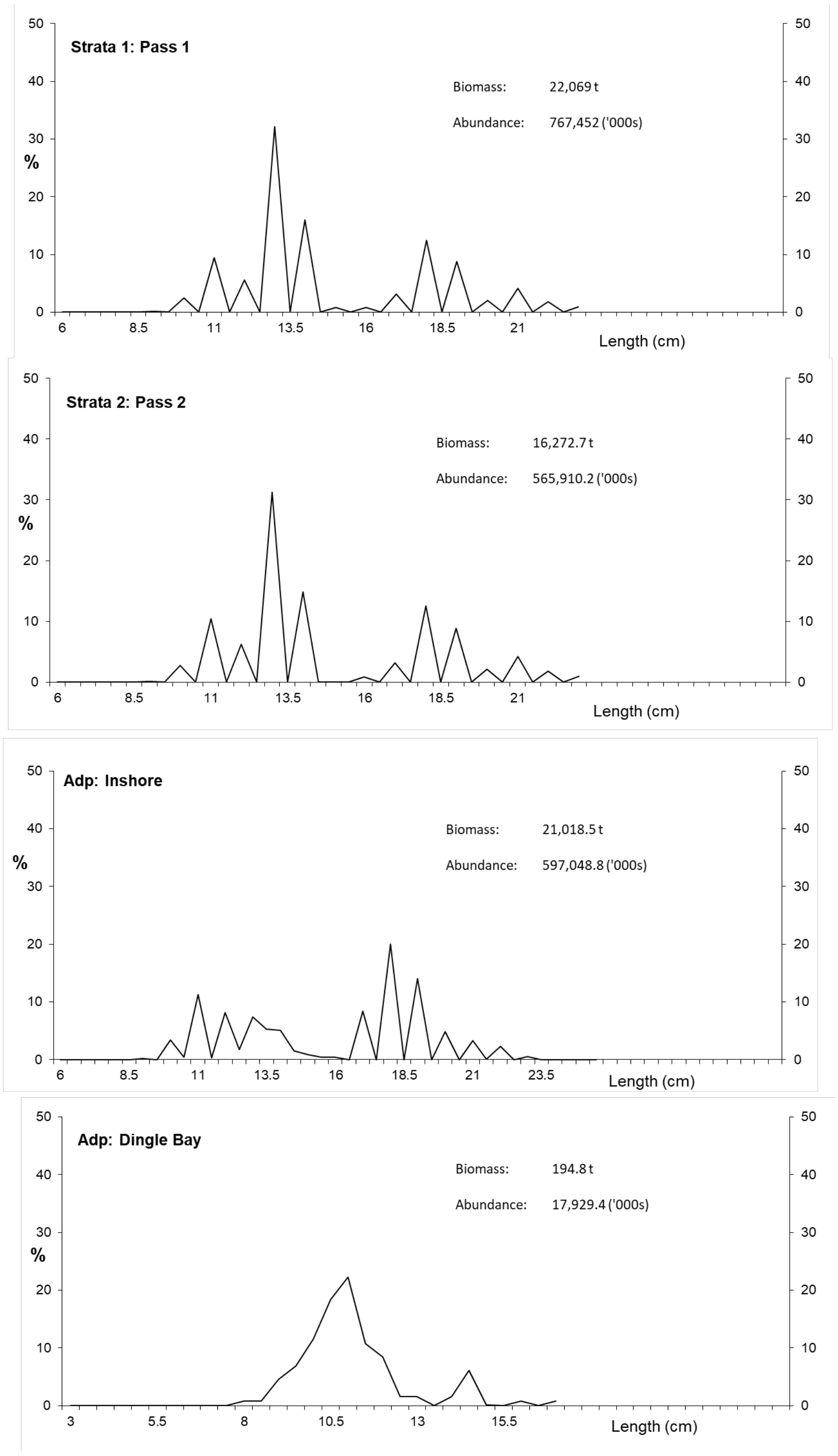
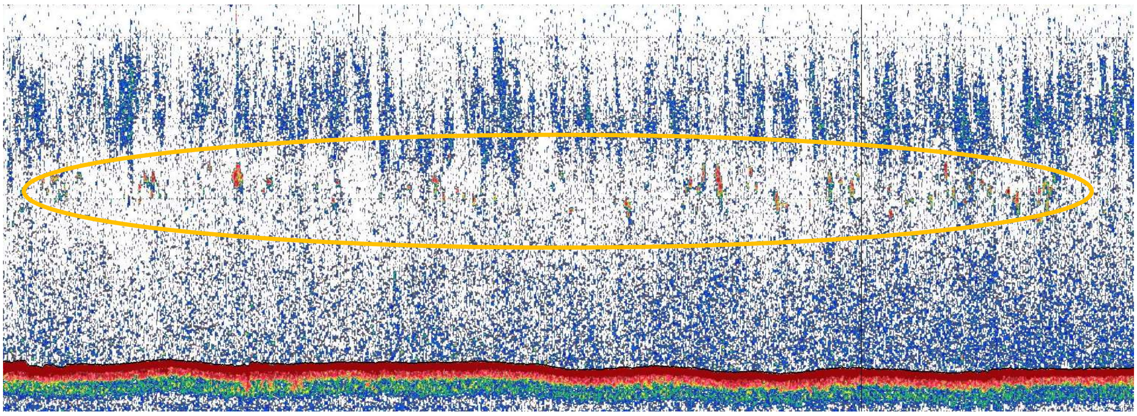
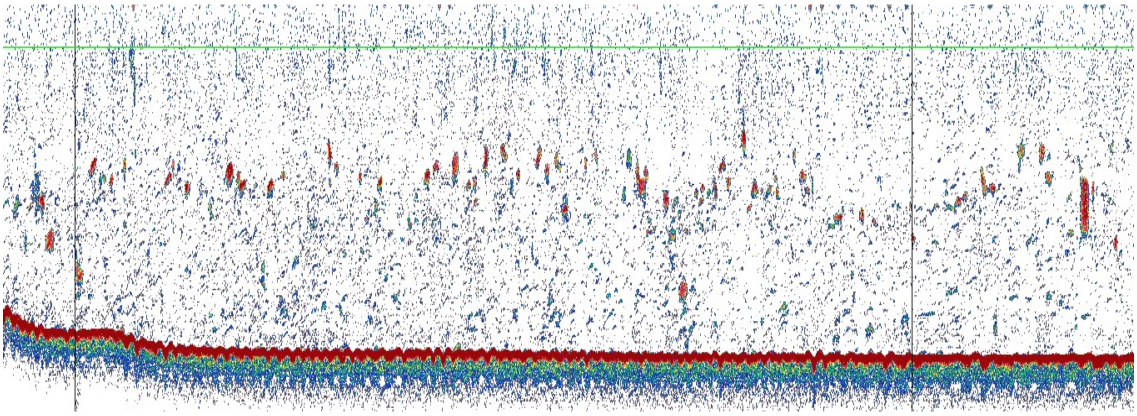


