FEAS Survey Series: Industry Acoustic Survey/01/2019

Atlantic Herring in 6aS/7b, Industry Acoustic Survey Cruise Report

1 – 17 December, 2019

Herring (*Clupea harengus*) Linnaeus 1758

RV *Celtic Voyager and* MFV *Ros Ard SO745*

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Marine Institute
Foras na Mara

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

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1. Introduction

An acoustic survey of Atlantic herring *Clupea harengus* was conducted in ICES areas 6aS/7b in December 2019. This survey is the fourth in a time series that is hoped will be developed into a long-term index of spawning/pre-spawning herring in 6aS/7b, for use in stock assessments. The previous surveys in 2016, 2017 and 2018 are reported in O'Malley et al (2017, 2018 and 2019). Following the ICES benchmark workshop on Atlantic herring in 6aN and 6aS/7b, c (ICES 2015a), the individual stock assessments have been combined into one assessment encompassing both stocks. ICES still considers two separate stocks exist. The main reason for the merging for assessment purposes has been that the catches of mixed aggregations in the commercial fishery and in the summer acoustic survey could not be separated into the different stock components. The consequence of this has been a zero TAC advice for herring in these areas since 2015 (ICES 2015b). To better understand the individual stocks, acoustic/trawl surveys are conducted on both stocks close to spawning time. The 6aN survey is conducted on spawning aggregations there in autumn. This survey for 6aS and 7b herring is conducted in winter. The timing of these surveys coincides with herring spawning/pre-spawning aggregations of these stocks; therefore abundance indices could be used as stock specific indices in the future.

The 2019 survey was completed in 6aS/7b during December on the more dominant winter spawning herring in this area. Spawning is known to occur outside these times in 6aS/7b; however the timing was considered to be appropriate considering the resources available. Results from the survey was presented to the ICES Working Group meeting for International Pelagic Surveys (WGIPS) in January 2020 and the data and results are documented there also.

Figure 1. 6aS/7b industry acoustic survey in 2019: The two vessels, RV *Celtic Voyager* and MFV *Ros Ard SO745* were used in the Atlantic Herring in 6aS/7b Industry Acoustic Survey in 2019.

Survey objectives

Both 6aN and 6aS/7b surveys are part of a collaborative partnership between Ireland, The Netherlands and UK (Scotland) that aims to improve understanding of the individual stock components of herring in 6a and 7b. The work continues the time-series of abundance and biomass data on the individual spawning components of herring stocks in 6aN and 6aS/7b. Abundance and biomass indices for herring in 6aS/7b are generated as per standard acoustic survey protocols. Samples from spawning herring are used for morphometric studies, ageing, genetic analyses and otolith microstructure. The overall survey objectives are:

- Conduct an acoustic/trawl survey in 6aS/7b; targeting pre-spawning and spawning aggregations of herring
- Collect acoustic data and detailed biological information (length, weight, sex, maturity, age) of herring to allow estimation of the biomass and distribution of herring in 6aS/7b
- Collect morphometric and genetic data on spawning herring to distinguish whether the 6aS and 7b stocks can be differentiated from the stocks in 6aN

Survey plan

The 2019 survey was conducted using two vessels RV *Celtic Voyager* and MFV *Ros Ard SO745* (Figure 1; appendix 3). The weather was poor during the Celtic Voyager survey (1 – 10th December), and some of the survey areas were missed as a consequence. The *Ros Ard* was chartered to cover the Lough Swilly strata at short notice on the 17th December. The Lough Swilly strata is known to be an important area for pre-spawning herring during this time of the year. This behaviour was evident from the previous 3 year's surveys and information from the fishery, as part of a monitoring TAC that applies to 6aS/7b. The survey is designed to collect acoustic information and samples from pre-spawning aggregations of herring in 6aS and 7b. Known herring spawning areas are shown in Figure 2. The survey objective in 2019 covered the area in 6aS and 7b, focussed on areas where herring are known to be either spawning or in pre-spawning migrations during this time of the year. Spawning time in this area is variable, generally between October and February (Table 1), however, it is expected that a significant proportion of the 6aS/7b herring stock is contained by this survey design.

Survey design

The 2019 planned survey with parallel and zig/zag transect design (with 7.5 and 3.5 nmi spacing) is shown in Figure 3. The planned survey area covered up to the 55.6˚N line in the north and 7.3˚W line in the east. To the west, the survey was bounded by 10.6˚W and south to 53.2N approximately, off the west coast of Galway. Poor weather, including storm Atiyah meant that a lot of the survey area was not completed as planned in 2019. The straight line transects were completed at constant speed (or as close to as possible). Deviations from the planned transects were documented on acoustic log sheets. When the vessel deviated from transect for any reason (e.g. fishing) it returned to the same position to resume the survey.

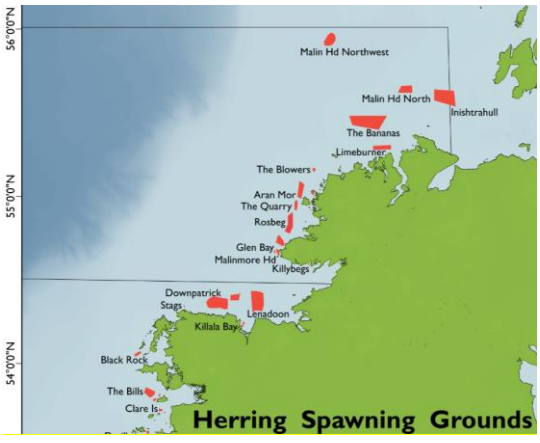

Figure 2. 6aS/7b industry acoustic survey in 2019: herring spawning grounds in 6aS and 7b (from O'Sullivan, 2013).

Table 1. 6aS/7b industry acoustic survey in 2019: Spawning areas, spawning grounds and spawning beds in 6aS and 7b. Area (km^2) and depth (m) refer to individual spawning beds (from O'Sullivan, 2013).

Spawning Area	Spawning Ground	Spawning Bed	Depth (m)	Area (Sq Km)	Activity
North Donegal	Malin Head	Inishtrahull	45	121.58	November
		Malin Head North	90	39.06	November
	Limeburner	Limeburner	30	33.28	November
		The Bananas	58	169.17	Nov and Feb
	Tory	Malin Head Northwest	70-90	47.42	Nov and Feb
West Donegal	The Blowers	The Blowers	30	3.96	Oct/Nov
		Stags	20	0.89	Nov/Dec
	Aran Mor	Aran Mor 1	43	32.35	Oct/Nov
		The Quarry	70-80	11.84	October
	Rosbeg 1	Rosbeg 1.1	32-36	0.13	Oct/Nov
	Rosbeg 2	Rosbeg 2.1	43	44.06	October
	Glen Head	Glen Bay	32-36	24.17	Nov/Dec
		Malinmore Head 1	18	6.31	November
		Malinmore Head 2	90	1.59	Jan/Feb
Donegal Bay	Killybegs	Killybegs 1	20	1.01	Dec/Jan
	Lennadoon	Lennadoon 1	32-42	101.92	Jan/Feb
		Killala Bay	25	3.05	January
	Downpatrick	Downpatrick West	32	23.66	November
		Downpatrick/Ceide Fields	34-45	97.05	Dec/Jan
Mayo	The Stags	The Stags 1	36	0.89	November
	Blackrock	Blackrock 1	36	7.74	Oct/Nov
	Clare Island	The Bills	36	29.83	November
		Clare Island 1	32	3.07	Oct/Nov
		Clare Island 2	36	1.58	Oct/Nov
		South Clare Island 1	45	3.71	December
		South Clare Island 2	~40-45	2.01	Nov/Dec
	Lecky Rock	Davillaun/Lecky Rock	20	3.63	Sept/Oct

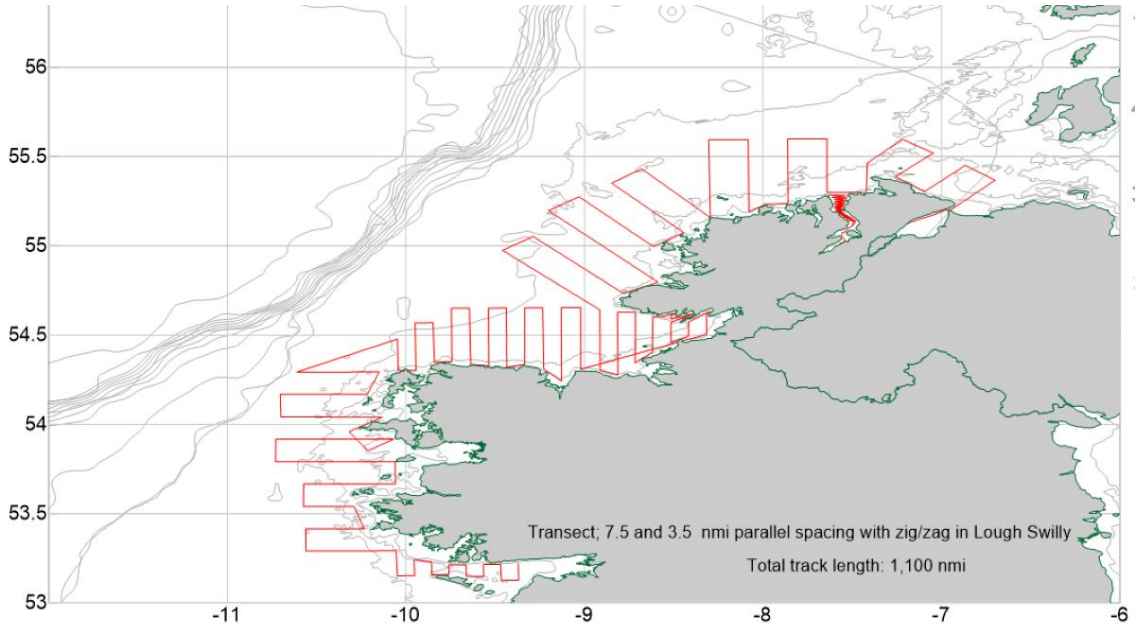

Figure 3. 6aS/7b industry acoustic survey in 2019: The total planned transect length was 1100 nmi (start 53˚13N and 9.22˚W) with progress from south to north. The survey design allows for some intense surveys in areas where fish are observed and also in areas known to contain herring from information from the fleet (e.g. Lough Swilly, Lough Foyle, Inver Bay).

Scientific personnel

Organisation	Name	Capacity	Vessel
MI (FEAS)	Michael O'Malley	Acoustics (Chief Scientist)	*Celtic Voyager and Ros Ard*
MI (FEAS)	Turloch Smith	Acoustics and Biology	*Celtic Voyager*
Contractor	John Power	Acoustics and Biology	*Celtic Voyager*
Contractor	Frankie McDaid	Acoustics and Biology	*Celtic Voyager*
MI (FEAS)	Michael Gras	Acoustics	*Celtic Voyager*
MI (FEAS)	Eugene Mullins	Acoustics and Biology	*Ros Ard*

2. Materials and Methods

Sampling protocols and equipment specifications

Acoustic data were collected using a SIMRAD EK60 scientific echosounder with transducers (38 kHz and 120 kHz) on a towed body on the RV *Celtic Voyager* and from a pole-mounted system on the the MFV *Ros Ard* (120 kHz only). GPS feeds were obtained from the vessels, and the whole topside system was powered by an un-interrupted power source (UPS) and located in the wheelhouse. Vessel details and set up are provided in Appendices 3 and 4.

