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THE 2022 INDUSTRY-SCIENCE ACOUSTIC SURVEY OF HERRING IN THE WESTERN SCOTLAND (ICES DIV 6AN)

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Resolute (Alexander West, Matthew West).

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Contents

Executive summary

2022 was the seventh industry-led surveys of herring in 6a.7bc. This summary refers to the survey in 6aN only, since from 2022 onward surveys in 6aN and 6aS7bc will be reported separately.

Results of the ICES Benchmark Workshop on North Sea and Celtic Sea stocks (WKNSCS, ICES 2023) show that remaining uncertainties surrounding the identity of herring stocks in 6aN, as well as uncertainties with acoustic survey abundance indices and reliably obtaining information on commercial catch-at-age, make the use of analytical stock assessment problematic at this time. The benchmark workshop concluded that, at the present time, a full analytical assessment was not possible, and a category 3 assessment method based on life-history and optimal length would be most appropriate for advice on fishing opportunities for herring in 6aN. The findings of the benchmark workshop were used to inform plans for the future monitoring requirements of herring stocks in 6aN and 6aS 7bc in 2022 and beyond, some of which are well suited to be undertaken by industry surveys.

The aim of the survey in 6aN is to maintain and improve the knowledge base of the genetic identity of herring stock components in 6aN and provide an age-disaggregated acoustic abundance index that may be used by ICES to assist in assessing the herring stocks and establishing a rebuilding plan.

One Scottish vessel equipped with a hull mounted calibrated 38KhZ Simrad EK80 echosounder was deployed for 8 days. Unexpected maintenance needs due to mechanical issues delayed the start date by 1 week and cut the duration by 3 days. Weather was fair-good throughout the survey and the vessel provided a stable platform for data recording. Following the guidance arising from WKHASS, the survey again focussed on two principal spawning areas, with timing planned to coincide with the known spawning period. Marks of sprat were abundant throughout the area in larger schools than seen since 2016. Norway pout were present throughout the area also. Only one herring mark was detected and verified during the survey period. The mark was caught opportunistically during a trawl directed at other marks. It contained spawning herring, which were sampled for genetics. A few 0-group herring were found mixed with sprat from one haul and were measured and sampled for genetics.

Despite concerted searching, efforts to obtain a commercial catch of 6aN herring as payment for the survey were unsuccessful, so no commercial samples are available for use in assessment.

Following the benchmark workshop (ICES 2023), in 2022 the ICES herring assessment working group used a category 3 CHR rule to provide advice for catches in 2023 of 1,212t (ICES 2022a, 2022b). Of this, the UK quota is 791t (Defra 2022). Pending confirmation of details in discussion with Marine Scotland, plans for the 8th industry-led survey in 6aN are underway, based on provisions for a monitoring quota of 680t.

1 Rationale, aim and objectives

1.1 Rationale

During the ICES benchmark workshop on herring west of the British Isles, the stock assessments of 6aN herring and 6aS/7bc herring (Figure 1.1) were merged into one combined assessment (ICES 2015a). The reason for this is that the summer acoustic surveys and fishery occur at a time when the northern and southern components are mixed, and the baseline morphometric information required to separate the two components was found to be unreliable due to evidence of changes over time. The consequence was that from 2015 to 2022, ICES advised a zero TAC, and recommended that a rebuilding plan be developed (ICES 2017a). The ICES HAWG also stated in its March 2015 report that there is a clear need to determine the relative stock sizes (ICES 2015b).

Under the auspices of the Pelagic Advisory Council, this situation catalysed fishing industry associations representing Scottish, English, Dutch, Irish, Northern Irish and German fishery interests to set about providing the much needed evidence required to establish reliable stock assessments for the separate stocks, and develop a rebuilding plan. In response to the STECF 2015 autumn plenary recommendation that it would be beneficial to maintain an uninterrupted time series of fishery-dependent catch data, and a subsequent special request (to ICES) by the European Commission, ICES provided advice on methods for undertaking a scientific monitoring fishery for the purpose of obtaining relevant data for assessment (ICES 2016a). In particular, the advice referred to collection of data necessary to determine the identity and structure of the two stocks, collected in a way that (i) satisfies standard length, age, and reproductive monitoring purposes by EU Member States for ICES, and (ii) ensures that sufficient spawning-specific samples are available for morphometric and genetic analyses as agreed by the Pelagic Advisory Council monitoring scheme 2016 (Pelagic Advisory Council, 2016).

This advice, and a resulting EU Council regulation (EU 2016/0203) that made provision for a scientific monitoring TAC of 5 800 tonnes (4 170 t in 6aN and 1 630 t in 6aS, 7bc) were the enablers for the first industry-led survey to take place. Similar provisions were established prior to UK exit from Europe, allowing continuation of the industry-led collaborative survey. The survey provided critical data on genetic stock identity and spawning distributions of herring that was used in the ICES Benchmark Workshop on North Sea and Celtic Sea stocks (WKNSCS, ICES 2023). An important outcome of the benchmark workshop was that the assessments for herring have since been split once more into two components: 6aN autumn spawning herring and 6aS/7bc winter spawning herring, based on their genetic identity.

However, results of the Benchmark Workshop show that remaining uncertainties surrounding the identity of herring stocks in 6aN, as well as uncertainties with acoustic survey abundance indices and reliably obtaining information on commercial catch-at-age, make the use of analytical stock assessment problematic at this time. In particular, results from the EASME project which led the genetic analysis used in the Benchmark, were not able to differentiate 6aN spring spawning fish from late-spawning 6aS fish (Farrell et al. 2021, 2022). The consequence of this is that these genetically distinct components currently sit outside of the assessment and are not accounted for in the estimation of herring abundance West of Scotland (WoS). Analy sis of acoustic data undertaken as part of the international HERAS survey, and used in herring stock assessment, quantifies that this population may be of a similar size to the 6aN autumn spawning component (see 'her-67bc' in Figure 1.2) (O'Malley et al. 2022). The benchmark workshop concluded that, at the present time, a full analytical assessment was not possible, and a category 3 assessment method based on life-history and optimal length would be most appropriate for advice on fishing opportunities for herring in 6aN.

During the benchmark workshop, results from the industry acoustic-trawl survey conducted in Septembers were evaluated and showed evidence for cohort tracking and consistency with results from the WoS part of the HERAS survey. This indicates the potential utility of the index, but the time series was considered too short and recommended to be extended to improve tracking of the herring cohorts through their 9+ years of life.

The findings of the benchmark workshop have been used to inform plans for the future monitoring requirements of herring stocks in 6aN and 6aS 7bc in 2022 and beyond, some of which are well suited to be undertaken by industry surveys. The aim of future surveys in 6aN is therefore: to maintain and improve the knowledge base of the genetic identity of herring stock components in 6aN, and to provide an age-disaggregated acoustic abundance index that may be used by ICES to assist in assessing the herring stocks and establishing a rebuilding plan. Initially it is proposed that the 6aSPAWN acoustic survey in September should continue for a minimum period of 10 years (2016-2025).

Following the benchmark workshop (ICES 2023), in 2022 the ICES herring assessment working group used a category 3 CHR rule to provide advice for catches in 2023 of 1,212 t (ICES 2022a, 2022b). Of this, the UK quota is 791 t (Defra 2022). Pending confirmation of details in discussion with Marine Scotland, plans for the 8th industry-led survey in 6aN are underway, based on provisions for a monitoring quota of 680 t.

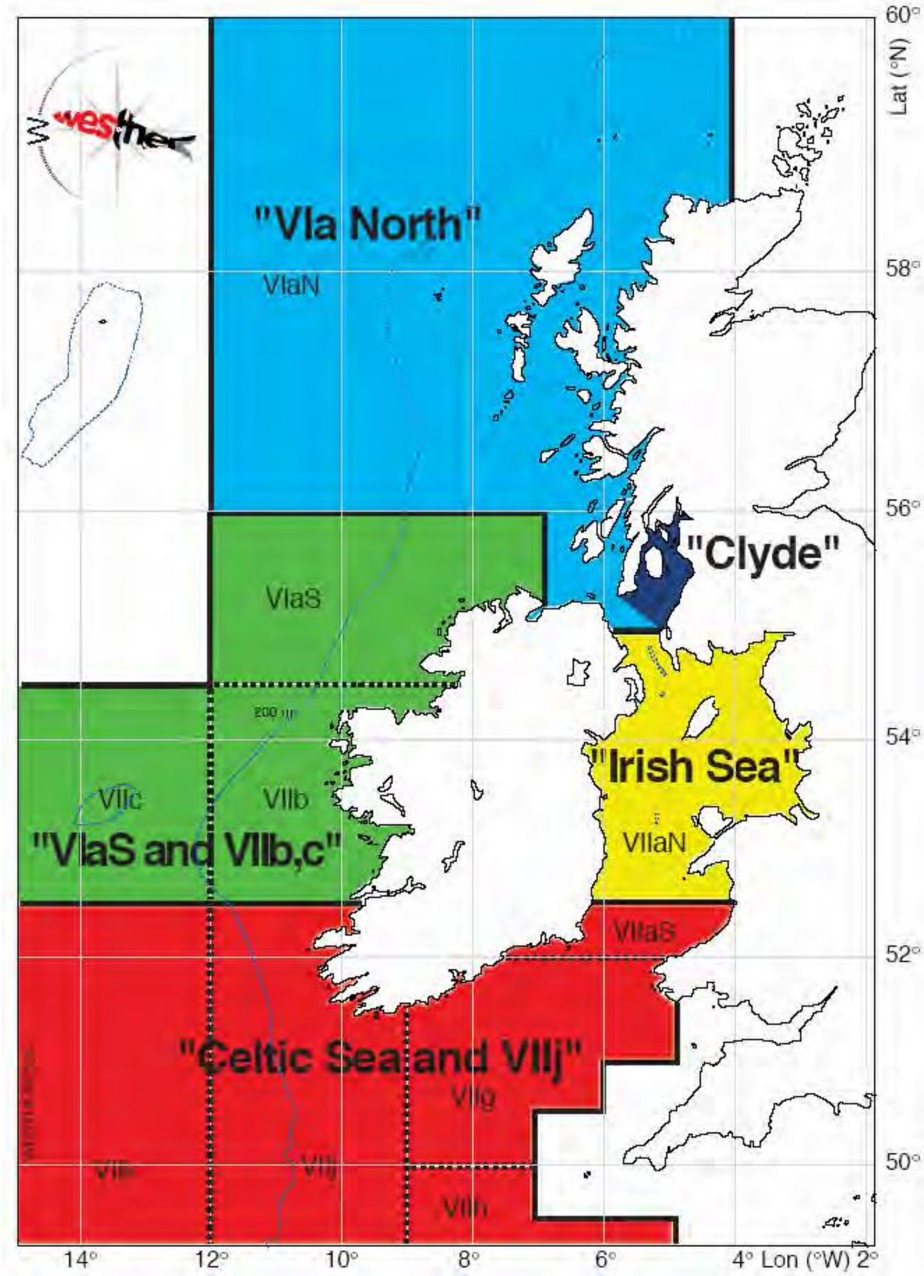


Figure 1.1. Herring stock assessment areas.

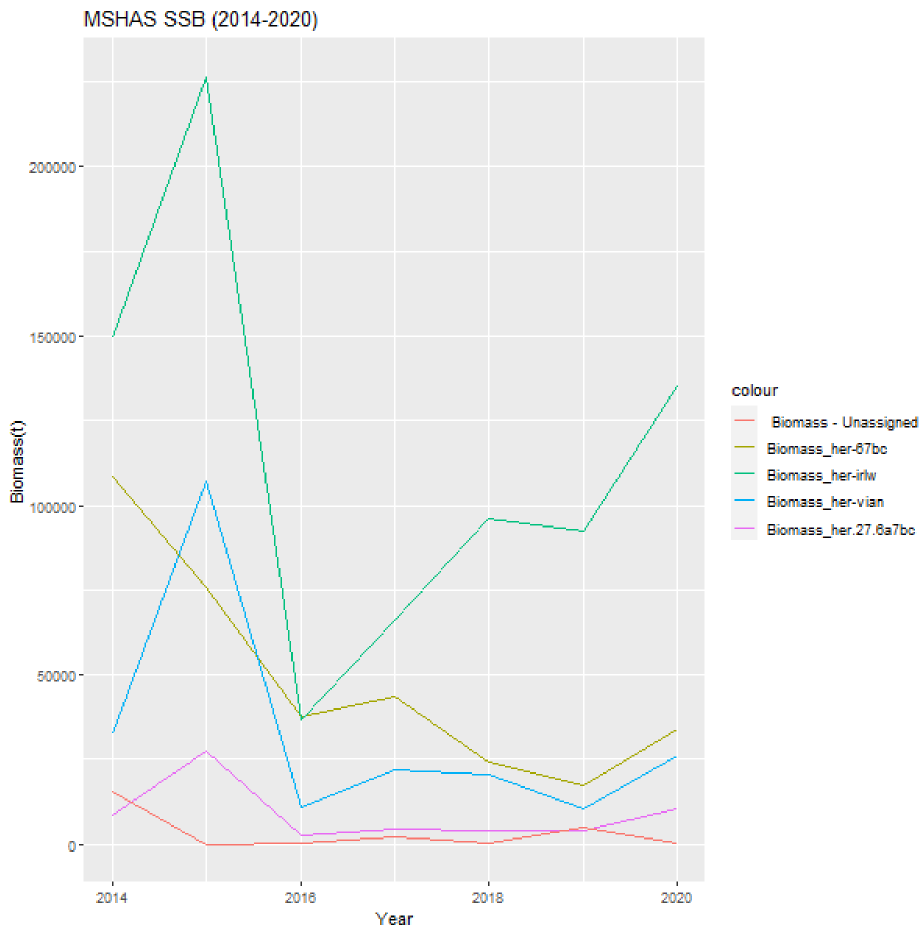


Figure 1.2 SSB (t) time-series for the individual split indices (2014 – 2020). (O'Malley et al. 2022)

Key to legend:

her-irlw (6aS and 7bc winter spawning herring)

The her-vian (6aN autumn spawning herring)

her-67bc (spring spawning herring of uncertain origin)

her.27.6a7bc (*mix of herring from 6.a and 7.b, c; i.e. unknown or below threshold fish*)

1.2 Overall Aim

To maintain and improve the knowledge base of the genetic identity of herring stock components in 6aN, and to provide an age-disaggregated acoustic abundance index that may be used by ICES to assist in assessing the herring stocks and establishing a rebuilding plan.

