

Identification of herring in Shetland waters - Summary Report -

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Summary

There are several populations of herring (*Clupea harengus*) in the northeast Atlantic. Around the Shetland Islands, North Sea autumn-spawning herring are present, for which there is a valuable commercial fishery. Those herring undergo sexual maturation between March and August, ready to spawn in September. In recent years there have been observations in Shetland waters of herring undergoing maturation in December, which could potentially be spring-spawning herring (maturing between May and January, to spawn in February/March). The presence of these fish is of interest to both science and industry, with the possibility of a stock distribution which is currently unknown and unaccounted for, and which could have implications for stock management.

To provide information on the identity of herring in Shetland waters, this study worked with local fishers to collect specimens of herring for biological sampling and analyses. Between December 2020 and April 2021, and January 2022 and March 2022, 656 herring were collected by local fishers for sampling. Length, sex and maturity stage were recorded for all fish, with a tissue sample taken for genetic analysis, and a gonad sample taken for histological examination (providing microscopic maturity stage).

The genetic analysis showed a baseline sample of the Shetland collected herring to be distinct from other herring populations of 6.a.S; North Sea and 6.a.N autumn spawning; 6.a.N spring spawning; and Downs winter spawning herring. And while the Shetland baseline herring were shown to be different, there was indication from the genetic analysis that these fish were most similar to spring spawning 6.a.N fish. These results provide evidence of spring spawning herring in Shetland waters; with the potential for a previously unidentified Shetland spring spawning population component (in the context of this study and the available data). However, the identity and origin of this population is not known, and Norwegian or Western Baltic spring spawning herring cannot be discounted as the source. Across all the herring samples collected in Shetland, there was evidence of the presence and potential mixing of multiple herring population components (including autumn spawning North Sea and 6.a.N, and spring spawning 6.a.N and the potential Shetland component), with overlap likely occurring at various stages of spawning, feeding and over-wintering.

The application of maturity stage classification alongside genetic assignment further substantiated the genetic results. Using gonad samples to identify the maturity stage of fish caught between December and March, herring were classified as either autumn spawners (if immature, spent, recovering/resting) or spring spawners (if early maturing, maturing, spawning prepared and spawning). The majority of fish classified by maturity stage as spring spawners were genetically assigned as the potential Shetland component, while the majority of fish classified by maturity stage as autumn spawners were assigned as North Sea autumn spawners.

The study had some limitations. No genetic baseline data were available for Norwegian or Western Baltic spring spawning herring. Owing to the small sample sizes involved and limits to the genetic analyses, the findings are intended as exploratory indicators to genetic identification only. Nonetheless, this study has gathered valuable new information to provide insight into the identity of herring populations around Shetland, with clear evidence of autumn spawning and spring spawning herring. New connections with other academic institutions and staff working on similar research have been established, with further collaboration planned (e.g. genetic comparisons with other herring populations such as Norwegian and Western Baltic spring spawning), to provide more detailed information and to contribute information to a wider body of work.

Background

Herring is one of the most important pelagic species in the North Atlantic, with a history of exploitation. In the Northeast Atlantic, herring are widely distributed and comprise a number of different ‘races’ or populations (**Figure 1**). Herring undertake migrations between feeding, spawning and over-wintering areas, with those from different stocks and/or populations coming together to mix on common feeding grounds. Such mixing can make it difficult to separate stock components within a single catch, which can have implications for stock assessment. Work has been carried out to distinguish herring populations, using different methods, including genetics, body morphometrics, otolith shape and chemistry analyses, tagging, parasite analysis and life-history analyses.

Around the Shetland Islands, North Sea autumn-spawning (NSAS) herring are present, for which there is a valuable commercial fishery. Those herring undergo sexual maturation between March and August, ready to spawn in September. In recent years, there have also been observations in Shetland waters of maturing herring in December, as well as historic reports of a winter fishery. Such fish could potentially be spring spawners (maturing between May and January, to spawn in February/March), rather than the typical NSAS herring known to be present. The identification of herring in Shetland is yet to be fully explored, and the potential presence of an unknown and unaccounted for spring spawning component requires further investigation, with correct population identification and discrimination fundamental to fisheries management and stock assessments.