Acoustic survey protocols

The survey was conducted continuously over 24 hours due to the limited daylight in December and scale of coverage planned. Survey speed was approximately 8 knots, reduced as needed depending on sea conditions. In addition, all other acoustic sounders that might cause interference with the EK60 were turned off. During fishing operations, the towed body was lifted out of the water and placed on the deck. Survey log sheets were used to record all transect data, including transect position, haul position and other events taking place on and off transect.

Calibration of acoustic equipment

A successful calibration of the EK60 120kHz echosounder was carried out in Lough Swilly at the end of the survey on 17/12/2019. The 38kHz echosounder was not calibrated and was not used for biomass estimation in 2019. A chain clump was dropped off the stern of the *Ros Ard* to assist in keeping the vessel in position during calibration. Water depth was approximately 25m at the calibration site. The calibration was carried out using standard methodology as described by Foote *et al* (1987). The SIMRAD Lobe calibration software (SIMRAD 2003) was used and the beam model was updated for the 120kHz echosounder. The calibration was made possible by good conditions in the deep water in the Lough. There was minimal interference from biota in the water column during the calibration. Acoustic settings are given in Table 2. Results of the calibration are presented in Appendix 1.

Acoustic data acquisition

Acoustic data were recorded onto the hard-drive of the processing computer. Acoustic settings are shown in Table 2. The "RAW files" were logged via a continuous Ethernet

connection as "EK5" files to a laptop and a HDD hard drive as a backup. Sonar Data's Myriax Echoview® Live viewer (V10.0) was used to display echograms in real time and to allow the scientists to scroll through noting the locations and depths of target schools to a log file. A member of the scientific crew monitored the equipment continually. Time and location were recorded for each transect start/end position within each stratum. This log was also used to monitor "off track events" such as fishing operations and intertransects. Acoustic raw data files were backed up every 24 hrs.

Acoustic settings

Table 2. 6aS/7b industry acoustic survey in 2019: Acoustic settings

Area	Vessel	Transducer and frequency	Echosounder	Power/ pulse duration ping interval	Environment	Calibration location/ date	Standard target reference
6aS/7b	*Celtic Voyager and Ros Ard*	Towed body and pole mounted split beam ES120 – 7CD (120kHz)	SIMRAD EK60	Power = 300W (120kHz); Pulse duration = 1.024ms Ping interval = 0.33	Temp = 10.0˚C, Salinity = 35ppt, Sound speed = 1493.89 m/s	Lough Swilly, Co. Donegal 17th December 2019	-39.48dB

Echogram scrutinisation

Scrutinising echograms involves identifying fish marks and assigning them to species, and ensuring that any non-fish acoustic signals are not included as fish (e.g. bottom signals). Assigning fish marks to species relies upon (i) evidence from the targeted hauls made during the survey, (ii) prior experience (e.g. fishermen and acoustic scientists), (iii) multi-frequency analysis where possible and (iv) knowledge of fish behavior. Following agreed guidelines for classification (e.g. ICES 2015c) of marks greatly improves the consistency in scrutiny, and hence in the quality and comparability of the biomass estimates.
Acoustic fish marks were classified in to the following categories (See example echograms showing herring and horse mackerel aggregations in Appendices 2a to 2f):

1. **Herring** – confident that the marks were herring based on either evidence from a targeted haul or proximity, similarity to other schools known to be herring, or information from the fishery
2. **Horse mackerel** – confident that the marks were horse mackerel based on either evidence from a targeted haul or proximity and similarity to other schools known to be horse mackerel, or information from the fishery
3. **Sprat** - confident that the marks were sprat based on either evidence from a targeted haul or proximity, similarity to other schools known to be sprat, or information from the fishery
4. **Unclassified** – confident that the marks were not herring, sprat or horse mackerel based on either evidence from a targeted haul or proximity and similarity to other schools known to not to be herring, or characteristic atypical of herring, sprat or horse mackerel schools, or information from the fishery

Some fishing took place in areas where the fleet had been actively fishing on herring previously. The current fishery is restricted to a relatively low monitoring TAC allowed on herring in 6aS (circa 1600 t). The stock is considered to be vulnerable, but the low-level

monitoring fishery is kept open as part of an effort to continue the long time series of catch data coming from the fishery (ICES 2016). It was decided that herring samples from the fishery would be adequate to work up an acoustic estimate from areas where the fishery was sampled at the same time as the survey. This was similar to the approach taken in 2016, 2017 and 2018. Herring marks were very strong in some areas and were in extremely localised aggregations, particularly in Lough Swilly.

Echograms were processed and subsequently analysed as separate transects. Off track events, such as data collected during fishing, transiting to the start point, and off-track searching using sonar were excluded from further analysis. Echo integration was performed on regions which were defined by enclosing selected parts of the echogram that corresponded to one of the three categories above. The echograms were generally analysed at a threshold of -70 dB. While it is desirable to be consistent in the setting of this parameter, in practice the setting is determined largely by the need to filter out fish schools from other acoustic signals that create noisy backscatter data.

Fishing operations for scientific samples

During the acoustic survey, selected fish marks were targeted to capture fish samples for the purposes of:

(i) Confirming the species identity of acoustic marks, particularly those suspected to be herring, horse mackerel or sprat
(ii) Collecting samples for biological analysis (length, weight, sex, maturity, age and genetics)

The fishing operations for samples were directed to take a catch of the smallest possible size sufficient for biological sampling A single pelagic midwater trawl was used during the survey. The trawl speed averaged about 5kts. The net was fished with a vertical mouth opening averaging 12m. The net opening during fishing was observed using a cable linked netsonde.

Haul information

Haul data were recorded using the same template for all Marine Institute surveys (one sheet per haul). Information was recorded on the date, time, fishing position, depth, gear, catch composition, total weight of catch and weight of the sub sample taken for length frequency and biological sampling. For hauls used in helping to scrutinize the acoustic data, additional information was recorded on the sheets to show how the acoustic traces looked on the netsonde and echosounder. A screen grab from the echosounder was also taken of each mark. In the comments box, comments were made on whether or not the targeted schools were captured by the trawl, and any other relevant information, including whether fish were spawning (based on "running" eggs and milt upon capture).

Biological sampling

All components of the catch were sorted to species level and weight by species was recorded. Length, weight, sex, maturity data were recorded and otoliths extracted for individual herring in a random 50 fish sample from each trawl haul. In addition, 100 length/weight and a further sample of fish length only measurements were taken up to 60 individual fish in a single length class. No ageing was carried out onboard and samples were analysed back in

the lab. The appropriate raising factors were calculated and applied to provide length frequency compositions for the bulk of each haul. For horse mackerel and sprat, length and weight measurements were taken for 100 individuals per trawl and a further sample of fish length only measurements were taken up to 60 individual fish in a single length class.

Length measurements

The length of herring in the subsample was measured and recorded to the nearest 0.5 cm below for herring. This data is used to determine a length frequency distribution of the catch and subsequently to apply an age-disaggregated estimate of biomass. Horse mackerel were measured to the nearest 1.0 cm below

Analysis methods - age disaggregated abundance estimate

The recordings of area back scattering per nautical mile (nautical area backscattering coefficient – NASC [m^2/nmi^2]) were averaged over a 0.1 nautical mile EDSU (Elementary distance sampling unit), and the allocation of NASC values to herring and horse mackerel schools and other acoustic targets was based mainly on the composition of the trawl catches, the appearance of the echotraces, multi-frequency techniques, reports from the fleet in the same area, and experience.

The following TS-length relationships are recommended in the manual for international acoustic surveys (ICES 2015d):

Herring (38kHz) $TS = 20\log_{10}L - 71.2$ dB per individual (L = length in cm)

Horse mackerel (38kHz) $TS = 20\log_{10}L - 67.5$ dB per individual (L = length in cm)

The TS-length relationship used to integrate herring at 120kHz recommended by Edwards (1984):

Herring (120kHz) $TS = 20\log_{10}L - 76$ dB per individual (L = length in cm)

The StoX (2.7) software (http://www.imr.no/forskning/prosjekter/stox/nb-no) was used to calculate the age disaggregated acoustic abundance and biomass estimates. StoX is an open source software developed at IMR, Norway to calculate survey estimates from acoustic and swept area surveys. The program is a stand-alone application built in Java for easy sharing and further development in cooperation with other institutes, and is now routinely used to derive abundance estimates from WGIPS coordinated surveys. Estimation of abundance from acoustic surveys with StoX is carried out according to the stratified transect design model developed by Jolly and Hampton (1990). Coefficient of variance (CV) estimates of biomass and abundance for the survey strata (Donegal Bay and Lough Swilly – Figure 4) and the overall strata areas combined were generated using the RStox package (version 1.11).

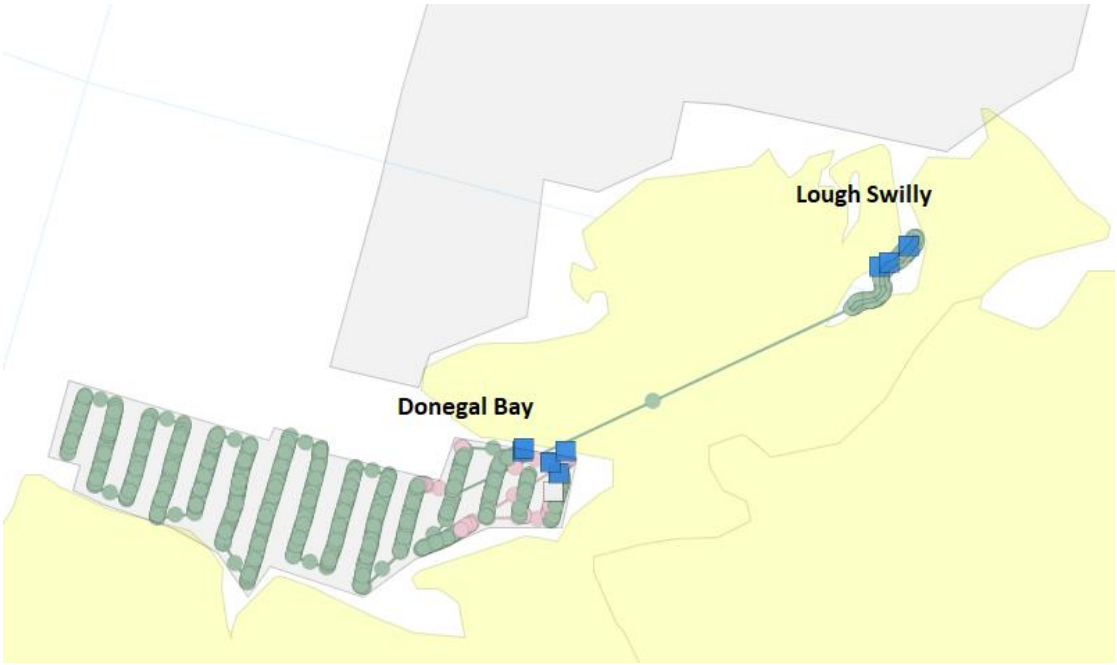

Figure 4. 6aS/7b industry acoustic survey in 2019: StoX strata delineated for the 2 scrutiny areas for herring (Lough Swilly and Donegal Bay). The haul samples stations where herring were obtained for length frequency analysis are also shown as blue squares.