1.3 Objectives

In this WGIPS report, only information on the methods and results pertaining to objective 1 and 2 are documented. A full survey report is available on request.

1. **Abundance estimation**: Collect acoustic data and information on the size and age of herring and use it to generate an age-disaggregated acoustic estimate of the biomass of pre-spawning/ spawning components of herring in 6aN. ('West of Scotland herring').
2. **Spawning stock identity separation:** Collect genetic data from spawning ready fish to maintain the genetic baseline used to split stock components in surveys and assessments.
3. **Identify stock components in commercial catches.** Collect genetic data from commercial catches to determine the identity of herring stock components of catches in 6aN. This will enable stock assessments to partition fishing mortality on different stock components and provide better estimation of sustainable fishing rates.
4. **Age composition of the commercial catch:** Collect catch-at-age data from the monitoring fishery to provide continuous fishery-dependent time series required for future analytical stock assessments.
5. **Evidence for a rebuilding plan:** Use the results of the surveys to contribute to the scientific basis for development of a rebuilding plan for herring in 6aN.

2 Materials and methods

2.1 Survey plan

2.1.1 Specific survey objectives

Specific objectives for the field survey followed objectives 1-4, described in section 1.3. Participating vessel(s) were assigned specific objectives and provided with a vessel-specific sailing plan and survey protocol manuals (example available on request). Sections 2.2 to 2.4 describe the survey methods in detail.

2.1.2 Survey areas and timing

The areas of interest for the 6aN surveys have been defined based on the ICES advice on the monitoring fishery (ICES 2016a) and discussions with fishing skippers during the present and past planning meetings.

Prior to the 2020, five areas were selected for surveying in 6aN (Figure 2.1). The areas coincided with the geographic distribution of known active herring spawning areas (Figure 2.2, and observed in previous surveys) and records of commercial catches (Figure 2.3). Areas 2-4 are considered to be active spawning areas and Area 1 a pre-spawning aggregation area that contains an unknown mixture of stocks of Western and North Sea herring, where a large proportion of catches has been taken in recent years (ICES 2015a). Area 5 was added in 2018 and 2019 based on evidence from 2017 and local creel fishermen of herring on the east side of the North Minch. Systematic acoustic surveys (see section 2.2) were conducted only in areas 2-5 in 6aN, but ad-hoc acoustic data was recorded by other vessels also.

Following guidance arising from the ICES Workshop on Herring Acoustic Spawning Surveys (WKHASS, ICES 2020), since 2020 the survey area in 6aN has focussed on two principal spawning areas (Figure 2.4, 2.5), with timing planned to coincide with the known spawning period. The new strata 1 & 2 are reduced version of previous area 2 and 3 and correspond to regions that have been covered consistently since 2016. Moreover, refocusing the survey to these new strata and re-analysis of surveys since 2016 has resulted in a consistency survey time series index (Mackinson and Berges 2022).

The timing of surveys is shown in Table 2.1.

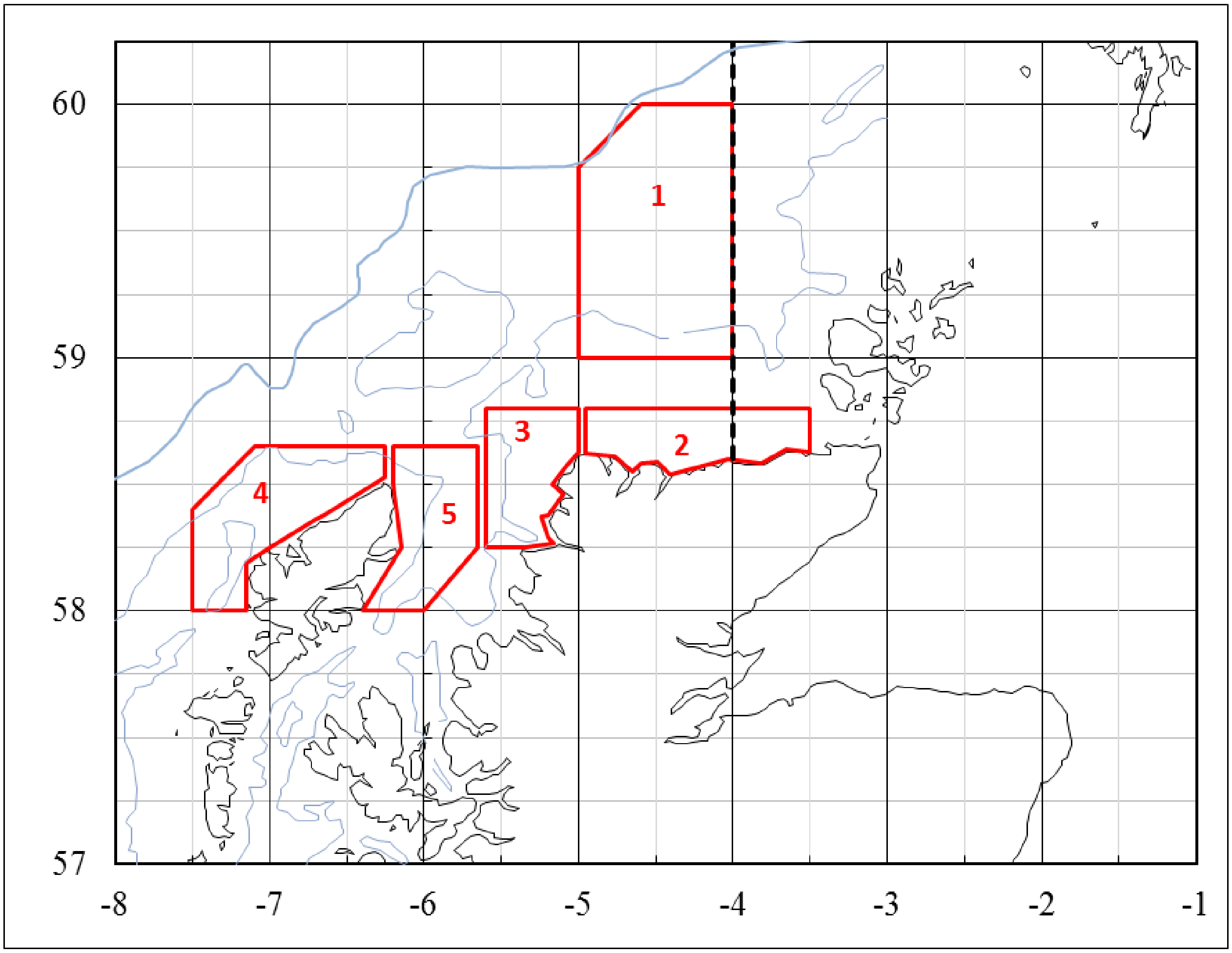


Figure 2.1. Planned survey areas used in the 6aNorth surveys prior to 2020. Area 1- North pre-spawning mixing area, Area 2 -East of cape Wrath, Area 3 – The Minch, Area 4 – Outer Hebrides, Area 5 – east Minch.

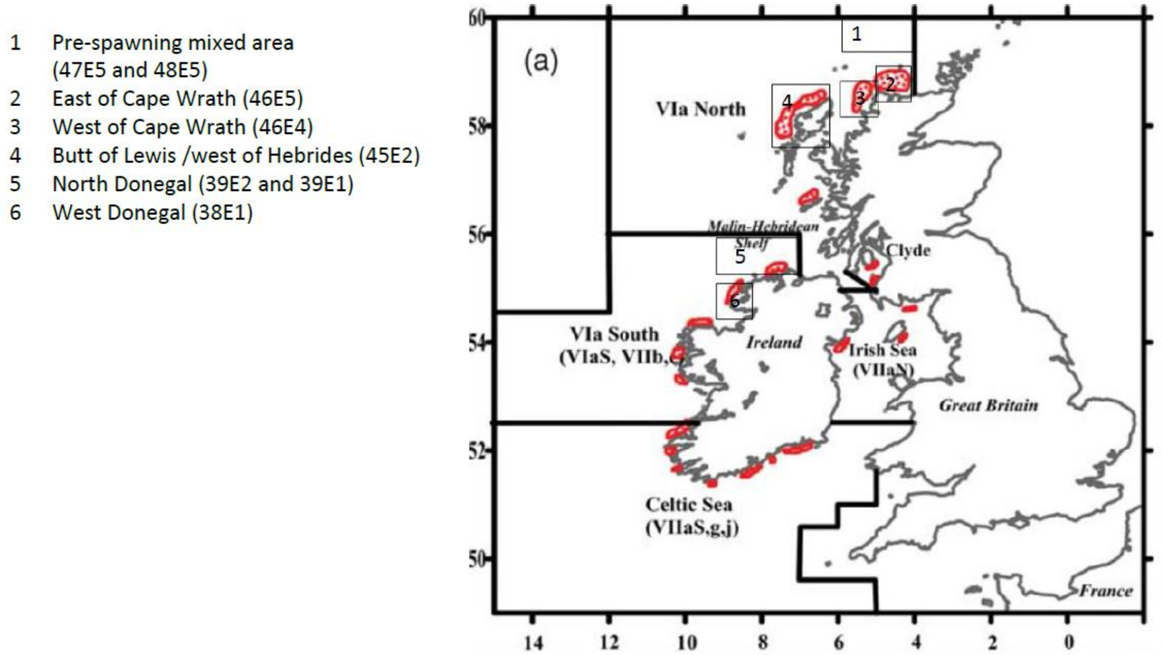


Figure 2.2. Spawning areas for herring in ICES subareas 6 and 7, with currently active spawning areas and pre-spawning aggregation areas for each stock indicated by black rectangles. Used in ICES 2016, redrawn from Geffen *et al.* (2011).

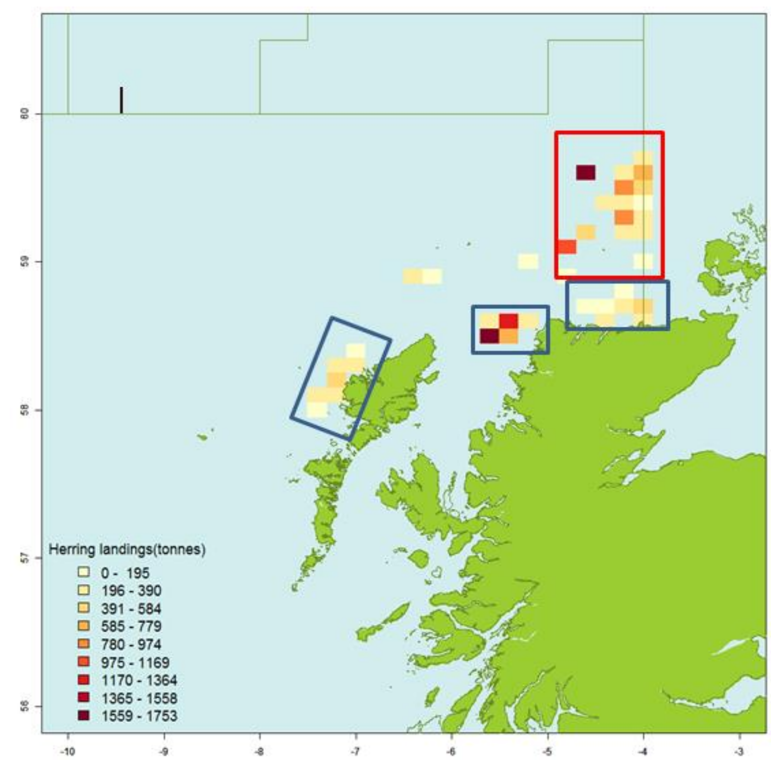


Figure 2.3. Distribution of commercial catches reported in 6aN in 2011.