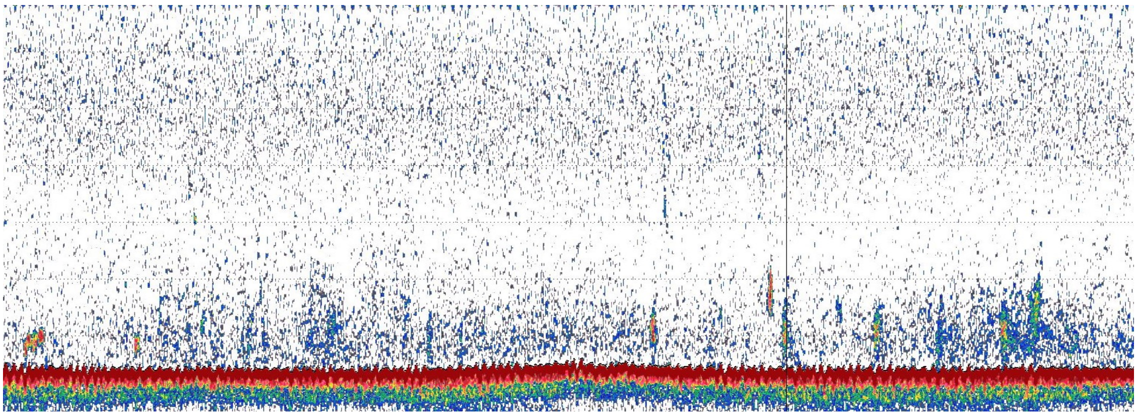
Figure 11. Length composition of sardine by strata 2023.



a). *Low density mixed species echotraces composed primarily of sprat (90%) and some immature herring (1.5%). Recorded in daylight hours prior to Haul 14. Water depth 102 m*

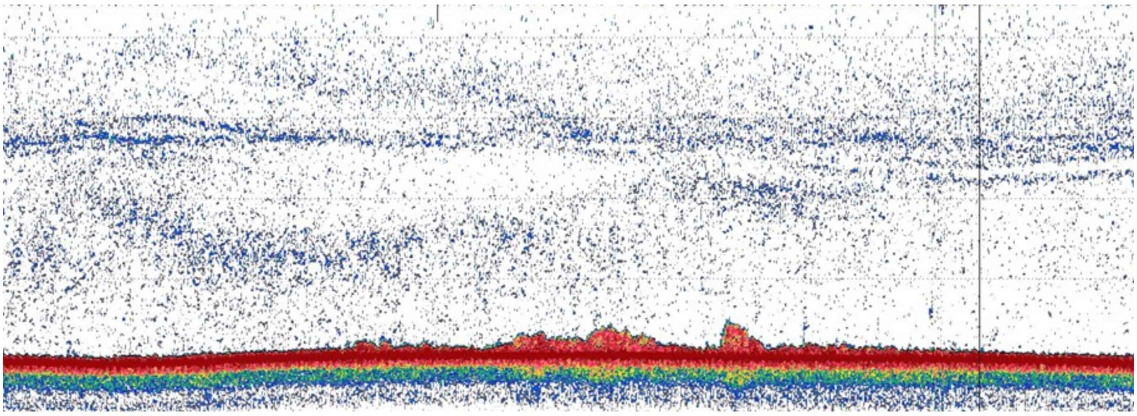


b). *Medium density mixed species echotrace containing herring (0.2%), sprat (54%), sardine (6%) and anchovy (23%). Observed during daylight hours, located inshore prior Haul 17. Water depth 55 m.*