Following scrutinisation of the echograms, the EDSU (0.1nmi) specific Nautical Area Scattering Coefficient (NASC - the area backscattering coefficient for a particular integration region in areal units (m^2/nmi^2)) assigned to herring marks (represented as PRC_NASC in Echoview) is exported. The calculation of age disaggregated abundance was as follows:

1. **Assigning fish length data from trawls to acoustic transects.** For each transect within each survey strata (where each of the 2 areas surveyed represents a strata in 6aS/7b [Figure 4]), the length distribution of herring associated with each transect was determined as the un-weighted mean of all trawls allocated to the respective transects.

2. **Expected backscattering cross section of fish in each length group.** The mean acoustic backscattering cross-section "sigma" (σ_{bs}) for each length group of herring was calculated from the length frequency data assigned to each transect using the target strength-length relationships for herring recommended by the ICES Working Group on International Pelagic Surveys (ICES 2015d). The target strength (TS) relationship used to calculate the mean acoustic backscattering cross-sections for herring is:

   $$TS = 20\log10\,(L) - 76 \qquad \text{[at 120 kHz] } \textit{for herring}$$

   The mean acoustic backscattering cross section is:

   $$\sigma_{bs} = 10^{(TS/10)}$$

3. **The average density of fish in each length class on a single transect** is calculated by dividing the NASC within each 1nmi EDSU of each transect by the length-specific σ_{bs} (acoustic backscatter cross-section) assigned to each transect. This is then averaged over the EDSUs.

4. **Numbers of fish in a single stratum & total numbers.** For each length group, a weighted average (weighted by transect length) of the mean density of herring in

each transect is multiplied by the area of the stratum. Total numbers at length is the sum for each stratum.

5. **The numbers and biomass per age & maturity class.** Trawl data on the relationship between length, age (wr) and maturity stage were used to partition the numbers at length in to estimates of numbers and biomass in each age class and maturity stage. The 9 point maturity stage classification was used for herring (Appendix 5).
6. **Estimate of the relative sampling error.** A bootstrap procedure using StoX was used to estimate the CV of the estimate of numbers at length. The procedure randomly selects transects within a stratum with replacement, and for each selected transect, the trawl stations which are assigned for the selected transect are randomly sampled with replacement. Thereafter, each run follows the same estimation procedure as used in StoX and described above.
7. **Estimates from the intensely surveyed (mini grids).** In Lough Swilly, a zig-zag transect pattern was executed, therefore this area was treated as a separate strata in StoX (Figure 4). The boundaries of the strata were delineated approximately 250m either side of the centre line of the deepest part of the Lough Swilly channel in approximately 10 – 20m water depth. The zig-zag transect lines were laid out within the boundaries set out. In the Donegal Bay and Achill strata, reduced transect spacing was used (3.5nmi). This included Bruckless and Inver Bays, where reports from the fishery indicated that fish were distributed in the area, particularly inshore. It was decided that reduced transect spacing would be beneficial in this small relatively small area.

Acoustic data were saved on hard-drives at sea and uploaded to network facilities at the Marine Institute. The acoustic metadata and cleaned post-processed EV files are stored at the Marine Institute following established procedures.

3. Results

Acoustic and biological

Approximately 600nmi of transects were completed successfully using 96 transects (81 in Lough Swilly). This resulted in a total area coverage of approximately 606 nmi², a significant reduction compared to previous surveys. There were 3 tows carried out during the survey with 2 containing herring. A total of six samples were obtained from commercial tows on herring during the fishery (Figure 5). The monitoring fishery was being conducted on smaller boats in the same areas and close to the same time as the survey. Biological samples from some of these vessels were used to augment the samples from the survey. Samples were taken from boats fishing in Lough Swilly and Inver Bay as close spatially and temporally as possible to the survey in these areas (Table 3).

Table 3. 6aS/7b industry acoustic survey in 2019: details and number of biological samples from the hauls used in the survey estimates.

Haul No	Date	Target Species	Location	Fish (measured lengths)	Weight,	Age, maturity, sex
1	25/11/2019	*Clupea harengus*	Drumanoo Head	319	77	77
2	25/11/2019	*Clupea harengus*	Drumanoo Head	313	77	77
3	27/11/2019	*Clupea harengus*	Lough Swilly	255	91	91
4	27/11/2019	*Clupea harengus*	Lough Swilly	372	81	81
5	18/12/2019	*Clupea harengus*	Inver Bay	182	66	66
6	18/12/2019	*Clupea harengus*	Inver Bay	304	93	93
7	04/12/2019	*Clupea harengus*	Inver Bay	520	150	50
7	04/12/2019	*Sprattus sprattus*	Inver Bay	312	100	NA
7	04/12/2019	*Trachurus trachurus*	Inver Bay	65	65	NA
8	06/12/2019	*Sprattus sprattus*	Inver Bay	373	100	NA
9	17/12/2019	*Clupea harengus*	Lough Swilly	665	150	55

The location of survey hauls and samples from the fishery is shown in Figure 5. The monitoring fishery in 6aS/7b began in early November and continued throughout the survey period. Most of the fishing activity was inshore in shallow water. Very strong herring marks were evident in Lough Swilly (appendix 2a and 2b) in the channel in marks that extended for many miles. This was also an area where smaller boats in the fishery were concentrating effort previously. These were fished on during the survey and a sample was obtained (haul 9). There was also a series of herring marks in Inver Bay (appendix 2c; haul 7) and Drumanoo Head (appendix 2d) in discreet areas. There were very few herring marks offshore in the Donegal Bay strata (e.g. north Mayo coast). Consequently, the distribution of herring NASC values is dominated by Lough Swilly in particular (Figure 6). There were a lot of horse mackerel marks in the area to the north and east of the Stags of Broadhaven off the north Mayo coast (Appendix 2f and 6). Sprat marks were confined mostly to the Donegal Bay area (appendix 2.e and 7).

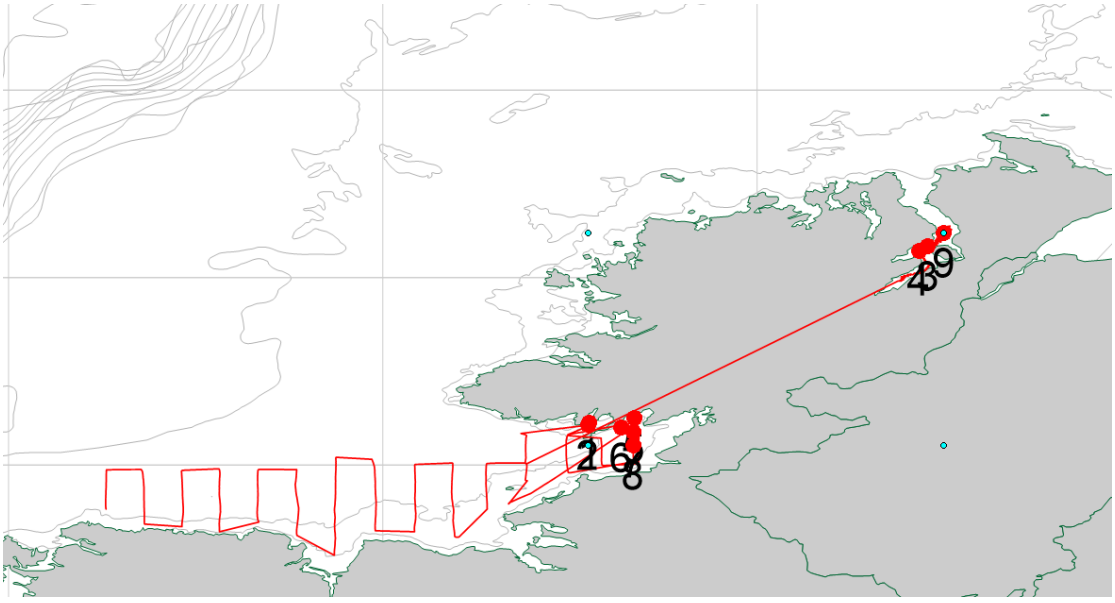

Figure 5. 6aS/7b industry acoustic survey in 2019: distribution of biological samples, including samples from the survey (hauls 7-9) and the monitoring fishery (1-6).

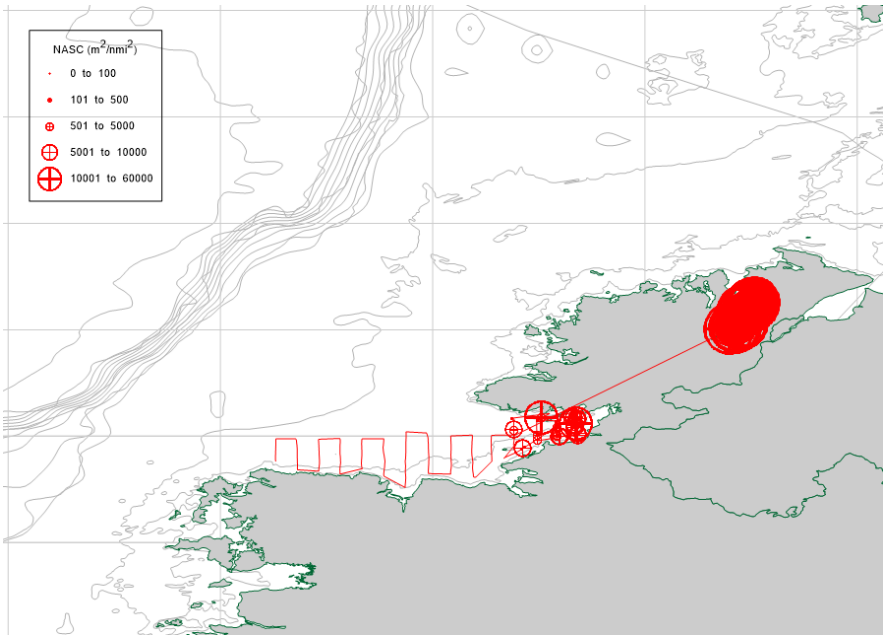

Figure 6. 6aS/7b industry acoustic survey in 2019: distribution of NASC (m²/nmi²) allocated to herring.

Length frequency

The relative length frequency distributions of herring in the hauls/samples that contained herring is shown in Figure 7. There was a good spread of length classes in all hauls, with most hauls dominated by larger (> 22 cm) mature fish. Smaller herring dominated in hauls 7 and 9. The samples were dominated by mature fish (Table 5), expected in fish captured close to areas and times where spawning is known to occur during this time (Table 1).