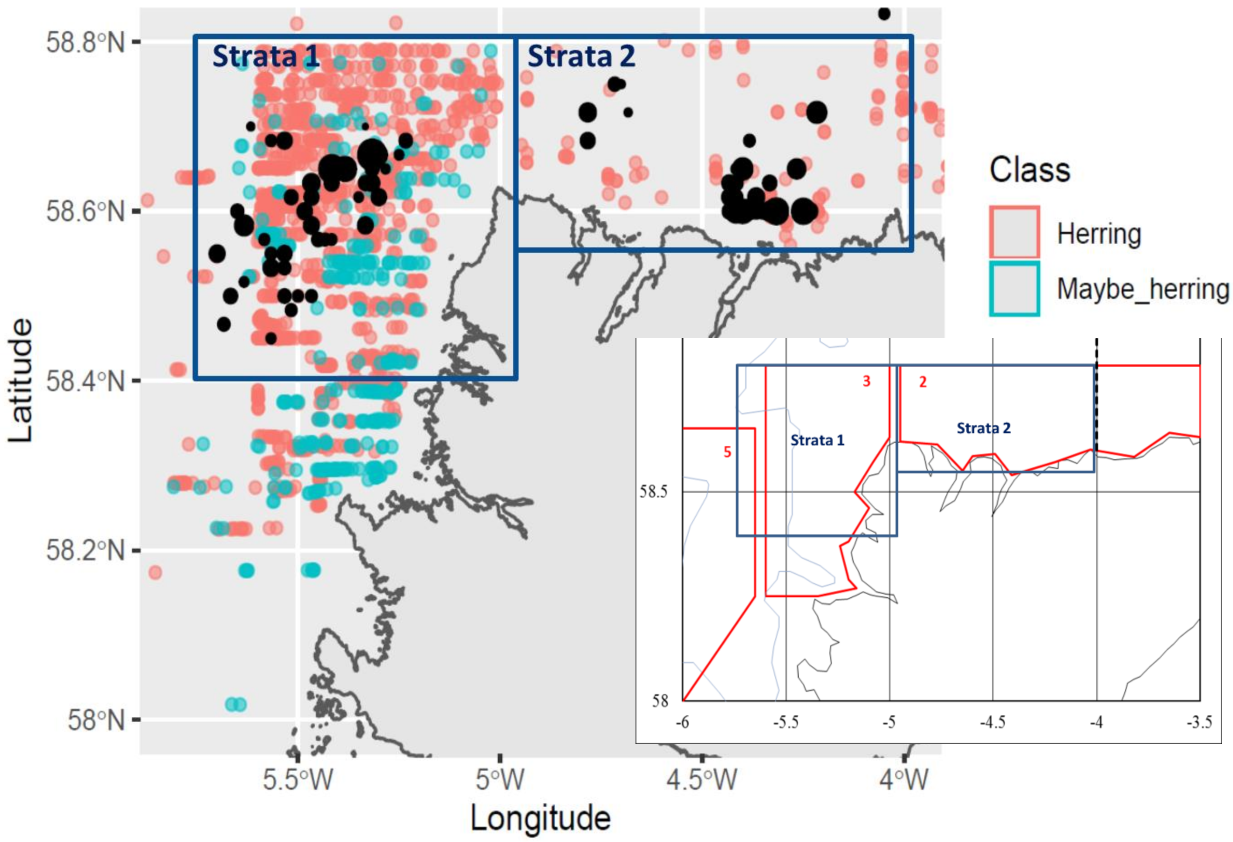


Figure 2.4. Acoustic survey recordings of herring and 'maybe herring' marks and locations of commercial catches 2016-2019 in the newly defined Strata 1 & 2, showing overlap with previous survey Areas 2,3,5 (inset) and noting that the distribution of catches reflect spawning grounds. Catches (black dots) scaled proportionally. Acoustic marks are not scaled and denote location only.

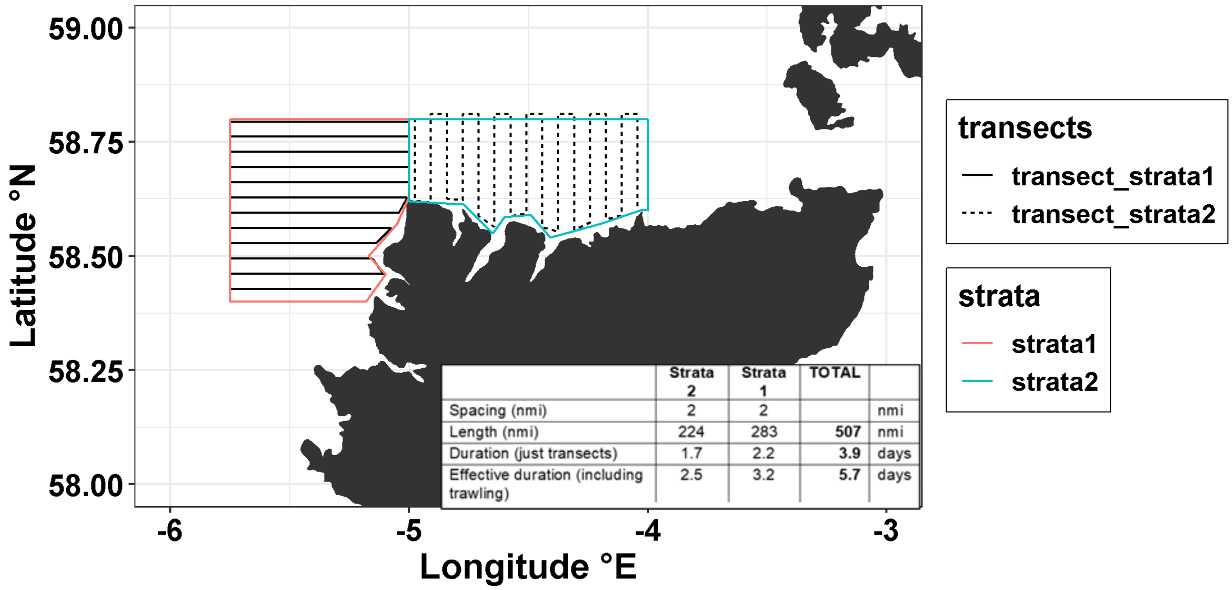


Figure 2.5. Planned survey areas used in the survey.

Table 2.1. Timing of the survey.

Vessel	Start	End	Duration	Timing and area coverage	Tue 23-Aug	Wed 24-Aug	Thu 25-Aug	Fri 26-Aug	Sat 27-Aug	Sun 28-Aug	Mon 29-Aug	Tue 30-Aug	Wed 31-Aug	Thu 01-Sep	Fri 02-Sep	Sat 03-Sep	Sun 04-Sep	Mon 05-Sep	Tue 06-Sep	Wed 07-Sep	Thu 08-Sep	Fri 09-Sep	Sat 10-Sep	Sun 11-Sep	Mon 12-Sep	Tue 13-Sep	Wed 14-Sep	Thu 15-Sep	Fri 16-Sep	Sat 17-Sep	Sun 18-Sep	Mon 19-Sep	Tue 20-Sep	Wed 21-Sep
Resolute	**12-Sep**	**19-Sep**	**7**	**Strata 1 & 2 (acoustic)**																				P										
C=Calibration																																		
P=Passage to/from grounds																																		

Table 2.2. Summary of equipment used for the acoustic survey.

Area surveyed	Vessel	Transducer and Frequency	Echo-sounder	Power Pulse duration Ping interval	Environment	Calibration Location/ date, supplier	Survey area changes
Strata 1 & and 2	Resolute (BF50)	Hull mounted EK80 at 38 kHz.	SIMRAD EK80	**@38kHz** Power: 2000W Pulse duration: 1.024ms Pulse form: Continuous wave Ping interval = 0.5 sec	Temp = 10C, Salinity =35ppt, Sound speed 1491.5 m/s	Scapa Flow 5 May, Echomaster Marine	NA

2.2 Abundance estimation

2.2.1 Acoustic survey design

The purpose of the acoustic survey is to estimate the minimum spawning biomass of adult herring and spawning ready herring within the boundaries of the survey areas.

Acoustic surveys were conducted in survey strata 1 and 2 (Figure 2.4) designed on regularly spaced parallel transects (Figure 2.5). Transect direction was assigned perpendicular to the narrowest dimension of the survey area to maximise precision of the estimation by having many short transects rather than a few long ones. Vessel(s) acoustically surveyed the two strata at different timings (Table 2.1). The survey dates aimed to give best chances to cover the peak time of spawning and were decided based on records of known spawning times and advice of fishermen familiar in working the areas.

Sufficient time was factored in to the survey design to provide opportunity for the survey transects and areas to be adapted according to the situation observed, such as changes to the survey boundary to ensure full coverage of fish aggregations, or undertaking finer scale observations in high density locations. Table 2.2 summarises the survey setup for vessel(s) that participated in the survey, and notes any adaptations to the original planned survey transects.

In 2022, one survey vessel was deployed.

2.2.2 Equipment specifications and calibration

See Table 2.2 for specification, e.g. frequency used and settings.

The standard calibration procedure described in Demer et al. (2015)[1] was used to calibrate the 38kHz channel of the echosounders deployed on the survey vessel (see Annex 1). Calibration settings from a previous calibration performed successfully by Echomaster Marine in Scapa flow in May 2022 when the vessel was undertaking another scientific survey, were used. The reason for this was to maximise survey time following delays cause by the need for urgent gearbox repairs to the vessel.

2.2.3 Acoustic survey protocols

The survey was conducted in daylight hours only, approx. 07:00 to 19:00 UTC/GMT. At the beginning of the next day, the survey restarted and continued from the position it ended on the day before. This maintained continuity in the coverage and avoided the

[1] http://courses.washington.edu/fish538/resources/CRR326_Calibration.pdf

possibility of double counting herring schools, which can occur if the survey does not continually progress in the same direction. Survey speed was ~10 knots throughout, reduced as needed depending on weather condition.

To maximise acoustic data quality, the survey vessel took on board ballast water to the fish holding tanks to aid stability of the vessel and minimise cavitation. The vessel proved to be very stable platforms in all the conditions experienced and at no time was the quality of acoustic data compromised. While surveying on transect, all other acoustic equipment was turned off to eliminate interference with the echosounder. Only during fishing operations were other acoustic instruments used. Compensate for heave, pitch and roll via a motion reference unit was not available on the survey vessel in 2022, but excellent weather conditions meant that there were no limitations caused as a result of this.

Raw acoustic data were recorded and stored on the ships PC and backed up each day on a portable hard disk drive for later processing. Survey log sheets were used to record haul position and other events relevant to aiding in the interpretation of the acoustic data.

2.2.4 Fishing operations for scientific samples

During the acoustic surveys, selected fish marks were targeted with a fishing operation (Figure 2.6 to capture fish for the purposes of:

(i) Confirming the species identity of acoustic marks, particularly those suspected to be herring or to confirm that they were definitely not herring.

(ii) Collecting samples for biological analysis and to enable disaggregation acoustic densities into length/age groups.

The fishing operations were directed to take a catch of the smallest possible size sufficient for biological sampling. The vessels were granted a derogation to discard fish that were not required to be retained for biological sampling, subject to specific conditions.

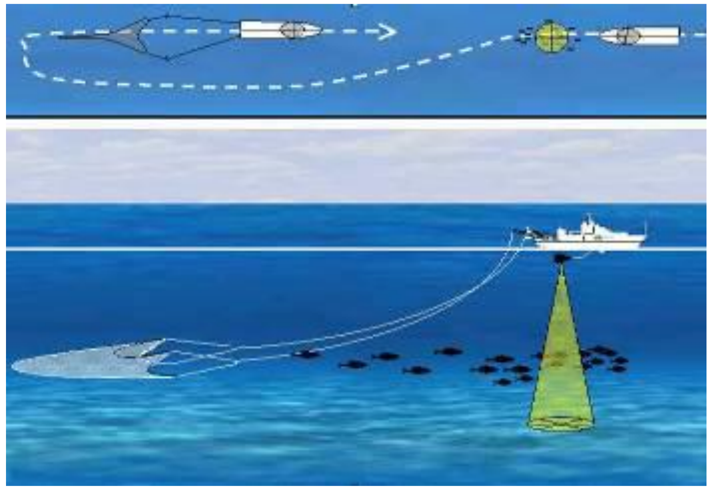


Figure 2.6. Schematic description of fishing operation to collect a biological catch sample during an acoustic survey.

