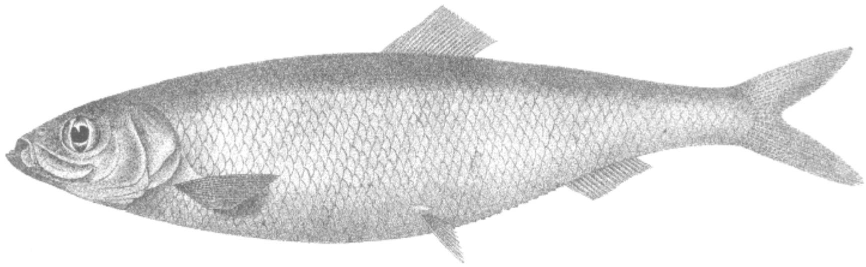
FSS Survey Series: 2016/04

Celtic Sea Herring Acoustic Survey Cruise Report 2016

07 - 27 October, 2016



Ciaran O'Donnell[1], Mairead Sullivan[1], Kieran Lyons[2], Niall Keogh[3] and Meadhbh Quinn[4]

[1]The Marine Institute, Fisheries Ecosystems Advisory Science Services,

Rinville, Oranmore, Co. Galway.

[2]The Marine Institute, Ocean Science Services

[3] BirdWatch Ireland

[4] Irish Whale and Dolphin Group (IWDG)

Cláir Chistí Eorpacha Struchtúrtha agus Infheistíochta na hÉireann 2014–2020
Cómhaoinithe ag Rialtas na hÉireann agus ag an Aontas Eorpach

Department of Agriculture, Food and the Marine
An Roinn Talmhaíochta, Bia agus Mara

EUROPEAN MARITIME AND FISHERIES FUND

Table of Contents

1 Introduction

In the southwest of Ireland and the Celtic Sea (ICES Divisions VIIaS, g & 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. 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 January, 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 investigated recently. 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. For the purpose of stock assessment and management divisions VIIaS, VIIg and VIIj have been combined since 1982.

For a period in the 1970s and1980s, 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.*

The geographical confines of the annual 21 day survey have been modified in recent years to include areas to the south of the main winter spawning grounds in an effort to identify the whereabouts of winter spawning fish before the annual inshore spawning migration. Spatial resolution of acoustic transects has been increased over the entire south coast survey area. The acoustic component of the survey has been further complemented since 2004 by detailed hydrographic, marine mammal and seabird surveys.

2 Materials and Methods

2.1 Scientific Personnel

Organisation	Name	Capacity	Leg
FEAS	Ciaran O'Donnell	Aco (SIC)	All
FEAS	Graham Johnston	Aco	All
FEAS	Mike O'Malley	Aco	All
FEAS	Eugene Mullins	Aco	1
FEAS	Turloch Smith	Aco	2
FEAS	Grainne Ni Chonchuir	Bio	All
FEAS	Grainne Ryan	Bio	All
FEAS	John Enright	Bio	1
FEAS	Mairead Sullivan	Bio	2
Contractor	Usna Keating	Bio	All
BWI	Niall Keogh	SBO	All
BWI	Stephanie Levesque	SBO	2
BWI	Gary Kett	MMO	All
IWDG	Meadhbh Quin	MMO	All
CSMAC	John O'Regan	Ind. Obs	All

*SBO- Seabird observer, MMO- marine mammal observer

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
- Investigate high abundance herring aggregations using adaptive survey techniques. Use the EM 2040 Bathymetric multibeam to map the extent of herring aggregations during adaptive surveys
- Collect biological samples from directed trawling on insonified fish echotraces to determine age structure and maturity state of the herring stock
- Determine an age stratified estimate of relative abundance of herring within the survey area (ICES Divisions VIIj, VIIg and VIIaS)
- Determine estimates of biomass and abundance for sprat within the survey area
- Collect physical oceanography data from vertical profiles from a deployed sensor array
- Survey by visual observations marine mammal, surface litter and seabird abundance and distribution

2.2.2 Area of operation

The autumn 2016 survey covered the area from Mizen Head in ICES Division VIIb (Figure 1) in Co. Cork and extended along the south coast into the Celtic Sea (Divisions VIIj , VIIg & VIIaS). The survey began in the south coast and worked in an easterly direction covering the large survey area during the first pass before turning westwards to complete the second pass using interlaced transects.

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

2.2.3 Survey design

2.2.3.1 Core survey

A change in survey design was implemented in 2016 by consolidating all existing strata into a single core survey stratum with uniform transect spacing of 8 nmi (nautical miles). This broad scale survey composed of 8 nmi spaced transects and progressed from west to east (Pass 1). A second pass was then carried from east to west (Pass 2). Survey transects for each pass were set at 8 nmi and offset resulting in a transect interlacing and an effective coverage of the grounds at a 4 nmi resolution.

A parallel transect design was used 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 3,092 nmi of transects covering an area of over 10,000 nmi^2.

2.2.3.2 Adaptive survey

Adaptive surveys were carried out in high abundance areas identified during the core survey. Candidate areas were identified from positional data from fishing activities during the co-occurring offshore fishery.

Each candidate area was scouted to determine geographical extent of target aggregations. A survey plan was then designed with transects running perpendicular to the lines of bathymetry. Parallel transects were spaced at either 0.5 or 1 nmi depending on area size. The EK60 single beam and EM2040 multibeam systems were run in parallel to provide quantitative and spatial data respectively. 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.

Combined, the four adaptive surveys accounted for 587 nmi of transects covering an area of 312 nmi^2.

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 3.3m below the vessel's hull or 8.8m 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 (ICES 2002). During fishing operations normal two-engine operations were employed to provide sufficient power to tow the net.

For the EM2040 bathymetric multibeam a manual fixed angular coverage was used (65° opening angle) to standardise the volume of water sampled. Pulse type and ping rate were set to auto to optimise data acquisition and the sampling frequency was set at 300 kHz to minimise interference on the EK60. The ping rate on the EK60 was maintained at 3 pings per second while the EM2040 auto setting produced a ping rate of approximately 3.5 pings per second.

2.3.2 Calibration of acoustic equipment

A calibration of the EK60 was carried out in Dunmanus Bay on the 8th of October at the start of the survey and in daylight hours following methods described by Demer *et al.* (2015). Calibration results and settings are provided in Table 1.

2.4 Survey protocols

2.4.1 Acoustic data acquisition

Acoustic data were observed and recorded onto the hard-drive of the processing unit using the equipment settings from previous surveys. The "RAW files" were logged via a continuous Ethernet connection to the vessels server and the ER60 hard drive as a backup in the event of data loss. In addition, as a further back up a hard copy was stored on an external hard drive. Myriax Echoview® Echolog (Version 7) live viewer was used to display the echogram during data collection to allow the scientists to scroll through echograms noting the locations and depths of fish shoals. A member of the scientific crew monitored the equipment continually. Time and location (GPS position) data was recorded for each transect within each strata. This log was used to monitor the time spent off track during fishing operations and hydrographic stations plus any other important observations.

2.4.2 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

15). 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 9m, which was observed using a cable linked Simrad FS70 netsonde. The net was also fitted with a Scanmar depth sensor. Spread between the trawl doors was monitored using Scanmar distance sensors, all sensors being configured and viewed through a Scanmar Scanbas system.

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

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

2.4.3 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 an observer kept a daylight watch on marine mammals from the crow's nest (18 m above sea level) when weather allowed or from the bridge (11 m).

During cetacean observations, watch effort was focused on an area dead ahead of the vessel and 45^{o} to either side using a transect approach. Sightings in an area up to 90^{o} 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 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.

Two observers (a primary observer and a primary recorder, who also acted as a secondary observer), in rotation from a pool of three surveyors, were allocated to survey shifts of two hours, surveying from 08.00 (or first light) to 18.00 hours (dusk) each day. Environmental conditions, including wind force and direction, sea state, swell height, visibility and cloud cover, and the ship's speed and heading were recorded at 2-hourly intervals during surveys. In the intervening time, any changes to environmental conditions were also noted, so that a discreet set of environmental conditions was obtained for each 5-minute interval. No surveys were conducted in conditions greater than sea state 5, when high swell made working on deck unsafe or when visibility was reduced to less than 300 m.

The seabird observation platform was the wheelhouse deck, which is 10.5m above the waterline and provided a good view of the survey area. The survey area was defined as a 300m wide band operated on one side (in a 90° arc from bow to beam) and ahead of the ship. This survey band was sub-divided (A = 0-50 m from the ship, B = 50-100 m, C = 100-200 m, D = 200-300 m, E > 300 m) to subsequently allow correction of differences in detection probability with distance from the observer. A fixed-interval range finder (Heinemann 1981) was used to periodically check distance estimates. The area was scanned by eye, with binoculars used only to confirm species identification.

All birds seen on the water within the survey area were counted, and those recorded within the 300 m band, were noted as 'in transect'. All flying birds within the survey area were also noted, but only those recorded during a 'snapshot' were regarded as 'in transect'. This method avoids overestimating bird numbers in flight (Tasker *et al.* 1984). The frequency of the snapshot scan was ship-speed dependent, such that they were timed to occur at the moment the ship passed from one survey block (300 m x 300 m) to the next. Survey time intervals were set at 5 minutes. Additional bird species observed outside the survey area were also recorded and added to the species list for the research cruise, but these will not be included in maps of seabird abundance or density.

On acoustic survey transects the vessel had an average speed of 10 knots, while speed was reduced to 4 knots for trawling effort. Tows lasted around 45 minutes and were mostly separated by extended sessions of steaming at 10 knots, so that few birds were attracted to the ship. CTD stations were conducted on some transects, during which the vessel remained stationary for, on average, 18 minutes. Seabird surveying was interrupted while the ship was stationary at CTD stations and while towing since this can attract large numbers of birds. Where fish sampling operations were prolonged or at close intervals, seabird surveying was only recommenced after a period (45min – 1hr) of prolonged steaming at 10 knots, allowing the associating birds to disperse. Any bird recorded in the survey area that stayed with the ship for more than 2 minutes was regarded as being associated with the survey vessel (Camphuysen *et al.* 2004) and was coded as such (to be excluded from abundance and density calculations).

The daily total count data per day for each species is presented along with the daily survey effort. It is envisaged that this data will be analysed in the future and the seabird abundance (birds per km traveled), and seabird density (birds per km^2) will be mapped per 1⁄4 ICES rectangle (15' latitude x 30' longitude), allowing comparison to the results of previous seabird surveys in Irish waters (e.g. Hall *et al.* in press, Mackey *et al.* 2004, Pollock *et al.* 1997). Through further analysis, species-specific correction factors will be applied to birds observed on the water. It is also hoped to combine this analysis with the results of the cetacean observation and acoustic survey. The binomial species names for the birds recorded are presented in the species accounts.

All visible marine litter was also recorded during bird observations. The litter was identified or described as accurately as possible; quantity, size and distance from the boat was noted. When possible, pictures of the objects were taken.

2.5 Analysis methods

2.5.1 Echogram partitioning

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

The RAW files were imported into Echoview for post-processing. The echograms were divided into transects. Echotraces belonging to 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 mono-specific 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 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).

3 Results

3.1 Celtic Sea herring stock

3.1.1 Herring biomass and abundance

Herring biomass and abundance was calculated from core and adaptive survey to stratum level. For strata where replicate surveys were carried out biomass and abundance is presented by replicate and as geometric mean (Table 3).

Total herring biomass (TSB) and spawning stock biomass (SSB) by survey strata is provided in Table 3 with CV estimate based on abundance figures. A detailed breakdown per strata stratified by age is provided in Appendix 1.

3.1.2 Herring distribution

A total of 29 trawl hauls were carried out during the survey (Figure 1), with 7 hauls containing >50% herring by weight of catch (Table 2).

Core Surveys

Two core surveys were carried out; Pass 1 and Pass 2. Herring distribution was comparable for both surveys with aggregations located within 10 nmi of the coast and no offshore aggregations detected (Figure 2). Transect spacing for each replicate was set at 8 nmi and offset in relation to the previous so providing an effective transect coverage of 4 nmi overall. In terms of effort (acoustic sampling) 2016 was comparable to the previous year. As no aggregations were detected at the extended survey boundary in the south, east or west the stock was considered to be contained within the survey area.

Off track scouting was undertaken in the Trench area during the core surveys as aggregations were detected in this area in 2015. However, no herring were detected during two separate searches extending to approximately 30 nmi.

A total of 18 echotraces were identified as herring during core surveys Pass 1 (n=9) and also during Pass 2 (n=9). However, Pass 2 produced individual echotraces of higher individual density. Inshore aggregations identified during core surveys were found to be dominated by immature herring (Figure 4, Table 3).