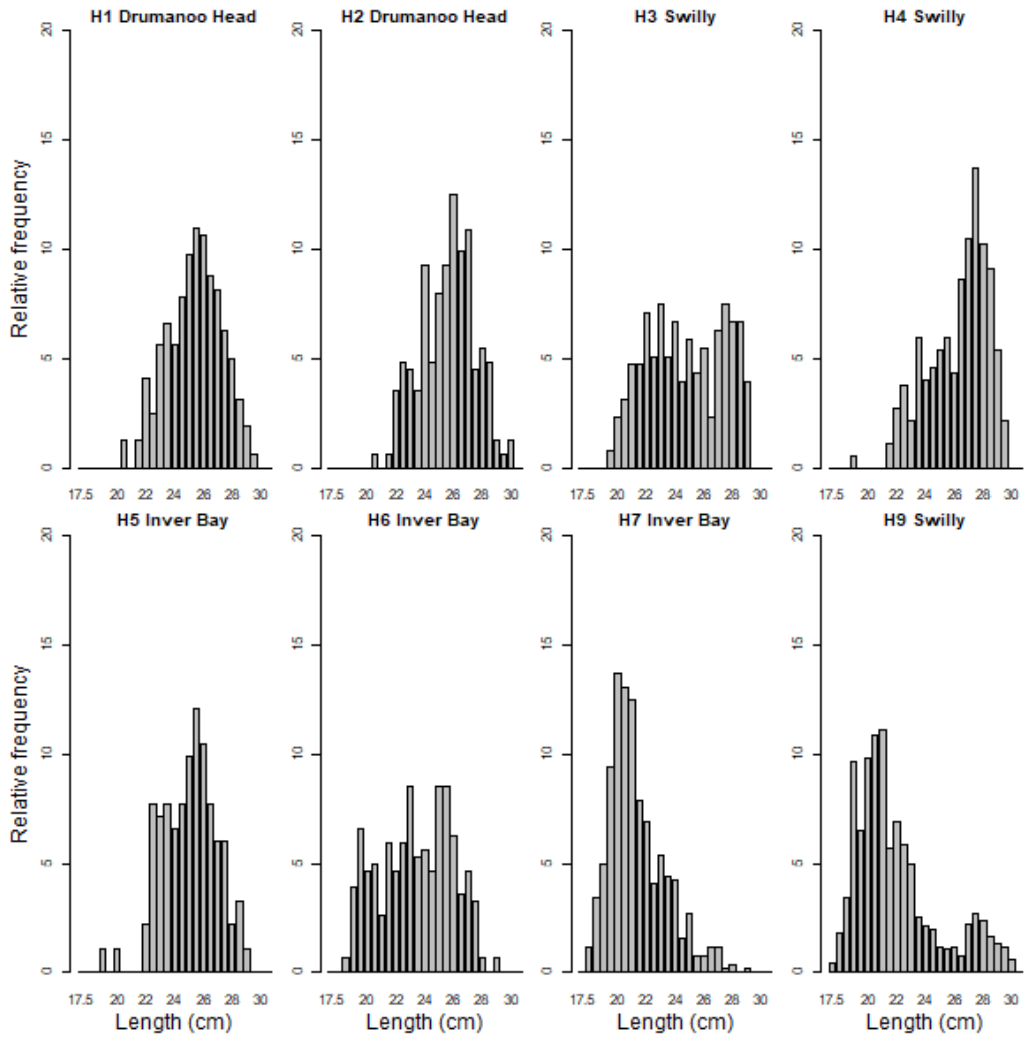

Figure 7. 6aS/7b industry acoustic survey in 2019: relative length (cm) frequency distributions of herring in each haul that contained herring.

Maturity and age (-wr) distribution

The 1- and 2-wr age class of herring constituted 52% of the overall numbers, (1-wr ~ 25% and 2-wr ~26%) followed by 15% at 3-wr, and 11% at 5-wr, 8% at 4-wr (Figure 8 and Table 4). Maturity at age for 6aS/7b herring is shown in Table 5. 74% of 1-wr herring were immature, and 10% of 2-wr herring were immature. Maturity scales used for herring are shown in Appendix 5.

The relative frequency of age (-wr) classes for herring for 2016, 2017, 2018 and 2019 is shown in Figures 10 and 11. The survey in 2019 was dominated by 1- and 2- wr fish. The 5-wr age class is still relatively strong following from relatively high numbers of 3-wr fish in 2017 and 4- fish in 2018. The 4-wr fish in 2016 and the corresponding 5-wr fish in 2017, 6-wr fish in 2018 and 7-wr fish in 2019 are all relatively low. There appears to be relatively good cohort tracking in this survey.

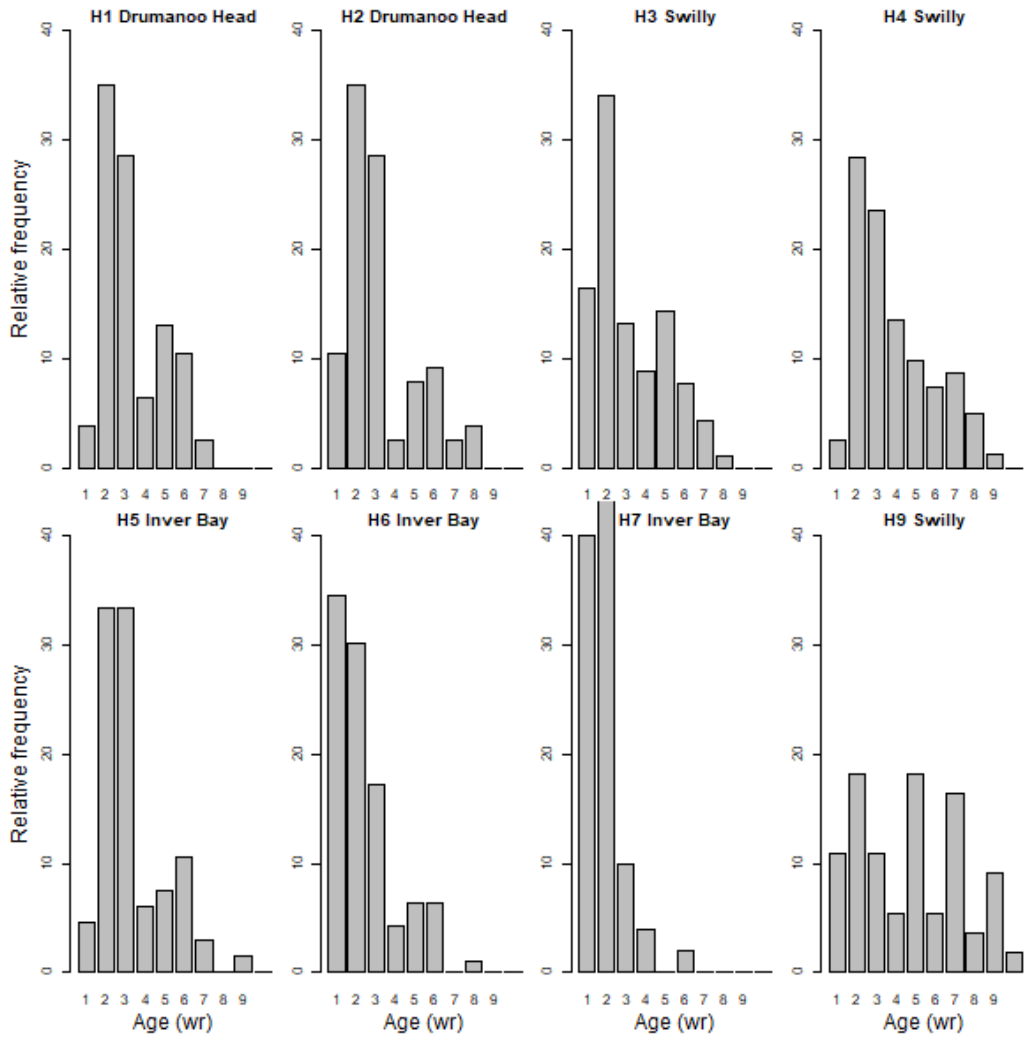

Figure 8. 6aS/7b industry acoustic survey in 2019: relative age (-wr) frequency distributions of herring in each haul.

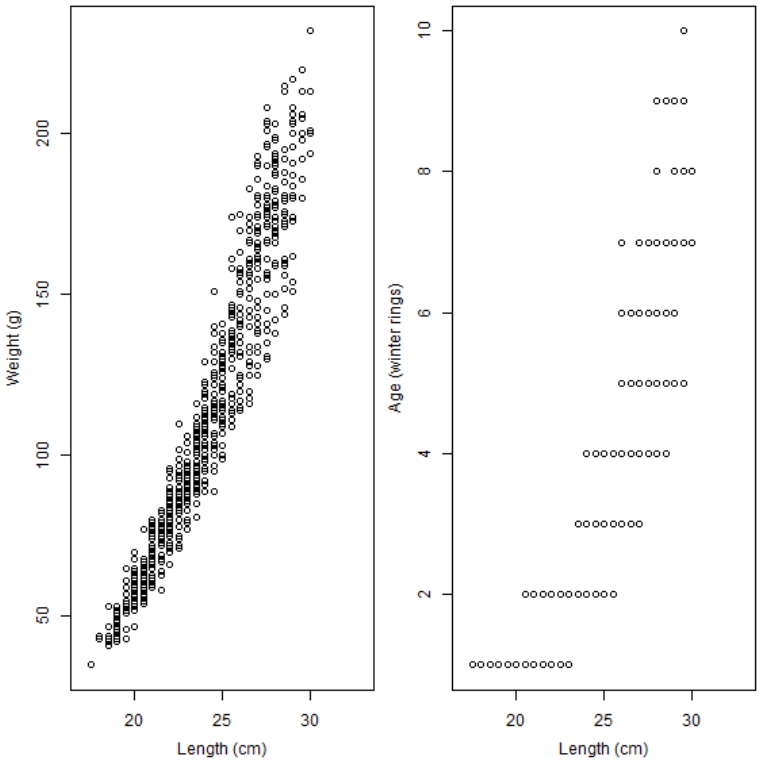

Figure 9. 6aS/7b industry acoustic survey in 2019: weight at length and age at length of herring.

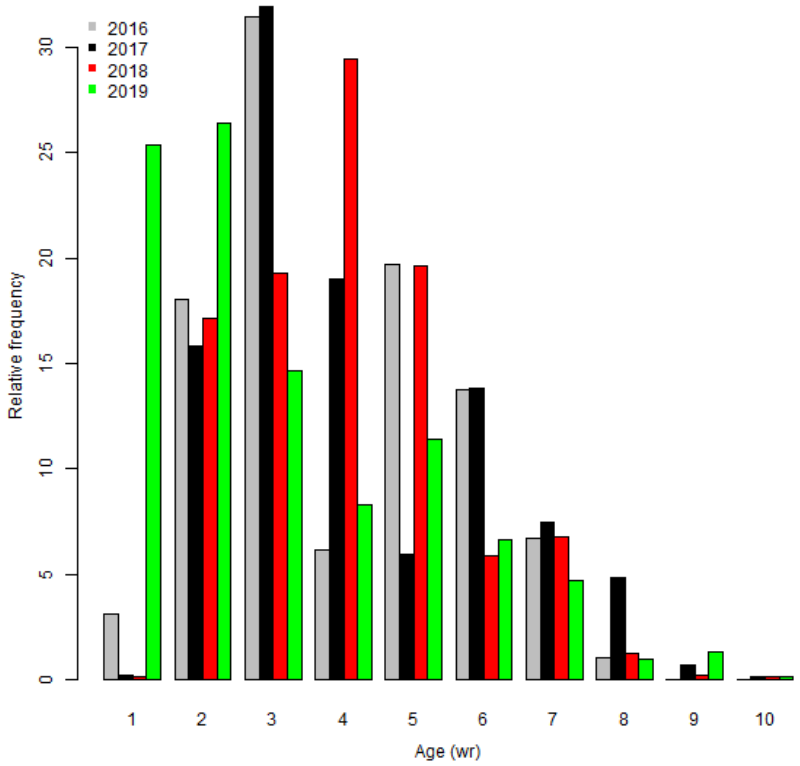

Figure 10. 6aS/7b industry acoustic survey in 2019: relative frequency of total herring ages (-wr) comparison between surveys in 2016, 2017, 2018 and 2019.