A sampling bag specifically designed for use by commercial vessels during the survey was attached to the end of the herring net (Figure 2.7). The purpose of the bag is to ensure that a representative sample of the catch can be retained, while at the same time allowing for release of fish in the event that the catch may be larger than required for a sample. Track record since 2016 shows that these events are very rare but may occur specifically when a very dense spawning mark is targeted for a sample. This is a particular risk during this survey because samples of spawning fish are specifically required to provide the stock-specific genetic identity baseline samples. There are benefits and drawbacks tousing the sampling bag and the performance of the bag is very difficult to assess because it is not possible to control the many variables that may affect the catch. On balance, both the result that successful biological samples were retained and fish were observed to escape the bag when full, it is considered that the use of the sample bag was appropriate.

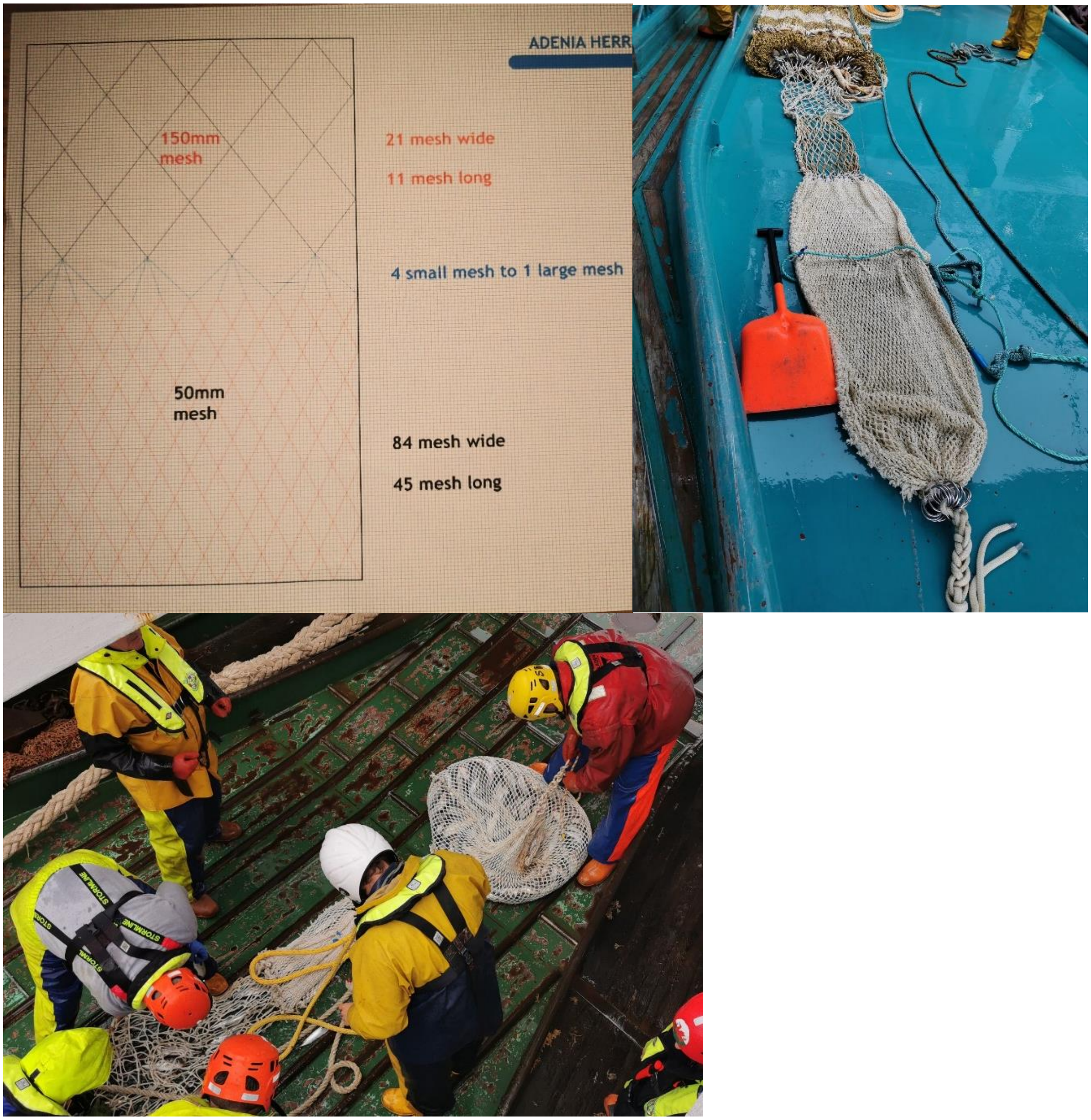


Figure 2.7. The sampling bag

2.2.5 Biological sampling

The purpose of the biological sampling was to

i. provide data on the relative abundance of 0.5cm each length and age class of herring, which is needed to make age-disaggregated acoustic abundance estimates.
ii. determine the maturation state of herring and indicate the location and timing of spawning.
iii. perform genetic analysis to identify stock ID.

2.2.5.1 *Haul information*

Haul data were recorded using the same template for all surveys, 1 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. To aid in processing the acoustic data, screen captures were taken during the haul operation; identifying first the targeted mark and later the marks covered while trawling. Comments about the marks were written on the haul sheet, as well as whether or not the herring were spawning (based on "running" eggs and sperm upon capture) and whether any catch remaining after biological sampling was retained or discarded.

2.2.5.2 *Catch sampling*

The catch sampling procedure was as follows:

- Catch is hauled astern and loaded into a large plastic pallet box, which when full holds approximately 500kg (Figure 2.8).
- Weight of the catch of all species, or where the catch was too large, 3-5 randomly mixed baskets were taken as a sample of the catch and weighed. The total catch weight was estimated based on the fullness of the pallet box.
- The catch sample was sorted and the total weight of each species recorded.
- One full basket (or 2 half) of herring was weighed (approx. 30kg). This subsample was used to determine lengths, weight, age and for genetic samples. (see below). (Figure 2.9)

Figure 2.8. Example of large plastic pallet bin (capacity when full ~500kg).

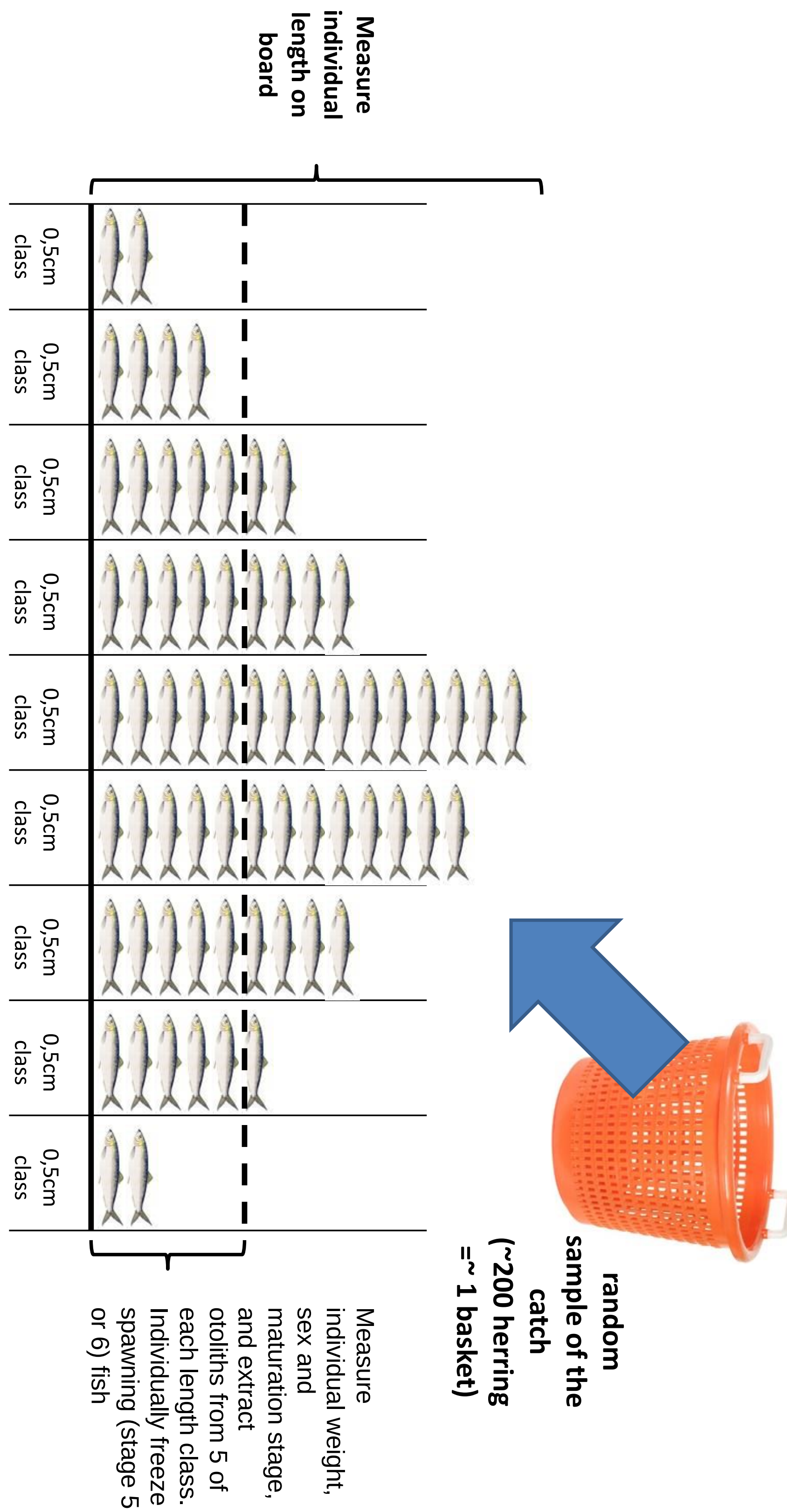


Figure 2.9. Illustration of the required catch sampling procedure.

2.2.5.3 *Length measurements*

The length of all the herring in the subsample was measured and recorded to the nearest half centimetre below (e.g. if the fish was 24.7cm then it was recorded as 24.5cm). This data is used to determine a length frequency distribution of the catch and subsequently to apply an age-disaggregated estimate of biomass. Additional biological measures (next section) were recorded from five fish within each half centimetre length class.

2.2.5.4 *Whole weight, Sex, Maturity stage, Otolith, Genetics*

Each fish from was assigned an ID number so that subsequent genetic samples can be cross-referenced to biological data. In addition to the length, the following information was recorded for each fish.

- Weight in g
- Sex
- Maturity stage from 1-9 based on the classification in the Scottish and Irish sampling (MSS manual 2011) and later converted to the ICES 6 point scale (ICES 2011) (Table 2.3).
- Otoliths were extracted for age determination at the lab. Standard procedures for age determination from the growth rings on the otoliths (ear bones) of herring were used to determine the age of fish sampled (ICES 2005). This age data was used to create an age-length key (ALK).
- If the fish was from a spawning haul tissue samples were collected following genetic sampling protocols (see 2.3.3).

Table 2.3. Translation of Marine Scotland 9 point maturity scale to ICES 6 point scale

NINE POINT MATURITY SCALE (MARINE SCOTLAND MANUAL)	EQUIVALENT ICES SCALE STAGE
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)

2.2.6 Acoustic Analysis methods

2.2.6.1 *Echogram scrutinisation – partitioning to species*

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 is a heuristic process that relies upon (i) evidence from the targeted hauls made during the survey, (ii) prior experience of 'experts' (fishermen and acoustic scientists) based on their knowledge of what was caught when certain types of fish marks were fished upon in the area in previous surveys occurring around the same time, and (iii) knowledge of fish behavior.

While it's impossible to be 100% confident when assigning fish marks to species, following some agreed guidelines for classification of marks greatly improves the consistency in the way that acoustic data from different surveys are scrutinized. Hence, this ensures the quality and comparability of the biomass estimates between the different surveys and between years.