Adaptive Surveys

Adaptive surveys focused on areas where high densities of herring had been recently reported during the co-occurring herring fishery. Two high abundance areas were identified and four adaptive surveys were carried out. Mini survey 1 yielded no herring. Mini survey 2 and 3 were carried out on the same area over a 48 hour period. A 1 nmi spacing was chosen to ensure containment of the entire aggregation (approximately 200 nmi2). Transect positioning of replicates were offset to provide an effective coverage of 0.5 nmi overall. A single mini survey (#4) was carried out on a discreet area (Table 3).

Surveys 2 and 3 yielded a comparable number of herring echotraces (n=35 and n=39 respectively) covering the largest offshore aggregation in replicate. Mature individuals dominated this stratum (Figure 5).

Mini survey 4, conducted on a small discreet area containing two herring echotraces and had an age composition dominated by immature fish, similar to aggregations observed inshore.

3.1.3 Herring stock composition

A total of 400 herring were aged from survey samples in addition to 2,384 length measurements and 792 length-weights. Herring age samples ranged from 0-9 winter-rings (Figures 4 & 5, Appendix 1).

Core survey

Age composition of Pass 1 was dominated by 1 winter ring fish representing 21.2% of the total stock biomass (TSB) and 38.6% of total stock numbers (TSN), followed by 5 winter ring (20.2% TSB and 14.8% TSN) and 4 winter ring (16.4% TSB and 12.9% TSN) herring respectively. Combined these age cohorts accounted for 57.9% of TSB and 65.9% of TSB. Immature fish accounted over 17% (65 t) of the 375 t estimate.

The age composition of Pass 2 was comparable with 1, 5 and 4 winter ring fish dominating. However, the contribution of 1 winter ring, immature fish was much higher accounting for 60.9% of TSB and 78.2% of TSN. The biomass estimate for pass 2 was significantly larger than pass 1 (10, 621 t) and was composed of 49% immature fish representing 5,412 t.

Adaptive surveys

Mini surveys 2 and 3 achieved comparable results (Table 3). Age structure was composed of mature fish with 4, 3 and 5 winter ring fish dominating (Figure 5 and Appendix 1).

Mini survey 4 had an age structure that was notably different from survey 2 and 3 considering aggregations were within 15 nmi of each other. Survey 4 contained fish aged from 1 to 5 winter rings with the largest proportion (68.7% TSB) composed of 1 winter ring fish.

3.2 Other pelagic species

3.2.1 Sprat

Sprat were found widely distributed throughout the survey area and sampled in 18 of 29 hauls (Figure 6, Table 2). In total 3,233 individual length measurements and 1,836 length/weight measurements were recorded. Mean length was 8.0 cm and mean weight was 4 g (8.6 cm and 5 g in 2015). Individuals ranged from 5 to 14 cm in length and 1 to 21 g in weight.

In total 337 individual sprat echotraces were identified during the core surveys (Pass 1: 152 and Pass 2: 185). Distribution was comparable between successive surveys and with distribution in 2015. However, during Pass 2 significantly more sprat were observed (Table 4).

3.3 Oceanography

A total of 48 CTD stations were carried out. Surface plots of temperature and salinity are presented using 20 m and 40 m depth profiles (Figures 8 & 9), while profiles for 60 m and near bottom profiles are overlaid with sprat and herring NASC data respectively (Figures 10 & 11).

Horizontal plots of temperature and salinity at 20 and 40 m depths (Figure 8 & 9) showed conditions were relatively uniform for the main body of the survey area. The presence of the thermocline was evident in some but not all individual stations indicating a full breakdown had yet to occur. The main features of note at 40 m were a cool plume of water centred on the Celtic Deep and in the western area where cooler Atlantic water was evident. At 60 m a more defined boundary frontal area was evident between warmer shelf waters and cooler water. This was most evident around the Celtic Deep and at the southernmost stations. The influence of less saline water from fluvial output is evident at more coastal stations. Cooler Atlantic water is clearly present at western and southern stations.

Sprat distribution data was overlaid with the profile from 60 m as sprat were most commonly encountered at this depth in the water column. The distribution of offshore aggregations aligns somewhat with the thermal boundary at the Celtic Deep. However, this maybe more related to feeding opportunity rather than thermal preference as no such pattern is evident for coastal distribution.

Herring distribution was overlaid with horizontal temperature and salinity profiles taken from near the seabed (Figure 11). All herring aggregations both offshore and inshore were encountered on or in close proximity to the seabed (Figures 7a-e). The bulk of the stock was observed offshore and within the Celtic Deep region as in 2015. This region was notably cooler than the surrounding waters of the Celtic Sea. Stomach contents analysis showed that herring sampled within this area were not actively feeding prior to sampling and so distribution may be more closely linked to thermal preference than feeding.

3.4 Marine mammal and seabird observations

3.4.1 Marine mammal sightings

For the first 10 days, observations were conducted by a single observer scanning 90° to port and starboard of the ships track line. For the remaining 8 days of the survey there were two dedicated observers. Each observer scanned a 90°arc each on either side of the vessel in a transect approach. While on effort the area was constantly scanned with the naked eye, using binoculars used to confirm species identification. Upon each sighting, the GPS position of each cetacean was digitally marked using Logger 2000™ software. The following data were recorded for each sighting: species, distance, bearing, heading, number of animals (i.e. adults, juveniles and calves) and behaviour. The distance of any cetacean(s) or other marine fauna sighted was estimated using a range finder. In the event that species identification could not be confirmed, sightings were recorded as follows; probable, possible, unidentified whale and unidentified dolphin. Any other marine fauna sighted during the survey was also entered and recorded in this way.

Visual survey effort took place on 18 days between the 7th and the 21st of October, amounting to a total of 135 hours and 02 minutes on effort. The majority of dedicated effort was recorded from the crow's nest, with an average of 7 hours and 25 minutes per day covering daylight hours. One and a half hours were recorded from the bridge on the 16th of October during poor sea conditions. Effort occurred on each of the active survey days, with the exception of the 24th when effort could not be maintained due to poor sea conditions.

Sea state during the hours of observation ranged from Beaufort Sea state 1 to 5. Out of the total time on effort 6% was recorded as sea state 1; 14% as sea state 2; sea state 3 was most prevalent accounting for 42% of time on effort: 32% as sea state 4; 3% as sea state 5 and the remaining 3% of observations were conducted in sea state 6. There was no swell (<1 m) for 7% of the total effort duration. 'Light' swell (1m) was recorded for 47% of effort; 'moderate' swell (1 to 2m) was recorded for 41% of effort. The remaining 5% of the total effort duration was recorded as 'high' (3 m). Visibility ranged from between 1 km to greater than 20km. For the majority of the survey (44%) visibility was between 6 and 10 km while on effort. Poor visibility (<1 km) accounted for 9% of survey effort, and occurred during periods of high sea state, rain (0.96% of effort) and fog (1.36% of effort).

A total of 216 cetacean sightings events occurred throughout the survey, comprising a minimum of 2387 individuals (Table 5 and Figure 13). Six different cetacean species were recorded, with a further 12 unidentified whale sightings of 13 individuals, and 11 unidentified dolphin sightings of 93 individuals. Fifteen sightings of four other marine species also logged comprising of 21 individuals, including bluefin tuna (Thynnus thynnus), basking shark (Cetorhinus maximus), blue shark (Prionace glauca), and grey seal (Halichoerus grypus) are provided in Table 6 and Figure 14. These sightings include those recorded during dedicated survey effort by the marine mammal observers as well as incidental sighting made by other scientific personnel and the ship's crew.

3.4.2 Seabird sightings and marine litter

A total of 73.58 hours (4415 minutes) of dedicated seabird surveys was conducted across seventeen days between 8th and 26th October 2016. Casual observations were made on 8th October while in transit to the survey tracklines and no surveys were conducted on 24th October due to inclement weather.

A total of fourteen point counts were made during fishing tow operations during the survey between and 9th and 25th October.

A cumulative total of 26,429 individual seabirds of 27 species was recorded, of which 8,571 were noted as 'off survey', outside of dedicated survey time or associating with the vessel (including during fishing operations point counts) and as such will be excluded from future analysis of abundance and density. A synopsis of daily totals for all seabird species recorded is presented in Table 7. In addition, daily totals for 22 species of migrant terrestrial birds recorded on or around the vessel are also presented (Table 8).

The seabird team recorded presence of marine litter or debris observed in transect areas. Details of distance from the survey vessel, estimated size, material involved, colour and any branding were noted. Recording of marine litter using this format has been ongoing during CSHAS surveys since 2013, data of which is being compiled for future analysis.

4 Discussion and Conclusions

4.1 Discussion

The objectives of the survey were carried out successfully and as planned. No down-time was recorded and good weather conditions prevailed allowing for extended adaptive survey effort.

Core strata boundaries were extended in 2016 in a bid to ensure containment of the stock. The observed distribution pattern would suggest that the stock was contained in 2016 as in 2015. The eastern boundary of the Celtic Deep was surveyed by the RV *CEFAS Endeavour as* part of the annual PELTIC survey program and reported low abundance of herring in this area in line with previous years (Van Der Kooij pers. com. Oct, 2016). Real time positional data was provided by the co-occurring herring fishery and onboard an industry observer relaying information. This allowed for directed survey effort on high abundance aggregations.

Estimates of abundance for individual strata show consistency between replicates for adaptive and core surveys and the survey proves its ability to track the important years classes within the stock. However, it should be noted that due to the behaviour of fish within highest abundance area, namely offshore stratum, the accuracy of acoustic measurement should be treated with a degree of caution. The carpeting behaviour of fish and the resulting large geographical spread of schools tight on the seabed within the deadzone does not allow for accurate acoustic measurement. The volume of fish observed during trawling operations did not compare to ‘on-track’ survey observations further proving the mismatch. Day/night observations in terms of vertical extent of schools was not conclusive in favouring day surveying over night or vice versa.

The Celtic Deep region is no doubt an important pre-migration staging post for herring. Large high density aggregations form in a localised and can remain stationary in some instances for weeks before moving northwards. Stomach contents analysis showed that herring sampled within this area were not actively feeding prior to sampling and so distribution may be more closely linked to thermal preference than feeding opportunity.

Large predators including common dolphin, humpback and minke whales as well as blue fin tuna were actively feeding on these offshore aggregations. However, the presence of these large predators is not unusual and this alone cannot be responsible for the carpeting behaviour observed. Tidal state and cycle were not in the extreme (Springs) and fell within the midpoint during adaptive surveys, as was the case in 2015. Reports from the fleet indicated seismic activity in the area. However, during the active period of the survey the vessel in question was in port or working off the south Cornish coast.

Sprat biomass and distribution follows a similar pattern to previous years with schools spread widely over the Celtic Sea. As sprat show strong diurnal migration into surface waters at night this makes acoustic measurement difficult. As the survey operates over 24 hrs estimates of abundance of sprat are therefore limited in terms accuracy.

4.2 Conclusions

- The stock was considered contained within the extended survey area in 2016 with two clear areas of distribution and no herring observed around the survey periphery.
- Overall herring distribution indicated that the bulk of the spawning stock was located offshore in a highly localised area as in 2015. Inshore aggregations contained a higher proportion if immature fish.
- Consistency between replicate estimates was considered reasonable considering the sources of error associated with acoustic survey methods in general. For the adaptive surveys consistency was more closely aligned due to the localised area of sampling and the close time frame in which replicates were carried out.
- The ability to accurately measure offshore abundance was limited in 2016 due to fish behaviour. A large proportion of aggregations were spread thinly (<0.4 m) over the seabed and within the acoustic deadzone (ADZ) hampering accurate acoustic measurements. This carpeting behaviour increased the geographical extent of aggregations from 20 nmi^2 in 2015 to 200 nmi^2 in 2016.
- The factors driving this behaviour are not readily explained. Tidal range and state are factors considered to influence behaviour in this area and were considered during planning where possible. Offshore adaptive surveys were carried out over a period of 48 hrs occurring at the midpoint of the Spring/Neap cycle. In 2015 tidal cycle was similar for offshore adaptive coverage.
- The dominate age classes of the stock were evident within the survey and comparable to commercial catch samples from the fishery. The presence of immature fish from coastal waters may indicate the presence of an emerging year class.
- Further work is planned to investigate correcting for the ADZ at higher frequency.

Acknowledgements

We would like to thank Denis Rowan (Captain) and the crew of the Celtic Explorer for their help and professionalism during the survey. We also thank John O' Regan for his expert advice on fishing operations and for liaising with the commercial fishing fleet. Many thanks also to the seabird and marine mammal survey teams, who worked tirelessly during the survey in all weathers and with great enthusiasm.

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. & 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 & 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 oceanograohic 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., & 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).

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

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, Porucpine Studies Group project P00/15 and Offshore Support Group (OSG) project 99/38. University College Cork.

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

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

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*. A&C Black, London.

Stone C.J., Webb A., Barton C., Ratcliffe N., Reed T.C., Tasker M.L,. Camphuysen C.J & 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., & 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 & G. Cracknell.