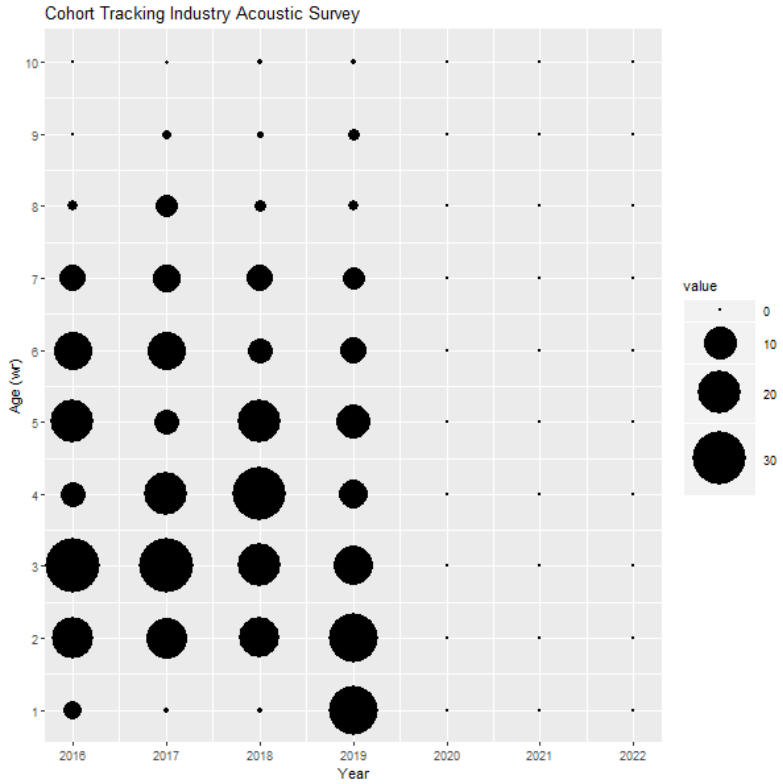

Figure 11. 6aS/7b industry acoustic survey in 2019: relative frequency of total herring ages (-wr) comparison between surveys in 2016, 2017, 2018 and 2019.

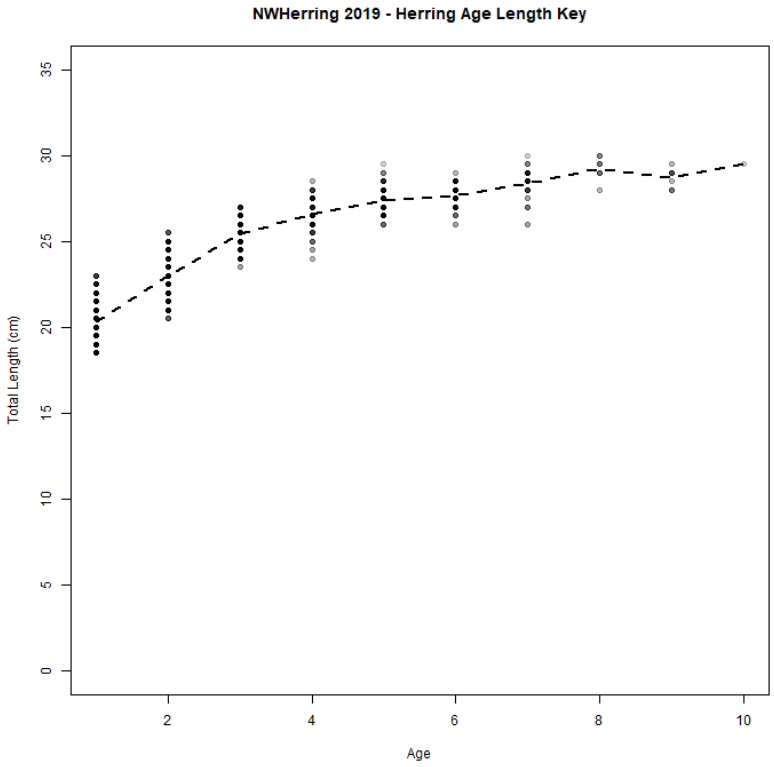

Figure 12. 6aS/7b industry acoustic survey in 2019: age (wr) length (cm) key for herring.

Table 4. 6aS/7b industry acoustic survey in 2019: relative age (wr) distribution for 6aS/7b herring in 2019.

Age (winter rings)	*Relative age distribution (%) Herring*
1	**25.36**
2	**26.35**
3	**14.66**
4	**8.31**
5	**11.42**
6	**6.67**
7	**4.70**
8	**1.00**
9	**1.35**
10	**0.16**

Table 5. 6aS/7b industry acoustic survey in 2019: maturity at age for 6aS/7b herring in 2019.

Age (winter rings)	*Immature (%)*	*Mature (%)*
1	73.6	26.4
2	10.2	89.8
3	2.3	97.7
4	0	100
5	0	100
6	0	100
7	1.5	98.5
8	0	100
9	0	100
10	0	100

Biomass and abundance

The estimated total stock biomass (TSB), number at age (TSN), numbers at length class and mean weight of herring found in each of the survey strata areas is shown in Tables 6 - 8. The transects in Lough Swilly were conducted in a zig-zag pattern due to the shallow nature of the habitat, therefore for estimation purposes, Lough Swilly was treated as a separate strata within StoX. There was only one other stratum in 2019, Donegal Bay (parallel transects with 3.5nmi. spacing). The combined estimated numbers at age and biomass at age over the entire survey area is also shown in Table 8. The TSB estimate of herring for the combined 6aS/7b area was 25,289 tonnes (Lough Swilly = 19,697 tonnes, Donegal Bay = 5,591 tonnes). The time series of age disaggregated herring data for the Industry acoustic survey is shown in table 9 and 10.

Table 6. 6aS/7b industry acoustic survey in 2019: age-disaggregated estimate of herring in survey Lough Swilly area. The estimated TSB for the Lough Swilly strata = 19,697 tonnes.

Variable: Abundance
EstLayer: 1
Stratum: Swilly
SpecCat: Clupea harengus
specialstage: TOTAL

	age												
LenGrp	1	2	3	4	5	6	7	8	9	10	Number (1E3)	Biomass (1E3kg)	Mean W (g)
17.5-18.0	249	-	-	-	-	-	-	-	-	-	249	8.7	35.00
18.0-18.5	996	-	-	-	-	-	-	-	-	-	996	42.8	43.00
18.5-19.0	1909	-	-	-	-	-	-	-	-	-	1909	80.4	42.13
19.0-19.5	5610	-	-	-	-	-	-	-	-	-	5610	250.9	44.73
19.5-20.0	4003	-	-	-	-	-	-	-	-	-	4003	213.9	53.44
20.0-20.5	6695	-	-	-	-	-	-	-	-	-	6695	369.5	55.20
20.5-21.0	7709	-	-	-	-	-	-	-	-	-	7709	447.0	57.99
21.0-21.5	8131	610	-	-	-	-	-	-	-	-	8741	577.0	66.01
21.5-22.0	5406	940	-	-	-	-	-	-	-	-	6346	416.8	65.69
22.0-22.5	1243	7956	-	-	-	-	-	-	-	-	9199	741.4	80.59
22.5-23.0	-	8129	-	-	-	-	-	-	-	-	8129	718.7	88.41
23.0-23.5	1876	6164	-	-	-	-	-	-	-	-	8040	707.1	87.95
23.5-24.0	-	6914	576	-	-	-	-	-	-	-	7490	784.6	104.75
24.0-24.5	-	6607	461	-	-	-	-	-	-	-	7068	770.1	108.96
24.5-25.0	-	2739	3028	-	-	-	-	-	-	-	5767	697.3	120.92
25.0-25.5	-	1600	4000	1280	-	-	-	-	-	-	6879	866.5	125.95
25.5-26.0	-	-	4826	1401	-	-	-	-	-	-	6227	863.7	138.70
26.0-26.5	-	-	2076	2875	639	-	479	-	-	-	6069	865.2	142.55
26.5-27.0	-	-	751	1954	2104	1653	-	-	-	-	6463	1038.2	160.65
27.0-27.5	-	-	750	3299	3149	2849	450	-	-	-	10496	1804.2	171.89
27.5-28.0	-	-	-	2545	8834	749	1048	-	-	-	13176	2238.7	169.91
28.0-28.5	-	-	-	1950	3749	3149	1200	150	450	-	10648	1940.4	182.24
28.5-29.0	-	-	-	466	2643	2643	3887	-	-	-	9639	1683.4	174.65
29.0-29.5	-	-	-	-	302	754	1508	1206	2111	-	5880	1138.0	193.54
29.5-30.0	-	-	-	-	-	-	810	463	231	347	1851	366.1	197.75
30.0-30.5	-	-	-	-	-	-	249	83	-	-	332	67.2	202.25
TSN(1000)	43826	41660	16468	15770	21419	11797	9630	1902	2792	347	165611	-	-
TSB(1000 kg)	2560.5	3968.2	2191.2	2544.0	3642.4	2113.5	1696.0	374.2	545.5	62.5	-	19697.9	-
Mean length (cm)	20.34	23.07	25.26	26.71	27.52	27.69	28.34	29.09	28.88	29.50	-	-	-
Mean weight (g)	58.42	95.25	133.06	161.32	170.05	179.16	176.11	196.73	195.38	180.00	-	-	118.94

Table 7. 6aS/7b industry acoustic survey in 2019: age-disaggregated estimate of herring in survey Donegal Bay area. The estimated TSB for the Donegal Bay strata = 5,591 tonnes.