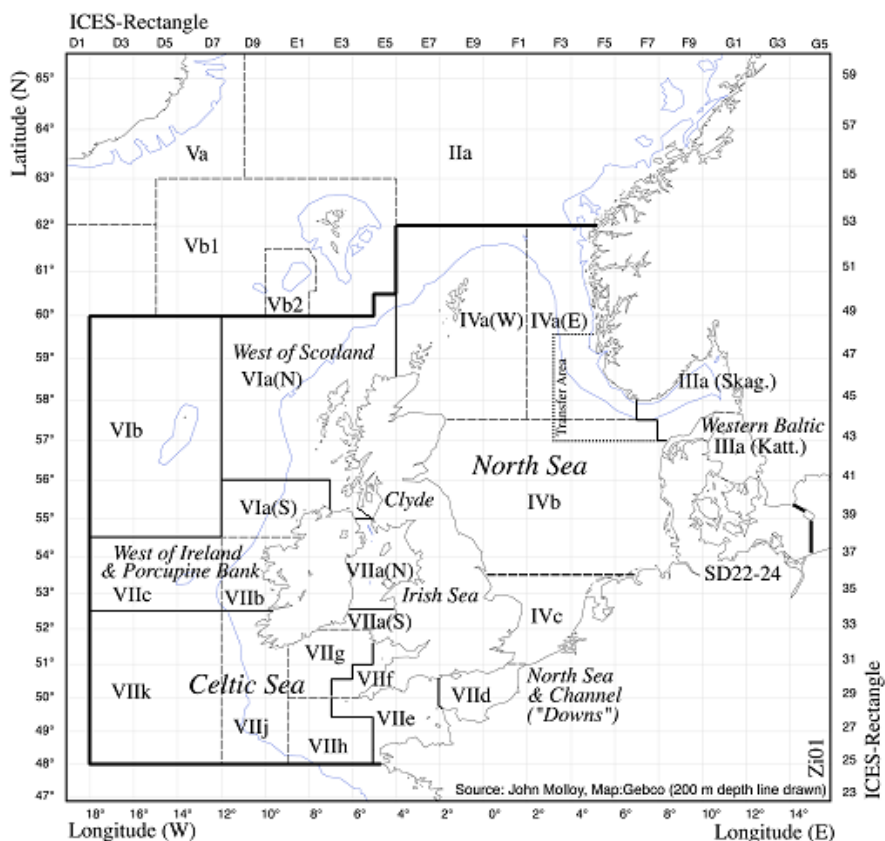


Figure 1. ICES areas used for the assessment of herring stocks south of 62°N (ICES HAWG). Area names in italics indicate the area separation applied to the commercial catch and sampling data kept in long term storage. "Transfer area" refers to assessment of the migratory western Baltic spring spawning herring (Rügen herring), where information about catches etc. in the North Sea are transferred to this stock. (Source: Report of the Workshop on Sexual Maturity Staging of Herring and Sprat (WKMSHS), ICES 2011).

Methods

To provide information on the identity of spawning herring in Shetland waters, this study worked with local fishers to collect specimens of herring for biological sampling and analyses. It was also intended to consult with local fishers to document observations of December mature herring, but owing to unsuccessful responses to a questionnaire and covid impacting on in-person interviews this work was not possible.

Local Shetland fishers were asked to retain any herring caught between December 2020 and April 2021, as well as between January 2022 and March 2022. A total of 719 herring were collected, from which 656 herring had associated metadata and were of sufficient quality to be fully utilised in analyses. The 656 herring were collected across twenty-eight samples, varying between 1 and 105 fish per sample. Total length (to the nearest lowest half cm), sex and macroscopic maturity stage were recorded for all fish, with tissue taken and sent to EDF Scientific in Ireland for genetic analysis. For all herring collected in 2020/21 (456 fish), a gonad sample was taken for histological examination, providing microscopic maturity staging. Otoliths were removed from all fish and retained but no ageing, microstructure or microchemistry was carried out owing to limited resources. (Since project completion, ageing is being investigated, which would provide a valuable addition to the dataset).

For the genetic analysis, Sample 16 (T) was selected as the Shetland baseline sample (Shetland_T), having the highest proportion of mature spawning fish. The Shetland baseline was compared to other existing herring baselines for 6.a.S, 6.a.N autumn spawning, 6.a.N spring spawning, North Sea autumn spawning, and Downs. Genetic differentiation was assessed between baseline samples with an indication provided of where Shetland baseline fish lie in comparison to adjacent baseline populations (using multi-locus pairwise F_{ST} analyses and Principal Coordinates Analysis (PCoA) of pairwise F_{ST} values). Clusters of genetically related individuals were identified through further examination of each of the non-baseline Shetland samples as a whole and by maturity stage (using Discriminant Analysis of Principal Components (DAPC) and Principal Component Analysis (PCA)).