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

5 Tables and Figures

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

Echo Sounder System Calibration

Vessel :	R/V Celtic Explorer	Date :	08/10/2016
Echo sounder :	ER60 PC	Locality :	Dunmanus Bay
Type of Sphere : CU-38,1	TS_{Sphere}: -33.50 dB (Corrected for soundvelocity or t,S)	Depth(Sea floor) :	36 m

Calibration Version 2.1.0.11

Comments:
Dunmanus Bay, flat calm

Reference Target:

TS	-33.52 dB	Min. Distance	16.00 m
TS Deviation	5.0 dB	Max. Distance	20.00 m

Transducer: ES38B Serial No. 30227

Frequency	38000 Hz	Beamtype	Split
Gain	26.50 dB	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	7.10 deg	Along. Beam Angle	7.10 deg
Athw. Offset Angle	-0.00 deg	Along. Offset Angl	-0.00 deg
SaCorrection	-0.0 dB	Depth	8.8 m

Transceiver: GPT 38 kHz 009072033933 1 ES38B

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

Sounder Type:
ER60 Version 2.4.3

TS Detection:

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

Environment:

Absorption Coeff.	8.8 dB/km	Sound Velocity	1506.9 m/s

Beam Model results:

Transducer Gain =	25.88 dB	SaCorrection =	-0.65 dB
Athw. Beam Angle =	6.91 deg	Along. Beam Angle =	6.85 deg
Athw. Offset Angle =	-0.02 deg	Along. Offset Angle=	-0.05 deg

Data deviation from beam model:
RMS = 0.17 dB
Max = 0.49 dB No. = 186 Athw. = 2.4 deg Along = 4.5 deg
Min = -1.03 dB No. = 44 Athw. = -0.4 deg Along = -4.9 deg

Data deviation from polynomial model:
RMS = 0.13 dB
Max = 0.49 dB No. = 186 Athw. = 2.4 deg Along = 4.5 deg
Min = -0.78 dB No. = 44 Athw. = -0.4 deg Along = -4.9 deg

Comments :

Wind Force : 1 **Wind Direction** SE
Raw Data File: \\Expfileclstr\ER-60_Data\CSHAS_2016\RAW\ER60 Files\Calibration\CSHAS_2016
Calibration File: \\Expfileclstr\ER-60_Data\ER-60\Calibrations 2016\CSHAS 2016\38 KHZ

Calibration : Ciaran ODonnell

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 %	Pilchard %	Others^ %
1	08.10.16	51.32	-9.75	19:54	80	20-40	85.0		94.0	0.3	1.8		3.9
2	09.10.16	51.45	-8.21	16:20	84	13-35	69.5		15.2	0.8	64.7		19.2
3	10.10.16	51.51	-7.98	09:02	82	15	86.7		13.5	1.8	76.4		8.3
4	10.10.16	51.53	-7.77	18:43	77	17	21.0		8.2	21.3	33.8		36.6
5	11.10.16	51.90	-7.57	13:40	52	0	141.3		92.9				7.1
6	11.10.16	52.10	-7.27	19:45	30	0	224.4	69.9	29.8				0.3
7	12.10.16	51.19	-7.15	19:08	90	10	11.8		0.3		53.2		46.5
8	12.10.16	51.59	-6.94	07:13	75	55	1000.0		88.0	11.7			0.3
9	13.10.16	51.20	-6.94	16:59	90	75	88.4		1.6	1.8	87.7		8.9
10*	14.10.16	51.11	-6.72	06:46	101	0	220.0						100.0
11*	14.10.16	51.25	-6.37	17:24	100	0	155.5		0.4	0.2	42.5		56.9
12	15.10.16	51.11	-6.67	06:34	95	0	250.0				2.40		97.6
13*	15.10.16	52.08	-6.70	15:52	35	0	23.3			100.0			
14	16.10.16	50.54	-6.33	12:29	90	0	31.0		39.9	47.6			12.5
15	17.10.16	51.94	-6.59	15:58	55	10	100.0		66.3	0.4			33.2
16	18.10.16	51.07	-5.88	08:17	75	15	130.0		25.6	15.4	55.0		4.0
17	18.10.16	51.51	-5.9	13:17	100	25	39.6	0.8	0.7	29.6	56.5		12.4
18	19.10.16	51.43	-5.8	09:51	25	15	280.0		74.1	0.2	24.2		1.5
19	19.10.16	52.31	-6.0	20:48	78	60	150.0	3.3	6.0	0.4	64.7		25.6
20	20.10.16	51.30	-6.6	22:00	86	0	3000.0	91.7			7.4		1.0
21*	21.10.16	51.25	-6.7	03:45	83	0	1500.0	89.6			2.2		8.2
22*	21.10.16	51.17	-6.6	09:19	102	0	1000.0	88.2	1.0	6.2	1.0		3.7
23*	21.10.16	51.11	-6.7	23:24	96	0	750.0	96.8	0.2		0.7		2.4
24	22.10.16	51.30	-6.6	12:40	100	0	220.0	0.6		22.9	69.2		7.4
25*	22.10.16	51.49	-6.5	00:01	80	0	200.0	99.5					0.5
26*	23.10.16	51.81	-6.8	07:39	70	0	300.0		3.4	96.5			
27*	24.10.16	52.08	-7.5	19:44	25	5	250.0	97.8	1.6				0.6
28*	25.10.16	51.76	-7.9	11:03	60	0	49.5		83.6		14.7		1.7
29	26.10.16	51.67	-8.3	00:11	35	5	200.0		2.0			90.4	7.6

^ Including pelagic, demersal fish and invertebrates, * Trawl camera

Table 3. Herring biomass and abundance by strata. Top table represents strata specific abundance estimates. Bottom table biomass (green) geometric mean for replicate surveys.

Actual

Strata	Name	Type	Area (nmi²)	Transects	TSN ('000)	TSB (t)	SSN ('000)	SSB (t)	CV (Abun)
1	Pass 1	Core	10,039.7	14	3,570	375.1	2,428	310.1	0.68
2	Pass 2	Core	7,794.1	18	144,233	10,621.0	51,381	5,412.1	0.78
3	Mini 1	Adpt	93.3	35	0	0	0	0	-
4	Mini 2	Adpt	209.2	17	120,875	15,583.1	118,925	15,424.3	0.33
5	Mini 3	Adpt	187.4	17	145,204	18,734.5	141,563	18,411.4	0.49
6	Mini 4	Adpt	10.0	5	12,693	703.1	1,802	175.2	0.84
	Total			106					

Geomean

Strata	Name	Type	Area (nmi²)	Transects	TSN ('000)	TSB (t)	SSN ('000)	SSB (t)	
1&2	Pass 1&2	Core	10,039.7	18	22,692	1,961.3	1,169	1,295.5	-
4&5	Mini 3&4	Adpt	209.2	17	133,647	16,981.3	129,751	16,851.8	-
6	Mini 4	Adpt	10.0	5	12,693	703.1	1,802	175.2	-
	Total		10,258.9	40					

Table 4. Sprat biomass and abundance by strata. Top table represents individual strata abundance estimates. Bottom table biomass (green) geometric mean for replicate surveys.

Actual

Strata	Name	Type	Time	Area (nmi²)	Transects	TSN ('000)	TSB (t)
1	Pass 1	Core	24Hrs	10,039.7	14	3,396,724	17,747.3
2	Pass 2	Core	24Hrs	7,794.1	18	8,171,306	42,693.7
3	Mini 1	Adaptive	24Hrs	93.3	35	22,522	77.6
4	Mini 2	Adaptive	24Hrs	209.2	17	259,346	969.7
5	Mini 3	Adaptive	24Hrs	187.4	17	418,370	1,564.3
6	Mini 4	Adaptive	Night	10.0	5	0	0
	Total				106		

Geomean

Strata	Name	Type	Time	Area (nmi²)	Transects	TSN ('000)	TSB (t)
1&2	Pass 1&2	Core	24Hrs	10,039.7	18	5,268,365	27,526.3
4,5,6	Mini 1-3	Core	24Hrs	209.2	17	134,694	490.1
	Total			10,248.9	35		

Table 5. Marine mammal sightings, counts and group size ranges for cetaceans sighted during the survey.

Species	No. of sightings	No. of individuals	Group size range
Fin whale (*Balaenoptera physalus*)	16	21	1-3
Humpback whale (*Megaptera novaeangliae*)	2	2	1
Minke whale (*Balaenoptera acutorostrata*)	19	22	1
Bottlenose dolphin (*Tursiops truncatus*)	1	6	1
Common dolphin (*Delphinus delphis*)	133	2039	1-300
Harbour porpoise (*Phocoena phocoena*)	22	191	1-35
Unidentified whale	22	191	1
Unidentified dolphin	1	6	2-30
Total	**216**	**2387**	**n/a**

Table 6. Sightings summary of other marine fauna.

Species	No. of sightings	No. of individuals	Group size range
Basking Shark (*Cetorhinus maximus*)	1	1	1
Bluefin Tuna (*Thunnus thynnus*)	7	13	1-4
Blue Shark (*Prionace glauca*)	4	4	1
Grey Seal (*Halichoerus grypus*)	3	3	1
Total	**15**	**21**	**n/a**

Table 7. Totals for all seabird species recorded between 8th and 26th October 2016.

Vernacular Name	Scientific Name	On Survey	Off Survey	Total
Red-throated Diver	*Gavia stellata*	3		3
Great Northern Diver	*Gavia immer*	3		3
Fulmar	*Fulmarus glacialis*	310	53	363
Great Shearwater	*Puffinus gravis*	23	161	184
Sooty Shearwater	*Puffinus griseus*	179	27	206
Manx Shearwater	*Puffinus puffinus*	50	10	60
Balearic Shearwater	*Puffinus mauretanicus*	2		2
European Storm-petrel	*Hydrobates pelagicus*	38	12	50
Gannet	*Morus bassanus*	10665	4484	15149
Cormorant	*Phalacrocorax carbo*	3		3
Shag	*Phalacrocorax aristotelis*	1		1
Grey Phalarope	*Phalaropus fulicarius*	5		5
Pomarine Skua	*Stercorarius pomarinus*	3		3
Arctic Skua	*Stercorarius parasiticus*	5		5
Great Skua	*Stercorarius skua*	203	142	345
Puffin	*Fratercula arctica*	10	1	11
Razorbill	*Alca torda*	698	65	763
Guillemot	*Uria aalge*	3277	16	3293
Razorbill / Guillemot		648		648
Kittiwake	*Rissa tridactyla*	725	203	928
Black-headed Gull	*Chroicocephalus ridibundus*	3	10	13
Little Gull	*Hydrocoloeus minutus*	1	2	3
Mediterranean Gull	*Larus melanocephalus*	4	2	6
Common Gull	*Larus canus*	18	10	28
Lesser Black-backed Gull	*Larus fuscus*	492	1409	1901
Herring Gull	*Larus argentatus*	52	148	200
Yellow-legged Gull	*Larus michahellis*	1	7	8
Great Black-backed Gull	*Larus marinus*	165	199	364
Unidentified Large Gull sp.	*Larus sp.*	271	1610	1881
Total		17858	8571	26429

Table 8. Totals of migrant terrestrial bird species recorded between 8th and 26th October 2016.