Variable: Abundance
EstLayer: 1
Stratum: Donegal Bay
SpecCat: Clupea harengus
specialstage: TOTAL

	age											
LenGrp	1	2	3	4	5	6	7	8	9	Number (1E3)	Biomass (1E3kg)	Mean W (g)
17.5-18.0	-	-	-	-	-	-	-	-	-	-	-	-
18.0-18.5	115	-	-	-	-	-	-	-	-	115	5.0	43.17
18.5-19.0	410	-	-	-	-	-	-	-	-	410	17.6	42.80
19.0-19.5	1001	-	-	-	-	-	-	-	-	1001	45.6	45.55
19.5-20.0	1594	-	-	-	-	-	-	-	-	1594	90.7	56.93
20.0-20.5	1928	-	-	-	-	-	-	-	-	1928	114.4	59.32
20.5-21.0	1938	45	-	-	-	-	-	-	-	1983	125.7	63.43
21.0-21.5	1361	209	-	-	-	-	-	-	-	1571	109.0	69.39
21.5-22.0	825	1025	-	-	-	-	-	-	-	1850	136.2	73.62
22.0-22.5	823	1427	-	-	-	-	-	-	-	2251	178.6	79.38
22.5-23.0	556	1897	-	-	-	-	-	-	-	2454	205.3	83.69
23.0-23.5	251	2761	-	-	-	-	-	-	-	3012	276.8	91.90
23.5-24.0	-	3310	-	-	-	-	-	-	-	3310	328.4	99.22
24.0-24.5	-	1719	860	96	-	-	-	-	-	2675	289.3	108.17
24.5-25.0	-	1580	1271	103	-	-	-	-	-	2954	338.1	114.44
25.0-25.5	-	677	3319	-	-	-	-	-	-	3996	476.7	119.30
25.5-26.0	-	461	3758	248	-	-	-	-	-	4467	601.1	134.57
26.0-26.5	-	-	3681	-	-	106	-	-	-	3787	534.7	141.20
26.5-27.0	-	-	1891	550	653	103	-	-	-	3198	479.9	150.06
27.0-27.5	-	-	343	514	1199	377	-	-	-	2433	387.3	159.20
27.5-28.0	-	-	-	430	1147	538	-	-	-	2114	364.3	172.29
28.0-28.5	-	-	-	200	100	900	100	-	-	1300	228.1	175.51
28.5-29.0	-	-	-	-	-	538	115	-	115	768	136.3	177.55
29.0-29.5	-	-	-	-	35	-	277	69	-	381	69.3	181.55
29.5-30.0	-	-	-	-	63	-	-	63	-	126	25.5	202.50
30.0-30.5	-	-	-	-	-	-	-	127	-	127	27.5	216.00
TSN(1000)	10803	15112	15122	2141	3197	2561	493	260	115	49804	-	-
TSB(1000 kg)	682.8	1454.1	2004.0	325.5	537.0	426.4	93.1	51.1	17.5	-	5591.5	-
Mean length (cm)	20.44	23.25	25.50	26.64	27.18	27.71	28.68	29.61	28.50	-	-	-
Mean weight (g)	63.21	96.22	132.52	152.05	167.95	166.48	189.01	196.77	152.00	-	-	112.27

Table 8. 6aS/7b industry acoustic survey in 2019: age-disaggregated estimate of herring in total survey area. The total estimated TSB for the entire survey area = 25,289 tonnes.

Variable: Abundance
EstLayer: 1
Stratum: TOTAL
SpecCat: Clupea harengus
specialstage: TOTAL

	age												
LenGrp	1	2	3	4	5	6	7	8	9	10	Number (1E3)	Biomass (1E3kg)	Mean W (g)
17.5-18.0	249	-	-	-	-	-	-	-	-	-	249	8.7	35.00
18.0-18.5	1111	-	-	-	-	-	-	-	-	-	1111	47.8	43.02
18.5-19.0	2320	-	-	-	-	-	-	-	-	-	2320	98.0	42.25
19.0-19.5	6610	-	-	-	-	-	-	-	-	-	6610	296.5	44.85
19.5-20.0	5596	-	-	-	-	-	-	-	-	-	5596	304.7	54.44
20.0-20.5	8623	-	-	-	-	-	-	-	-	-	8623	483.9	56.12
20.5-21.0	9647	45	-	-	-	-	-	-	-	-	9691	572.8	59.10
21.0-21.5	9492	819	-	-	-	-	-	-	-	-	10312	686.0	66.53
21.5-22.0	6231	1965	-	-	-	-	-	-	-	-	8196	553.0	67.48
22.0-22.5	2067	9383	-	-	-	-	-	-	-	-	11450	920.1	80.36
22.5-23.0	556	10027	-	-	-	-	-	-	-	-	10583	924.1	87.32
23.0-23.5	2127	8925	-	-	-	-	-	-	-	-	11052	983.9	89.03
23.5-24.0	-	10224	576	-	-	-	-	-	-	-	10800	1113.0	103.06
24.0-24.5	-	8327	1321	96	-	-	-	-	-	-	9743	1059.4	108.74
24.5-25.0	-	4319	4299	103	-	-	-	-	-	-	8721	1035.4	118.73
25.0-25.5	-	2277	7318	1280	-	-	-	-	-	-	10875	1343.2	123.51
25.5-26.0	-	461	8584	1649	-	-	-	-	-	-	10694	1464.8	136.98
26.0-26.5	-	-	5757	2875	639	106	479	-	-	-	9856	1399.9	142.03
26.5-27.0	-	-	2643	2504	2757	1756	-	-	-	-	9661	1518.1	157.15
27.0-27.5	-	-	1092	3813	4348	3226	450	-	-	-	12929	2191.5	169.50
27.5-28.0	-	-	-	2975	9980	1286	1048	-	-	-	15290	2602.9	170.24
28.0-28.5	-	-	-	2150	3849	4049	1300	150	450	-	11947	2168.5	181.51
28.5-29.0	-	-	-	466	2643	3180	4002	-	115	-	10407	1819.7	174.86
29.0-29.5	-	-	-	-	336	754	1785	1275	2111	-	6261	1207.2	192.81
29.5-30.0	-	-	-	-	63	-	810	526	231	347	1977	391.6	198.05
30.0-30.5	-	-	-	-	-	-	249	210	-	-	459	94.7	206.06
TSN(1000)	54629	56772	31590	17911	24616	14358	10123	2162	2907	347	215414	-	-
TSB(1000 kg)	3243.3	5422.3	4195.2	2869.5	4179.4	2539.9	1789.1	425.3	563.0	62.5	-	25289.5	-
Mean length (cm)	20.36	23.12	25.38	26.70	27.47	27.70	28.35	29.15	28.87	29.50	-	-	-
Mean weight (g)	59.37	95.51	132.80	160.21	169.78	176.90	176.74	196.73	193.66	180.00	-	-	117.40

Table 9. 6aS/7b industry acoustic survey in 2019: Time series of TSB age-disaggregated (-wr) numbers at age of herring ('000) from the industry acoustic survey 2016 – 2019.

Year	1	2	3	4	5	6	7	8	9	10	TSB
2016	7,284	34,055	71,229	15,781	46,066	31,877	14,956	2,244	0	0	35,475
2017	587	45,184	91,109	54,292	17,021	39,439	21,321	13,938	1,998	387	40,646
2018	655	59,268	66,776	101,824	67,951	20,334	23,443	4,336	931	672	50,145
2019*	54,629	56,772	31,590	17,911	24,616	14,358	10,123	2,162	2,907	347	25,289

*Reduced survey area in 2019, only Lough Swilly and partial Donegal Bay covered

Table 10. 6aS/7b industry acoustic survey in 2019: Time series of SSB age-disaggregated (-wr) numbers at age of herring ('000) from the industry acoustic survey 2016 – 2019.

Year	1	2	3	4	5	6	7	8	9	10	SSB
2016	1,894	34,048	71,229	15,781	46,066	31,877	14,956	2,244	0	0	35,038
2017	194	42,157	89,924	54,075	17,021	39,439	21,321	13,938	1,998	387	40,132
2018	328	56,127	66,242	101,500	67,951	20,334	23,443	4,336	931	672	49,523
2019*	14,438	50,961	30,869	17,911	24,616	14,358	9,972	2,162	2,907	347	22,386

*Reduced survey area in 2019, only Lough Swilly and partial Donegal Bay covered

Estimates of uncertainty

The results of the uncertainty estimates (CV) for abundance and biomass of herring in 6aS/7b are shown in Table 11. The CV for the survey overall is low (0.17), and the lowest in the time-series so far. The CV estimates on biomass and abundance are high (~0.63) for the Donegal Bay strata, but low for the Lough Swilly strata (0.13) for the survey in 2019. The biomass is dominated by herring from Lough Swilly, and as a consequence the CV for the survey overall is low. The survey design in Lough Swilly has improved in 2019 compared to 2016-2018, with increased intensity of survey transects. The ICES workshop on herring acoustic surveys on spawning fish (WKHASS) held in 2019 (ICES 2020) investigated some of these issues and results from the workshop suggested that an increased transect intensity would improve the CV in such circumstances when herring are tightly aggregated. For herring in Donegal Bay, the high CV is mostly caused by the over-reliance on a few strong acoustic marks and many transects with little or no herring marks in the strata. The survey design in the bays (Inver, Bruckless, etc.) in the Donegal Bay strata needs to be improved further as evidenced from these results.

Bias considerations for the survey are outlined in Table 12. Many of the considerations are common to all acoustic surveys and should be dealt with and reduced if possible at the survey design stage.

Table 11. 6aS/7b industry acoustic survey in 2019: uncertainty estimates of herring (with CV) by weight and number for the Donegal Bay and Lough Swilly (Swilly) and the total survey area.

```
[1] "Ton by stratum"
       Stratum     Ton.5%   Ton.50%  Ton.95%  Ton.mean   Ton.sd    Ton.cv
1: Donegal Bay   837.1315  5373.484 12567.48  5778.208 3639.277 0.6298280
2:      Swilly 15541.1950 19544.850 24210.39 19611.442 2576.146 0.1313593
[1] "Total number by stratum (mill)"
       Stratum Ab.Sum.5% Ab.Sum.50% Ab.Sum.95% Ab.Sum.mean Ab.Sum.sd Ab.Sum.cv
1: Donegal Bay   7663853   48447483  111002564    51165466  31204139 0.6098672
2:      Swilly 130287631  167697674  215107011   169344170  26011458 0.1536011
[1] "Ton by survey"
     Ton.5%  Ton.50%  Ton.95% Ton.mean   Ton.sd    Ton.cv
1: 18129.55 25103.58 33026.11 25354.98 4523.639 0.1784122
[1] "Total number by survey (mill)"
   Ab.Sum.5% Ab.Sum.50% Ab.Sum.95% Ab.Sum.mean Ab.Sum.sd Ab.Sum.cv
1: 161795140  217976474  285697115   220202643  37588416 0.1706992
```

Table 12. 6aS/7b industry acoustic survey in 2019: Bias considerations for acoustic surveys

Bias Considerations	Comment
Directed movement of fish with respect to the survey tracks	No strong directed movement at this time that would make the 'flow' of herring across the strata greater than within. Pre-spawning and spawning aggregations.
Avoidance effect	unquantified
Overlapping survey layers	NA
Shallow water	Better survey design needs to be adapted in inshore shallow areas (e.g. Inver and Bruckless Bays).
Water temperature and the propagation of the sonar beam	No problems
Quality of raw material used	There was poor weather throughout the survey in 2019 and surveys days were lost. However, the towed body performed well and good quality raw data was collected
Accuracy of calibration constant	Calibration in 2019 was successful for the 120kHz echosounder, (results shown in Appendix 1) and this frequency was used to work up the biomass and abundance estimates. The 38kHz was not calibrated and therefore not used to work up estimates.
Biomass species composition	Trawl information, results from monitoring fishery and acoustic expert agreement
The actual accuracy problem of acoustic surveys	Bias and sampling error – the CV was low (~0.17) due to the improved survey design in Lough Swilly. The CV was high in the Donegal Bay strata due to the over reliance of the estimates on relatively few very strong herring marks. The majority of the biomass was distributed in the Lough Swilly strata, therefore the overall CV for the survey was also low.