Acoustic fish marks were classified in to the following categories (See examples in Figure 2.10):

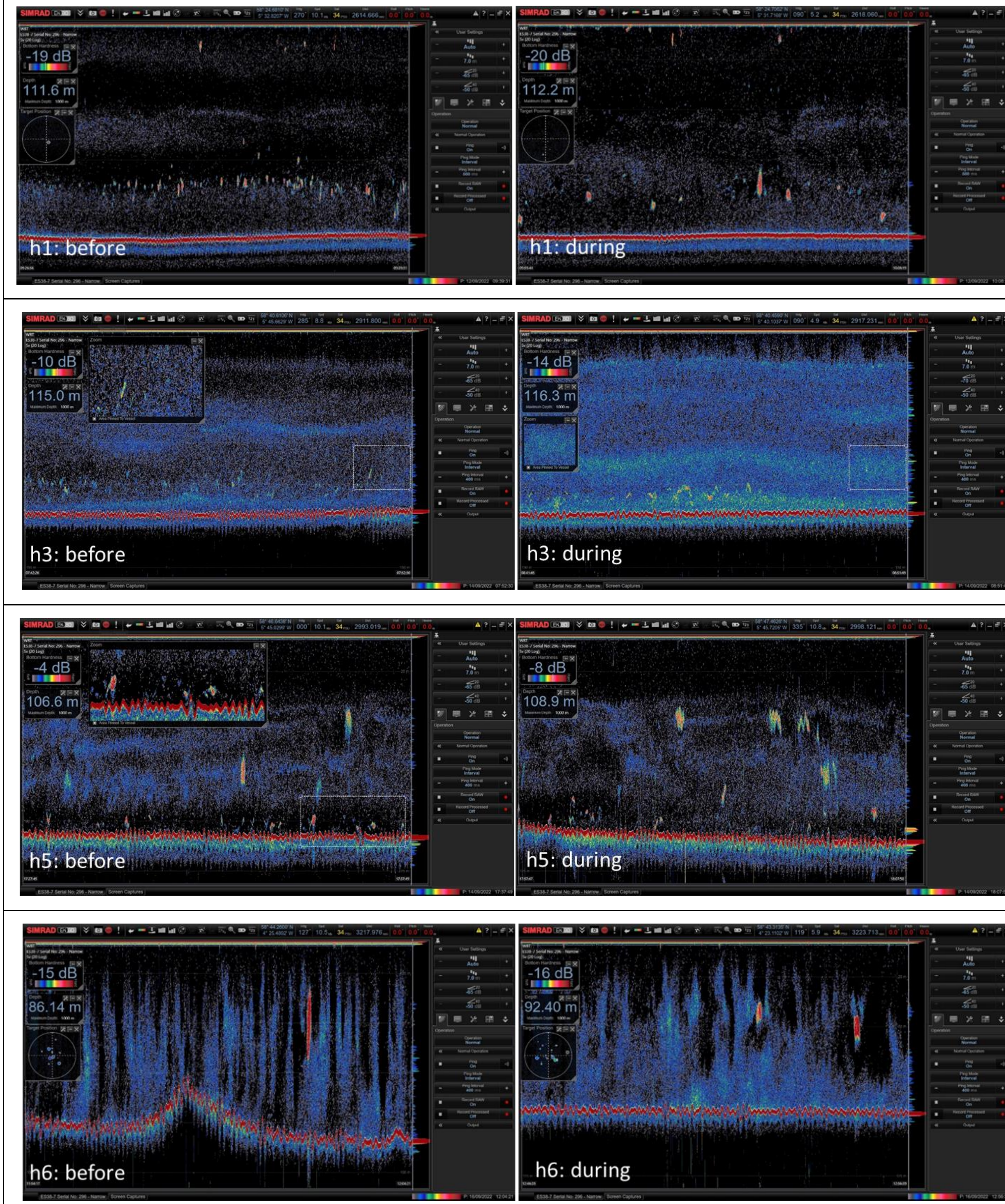
- **Herring** – confident that the marks were herring based on either evidence from a targeted haul or proximity and similarity to other schools known to be herring.
- **Probably herring** – aggregations/ collections of marks within reasonable vicinity of definite herring marks (approx. 10nm radius) and shape and appearance similar to definite herring marks but often associated with hard ground where identity cannot be confirmed by trawling.
- **Possibly herring** – Marks that look like herring, but possibly isolated individual marks and found in areas beyond the immediate vicinity of confirmed herring marks.
- **Cap-hugging marks** – from 2016-2018, significant marks have been observed on rocky outcroppings that are not possible to trawl (see examples in 2019 report). Despite consulting acousticians and fishermen, the expert knowledge on these marks was inconclusive, hence they were classified separately. In July 2019, FV Grateful sought to identify these marks with a drop-down camera, the evidence from which suggests that they are not herring, but more

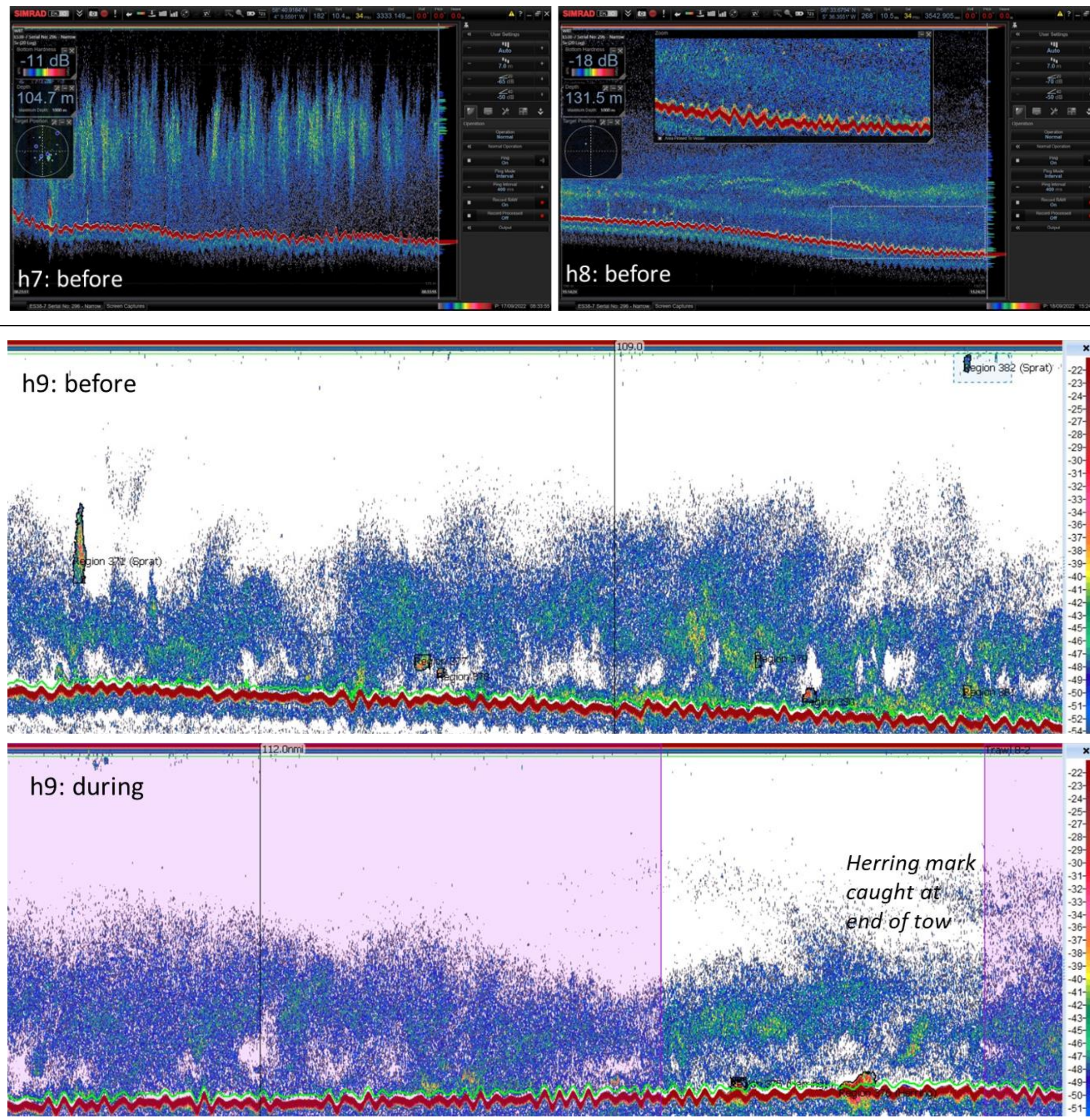
likely Norway pout, juvenile gadoids and zooplankton concentrations. However, there is a need to verify this for the September surveys, and some uncertainty still remains regarding possible avoidance by herring, which we hope to address in future work. It is important to note that where marks on the sides of steep slopes of outcropping occurred, they were excluded from the analysis because of the possibility of being registration of acoustic side lobes.

- **Sprat** – confident that the marks were sprat based on either evidence from a targeted haul or proximity and similarity to other schools known to be sprat. A lot of very dense discrete schools close to the surface are believed to be sprat. Targeted hauls generally have low success rate due to fish going through the net and difficulties in fishing close to the surface. Sprat schools tend to be sharp streak-like marks that are very dense. They can also occur in mixed
- **Unclassified –** confident that the marks were not herring or sprat based on either evidence from a targeted haul or proximity and similarity to other schools known to not be herring, or characteristics atypical of herring schools.
- **Horse mackerel –** routinely found in the 6aN survey area. They can be difficult to identify and require trawl verification because they look a lot like herring marks, although they are generally more amorphous in shape and form more extended layer-like aggregations near the bottom.
- **Mackerel** – The difference in frequency response from 38 to 200 KHz (stronger) makes mackerel easier to identify. They tend to be found in layers (can be at different depths) and are ubiquitous in 6aN with some mackerel caught in most hauls.
- **Norway pout** - at 38 KHz, norway pout marks can look very similar to herring marks and separating them can be difficult. In 6aN during September, whereas herring marks are typically found of flat ground of suitable spawning substrate, verifiable norway pout marks are found over more undulating areas. They may form large schools, and often exhibit a shape characteristic that looks like 'old men leaning into the wind'. Being small, they tend to mark hard on the echosounder. They are particularly problematic to separate from herring if found on the same ground, not least because they are small and most fish that may have been caught are not retained in the net.

How strongly the acoustic marks are displayed on the screen (backscatter threshold) can have a bearing on the interpreters classification of the acoustic marks and their selection using school detection algorithms. 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. The echograms were generally analysed at a threshold of -60 to70 dB. Other methods used to help distinguish herring marks from other fish and organisms causing backscatter included looking at the ‘frequency response’ (i.e. how the backscatter properties look at different acoustic frequencies). Great attention was given to comparing and discussing the types of marks recorded and validated by trawls from all of the vessels involved in the survey. In the end, every school was manually scrutinised thereafter to ensure that it was appropriately classified and delineated based on the available information.

(a)


SIMRAD
-19 dB
111.6 m
h1: before
SIMRAD
-20 dB
112.2 m
h1: during
SIMRAD
-10 dB
115.0 m
h3: before
SIMRAD
-14 dB
116.3 m
h3: during
SIMRAD
-4 dB
106.6 m
h5: before
SIMRAD
-8 dB
108.9 m
h5: during
SIMRAD
-15 dB
86.14 m
h6: before
SIMRAD
-16 dB
92.40 m
h6: during



(b)

Haul	HER	MAC	NOP	WHG	HAD	SPR	Catch weight (kg)
1							
2							
3							
4		32%		8%	61%		145
5			100%				79
6	7%	9%				84%	120
7		100%	0%				5

8	1%	36%	9%	13%	41%	0.2%	63.5	
9	100%						1500	
10	1%	11%	45%	3%	40%		64.75	

Figure 2.10. (a) Echograms of representative sample hauls. (b) catch composition of hauls (to aid interpretation).

2.2.6.2 *Age disaggregated abundance estimation*

The general process for estimating abundance and biomass from the acoustic data is shown in Figure 2.11, with additional description given below.

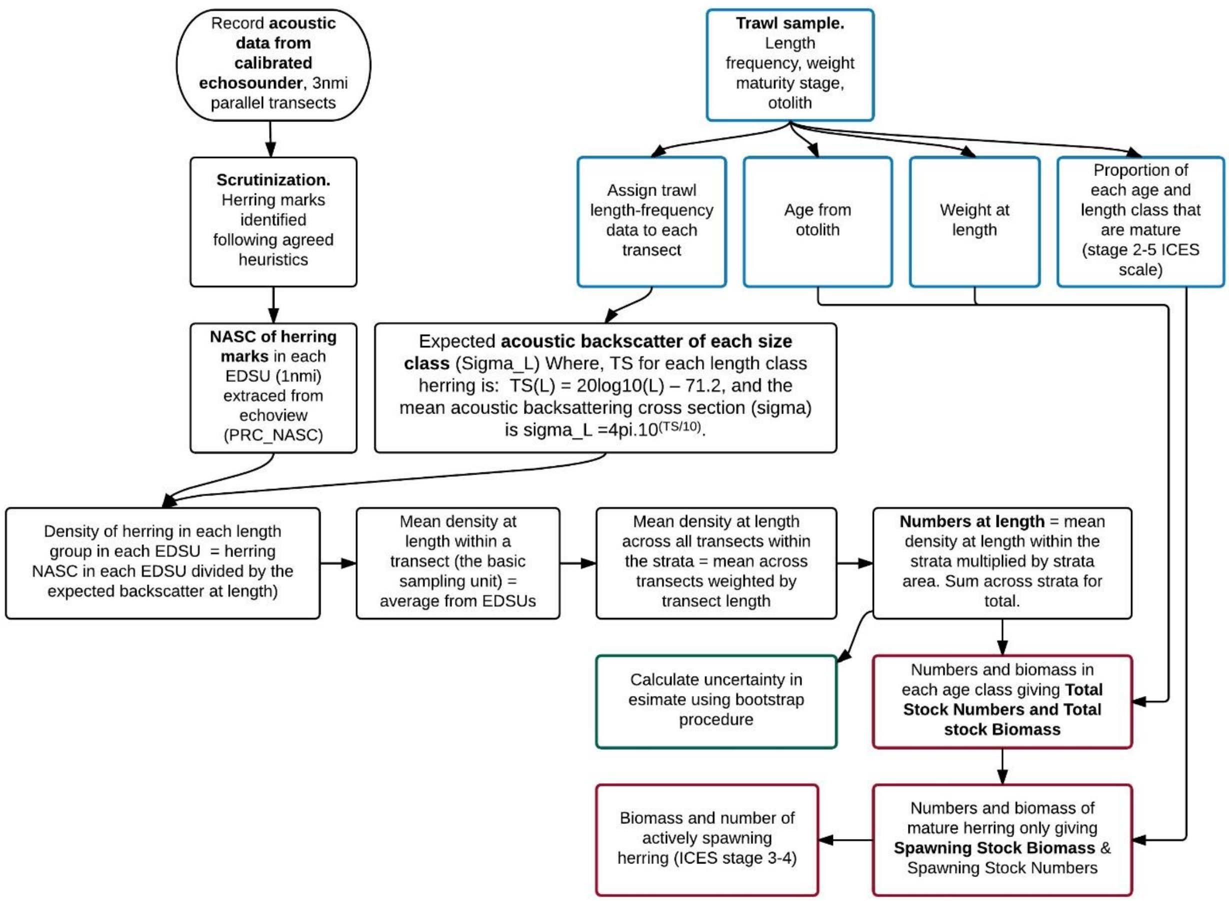


Figure 2.11. Flow diagram of the analysis methods to estimate abundance and biomass. Blue boxes – biological data; black boxes – treatment of acoustic data; red boxes- derived abundances indices; green box – uncertainty estimates

The StoX software (Johnsen et al, 2019)[2] (version 2.7) (http://www.imr.no/forskning/prosjekter/stox/nb-no) was used to calculate the age disaggregated acoustic abundance 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. Documentation and user guides are available from the website. 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 and the overall strata areas combined were generated using the RStox framework package (version 3.1.0).