Vernacular Name	Scientific Name	Total
Light-bellied Brent Goose	*Branta bernicla hrota*	1
Wigeon	*Anas penelope*	1
Golden Plover	*Pluvialis apricaria*	11
Turnstone	*Arenaria interpres*	2
Collared Dove	*Streptopelia decaocto*	1
Merlin	*Falco columbarius*	2
Goldcrest	*Regulus regulus*	1
Skylark	*Alauda arvensis*	2
Swallow	*Hirundo rustica*	6
Yellow-browed Warbler	*Phylloscopus inornatus*	1
Chiffchaff	*Phylloscopus collybita*	7
Blackcap	*Sylvia atricapilla*	2
Starling	*Sturnus vulgaris*	13
Fieldfare	*Turdus pilaris*	2
Song Thrush	*Turdus philomelos*	5
Redwing	*Turdus iliacus*	4
Robin	*Erithacus rubecula*	1
Grey Wagtail	*Motacilla cinerea*	1
‘alba' wagtail	*Motacilla alba/yarrellii*	5
Meadow Pipit	*Anthus campestris*	101
Chaffinch	*Fringilla coelebs*	2
Goldfinch	*Carduelis carduelis*	2
Total		173

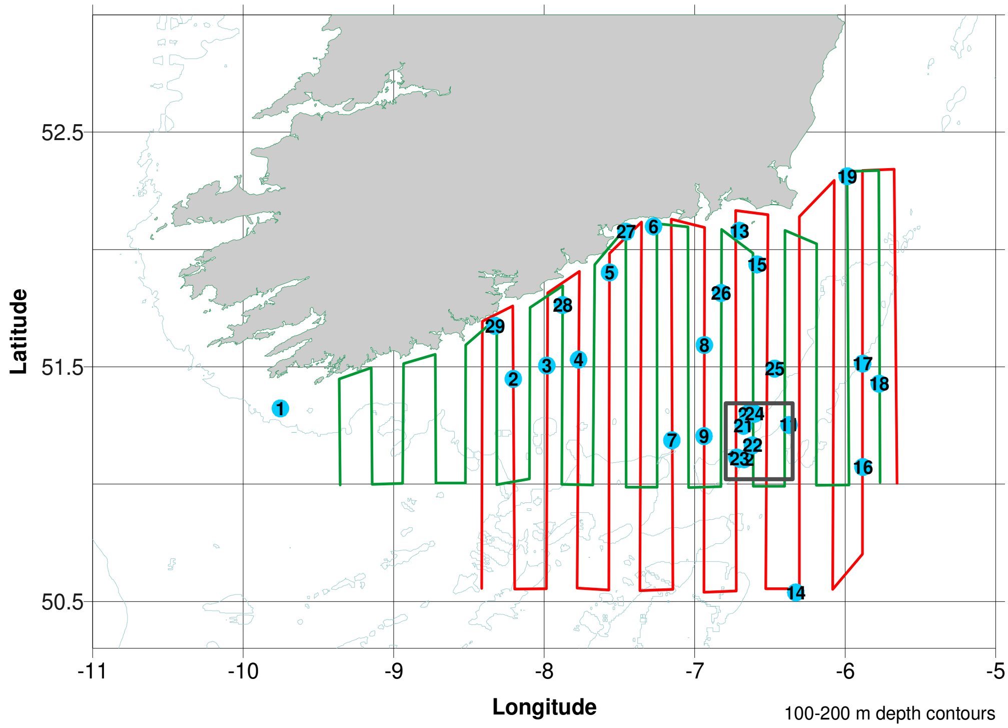


Figure 1. Survey cruise tracks (Pass 1: green track, Pass 2: red track) and adaptive area (grey box). Pelagic trawl positions appear as numbered stations.

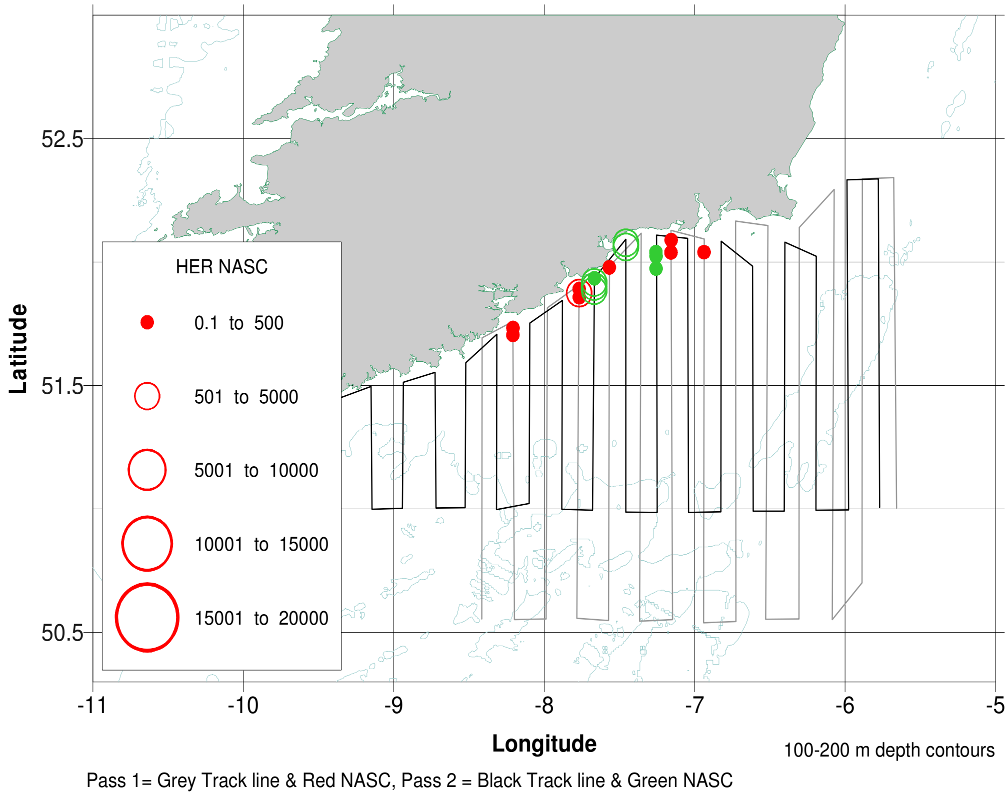


Figure 2. Herring NASC (Nautical area scattering coefficient) plot of the distribution from replicate core survey effort.

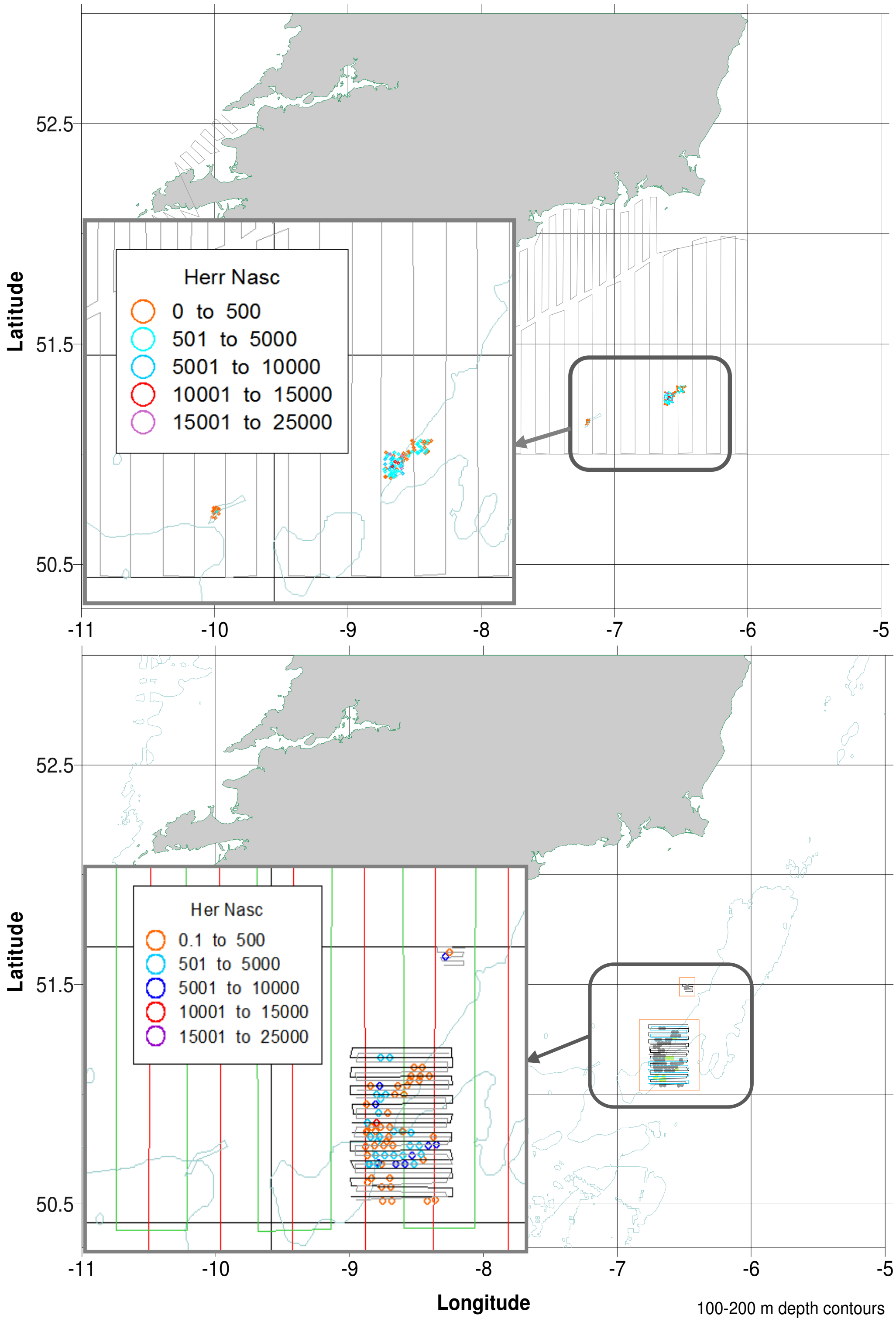


Figure 3. Herring NASC (Nautical area scattering coefficient) plot of the distribution from adaptive survey effort. Top Panel 2015, bottom panel 2016 Note: In 2015 core survey transects (vertical grey lines) at 4 nmi spacing and in 2016 (inset) Pass 1 (green) & Pass 2 (red) at 8 nmi respectively.

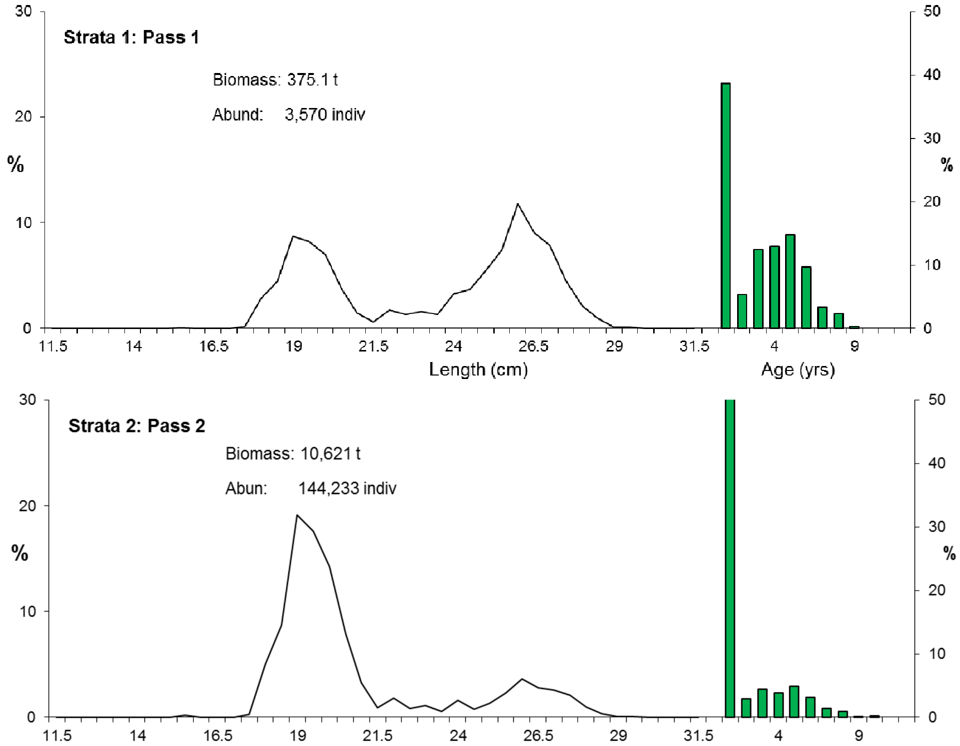


Figure 4. Age and length composition of herring from core surveys (Pass 1 & 2).