Stock containment

The survey did not contain the herring stock in 6aS/7b in 2019, however, the core areas of Lough Swilly and Donegal Bay were covered and containment most likely achieved for these areas. There was hyper-aggregating behaviour and shallow distribution (<15m) of herring in Lough Swilly in paticular. These fish were primarily in the middle of the channel in Lough Swilly, with little or no marks of fish observed in the shallow edges of the Lough. The new survey deign in Lough Swilly (tighter and more intense zig/zag transects) alleviated the concern that the stock was not contained in this area. The improvements to the survey design adapted following WKHASS workshop have improved the survey in the Lough Swilly strata. The improved methods need to be adapted in other areas for surveys in future years. The over-reliance of the estimate on few areas of high herring density led to the high CV on the estimates of abundance and biomass in the Donegal Bay strata. This could be improved in the future with better survey design in these areas. Additional areas off the west Mayo and Galway coasts were covered by this survey in searching mode again in 2019. These included a number of grounds that were known to have spawning in the past including areas around the Bills of Achill and Clare Island (Figure 1), however, no herring aggregations were located

in these areas. Spawning is known to occur outside of the areas covered by the survey in 2019, but the lack of occurrence of herring marks in the areas searched suggest that herring were in low numbers in these areas, even though containment was most likely not achieved in 2019. There were substantial areas not covered by the survey in 2019, including areas where herring have been observed by the fleet (e.g. Lough Foyle).

4. Discussion

Industry/science surveys are becoming more common as a way of improving understanding of some commercial stocks (ICES 2007; Fassler *et al* 2016; FAO 2012; O'Donnell and Nolan 2015). Using transducers already installed on the hull is a preferred option for this type of industry collaboration survey, but the towed body with 38 and 120 kHz and the pole mounted system with the 120 kHz transducer was sufficient to complete a successful survey in 2019. The timing of the survey was 4 weeks later compared to 2018. Herring were again distributed inshore, particularly in Lough Swilly. The inshore distribution of herring generally makes containment of the stock difficult in this area, however, the improved survey design in Lough Swilly resulted in a much lower measure of uncertainty (CV), compared to previous years. Although there is a lot of good information on spawning areas of herring in 6aS, the timing of migration into the spawning areas is variable. This needs to be weighed up against the need for the stock to be within the 6aS/7b area and also separated from the 6aN stock geographically at the time of the survey.

Approximately 600 miles of transects were completed, with three fishing hauls completed during the survey and 6 samples from the fishery also used. Ideally more haul samples of herring would be obtained from the survey itself, but because the monitoring fishery occurs at the same time as the survey in this area, it is appropriate to use herring samples from the monitoring fishery in this survey in these areas. This reduces the impact of the survey on the stock, particularly a concern where herring are hyper-aggregating and any unwanted catch can be avoided. There was evidence of very large marks of herring inshore in shallow areas, particularly in Lough Swilly. Most of the obvious herring marks were inshore in shallow water. Mostly smaller boats in the fleet were fishing in these inshore areas during the survey and samples from this fishing were used to work up estimates from the survey. The results from the survey in 2019 were also confirmed from reports coming from the fleet; i.e. herring hard to find offshore, herring only found in shallow inshore areas, and there were lots of horse mackerel in the area to the north and west of the Broadhaven Stags.

The low CV on the estimates of abundance and biomass was not unexpected due to the change of survey design used in 2019. This was particularly successful in Lough Swilly strata where fish are often hyper-aggregating and in the shallow channel in the upper part of the estuary. The more intense survey transects and better inshore coverage with the smaller vessel used in 2019 led to improved CV measure and resulted in most likely containing the stock in this area. Weather was poor throughout the survey and this resulted in a severely reduced area coverage for the survey. Some increased searching was achieved in Donegal Bay due to the extra time gained as a result of the reduced area coverage, when offshore areas could not be covered.

There appears to be good cohort tracking of herring in the survey between 2016, 2017, 2018 and 2019. This is encouraging; for the survey to be useful in an assessment in the future, both containment and cohort tracking in the survey are important. The survey in space and time occurred close to predicted spawning of herring in this area, therefore the survey most likely provides a measure of 6aS/7b fish only. This is also a prerequisite for its use as an

independent index for this stock in an assessment in the future. The reduced survey area in 2019 and therefore lack of containment is a concern.

This is the fourth year of this current survey effort; the survey is a good proof of concept that industry/science partnership is possible on this stock and can provide a fisheries independent survey index for this stock. The survey has provided the fourth data point on a new index of 6aS/7b herring for the surveyed area. The survey provides also a platform to continue work on splitting and stock identification of herring in the greater Malin Shelf area and also provides information on pre-spawning behaviour in inshore areas.

5. Conclusions

- The 2019 TSB estimate of 25,289 tonnes is considered to be a minimum estimate of herring in the 6aS/7b survey area at the time of the survey; all areas were not covered in 2019, and therefore the stock was not contained in the survey area.
- The majority of herring marks were observed inshore in shallow areas, particularly in upper Lough Swilly. The stock appears to have been largely contained by the survey design in this strata, an improvement on previous years. However there is still a concern regarding containment inshore in areas not covered by the survey
- The monitoring fishery is conducted on the same marks and at the same time as the survey, therefore the sampling is considered representative of the surveyed biomass.
- The survey estimation of biomass and abundance is normally conducted by integrating backscatter with the 38kHz echosounder, however, it was only possible to conduct the full survey using the 120kHz echosounder in 2019. The Swilly survey had to be organised in short time, and the pole-mounted system with the relatively smaller 120kHz transducer was the only option available for this survey.
- The target strength to length relationship used (Edwards and Armstrong, 1984) comes from empirical work done on caged herring in a Scottish sea loch; it is considered to be suitable for inshore herring in Irish waters.
- It is reasonable to consider the herring surveyed were 6aS/7b fish due to the inshore distribution and proximity to the spawning grounds.
- The survey reflected what was experienced in the monitoring fishery occurring at the same time.
- Cohort tracking - there appears to be good cohort tracking in the survey over the 4-year time-series
- The survey in 2019 was conducted ~ 4 weeks later than in 2018. This was due to vessel availability. The survey began after the fishery started in 2019. The fish were in Lough Swilly in large numbers before the beginning of the survey.
- There is a need to reduce uncertainty of estimate further through better survey design, particularly in the Donegal Bay strata (Inver, Bruckless Bays, etc.). The CV would be reduced with more intense transects particuarliy when schools are hyper-aggregating in inshore areas. The improved design in Lough Swilly in 2019 was instigated following the workshop held in 2019 (WKHASS). A similar design that deals with the inshore behaviour in Donegal Bay during this time could overcome this issue. It is hoped that an improved survey design will be used in 2020.

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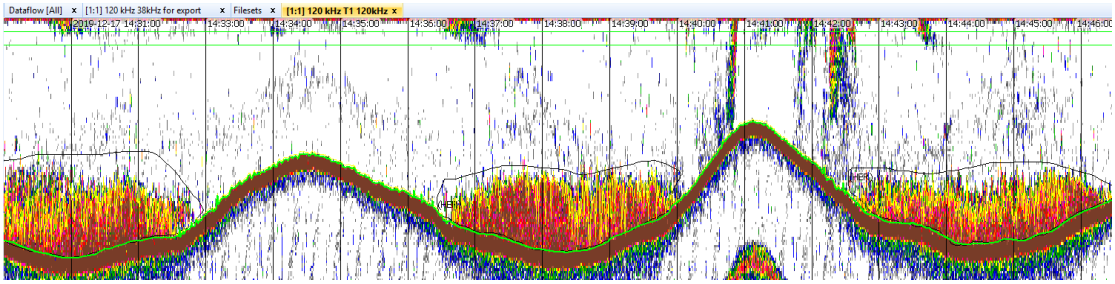
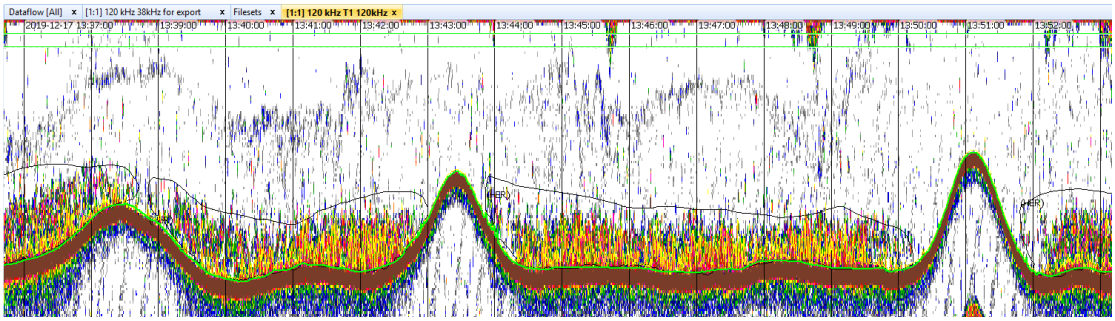
7. Appendices

Appendix 1. 6aS/7b industry acoustic survey in 2019: 120 kHz calibration results for *Ros Ard* 17/12/2019

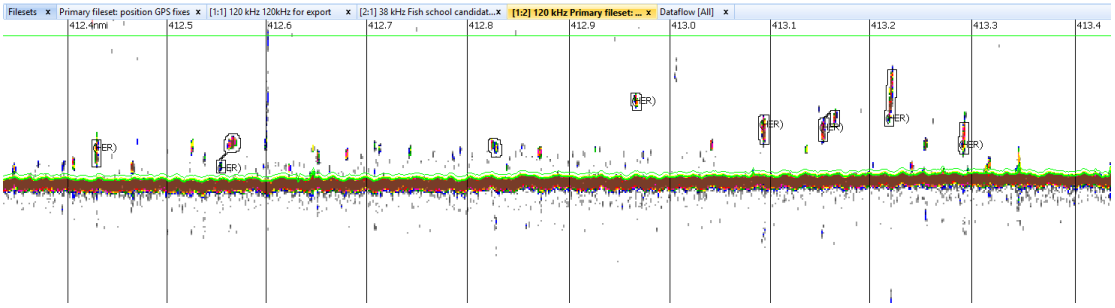
```
Calibration  Version   2.1.0.12

Date:  17.Dec.2019

Comments:
  NW Herring 2019 Calibration lough Swilly 2019/12/17 120kHz

Reference Target:
  TS                  -39.48 dB       Min. Distance         15.00 m
  TS Deviation          5.0 dB        Max. Distance         20.00 m

Transducer:  ES120-7CD  Serial No.   120
  Frequency           120000 Hz       Beamtype                Split
  Gain                 26.00 dB       Two Way Beam Angle   -20.7 dB
  Athw. Angle Sens.       23.00       Along. Angle Sens.      23.00
  Athw. Beam Angle     7.00 deg       Along. Beam Angle    7.00 deg
  Athw. Offset Angle   0.00 deg       Along. Offset Angle  0.00 deg
  SaCorrection          0.00 dB       Depth                 1.00  m

Transceiver:  GPT 120 kHz 009072034686 2-1 ES120-7CD
  Pulse Duration       1.024 ms       Sample Interval     0.191   m
  Power                  300  W       Receiver Bandwidth   3.03 kHz

Sounder Type:
  EK60 Version  2.2.1

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.  37.4 dB/km       Sound Velocity     1493.9 m/s

Beam Model results:
  Transducer Gain    = 26.95 dB       SaCorrection       = -0.34 dB
  Athw. Beam Angle   = 6.44 deg       Along. Beam Angle  = 6.43 deg
  Athw. Offset Angle = 0.01 deg       Along. Offset Angle= 0.10 deg

Data deviation from beam model:
  RMS =    0.26 dB
  Max =    1.64 dB  No. =   257  Athw. =  2.1 deg  Along = -1.7 deg
  Min =   -1.36 dB  No. =    27  Athw. = -1.5 deg  Along = -4.6 deg

Data deviation from polynomial model:
  RMS =    0.21 dB
  Max =    1.43 dB  No. =   257  Athw. =  2.1 deg  Along = -1.7 deg
  Min =   -1.08 dB  No. =    27  Athw. = -1.5 deg  Along = -4.6 deg
```