The scrutinisation of the echograms was first performed using Echoview post-processing software and Nautical Area Scattering Coefficient values assigned to herring marks were exported for each 1nm cell. Then, the calculation of age disaggregated abundance was as follows:

1. **Define survey strata.** In 6aN, two strata were defined (Figure 2.5).
2. **Assigning herring length data from trawls to acoustic transects.** For each transect within each survey strata, the length distribution of herring associated with the transect was determined as the un-weighted mean of all trawls allocated to the respective transects. The allocation of trawls to each transect is shown in Figure 2.12.
3. **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. Where, the target strength (TS) relationship used to calculate the mean acoustic backscattering cross-sections for herring is:

$$TS = 20\log10 (L) - 71.2 \quad \text{[at 38 kHz]} \textit{ for herring}$$

and the mean acoustic backscattering cross section is:

$$\sigma_{sp} = 4\pi . 10^{(TS/10)}$$

[2] http://www.imr.no/forskning/prosjekter/stox/nb-no

4. **The average density of herring in each length class on a single transect** was calculated by dividing the Nautical Area Scattering Coefficient (NASC - the area backscattering coefficient for a particular integration region in areal units (m^2/nmi^2), within each Elementary Distance Sampling Unit (EDSU, here =1nmi) on each transect by the length-specific σ_{bs} (acoustic fish backscatter) assigned to the transect, then averaging over the EDSUs.
5. **Numbers of herring 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.
6. **The numbers and biomass per age & maturity class.** Trawl data on the relationship between length, age and maturity stage were used to partition the numbers at length to estimates of numbers and biomass in each age class and maturity stage. The 9 point maturity stage classification used by Marine Scotland (MSS manual 2011) was converted to the ICES 6 point scale prior to analysis (Table 2.3) (ICES 2011).
7. **Estimate of the relative sampling error.** Within StoX a bootstrap procedure was used to estimate the coefficient of variance (CV) of the estimate of numbers at length. The procedure randomly selects transects within a stratum in every n bootstrap iteration (n =1000). For each selected transect, biological information from trawl stations that were assigned to the transect are randomly sampled and used as input to estimate fish abundance in the stratum in that particular bootstrap iteration. Each bootstrap iteration follows the same estimation procedures as used in StoX and described above (using the combination of mean acoustic density per transect and associated biological information, to estimate fish numbers at length in each stratum).
8. **Choosing the best estimate from replicates**. Where replicate acoustic surveys were conducted for each stratum, the maximum biomass estimate of these was chosen as the best estimate.

Acoustic data were recorded on hard-drives at sea and uploaded to network facilities back at the laboratory. The acoustic metadata and cleaned post-processed EV files are stored on the SPFA’s secure cloud storage and in Marine Scotland Science data base following established procedures. Estimates of NASC values and biological sample data from the surveys are stored in the ICES acoustic database, since surveys began in 2016.

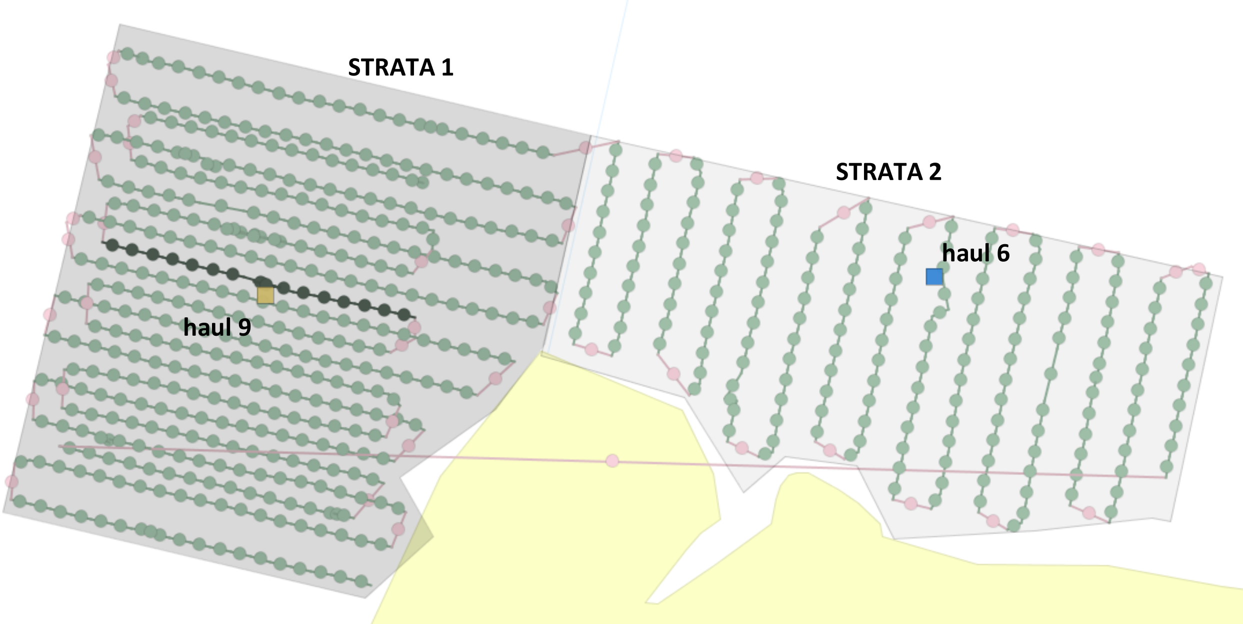


Figure 2.12. Acoustic transects and haul identifiers used in analyses and assignment of biostations. All trasects in strata 1 assigned to haul 9. All transects in strata 2 assigned to haul 6.

2.3 Stock identity separation

2.3.1 Sampling design, key requirements

Samples for discrimination of the genetic baseline identity were collected from selected survey hauls, and any commercial catches.

Key requirements:

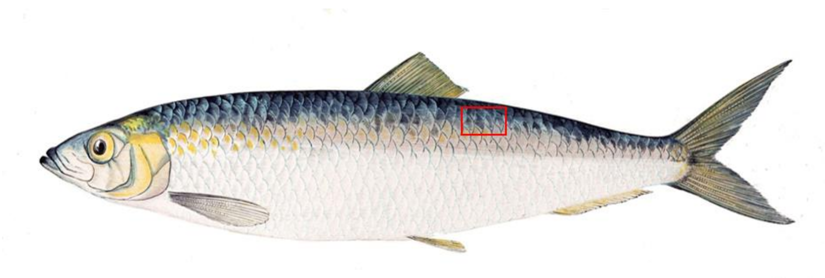
- The herring caught are close to or actually spawning, so that we can be certain they are not just moving through the area.
- Samples should cover the survey area. This is achieved by taking more small hauls, rather than a few large ones.
- To enable the quality of fish for scientific sampling to be maintained, sufficient time needs to be allowed between hauls to ensure that sampling personnel can process the sample immediately while fresh.

2.3.2 Catch sampling procedure for genetic samples

See 2.2.5.4

2.3.3 Genetic sampling protocols

Genetic samples were collected during the biological processing of samples according to the protocol below.



- Clean scissors were used to cut a 0.5-1 cm^3 piece of white muscle tissue from each fish in the area indicated on the image above. Care was taken not to include skin and scales with the samples.
- Tissue was placed into the sample tube with molecular grade ethanol and the lid secured tightly.
- Care was taken to ensure that the sample was not too big and was completely surrounded by ethanol in the sample tube.
- Boxes of sample tubes were stored upright in a fridge (4°C).

2.3.4 Genetic Analysis

The ICES benchmark workshop covering 6a7bc herring (WKCSNS, ICES 2023) concluded that genetic information should be used as the future basis for splitting herring stocks in 6aN and 6aS7bc. This requires that genetic samples of spawning or spawning ready fish are required to maintain the genetic baseline used to identify and split the stocks in surveys and assessments.

In addition, the benchmark also recommended the collection of genetic samples from commercial catches. The purpose of this to be able to partition commercial catches into different stock components so that the fishing mortality and sustainable fishing rates on the stock being assessed can be correctly determined. This is relevant in 6aN where recent genetic results from survey and commercial catches in autumn show that 6aN autumn spawners are genetically the same as the stock of North sea autumn spawning herring, and that spring spawning fish, of uncertain origin, may also be caught during commercial catches in September, albeit infrequently.

No financial provision was made for the analysis of 2021 or 2022 industry survey and monitoring fishery samples. The Marine Institute agreed to take these samples and include them with their own analysis arrangements where possible.

In the absence of an arrangement with the MI samples or where the MI does not have capacity samples taken will be kept in storage until such time that arrangements have been made for analysis. A decision on this is pending.

2.3.5 Data storage

Data from genetic analyses will be stored in the Marine Institute.

2.3.6 Age determination (otolith reading)

Standard procedures for age determination from the growth rings on the otoliths (ear bones) of herring (ICES 2005) were used to determine the age of fish sampled. This age data was used to create an age-length key (ALK).

2.3.7 Data storage

Data are stored on dedicated dropbox owned by SPFA and acoustic data submitted to ICES databased and stored Marine Scotland Science survey database following established procedures.

3 Results

3.1 Sampling summary

The notable feature of the 2022 survey, that was different to all previous years, was the near absence of any marks that could be classified with any confidence as herring. Only one verifiable herring school was recorded acoustically during the survey (Figure 3.1). A sample of the mark was captured during haul 9 (Figure 2.10).

Locations of sample hauls whose biological data were used for the estimation of the biomass of herring in 6aN are shown in Figure 3.2, Table 3.1. Haul 6 contained juvenile herring that were mixed (7% of sample) in with a much larger sample of sprat (84%) of the sample size, whereas haul 9 was a clean sample of adult herring (Figure 3.3, 3.4), many of which were spawning ready. Genetic samples were taken from both hauls.