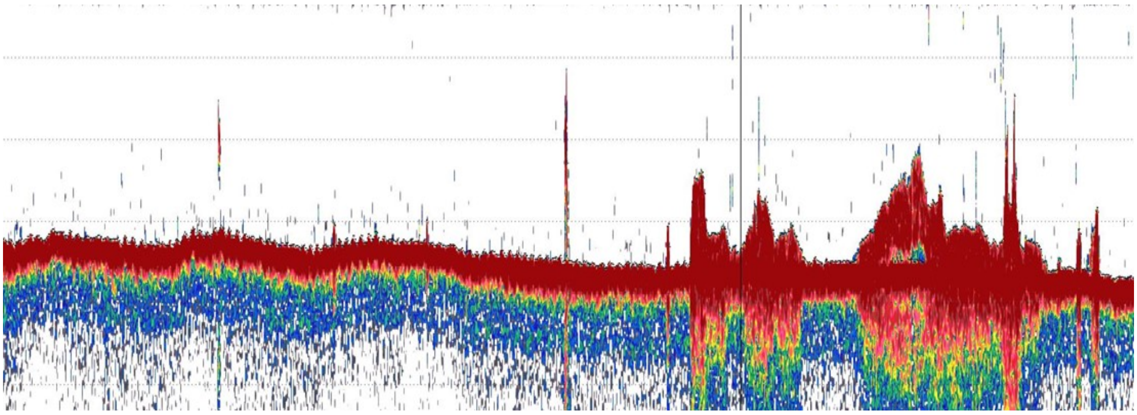


c). *Evening offshore scattering layer containing immature herring (1%) and sprat (80%). Recorded prior to Haul 15. Water depth 76 m.*

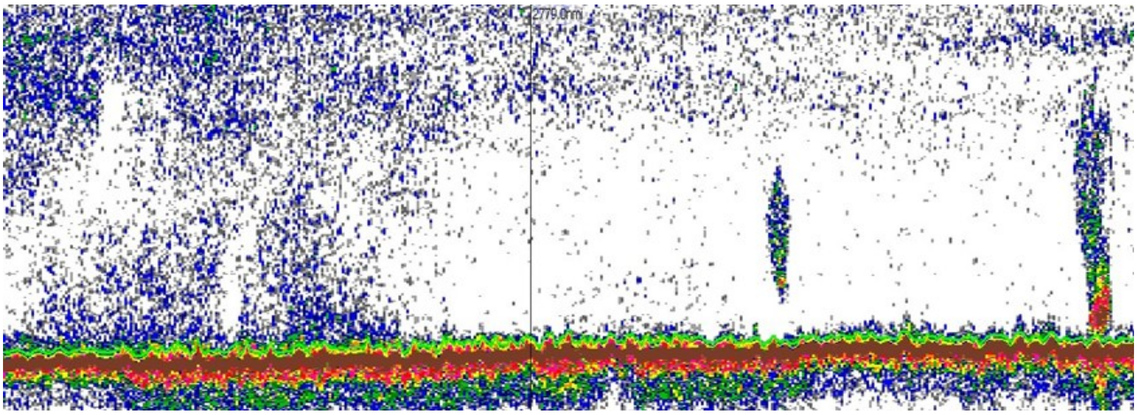
Figure 12. EK60 echograms (38 kHz) recorded prior to directed trawl stations.



d). *High density herring echotrace recorded during the offshore adaptive survey prior to trawl sampling (Haul 02). Water depth 100 m.*



e). *High density sardine (95%) echotrace recorded prior to trawl sampling (Haul 08) during the inshore adaptive survey. Water depth 28 m.*



f). *High density offshore anchovy echotraces recorded during Pass 2 and prior to Haul 19. Water depth is 94 m.*