Fish sampled were classified as either autumn or spring spawners based firstly on maturity stage at month of capture, then on genetic assignment; with the outcomes of the two classifications compared. Using maturity stage, herring of maturity stages 2, 7 and 8 (immature, spent, recovering/resting) caught between December and March were classified as autumn spawners (having spawned in September, with subsequent maturation between March and August). Herring of stages 3, 4, 5 and 6 (early maturing, maturing, spawning prepared, spawning) caught in the same period were classified as spring spawners (with spawning occurring in February-April, following maturation between May and January). An exploratory genetic assignment model was used to classify each fish to either North Sea Autumn, Shetland Spring or Downs winter herring, using a probability score derived from baseline datasets which provided input training to the model.

Note that owing to the small sample sizes involved in this study and limitations to the work, the analyses are intended as exploratory indicators to genetic identification only.

Results

The opportunistic approach to sampling achieved a broad range of samples, spatially distributed around Shetland throughout the winter sampling period (**Figure 2**). While samples were obtained in all months requested (December 2020 - April 2021, and January 2022 - March 2022), the majority

were caught in December 2020 (82 fish), January 2021 (270 fish) and January 2022 (170 fish). All fish caught were between 20 and 33.5 cm, typical of the adult fish found and commercially exploited in the North Sea. The majority were either maturity stage 4 maturing (152 fish), stage 5 spawning prepared (170 fish) or stage 7 spent (258 fish), with fewer than 25 fish in each of the stages 1, 2, 3, 6 and 8 (immature virgin, immature, early maturing, spawning and recovering/resting).

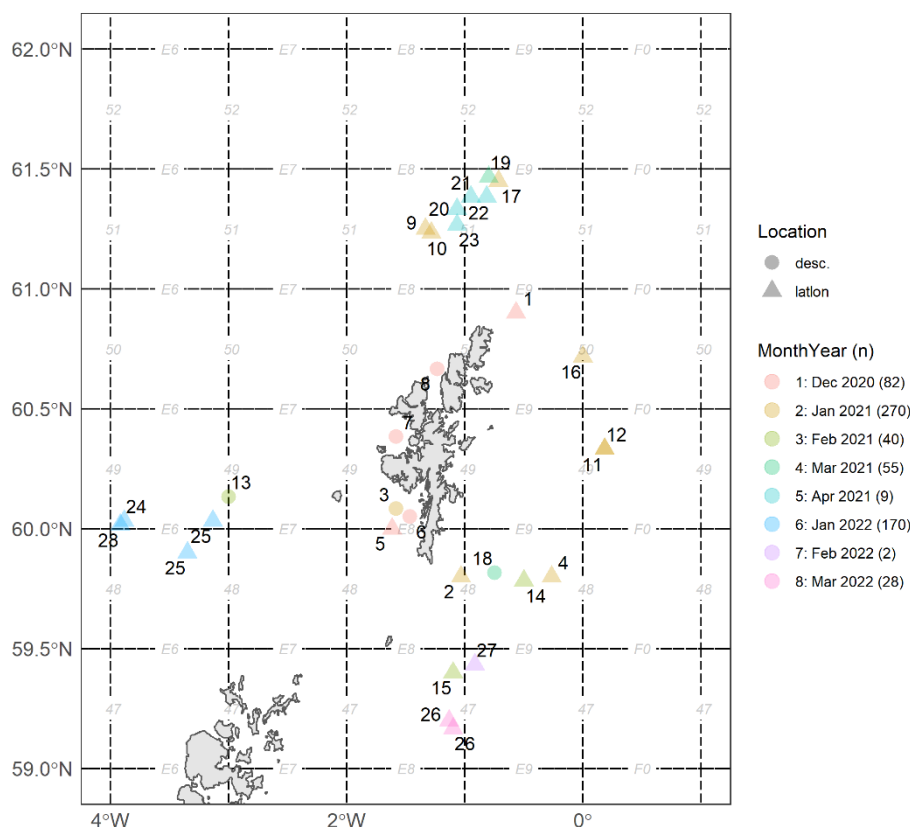


Figure 2. Location of herring samples. Where Location=desc, only a descriptive location was provided for samples [e.g. ‘approximately 10 miles W of Burra’]. Where Location=latlon, latitude and longitude were provided for samples.