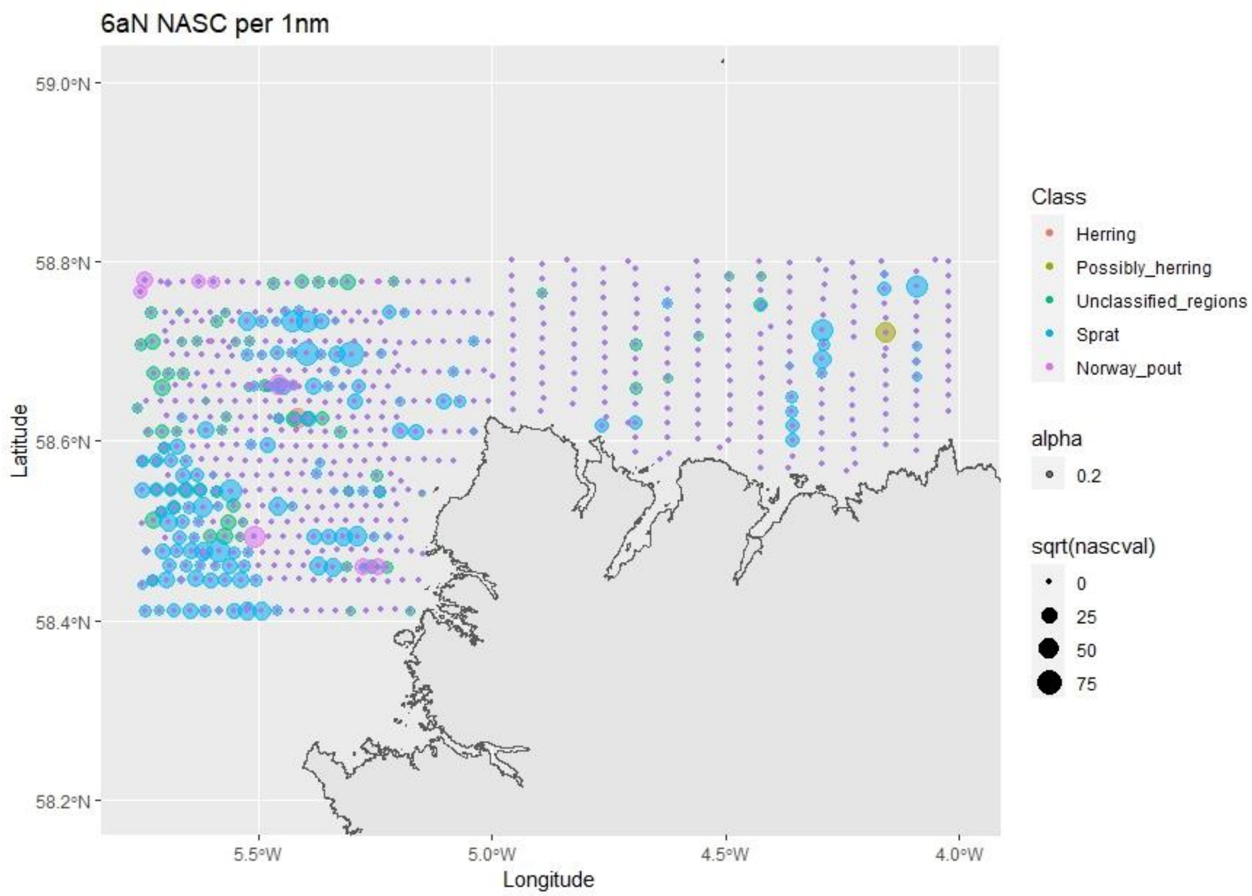


Figure 3.1. Map of relative acoustic density.

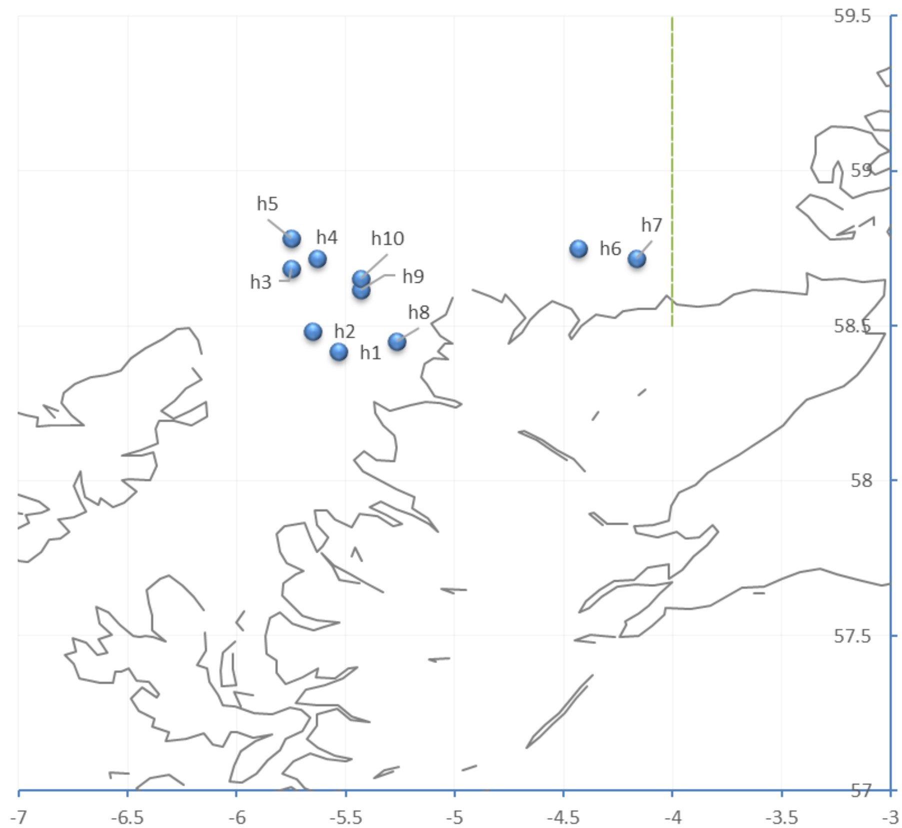
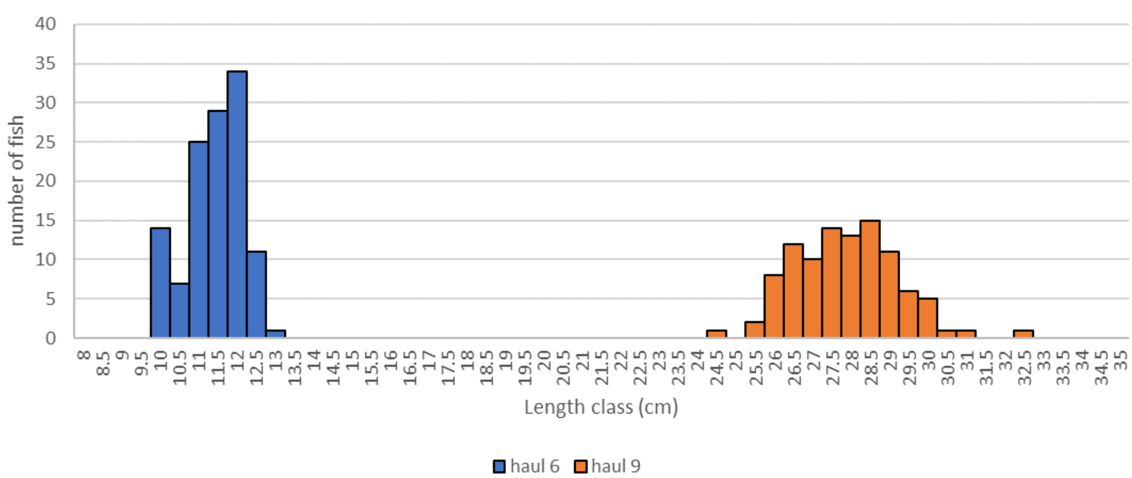


Figure 3.2. Locations of biological sample hauls.

(a)



(b)

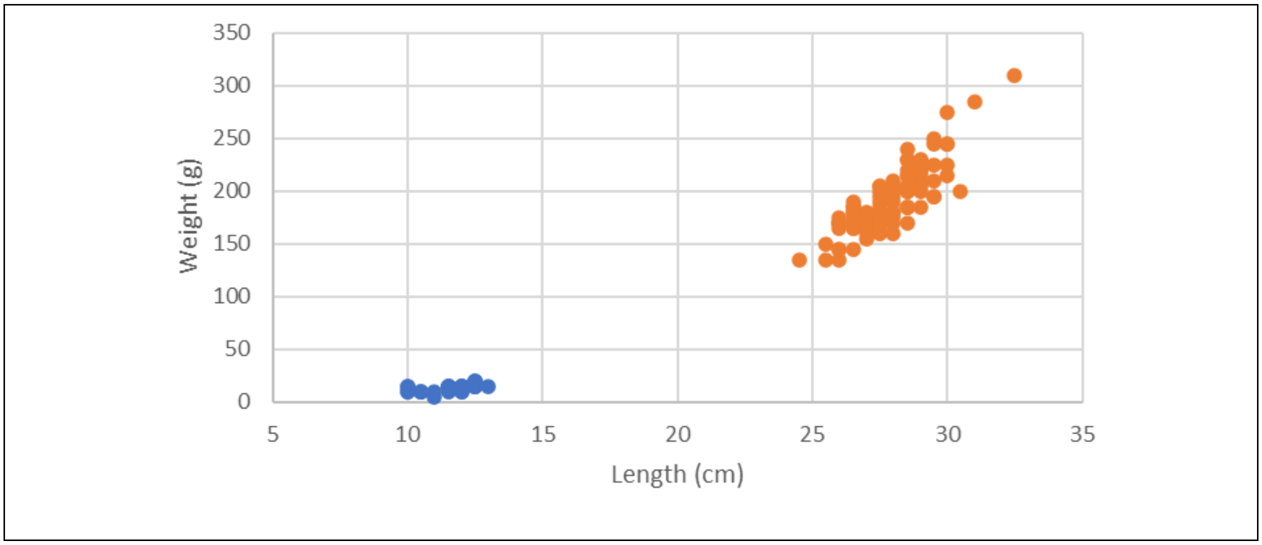


Figure 3.3. Length frequencies (a) and Length-weight relationship (b) for the sample hauls

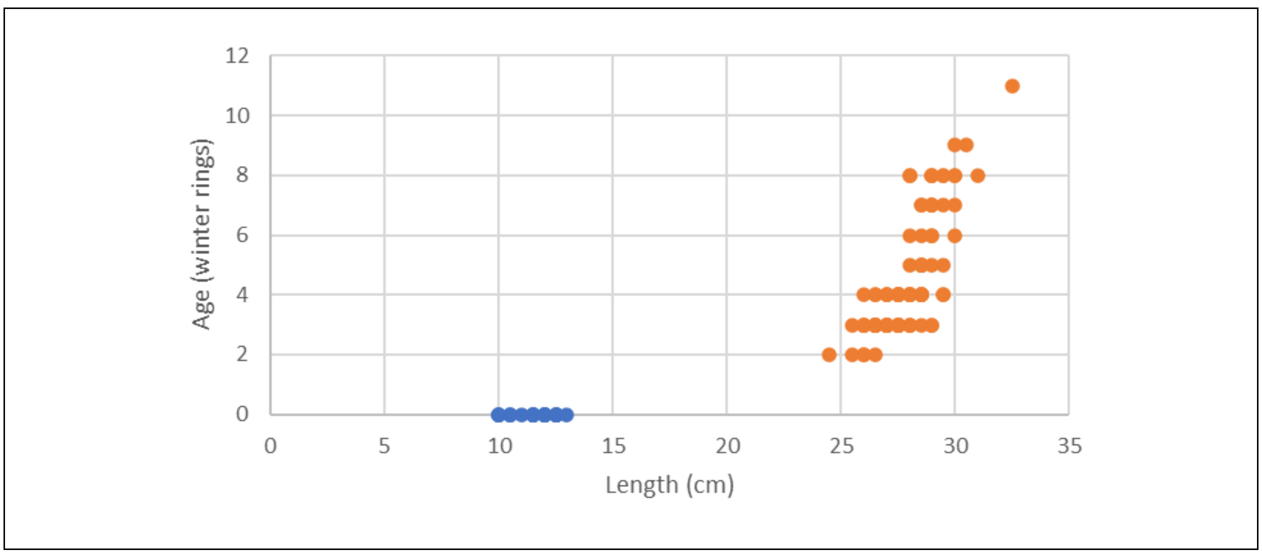


Figure 3.4. Herring age length keys for the sample hauls.

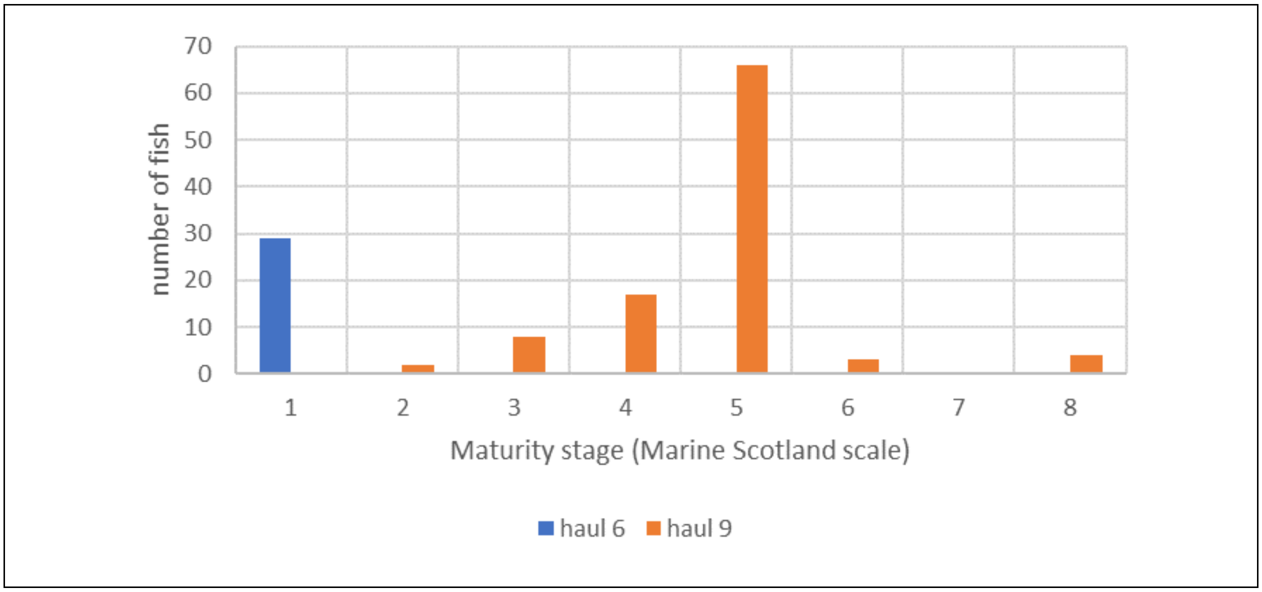


Figure 3.5. Herring maturity scales for the sample. Marine Scotland scale, where stage 5 is spawning ready and stage 6 is spawning (see Table 2.3).