Figure 12a-f. Continued

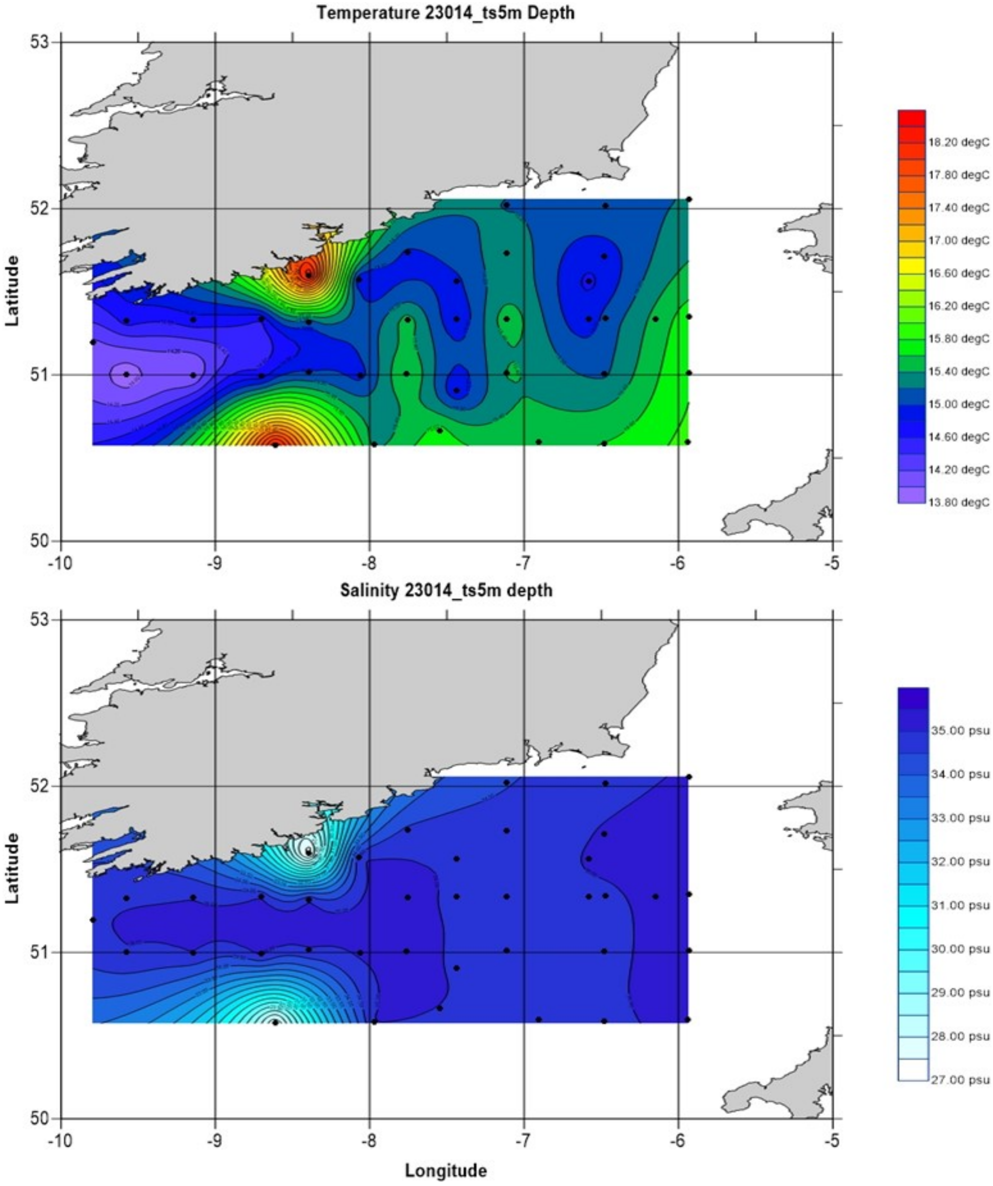


Figure 13. Surface (5 m) plots of temperature and salinity compiled from CTD cast data. Station positions shown as black circles (n=38).

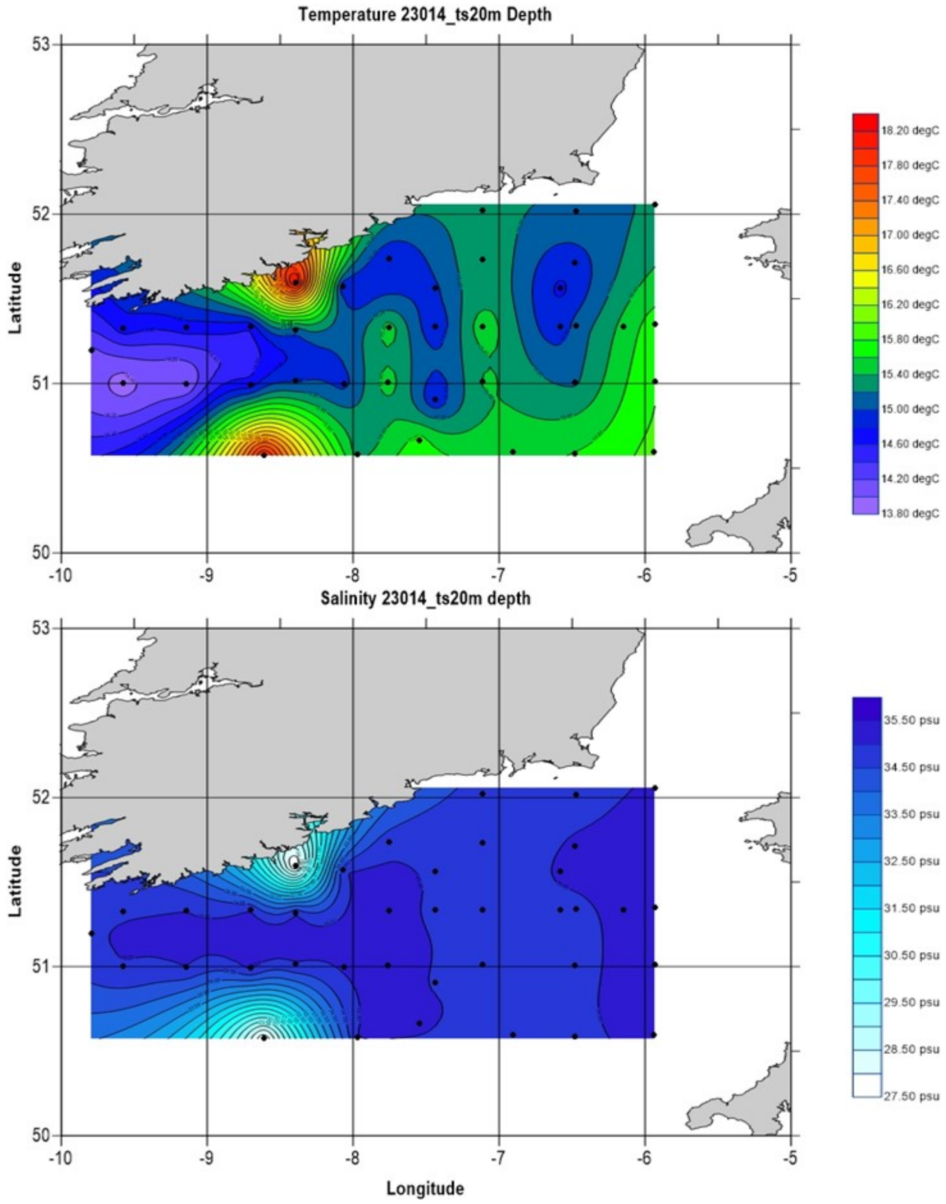


Figure 14. Surface (20 m) plots of temperature and salinity compiled from CTD cast data. Station positions shown as black circles (n=38).