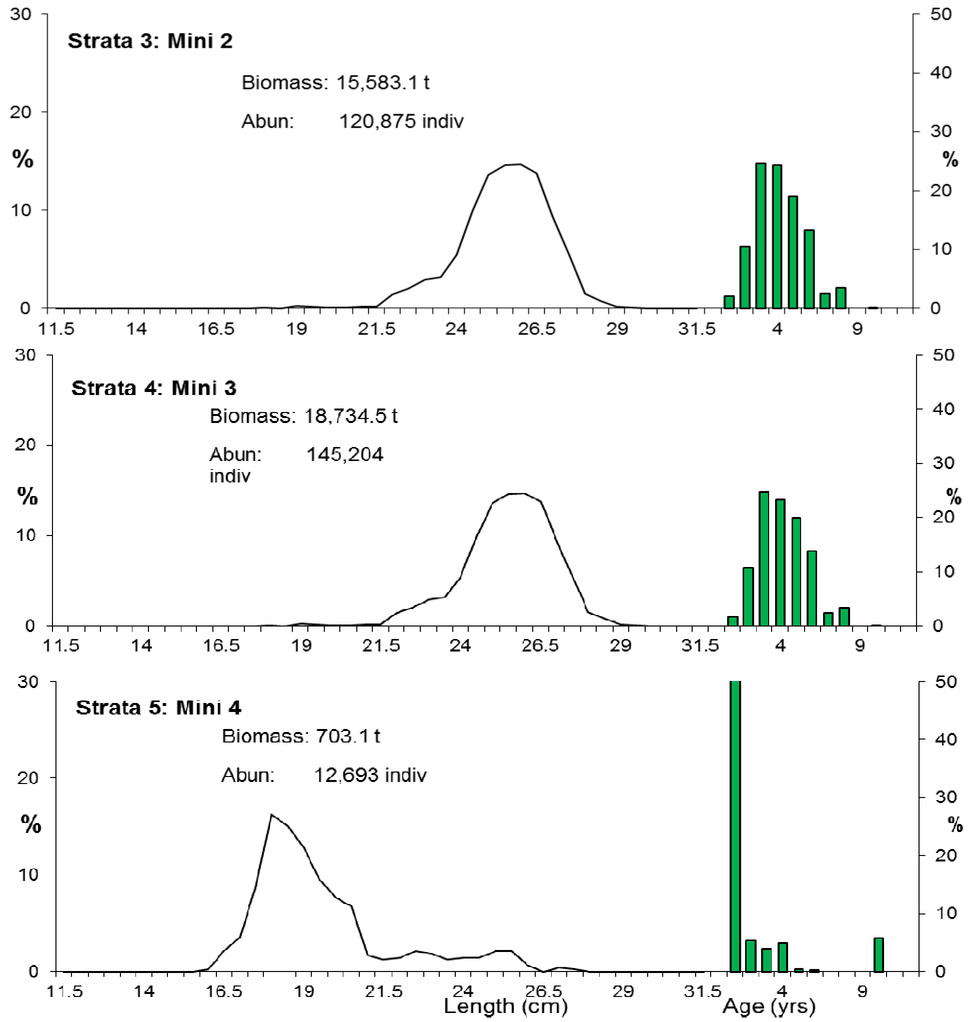


Figure 5. Age and length composition of herring from adaptive survey effort.

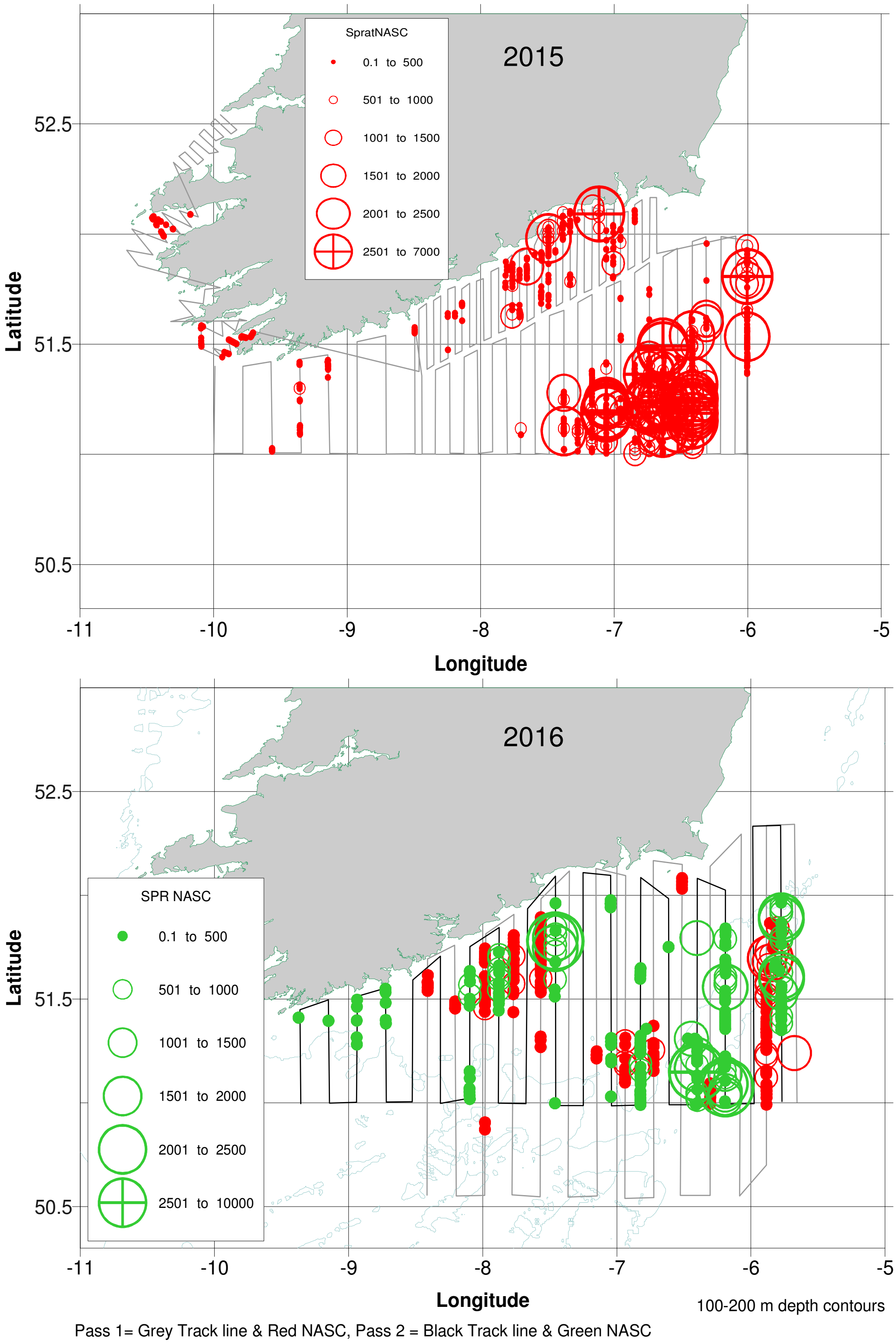
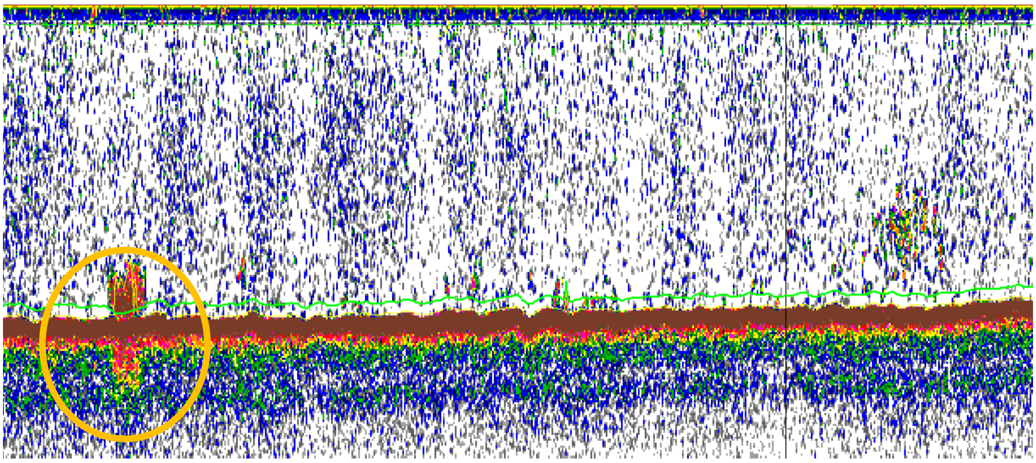
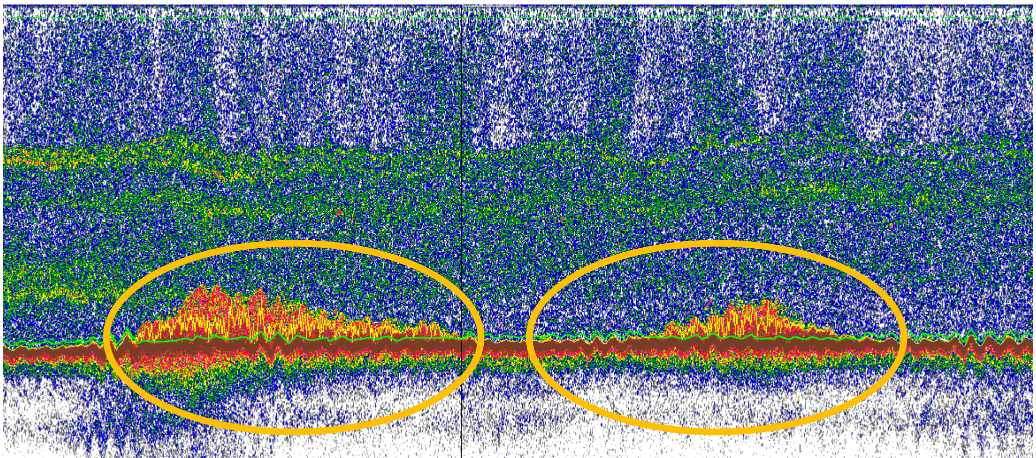


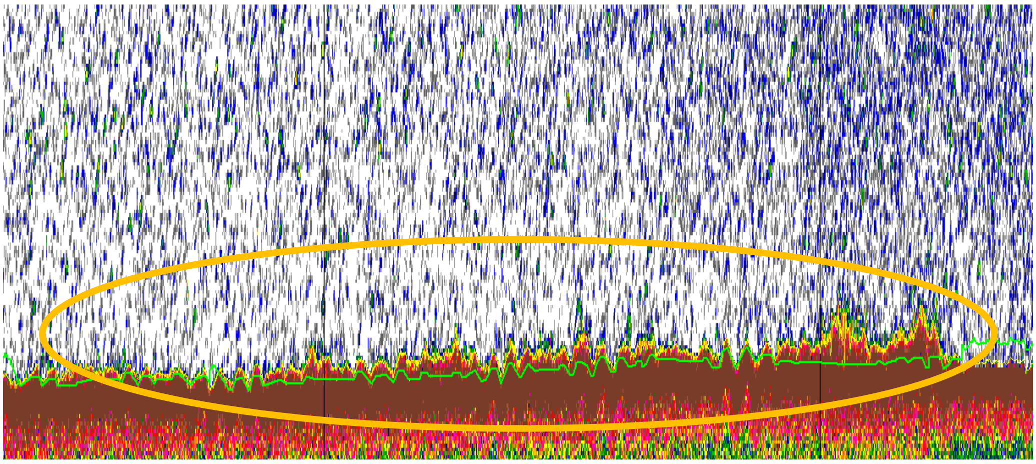
Figure 6. Sprat NASC (Nautical area scattering coefficient) plot of the distribution from replicate core survey effort.



a). *Low density herring bottom echotrace observed at night prior to Haul 06. Recorded inshore during Pass 1 core survey. Water depth 30 m school extending vertically to 5 m.*

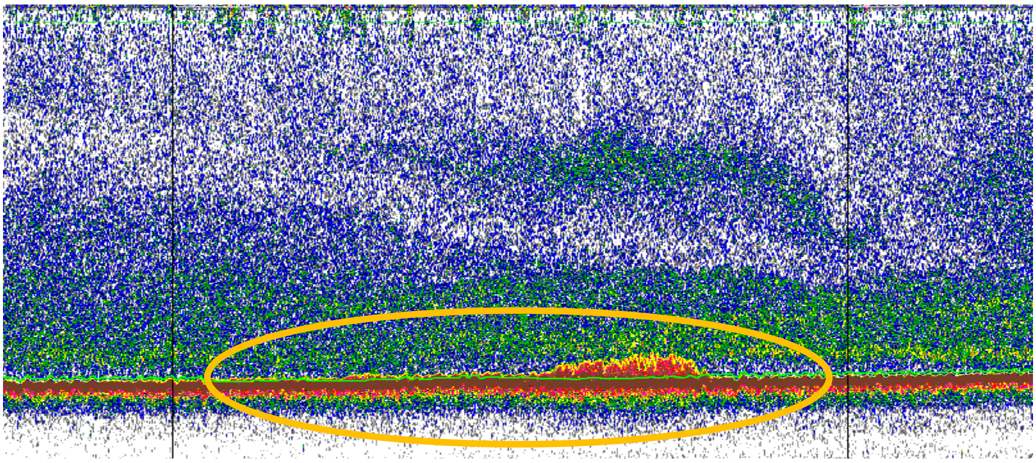


b). *High density herring bottom echotrace observed at night recorded at night prior to Haul 20. Recorded offshore during Adaptive survey 2. Water depth 86 m school extending to 1.2 nmi.*