Table 3.1. Haul information and catch composition for hauls relevant to the analysis of the acoustic surveys in 6aN.

			Position		**Catch by species (kg)**						
Haul	date	haultype	plot_lon	plot_lat	HER	MAC	NOP	WHG	HAD	SPR	TOTAL (kg)
1	12/09/2022	S	-5.53	58.42							
2	12/09/2022	S	-5.65	58.48							
3	14/09/2022	S	-5.75	58.68							
4	14/09/2022	S	-5.63	58.72		46		11	88		145
5	14/09/2022	S	-5.75	58.78			79				79
6	16/09/2022	S	-4.43	58.75	8	11				101	120
7	17/09/2022	S	-4.17	58.72		5					5
8	18/09/2022	S	-5.27	58.45	0.45	22.98	6.00	7.99	25.98	0.10	63.5
9	18/09/2022	S	-5.43	58.62	1500						1500
10	19/09/2022	S	-5.43	58.65	0.75	7	29	2	26		64.75

3.2 Abundance estimation

Biological data were used to estimate the abundance and biomass of herring in each strata according to length, age and maturity stage.

A summary table for the entire surveyed area (Table 3.2) and breakdown for each area (Table 3.3) is followed by the CV of the abundance at age (Table 3.4, Figure 3.6) and biomass estimate for each strata (Table 3.5). Note again that only one herring mark was detected in the whole combined survey area. This means the CV estimates reflect the precision of the estimation for the one transect where the mark was located rather than the whole survey area in this instance.

Table 3.2. Combined results for all strata. (Figures in bold are weighted averages based on the numbers in each age group).

Results for all strata combined 2022					
Age (ring)	Numbers (mill)	Biomass (kt)	Maturity	Mean Weight (g)	Mean Length (cm)
0	0	0.0		#DIV/0!	#DIV/0!
1	0	0.0	#DIV/0!	#DIV/0!	#DIV/0!
2	0	0.0	0.80	151.0	25.7
3	1	0.2	1.00	175.4	27.0
4	1	0.2	1.00	188.6	27.8
5	0	0.1	1.00	220.0	28.6
6	0	0.0	1.00	211.0	28.9
7	0	0.1	1.00	222.9	29.1
8	0	0.1	0.90	220.0	29.3
9+	0.1	0.0	1.00	251.7	31.0
Immature	0	0.016		197.5	27.8
Mature	4	1		192.8	27.9
Spawning	3	1			
unknown	0	0			
Total	4	**0.77**	0.98	**192.9**	27.9

Table 3.3. Strata summary

	Strata summary 2022				
Strata	Abundance (mill)	Biomass (kt)	Mean length (cm)	Mean weight (g)	% Mature
Strata 1	4	0.8	27.9	192.9	0.98
Strata 2	0.0	0.0	#DIV/0!	#DIV/0!	#DIV/0!
TOTAL	4	0.77			

Table 3.4. Summary CV estimates on abundance at age.

Abundance estimates are only available for Strata 1 because no herring NASC was recorded in Strata 2.

age	Ab.Sum.5%	Ab.Sum.50%	Ab.Sum.95%	Ab.Sum. mean	Ab.Sum.sd	Ab.Sum.cv
2	0.19	0.20	0.61	0.29	0.14	0.50
3	1.33	1.43	4.27	2.05	1.01	0.50
4	1.07	1.15	3.42	1.64	0.81	0.50
5	0.27	0.29	0.85	0.41	0.20	0.50
6	0.19	0.20	0.61	0.29	0.14	0.50
7	0.27	0.29	0.85	0.41	0.20	0.50
8	0.38	0.41	1.22	0.59	0.29	0.50
9	0.08	0.08	0.24	0.12	0.06	0.50
11	0.04	0.04	0.12	0.06	0.03	0.50

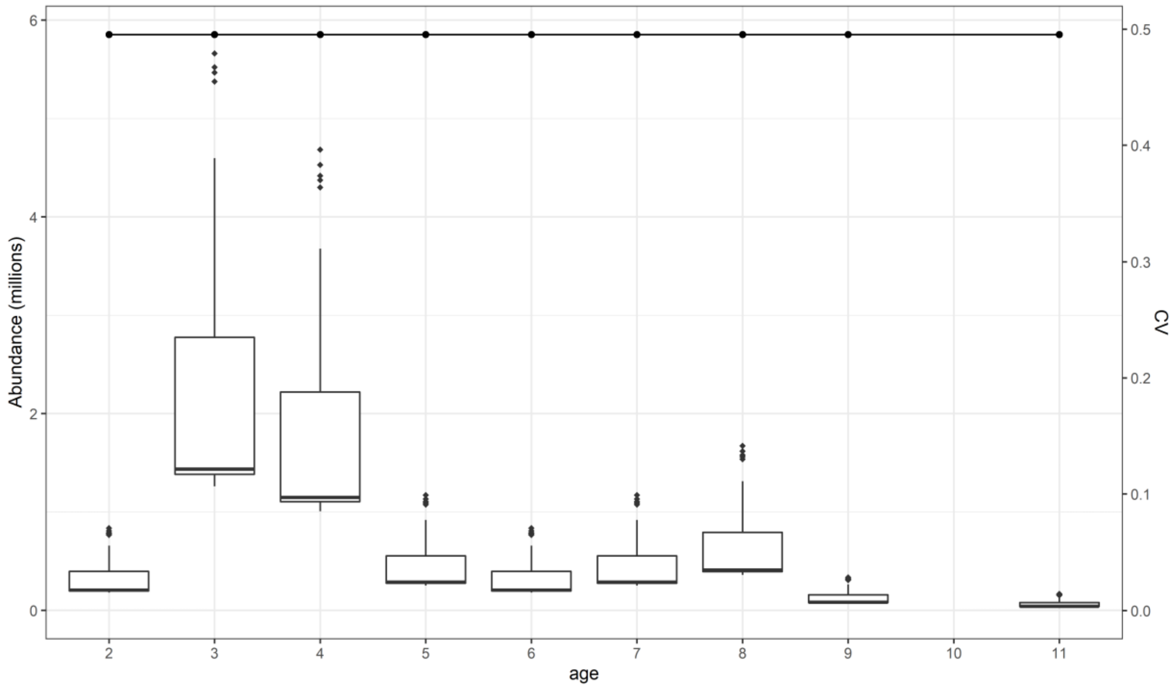


Figure 3.6. Abundance at age with CV estimate

Table 3.5. Summary CV estimates for survey areas in 2021.

Ton by stratum	**Ton.5%**	**Ton.50%**	**Ton.95%**	**Ton.mean**	**Ton.sd**	**Ton.cv**
Strata1	735	790	2355	1129	559	0.50
Strata2						
Total number by stratum (mill)	**Ab.Sum.5%**	**Ab.Sum.50%**	**Ab.Sum.95%**	**Ab.Sum.mean**	**Ab.Sum.sd**	**Ab.Sum.cv**
Strata1	3812594	4096095	12213193	5852844	2899060	0.50
Strata2						
Ton by survey	**Ton.5%**	**Ton.50%**	**Ton.95%**	**Ton.mean**	**Ton.sd**	**Ton.cv**
	735	790	2355	1129	559	0.50
Total number by survey (mill)	**Ab.Sum.5%**	**Ab.Sum.50%**	**Ab.Sum.95%**	**Ab.Sum.mean**	**Ab.Sum.sd**	**Ab.Sum.cv**
	3812594	4096095	12213193	5852844	2899060	0.50

3.2.1.1 *Survey uncertainty and limitations*

Due to the near absence of verifiable herring marks recorded either by the echosounder or during sample trawls, estimation of the acoustic abundance across the two strata is, in effect, reduced to estimating the abundance of herring that were recorded on one transect alone, and for which a biological sample was successful. Extrapolating this one sample to the entire survey area is not meaningful, with the estimation uncertainty being extremely high.

3.3 Stock identity separation

Samples were collected from 2 hauls in 2022 and have been stored for analysis at a later date. (see section 2.3.4).

4 Achievements and Recommendations

4.1 Abundance estimation -acoustics

4.1.1 Recommendations for data users

The acoustic survey is considered to have:

- Contained a significant part of the area where herring spawn in 6aN during autumn.
- Been limited in the period of observation in relation to the extended period that herring may potentially spawn. The survey was limited to one vessel only, which reduced the period of observation compared to surveys from 2016-2021. The survey was also shorter than the usual survey duration because of prior mechanical issues causing a delayed start. However, the timing of the survey was consistent with previous observations of herring aggregating in this area and in condition for spawning.
- Shown that herring were nearly absent in the survey area during the period of the survey.
- Provided a reliable estimate (despite the lack of herring) of
  - the minimum biomass of mature herring at age observed in survey areas during the survey period.
  - the minimum spawning biomass during the survey period.

The industry-led acoustic survey continues to have particular value in relation to:

- Monitoring the age structure and providing an index of abundance and biomass of herring in 6aN in known spawning areas (see Mackinson and Berges 2022, ICES 2022), which provides a source for comparison and validation of trends of abundance with the MALIN Shelf/ WoS herring acoustic survey.
- (Subject to achieving an appropriate spatial and temporal coverage), monitoring any changes in the timing of spawning and distribution at this time of year and mapping in detail the spawning locations in 6aN, which is useful in relation to marine spatial planning considerations.
- Promoting a positive example of a collaborative industry-science initiative, helping to develop both industry and researchers skills in assessing pelagic stocks.

4.1.2 Recommendations for future surveys from WGIPS

- Following the outcomes of the benchmark (WKNSCS, ICES 2023) that the index shows promise in tracking cohorts but is presently too short to fully assess it utility in an Category 1 stock assessment, work with Marine Scotland Science to agree a strategy and plan to maintain the acoustic survey for a minimum of 10 years and then re-evaluate its utility for use as an abundance index to be used in the 6aN herring stock assessment.
- Seek to find ways provide flexibility to search more widely over 6aN, and over and extended period of time during the autumn spawning period so that relevant information on the distribution of herring is in the area is used to ensure the 6aSPAWN survey design is fit-for-purpose.
- For Marine Scotland to considered the scientific monitoring requirements necessary to address the findings that according to the genetic split of stock components, there may be a significant abundance of herring in 6aN that spawn in the spring and are not presently accounted for in ICES assessment and fisheries advice.
- Continue to ensure that future surveys follow standard protocols whereby all fish recordings (even of non-commercial size) encountered on the echogram be sampled regularly. This is paramount to improve analysis of the acoustic data and accuracy of the estimated abundance and stock composition for different species in the survey area.
- Continue to ensure that industry vessels are equipped with appropriate nets/sampling bag and fishing is directed as appropriate for taking small samples for biological analysis.
- To prevent any spatial conflicts, continue to notify local creel fishermen of survey transects in advance.

4.2 Stock identity

Medium to long term arrangements need to be established for carrying out and financing the ongoing genetic sampling needs. As of 2023, and arrangement is being established between Marine Scotland and the Irish Marine Institute.

Acknowledgements

Skippers and crew of the Resolute

Echomaster Marine.

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Annex 1. Calibration and acoustic settings on Resolute BF50

Calibration Results

<PulseLength>0.001024</PulseLength>
<Frequency>38000</Frequency>
<Gain>26.62</Gain>
<SaCorrection>-0.0408</SaCorrection>
<BeamWidthAlongship>6.35</BeamWidthAlongship>
<BeamWidthAthwartship>6.54</BeamWidthAthwartship>
<AngleOffsetAlongship>-0.07</AngleOffsetAlongship>
<AngleOffsetAthwartship>0.05</AngleOffsetAthwartship>
<TsRmsError>0.0861</TsRmsError>
<Impedance>75.00</Impedance>
<Phase>0.00</Phase>

Operation Settings

Ping interval: 500ms (0.5 second)

Pulse type: CW

Ramping: fast

Sample interval: 0.043ms

Power: 2000w

Maximum depth (listed as Channel Recording Range under OUTPUT) for data): Automatic

Maximum file size: 1000MB

Environment: Temp = 10C, Salinity =35ppm, Sound speed 1490.5 m/s

Draft: 6m (water taken on)

Position of transducer: Alongship =, Athwartship =

Interference: While surveying, switched off all other sounders and sonars because they were found to create interference. The exception as the WASP multibeam