The genetic analysis showed the Shetland baseline sample (Shetland_T) to be significantly different and distinct from baselines of the adjacent populations of 6.a.S, 6.a.N autumn spawning, 6.a.N spring spawning, North Sea autumn spawning, and Downs (**Figure 3**). While the Shetland baseline was shown to be different, the results of genetic analysis indicate that the Shetland baseline was more similar to the baseline of spring spawning 6.a.N fish than the other baseline datasets.

When comparing each sample to baseline datasets, the results showed Shetland fish clustering with different baselines across – and within – samples, indicating varied genetic differentiation across the samples. Generally, fish from the Shetland samples tended to show genetic clustering with autumn spawning North Sea and 6.a.N, and spring spawning 6.a.N and Shetland_T. The differences in sample clustering (within and across samples) were substantiated by the addition of maturity data, whereby stages 3,4 and 5 fish (early maturing, maturing, spawning prepared) largely grouped with the Shetland baseline spring spawners, and stage 2 and 7 fish (immature, spent) largely grouped with North Sea autumn spawners.

When looking at the spatio-temporal distribution of autumn and spring spawning fish, no clear overall patterns were apparent, though there was some grouping of fish at locations offshore. For example, to the north of Shetland, there was a collection of eight samples which predominately demonstrated clustering with autumn spawning North Sea and 6.a.N fish. To the west of Shetland and to the south, there were two groups of samples which generally demonstrated clustering with the spring spawning Shetland and 6.a.N baselines. In general, fish of both spawning strategies were present in samples throughout Shetland waters, across the sampling period December-April.

The majority of fish classified by maturity stage as spring spawners were genetically assigned as Shetland spring spawners (based on the Shetland_T baseline) (189 fish); and, similarly, the majority of fish classified by maturity stage as autumn spawners were assigned as North Sea autumn spawners (248 fish). There were 76 fish maturity classified as spring spawners which were then genetically assigned as North Sea autumn spawners. These were mainly stage 4 maturing (38) and stage 5 spawning prepared (25) fish. Very few fish (6) classified as autumn spawners were genetically classified as Shetland spring spawners; and overall, only 11 were genetically assigned as Downs winter spawners.