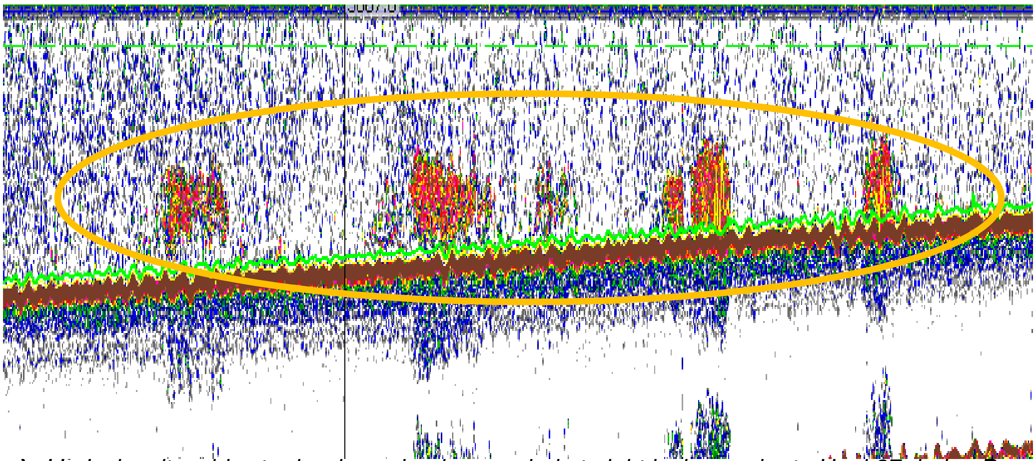


c). *High density herring echotrace (zoomed) showing hard bottom contact, observed during day-light prior to Haul 22 . Recorded offshore during Adaptive survey 2. Water depth 98 m.*

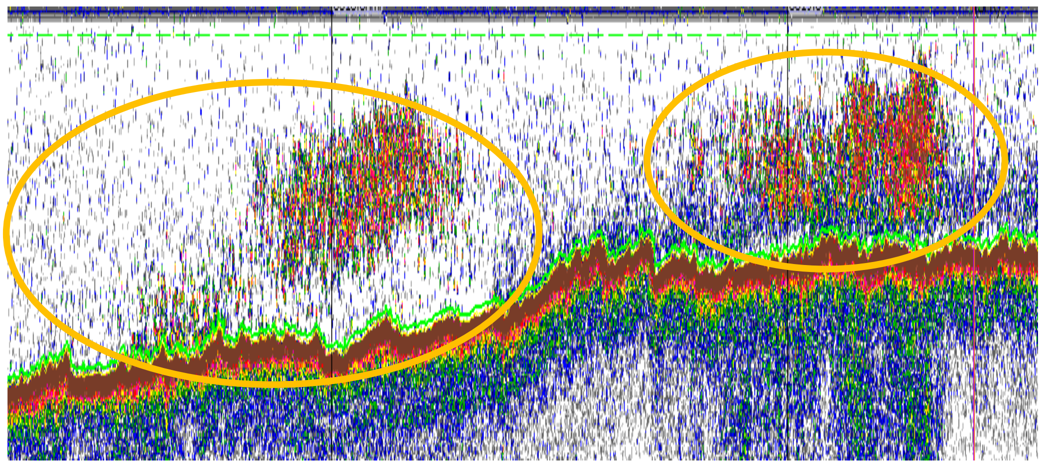
Figure 7. EK60 echograms (38 kHz) recorded prior to directed trawl stations.



d). *Medium density herring echotrace showing hard bottom contact, observed at night prior to Haul 25. Recorded offshore during Adaptive survey 4. Water depth 80 m.*



e). *High density midwater herring schools recorded at night inshore prior to Haul 27 during Pass 2. Water depth 25 m with schools extending vertically to 12m.*



f). *High density inshore echotraces composed of 90% pilchard and 10% anchovy, recorded inshore at night prior to Haul 29 during Pass 2. Water depth is 35 m*

Figure 7a-f. Continued

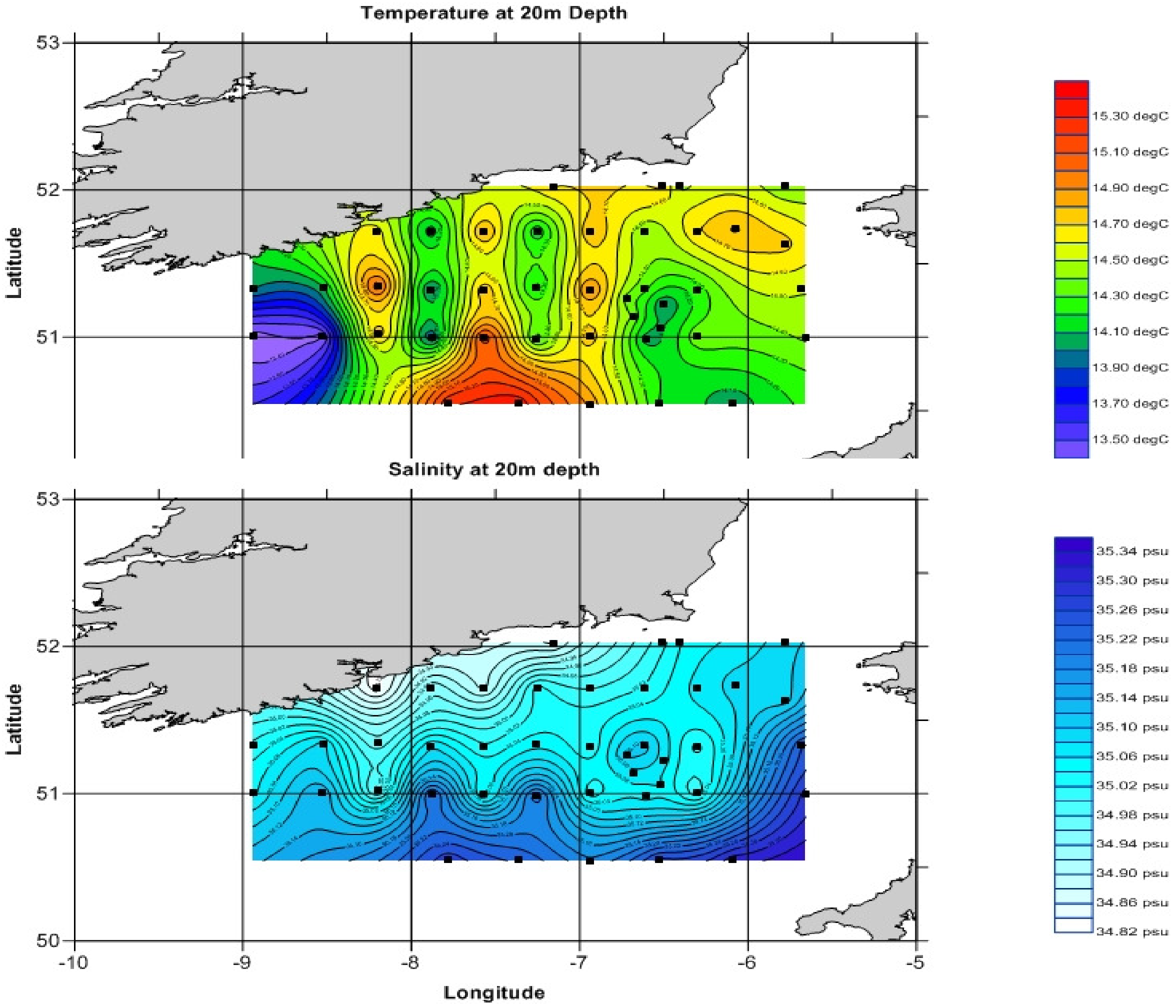


Figure 8. Surface (20 m) plots of temperature and salinity compiled from CTD cast data. Station positions shown as block dots (n=42).

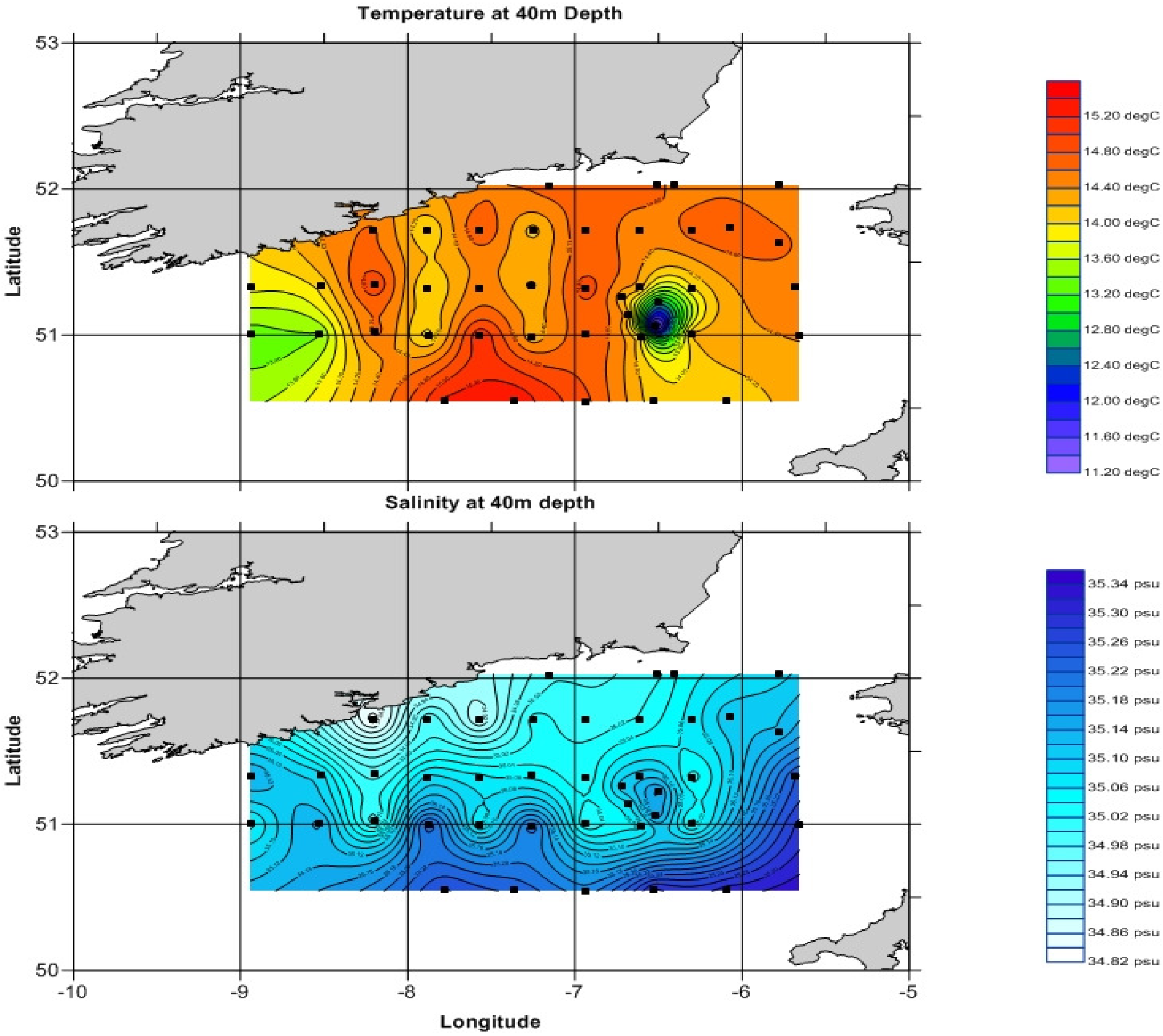


Figure 9. Surface (40 m) plots of temperature and salinity compiled from CTD cast data. Station positions shown as block dots (n=42).

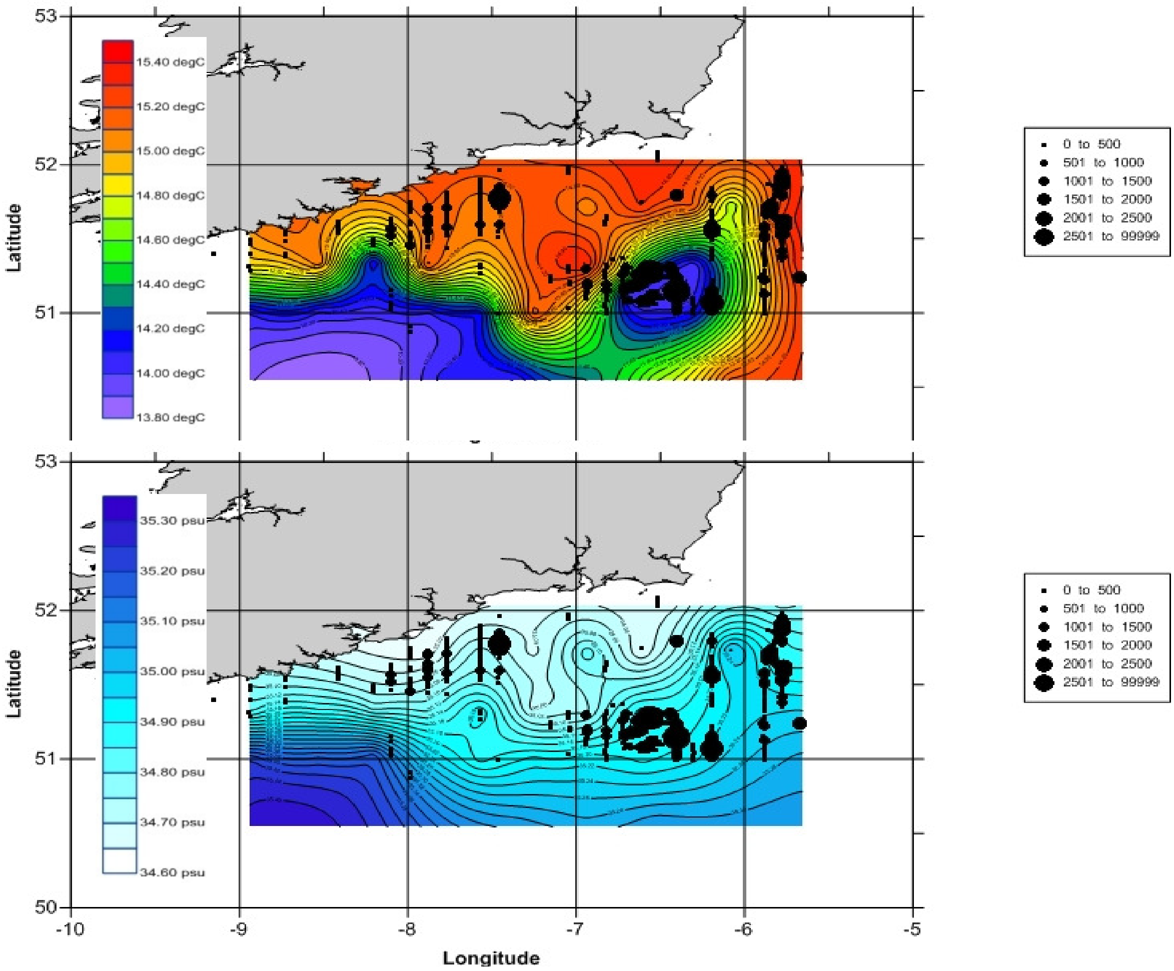


Figure 10. Habitat plots of temperature and salinity at 60 m overlaid with sprat NASC values (black circles).