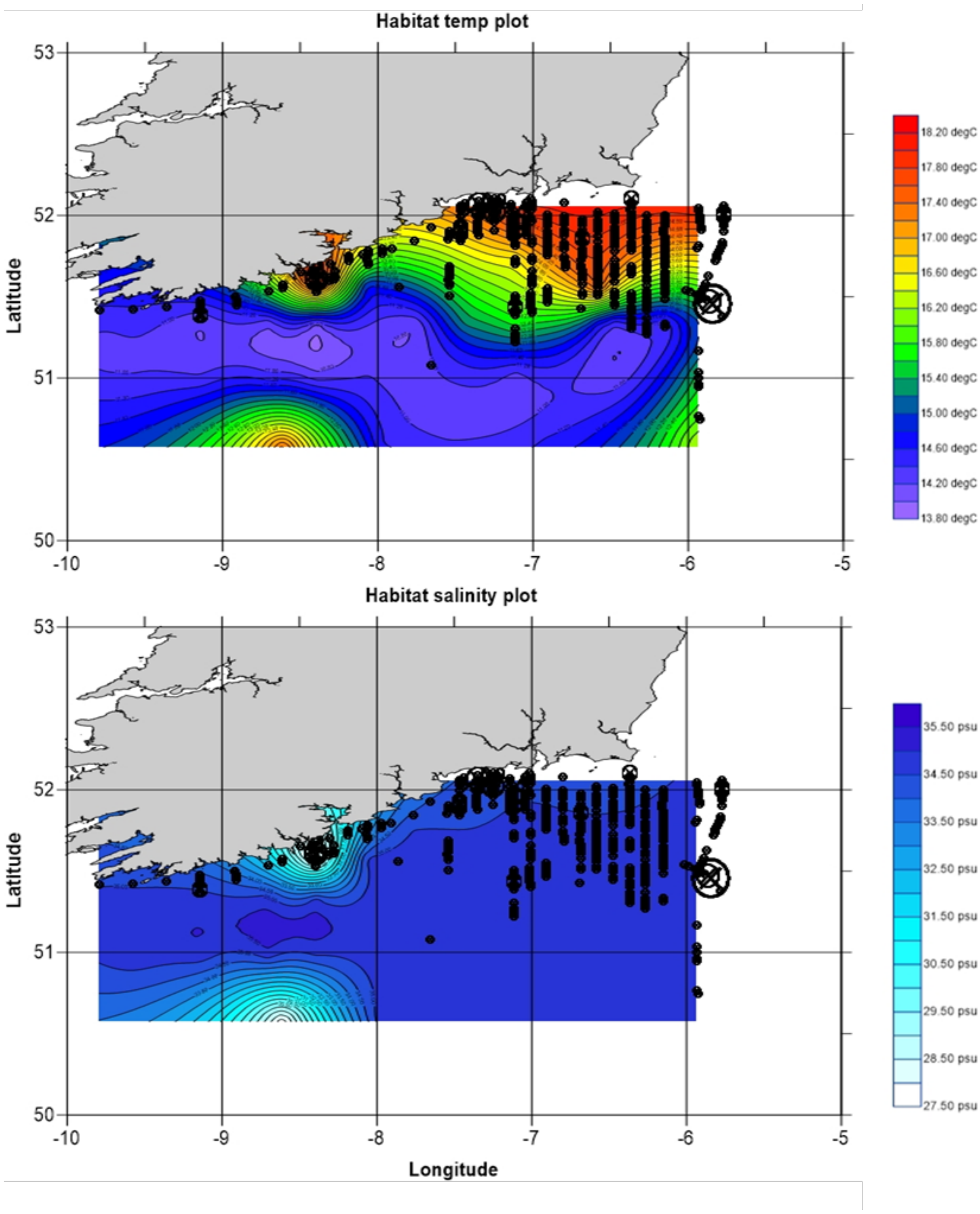


Figure 15. Habitat plots of temperature and salinity at the seabed overlaid with sprat NASC values (black circles).