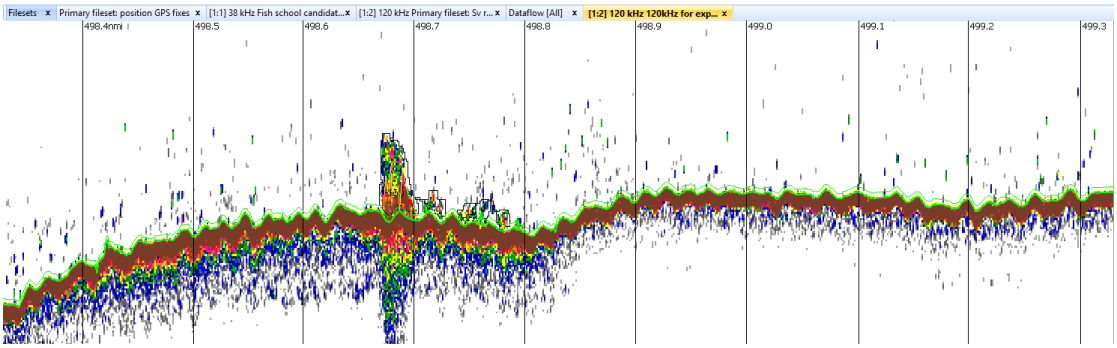
Appendix 2a. 6aS/7b industry acoustic survey on 17/12/2019: Series of herring marks (120kHz) in Lough Swilly, Co. Donegal (ICES area 6aS). Water depth max ~ 18m approximately.



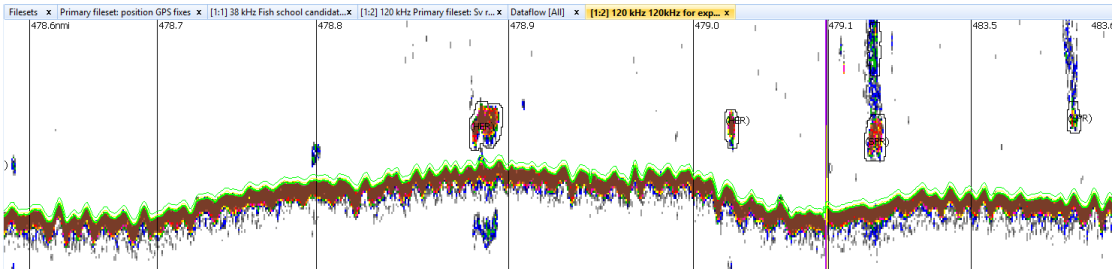
Appendix 2b. 6aS/7b industry acoustic survey on 17/12/2019: Series of herring marks (120kHz) in Lough Swilly (ICES area 6aS). Water depth max ~ 20m approximately.



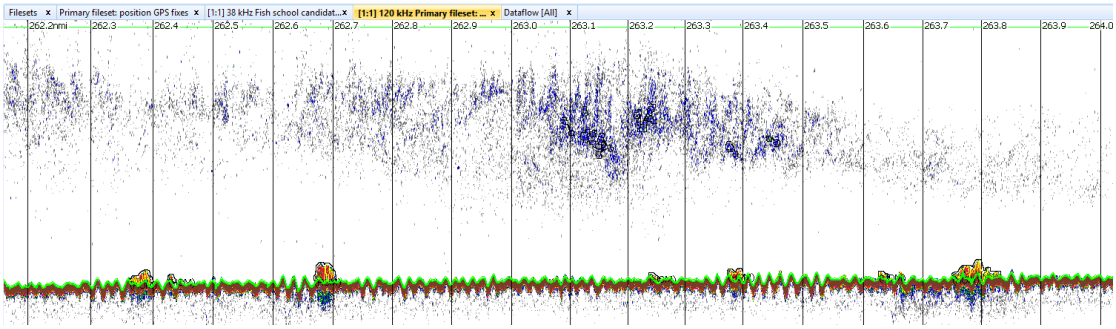
Appendix 2c. 6aS/7b industry acoustic survey in 04/12/2019: Haul 7 - series of herring marks (120kHz) in Donegal Bay (ICES area 7b). Water depth ~ 30m approximately.



Appendix 2d. 6aS/7b industry acoustic survey on 04/12/2019: Herring mark at Drumanoo Head (ICES area 6aS). Water depth max ~ 30m approximately.



Appendix 2e. 6aS/7b industry acoustic survey on 06/12/2019: Haul 8 - sprat and herring mix in Donegal Bay (ICES area 7b). Water depth ~ 30 m approximately.



Appendix 2f. 6aS/7b industry acoustic survey on 03/12/2019: Horse mackerel marks north and east of the Stags of Broadhaven area (ICES area 6aS). Water depth ~ 90m approximately.

Appendix 3. 6aS/7b industry acoustic survey in 2019: Vessels details

Vessel details:

Name: RV *Celtic Voyager*
Call sign: EIQN
Type: Research Vessel)
Registered: Dublin, Ireland
LOA: 32.45 m
Beam: 8.62 m
GT: 340 t
Net: Pelagic midwater trawl, 12m average vertical mouth opening during fishing
IMO No.: 9154842
MMSI No.: 250089000

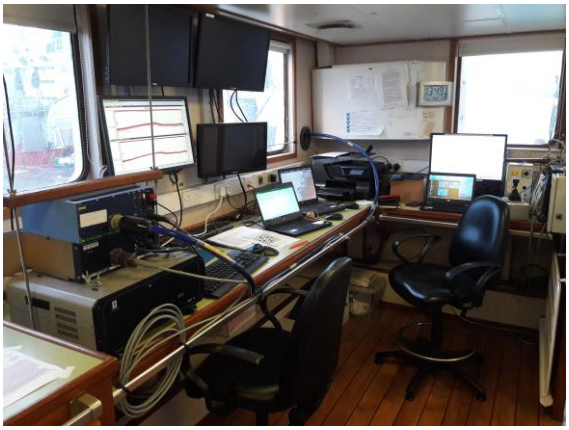
RV *Celtic Voyager*

Vessel details:

Name: MFV *Ros Ard*
Call sign: EI4580
Type: Fishing vessel
Registered: Sligo, Ireland
LOA: 15 m
Beam: 6 m
GT:
Net: Pelagic midwater trawl, 15m average vertical mouth opening during fishing
IMO No.:
MMSI No.: 250000315

MFV *Ros Ard SO745*

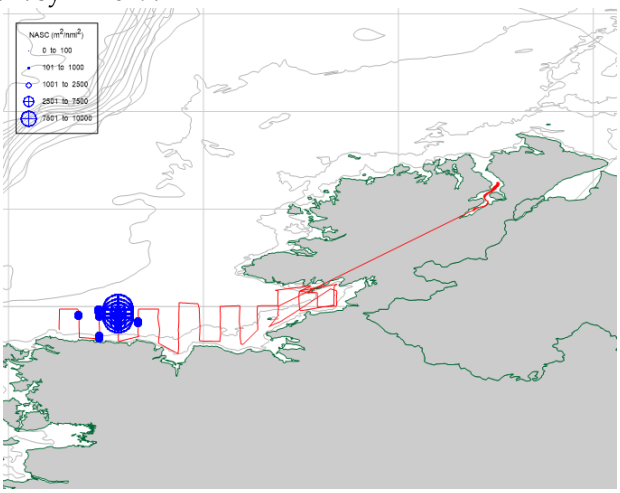
Appendix 4. 6aS/7b industry acoustic survey in 2019: Top side monitoring station located in the dry lab of the *RV Celtic Explorer* (left). Laptop running Echoview and EK60 topside PC unit. GPS feeds (x2) from the ship were connected via straight (patch) ethernet cables to both the SIMRAD operating computer and the Sodena navigation computer. A cross-over ethernet cable linked the raw data from the SIMRAD computer to the Echoview computer for live-viewing. The entire system was powered through an Uninterrupted Power Source (UPS) to prevent data loss in the event of power outage. All data was backed up on external hard-drives after every 24 hour period. Tow body mounted 38 and 120 kHz transducers (right)



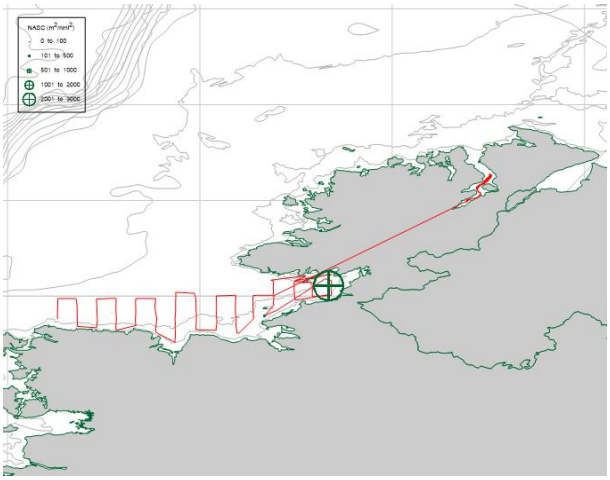
Appendix 5. 6aS/7b industry acoustic survey in 2019: the 9-point herring maturity scale used by Marine Institute and the equivalent 6-point ICES scale

NINE POINT SCALE	EQUIVALENT ICES 6-POINT SCALE
1 Immature virgin	1 (Immature)
2 Immature	1 (Immature)
3 Early maturing	2 (Mature – but not included in spawning category))
4 Maturing	2 (Mature – but not included in spawning category)
5 Spawning prepared	3 (Mature – included in spawning category)
6 Spawning	3 (Mature – included in spawning category)
7 Spent	4 (Mature – Spent – included in spawning category)
8 Recovering/resting	5 (Mature – resting - not included in spawning category)
9 Abnormal	6 (Abnormal – not included in Mature or spawning categories)

Appendix 6. 6aS/7b industry acoustic survey in 2019: Horse mackerel NASC (m^2/nmi^2) distribution on the survey in 2019.



Appendix 7. 6aS/7b industry acoustic survey in 2019: Sprat NASC (m^2/nmi^2) distribution on the survey in 2019.



8. Acknowledgements

We would like to express our thanks to Colin McBrearty, Philip Baugh and the crew of the Celtic Voyager for their good will and professionalism during the survey. We would also like to thank Edward Gallagher (skipper) and crew of the MFV *Ros Ard*, for their help and local knowledge imparted during the survey; it was greatly appreciated and the survey was enhanced because of it. Thanks also to Damian Crean, Gordon Furey, Tom Flynn and Shane Horan at P&O maritime for help with setting up the towed body and transducer. Thanks also to the Irish South and West Fish Producers Organisation (IS&WFPO), Killybegs Fishermen's Organisation (KFO), Scottish Pelagic Fishermen's Association (SPFA), Marine Scotland Science (Aberdeen), and Barry Electronics (Killybegs).

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