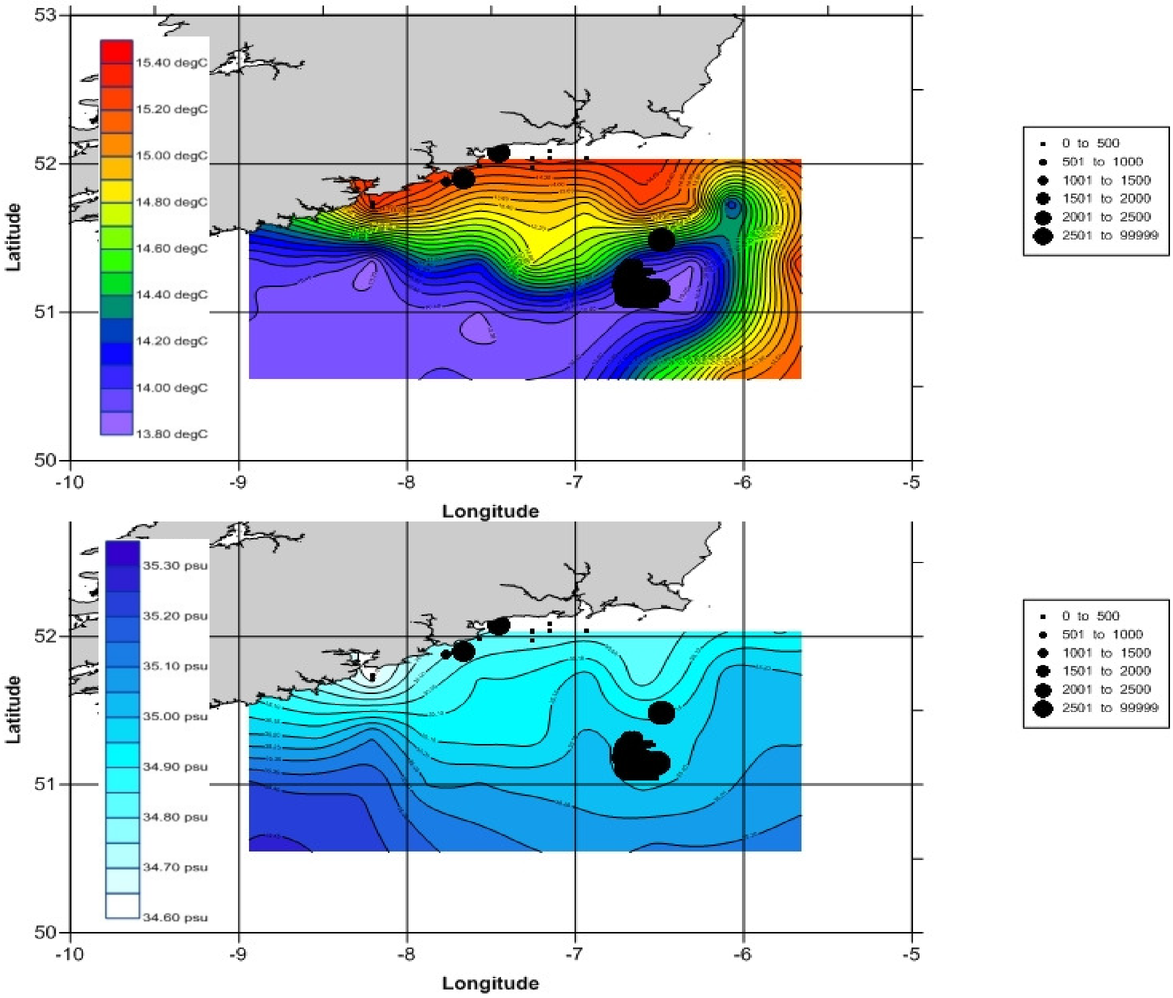


Figure 11. Habitat plots of temperature and salinity at the seabed overlaid with herring NASC values (acoustic density) shown as black circles.

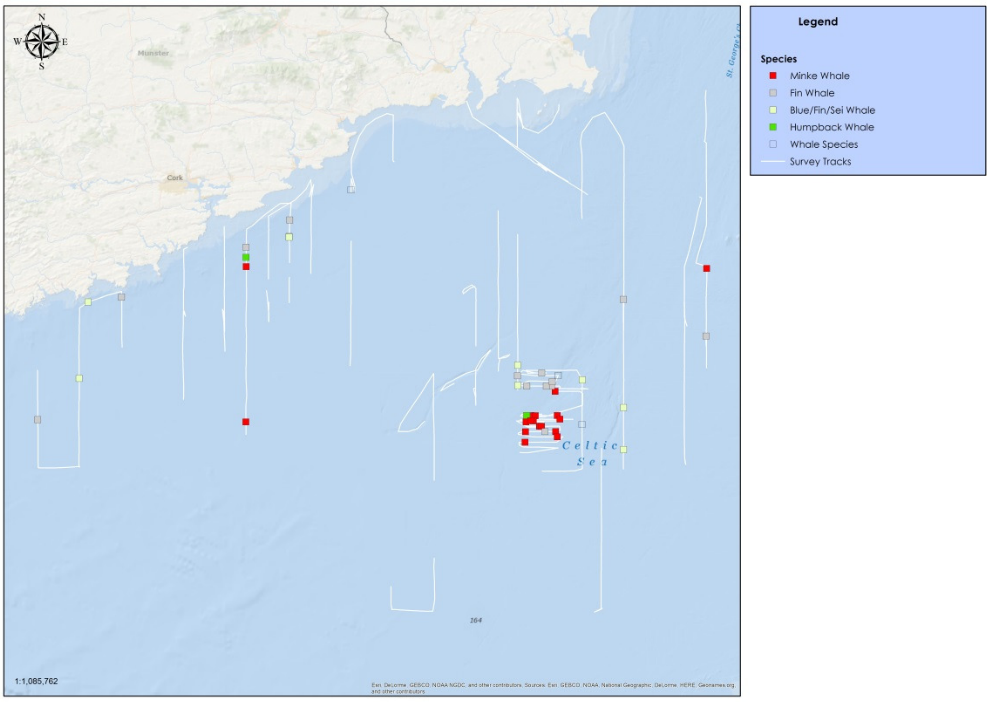


Figure 12. Whale sightings and survey effort.

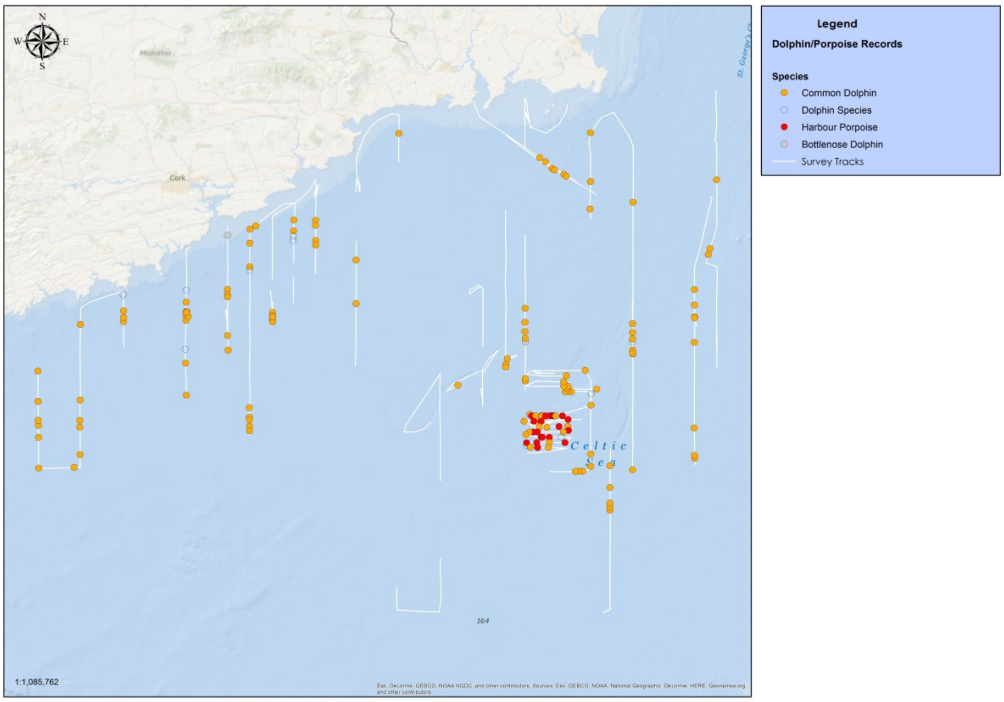


Figure 13. Sightings of dolphin and porpoise species and survey effort.

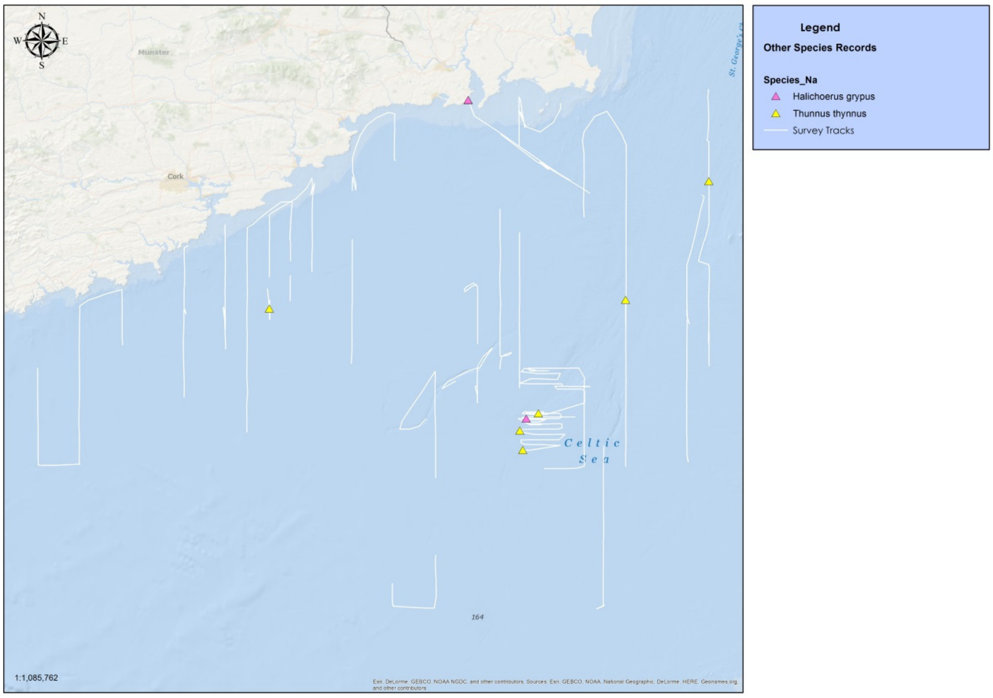


Figure 14. Other Marine Fauna sightings and survey effort.