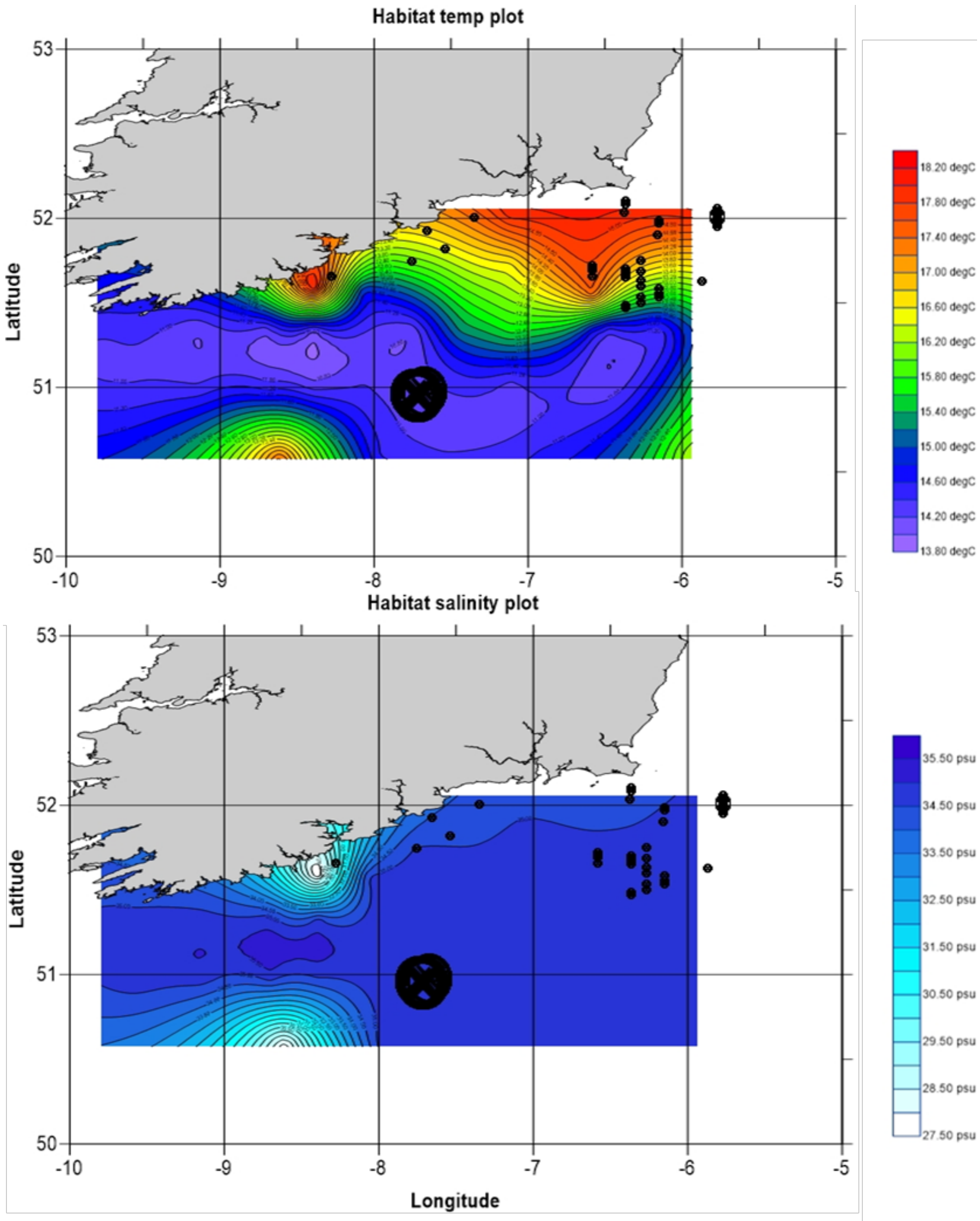
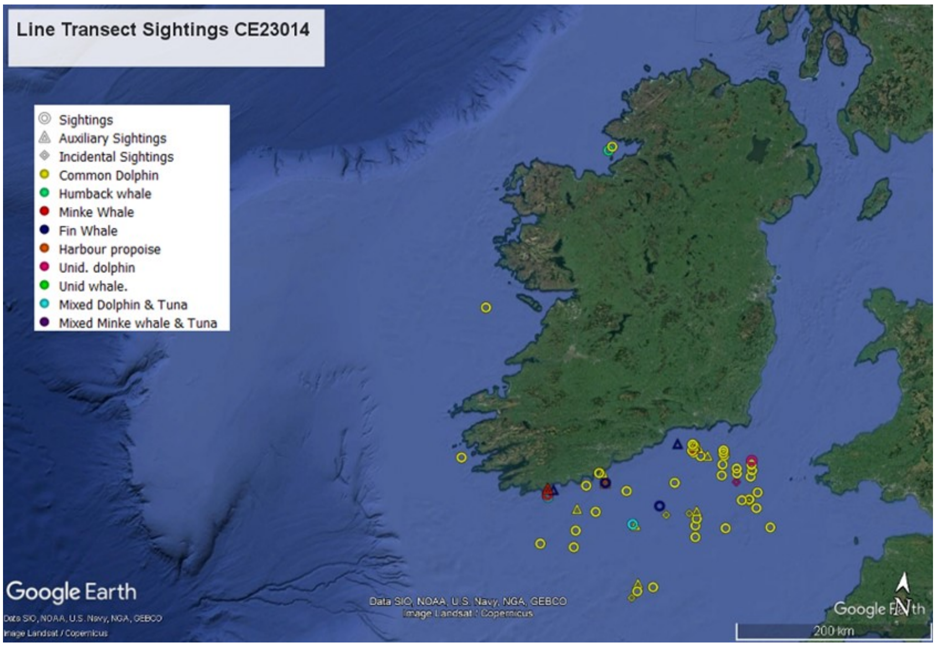


Figure 16. Habitat plots of temperature and salinity at the seabed overlaid with herring NASC values (acoustic density) shown as black circles.