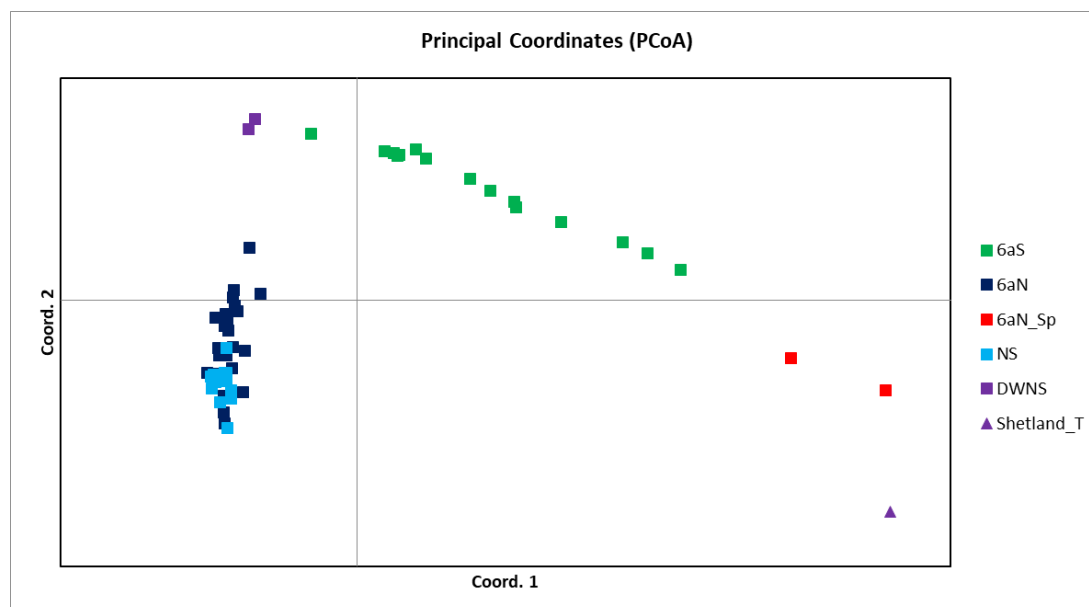


Figure 3. Principal Coordinate Analysis (PCoA) of F_{ST} of the baseline datasets. Datasets: 6.a.S ('6aS'), 6.a.N autumn spawning ('6aN'), 6.a.N spring spawning ('6aN_Sp'), North Sea autumn spawning ('NS'), Downs ('DWNS'), Shetland Sample 16 (T) ('Shetland_T'). Shetland_T indicated to be distinct from other baselines examined, with closest similarity to 6aN_Sp baseline.

Discussion

This study has gathered valuable new information to provide insight into the identity of herring populations around Shetland, with clear evidence of the presence of autumn and spring spawning herring, as well as Downs winter spawning herring between the months of December and March.

Genetic analysis showed the Shetland baseline to be significantly different and distinct from adjacent populations (6.a.S; North Sea and 6.a.N autumn spawning; 6.a.N spring spawning; and Downs winter spawning herring), with most similarity to spring spawning 6.a.N fish; indicative of spring spawning herring in Shetland waters, with the potential for a previously unidentified Shetland spring spawning

population component in the context of this study and the available baseline datasets. Comparison of the Shetland non-baseline samples against baseline data indicated genetic clustering with the Shetland baseline, as well as with other baseline datasets, demonstrating the presence of multiple herring population components (e.g. autumn spawning North Sea and 6.a.N, and spring spawning Shetland and 6.a.N), and the potential mixing of such populations, with overlap likely occurring at various stages of spawning, feeding and over-wintering.

There was good agreement of spawner classification between maturity stage at month of capture and genetic assignment, with results demonstrating the two main herring populations present in Shetland waters to be North Sea autumn spawning and Shetland spring spawning. North Sea autumn spawning fish are known to be present, with a valuable commercial fishery in place since the 1970s. Less is known about the presence of spring spawning herring in Shetland waters, though there have been historical reports of such 'winter fish' and a 'winter fishery'. The agreement between the two methods of spawner classification provides confidence in using maturity stage at time of capture as an indicator of population identity. This is useful to know as genetic analysis is not always practical or affordable; though genetic analysis remains preferable as the most robust method for discriminating population.

While the results here have provided evidence of spring spawning fish in Shetland waters, the origin of this population is not known. No baseline datasets were available for Norwegian or Western Baltic spring spawning herring (NSSH and WBSSH), which cannot be discounted as the source of spring spawning fish found in Shetland waters. (Work is underway to source NSSH and WBSSH baseline data).

No clear spatio-temporal relationship was observed in the presence and distribution of autumn and spring spawning fish. It is noted that the timing of the Shetland spring spawners seemed earlier than Norwegian and Western Baltic spring spawning fish. Spawning of NSSH is typically between February-April and WBSSH is generally April-June. Spring spawning in Shetland herring samples in this study was generally observed mid-late January, with some in December, February and March. Owing to the limited scope of this study, the information provides a snapshot in time, with further sampling necessary to better understand the presence of spring spawning herring in Shetland waters.

The opportunistic nature of the sampling carried out provided a sound sample base from which to examine the morphometrics, biology and genetics of herring found in Shetland waters during the winter. The histological analysis carried out provided improved accuracy to the maturity staging of the herring, which was of value when assessing spawning strategies as an indicator of population identity. Being reliant on opportunistic samples from commercial vessels had the potential to impact on the outcomes of the study (for example, not knowing if, or how many, samples could be obtained to address the aims and objectives). However, there are benefits to such ways of sampling: dedicated ship time was not constrained by limited funds or poor weather; a wider spatio-temporal distribution of sampling could be covered; and relationships with industry developed.

Similarly, utilising skills and expertise from external organisations has had the advantage of establishing connections with other academic institutions and staff working on similar research. Preliminary results were presented to the ICES Working Group of International Pelagic Surveys (made up of staff from a number of research and academic institutes), whose work includes reviewing the use of genetic stock separation methods. Additional collaboration is planned, with further genetic assessment of the samples obtained in this study, to provide more detailed information and to contribute information to a wider body of work. Such work can contribute to addressing questions of stock discrimination which can inform science and management.