HERRING MIDWATER TRAWL

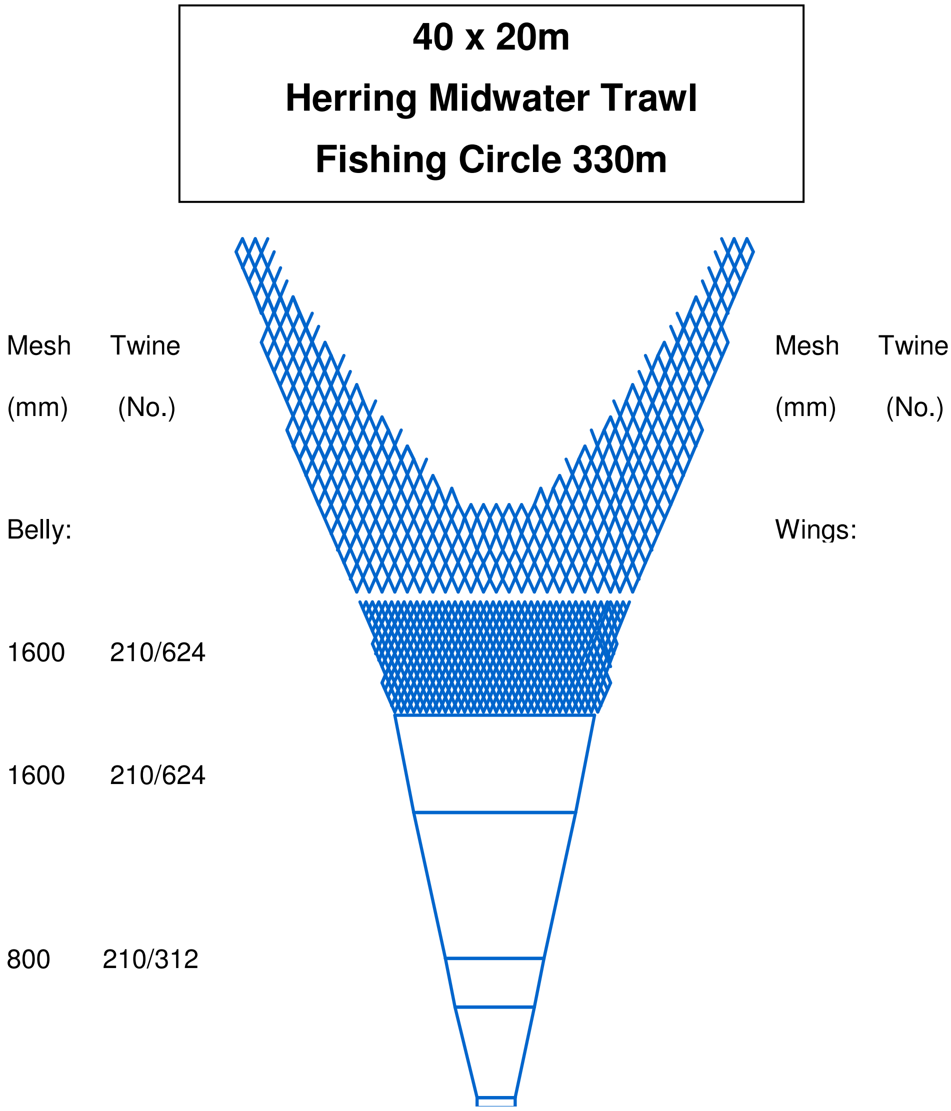


Figure 15. Single herring midwater trawl net plan and layout. Celtic Sea herring acoustic survey, October 2016.

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

6 Appendix

Table 1. Total herring biomass and abundance by age for Pass 1 of the Core survey.

	Age (years)										Numbers	Biomass	Mn Wt
Length	1	2	3	4	5	6	7	8	9	UKN	(*10-6)	('000 t)	(g)
11.5													
12													
12.5													
13													
13.5													
14													
14.5													
15													
15.5										3	3	0.2	47
16													
16.5													
17													
17.5	7										7	0.2	36
18	103										103	4.4	43
18.5	160										160	8	50
19	312										312	16.9	54
19.5	293										293	16.5	56
20	248										248	15.5	62
20.5	135										135	9	66
21	53										53	3.6	68
21.5	22										22	1.6	70.6
22	46		16								62	5.6	90.15
22.5		46									46	4.1	90.31
23		50	5								56	5.2	92.93
23.5		21	27								48	4.9	102.97
24		59	57								116	12.2	105.06
24.5			87	47							133	15.4	115.4
25			127	58	10						195	23.9	122.35
25.5		5	73	124	48	15					265	33.9	127.89
26			50	126	165	55	18	7			422	57.4	135.78
26.5		10		88	134	74	12	7			325	47.4	146.07
27			3	18	125	107	22	6			282	42.8	151.78
27.5					31	77	33	12	10		163	26.4	161.64
28					14	18	23	24			78	12.7	163.27
28.5							7	27			35	5.9	171.33
29										4	4	0.8	187
29.5							4				4	0.8	177
30													
30.5													
31													
31.5													
TSN (*10-3)	1379	192	445	461	527	346	119	84	10	8	3570		
TSB ('000 t)	79.7	18.9	52.6	61.7	75.7	51.4	18.6	13.7	1.7	1		375.1	
Mean length (cm)	19.51	23.5	24.76	25.72	26.44	26.83	27.31	27.72	27.5	23.25			
Mean weight (g)	57.77	98.44	118.32	133.85	143.7	148.74	156.09	163.6	177.33	127.38			105.06

Table 2. Total herring biomass and abundance by age for Pass 2 of the Core survey.

	Age (years)										Numbers	Biomass	Mn Wt
Length	1	2	3	4	5	6	7	8	9	UKN	(*10^{-3})	('000 t)	(g)
11.5													
12													
12.5													
13													
13.5													
14													
14.5													
15													
15.5										296	296	13.9	47
16													
16.5													
17													
17.5	355										355	14.7	42
18	7219										7219	307.5	43
18.5	12549										12549	626.6	50
19	27652										27652	1493.5	54
19.5	25400										25400	1426.8	56
20	20543										20543	1273.6	62
20.5	11426										11426	773.5	68
21	4737										4737	320.1	68
21.5	1301										1301	91.9	70.6
22	1548		1051								2599	240.5	92.53
22.5		1239									1239	112.6	90.85
23		1419	175								1594	148.7	93.32
23.5		347	417								764	78.4	102.58
24		991	1305								2296	242.1	105.47
24.5			668	444							1111	128.2	115.35
25			1098	732	104						1934	236.9	122.51
25.5		66	927	1367	712	215					3286	421.8	128.34
26			545	1650	2102	705	133	133			5268	717.5	136.2
26.5		148		1153	1621	811	160	91			3985	580.2	145.6
27			129	187	1752	1307	273	101			3747	565.6	150.93
27.5					516	1290	735	298	159		2998	484.6	161.65
28					311	208	441	389			1349	220.7	163.62
28.5							156	312			468	79.8	170.58
29										58	58	10.9	187
29.5							58				58	10.4	177
30													
30.5													
31													
31.5													
TSN (*10^{-3})	112730	4210	6314	5532	7118	4535	1956	1324	159	355	144233		
TSB ('000 t)	6464.8	406.6	723.5	741.6	1031.2	673.9	312.3	214.7	27.6	24.9		10621.0	
Mean length (cm)	19.48	23.29	24.29	25.76	26.49	26.87	27.5	27.62	27.5	17.73			
Mean weight (g)	57.35	96.58	114.58	134.05	144.89	148.59	159.68	162.22	173.62	70.1			73.64

Table 3. Total herring biomass and abundance by age for Mini survey 2 of the Adaptive survey coverage.

Length	Age (years) 1	2	3	4	5	6	7	8	9	UKN	Numbers $(*10^{-3})$	Biomass ('000 t)	Mn Wt (g)
11.5													
12													
12.5													
13													
13.5													
14													
14.5													
15													
15.5													
16													
16.5													
17													
17.5													
18	123										123	4.9	40
18.5													
19	290										290	14.7	51
19.5	238										238	13.2	55
20	58										58	3.4	59
20.5	110										110	7	64
21	164										164	10.6	65
21.5	231										231	16	69.5
22	1234	56	449								1739	157.7	90.71
22.5		2445									2445	222	90.79
23		3500									3500	318.4	90.97
23.5		1803	2028								3831	394.8	103.04
24		3632	2951								6583	684.5	103.97
24.5			7028	4914							11941	1375.2	115.16
25			9767	6283	400						16449	2001.6	121.68
25.5		460	5344	7815	2931	1092					17642	2266.6	128.48
26			2290	5324	6298	2805	630	401			17748	2407.3	135.64
26.5		866		4794	6180	4043	347	462			16693	2411.3	144.45
27				284	6527	4087	511				11409	1688	147.96
27.5					686	4004	1144	801			6636	1058	159.45
28								1855			1855	319.7	172.39
28.5							229	686			914	157	171.69
29										164	164	31.3	191
29.5							114				114	20	175
30													
30.5													
31													
31.5													
TSN $(*10^{-3})$	2447	12762	29856	29414	23022	16031	2974	4204		164	120875		
TSB ('000 t)	178.6	1265	3515.6	3841.9	3277.8	2338.5	447.2	687.3		31.3		15583.1	
Mean length (cm)	20.97	23.58	24.8	25.49	26.38	26.72	27.13	27.63		29			
Mean weight (g)	72.97	99.12	117.75	130.62	142.37	145.87	150.35	163.49		191			128.92

Table 4. Total herring biomass and abundance by age for Mini survey 3 of the Adaptive survey coverage.

	Age (years)										Numbers	Biomass	Mn Wt
Length	1	2	3	4	5	6	7	8	9	UKN	(*10-$^{6)}$	('000 t)	(g)
11.5													
12													
12.5													
13													
13.5													
14													
14.5													
15													
15.5													
16													
16.5													
17													
17.5													
18	148										148	5.9	40
18.5													
19	348										348	19.4	56
19.5	286										286	15.4	54
20	70										70	4.1	59
20.5	132										132	8.6	66
21	197										197	12.7	65
21.5	277										277	19.3	69.5
22	876	606	606								2089	186.7	89.35
22.5		2938									2938	269.4	91.72
23		4204									4204	381.3	90.69
23.5		2098	2504								4602	474.9	103.19
24		3886	4022								7908	824.2	104.22
24.5			9334	5010							14344	1650.4	115.05
25			11389	7410	961						19760	2402.5	121.58
25.5		828	6282	9457	2968	1657					21192	2703.9	127.59
26			1788	6671	7565	3989	688	619			21320	2904.5	136.23
26.5		1180		4718	7841	5690	278	347			20052	2911.2	145.18
27				409	8864	4227	205				13705	2036.8	148.62
27.5					756	4467	1855	893			7971	1268.8	159.17
28								2228			2228	384.1	172.39
28.5							343	755			1098	188.8	171.94
29										197	197	37.6	191
29.5							137				137	24	175
30													
30.5													
31													
31.5													
TSN (*10-³)	2333	15740	35926	33676	28954	20029	3506	4842		197	145204		
TSB ('000 t)	162.8	1569.3	4217.9	4367.3	4147.3	2907.2	534	791.1		37.6		18734.5	
Mean length (cm)	20.7	23.58	24.74	25.5	26.4	26.65	27.27	27.62		29			
Mean weight (g)	69.77	99.7	117.4	129.69	143.23	145.15	152.32	163.37		191			129.02

Table 5. Total herring biomass and abundance by age for Mini survey 4 of the Adaptive survey coverage.

	Age (years)										Numbers	Biomass	Mn Wt
Length	1	2	3	4	5	6	7	8	9	UKN	(*$10^{-6)}$	('000 t)	(g)
11.5													
12													
12.5													
13													
13.5													
14													
14.5													
15													
15.5													
16										26	26		
16.5										261	261	9	35
17										444	444	16.5	37
17.5	1097										1097	42.5	39
18	2063										2063	85.7	42
18.5	1907										1907	84.7	44
19	1619										1619	77	48
19.5	1201										1201	62.4	52
20	966										966	54.2	56
20.5	862										862	51.3	59
21	209										209	14	67
21.5	157										157	11.1	71
22		183									183	14.8	81
22.5		261									261	23	88
23		235									235	18	76.56
23.5			157								157	16.5	105.5
24				183							183	19.8	108.29
24.5			78	104							183	20.8	114
25			261								261	27.5	105.2
25.5				261							261	32	122.7
26				78							78	11	141
26.5													
27					52						52	7	134
27.5						26					26	4.1	158
28													
28.5													
29													
29.5													
30													
30.5													
31													
31.5													
TSN (*10^{-3})	10081	679	496	627	52	26				731	12693		
TSB ('000 t)	482.9	55.8	53.2	74.5	7	4.1				25.5		703.1	
Mean length (cm)	18.9	22.54	24.45	24.96	27	27.5				16.79			
Mean weight (g)	47.9	82.15	107.21	118.92	134	158				36.2			55.51