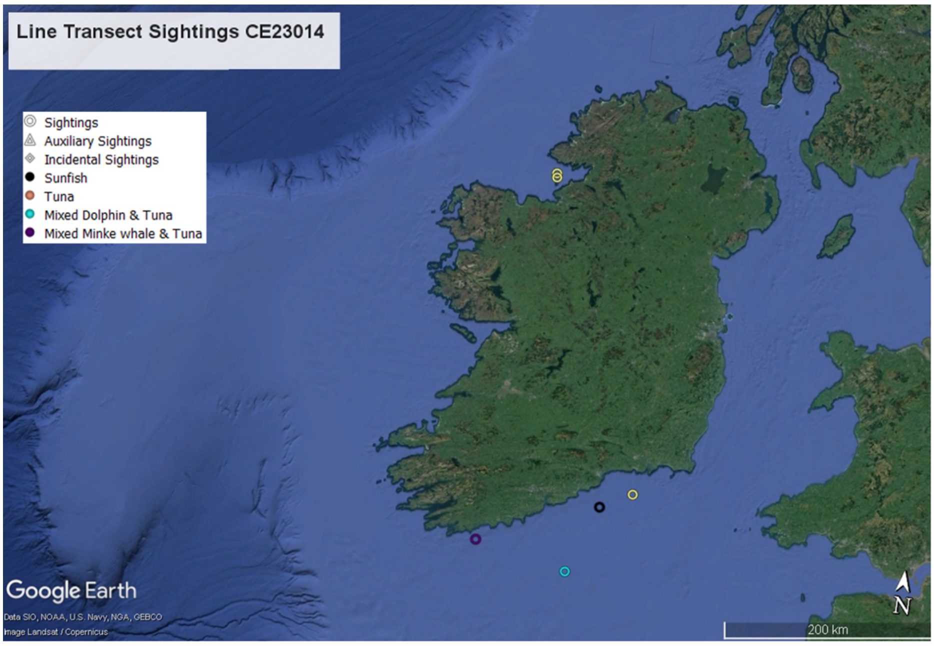


Figure 17. Distribution of sightings during the line transect survey. Top panel: marine mammals, bottom panel: marine megafauna.

HERRING MIDWATER TRAWL

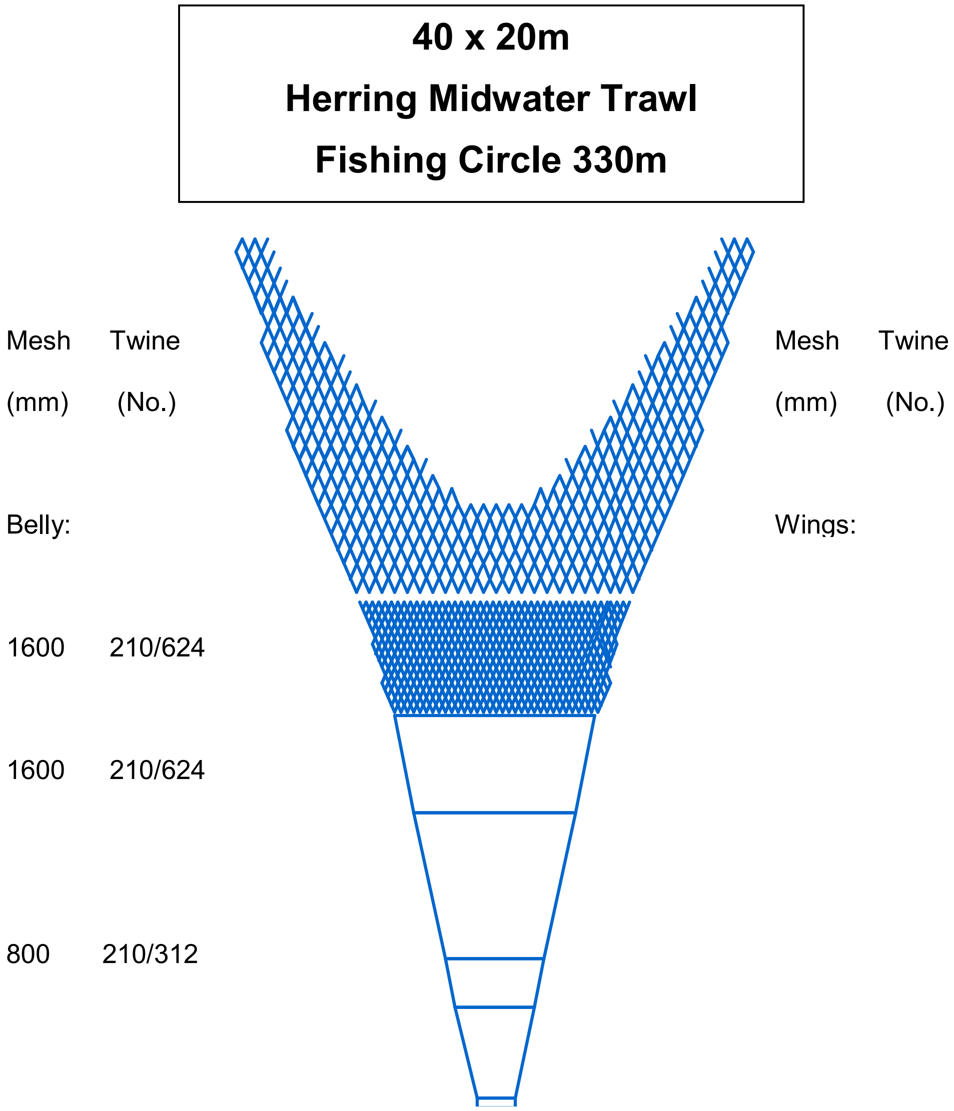


Figure 18. Single herring midwater trawl net plan and layout. Celtic Sea herring acoustic survey.

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

8 Appendix

Length	Age (years) 0	1	2	3	4	5	6	7	8	Ukn	Numbers (*10^{-3})	Biomass (t)
9												
9.5												
10												
10.5												
11												
11.5	706.0										706.0	7.5
12	3765.1										3765.1	49.4
12.5	16177.8										16177.8	223.6
13	29296.5										29296.5	426.6
13.5	30813.8										30813.8	517.6
14	19813.0										19813.0	350.3
14.5	6753.3										6753.3	135.3
15	929.5										929.5	20.4
15.5												
16												
16.5												
17												
17.5												
18		929.5									929.5	42.8
18.5												
19												
19.5												
20												
20.5												
21												
21.5												
22												
22.5												
23												
23.5												
24												
24.5												
25												
25.5												
26												
26.5												
27												
27.5												
28												
28.5												
29												
TSN (*10^{-3})	108,254.8	929.5									109,184.3	
TSB (t)	1,730.7	42.8										1,773.4

Figure 1. Biomass and abundance at length and age for Core survey: Pass 1.

	Age (years)										Numbers	Biomass
Length	0	1	2	3	4	5	6	7	8	Ukn	(*10-³)	(t)
9												
9.5												
10												
10.5												
11	604.9										604.9	6.0
11.5	963.3										963.3	9.9
12	3121.3										3121.3	38.1
12.5	10693.0										10693.0	146.3
13	16203.7										16203.7	236.1
13.5	13597.8										13597.8	269.3
14	8557.4										8557.4	147.9
14.5	1202.2										1202.2	24.4
15												
15.5												
16												
16.5												
17												
17.5		604.85									604.9	19.4
18												
18.5												
19												
19.5												
20												
20.5												
21												
21.5												
22												
22.5												
23												
23.5												
24												
24.5												
25												
25.5												
26												
26.5												
27												
27.5												
28												
28.5												
29												
TSN (*10-³)	54,943.5	604.9									55,548.3	
TSB (t)	878.0	19.4										897.4

Figure 2. Biomass and abundance at length and age for Core survey: Pass 2.

	Age (years)										Numbers	Biomass
Length	0	1	2	3	4	5	6	7	8	Ukn	(*106)	(t)
9												
9.5												
10												
10.5												
11												
11.5	25.9										25.9	0.3
12	25.9										25.9	0.3
12.5	100.7										100.7	1.0
13	207.2										207.2	2.6
13.5	503.6										503.6	7.0
14	777.0										777.0	15.2
14.5	405.7										405.7	6.9
15	123.7										123.7	2.2
15.5	97.9										97.9	2.1
16												
16.5												
17												
17.5		25.9									25.9	
18												
18.5												
19												
19.5												
20												
20.5												
21												
21.5												
22												
22.5												
23												
23.5												
24												
24.5												
25												
25.5												
26												
26.5												
27												
27.5												
28												
28.5												
29												
TSN (*10^3)	2267.6	25.9									2293.5	
TSB (t)	37.5	0.8										38.4

Figure 3. Biomass and abundance at length and age for Adaptive survey: Inshore #1.

	Age (years)										Numbers	Biomass
Length	0	1	2	3	4	5	6	7	8	Ukn	(*10^{-6})	(t)
9												
9.5												
10												
10.5												
11												
11.5												
12												
12.5												
13												
13.5												
14												
14.5												
15												
15.5												
16												
16.5												
17												
17.5												
18												
18.5												
19												
19.5												
20												
20.5												
21												
21.5			218.0								218.0	0
22			654.0								654.0	51.7
22.5			218.0								218.0	19.6
23				1526.0							1526.0	148.2
23.5				1744.0							1744.0	193.4
24					2180.0						2180.0	253.3
24.5					6671.7	522.5					7194.2	899.4
25					10114.7	2965.6					13080.3	1642.0
25.5					7889.6	13474.9					21364.4	2807.3
26					6055.5	6806.8					12862.3	1803.5
26.5						4661.4	2096.8				6758.1	1014.6
27							1526.0				1526.0	225.9
27.5						891.1	416.9				1308.0	195.5
28												
28.5												
29												
TSN (*10^{-3})			1090.0	3270.1	32911.4	29322.3	4039.7				70633.5	
TSB (t)			71.3	341.6	4243.9	3991.5	606.0					9254.3

Figure 4. Biomass and abundance at length and age for Adaptive survey: Offshore.

	Age (years)										Numbers	Biomass
Length	0	1	2	3	4	5	6	7	8	Ukn	(*10-^{6})	(t)
9												
9.5												
10												
10.5												
11	37.9										37.9	0.4
11.5	37.9										37.9	0.4
12	75.9										75.9	0.8
12.5	303.4										303.4	3.9
13	379.3										379.3	5.3
13.5	698.2										698.2	14.9
14	481.9										481.9	8.1
14.5	448.2										448.2	8.6
15	307.7										307.7	6.4
15.5	307.7										307.7	7.6
16	205.2										205.2	5.7
16.5	102.6										102.6	3.1
17												
17.5		37.9									37.9	1.2
18												
18.5												
19												
19.5												
20												
20.5												
21												
21.5												
22												
22.5												
23												
23.5												
24												
24.5												
25												
25.5												
26												
26.5												
27												
27.5												
28												
28.5												
29												
TSN (*10-^{3})	3386	37.9									3423.9	
TSB (t)												66.4

Figure 5. Biomass and abundance at length and age for Adaptive survey: Dingle Bay.