1 Introduction

1.1 HAWG 2022 Terms of Reference

2020/2/FRSG03 The Herring Assessment Working Group for the Area South of 62ºN (HAWG), chaired by Afra Egan, Ireland, and Cecilie Kvamme, Norway will meet: online 25th –27th January 2022 to:

a) Compile the catch data of sandeel in assessment areas 1r, 2r, 3r, 4, 5r, 6, and 7r and address generic ToRs for Regional and Species Working Groups that are specific to sandeel stocks in the North Sea ecoregion;

and online 9th –12th May 2022 and the 18th of May 2022 to:

b) address generic ToRs for Regional and Species Working Groups for all stocks assessed by HAWG.

The assessments will be carried out based on the Stock Annex. The assessments must be available for audit on the first day of the meeting.

Material and data relevant for the meeting must be available to the group on the dates specified in the 2022 ICES data call.

HAWG will report by 11th February (sandeel), 30th April (sprat) and 23rd May (herring) 2022 for the attention of ACOM.

A summary of the HAWG stocks, assessment method and advice frequency is given in the table below.

Stock Name	Stock Coord.	Assesss. Coord.	Assessment Method
Sandeel in Divisions 4b-c, SA1r (central and southern North Sea, Dogger Bank)	Denmark	Denmark	SMS-effort
Sandeel in Divisions 4b-c and SD20, SA2r (central and southern North Sea)	Denmark	Denmark	SMS-effort
Sandeel in Divisions 4b-c and SD20, SA3r (northern and central North Sea, Skagerrak)	Denmark / Norway	Denmark	SMS-effort
Sandeel in Divisions 4a-b, SA4 (northern and central North Sea)	Denmark	Denmark	SMS-effort
Sandeel in Division 4a, SA5r (northern North Sea, Viking and Bergen banks)	Denmark / Norway		No assessment
Sandeel in SD20-22, SA6 (Skagerrak, Kattegat and Belt Sea)	Denmark		No assessment
Sandeel in Division 4a, SA7r (northern North Sea, Shetland)	Denmark / UK (Scotland)		No assessment
Sandeel in Division 6a (West of Scotland)	ICES		No assessment
Herring in Subdivisions 20–24 (Western Baltic Spring spawners)	Denmark	Denmark	SAM
Herring in Subarea 4 and Division 3.a and 7.d (North Sea Autumn spawners)	Germany	The Netherlands	SAM

Stock Name	Stock Coord.	Assesss. Coord.	Assessment Method
Herring in Division 7.a South of 52° 30′ N and 7.g-h and 7.j-k (Celtic Sea and South of Ireland)	Ireland	Ireland	ASAP
Herring in Divisions 6.aN	UK (Scotland)	UK (Scotland)	Survey biomass index and CHR rule for advice
Herring in Divisions 6.aS and 7.b and 7.c	Ireland	Ireland	Survey biomass index and CHR rule for advice
Herring in Division 7.a North of 52° 30′ N (Irish Sea)	UK (Northern Ireland)	UK (Northern Ireland)	SAM
Sprat in Division 3.a (Skagerrak - Kattegat) and Subarea 4 (North Sea)	Denmark	Denmark	SMS
Sprat in the Western Channel	UK (E&W)	UK(E&W)	Survey biomass
Sprat in the Celtic Seas	UK(E&W)		No assessment

1.2 Generic ToRs for Regional and Species Working Groups

2021/2/FRSG01 The following ToRs apply to: AFWG, HAWG, NWWG, NIPAG, WGWIDE, WGBAST, WGBFAS, WGNSSK, WGCSE, WGDEEP, WGBIE, WGEEL, WGEF, WGHANSA and WGNAS.

The working group should focus on:

a) Consider and comment on Ecosystem and Fisheries overviews where available;

b) For the aim of providing input for the Fisheries Overviews, consider and comment on the following for the fisheries relevant to the working group:

   i) descriptions of ecosystem impacts on fisheries

   ii) descriptions of developments and recent changes to the fisheries

   iii) mixed fisheries considerations, and

   iv) emerging issues of relevance for management of the fisheries;

c) Conduct an assessment on the stock(s) to be addressed in 2022 using the method (assessment, forecast or trends indicators) as described in the stock annex; - complete and document an audit of the calculations and results; and produce a **brief** report of the work carried out regarding the stock, providing summaries of the following where relevant:

   i) Input data and examination of data quality; in the event of missing or inconsistent survey or catch information refer to the ACOM document for dealing with COVID-19 pandemic disruption and the linked template that formulates how deviations from the stock annex are to be reported.

   ii) Where misreporting of catches is significant, provide qualitative and where possible quantitative information and describe the methods used to obtain the information;

   iii) For relevant stocks (i.e., all stocks with catches in the NEAFC Regulatory Area), estimate the percentage of the total catch that has been taken in the NEAFC Regulatory Area in 2021.

iv) For category 3 and 4 stocks requiring new advice in 2022, implement the methods recommended by WKLIFE X (e.g. SPiCT, rfb, chr, rb rules) to replace the former 2 over 3 advice rule (2 over 5 for elasmobranchs). MSY reference points or proxies for the category 3 and 4 stocks

v) Evaluate spawning stock biomass, total stock biomass, fishing mortality, catches (projected landings and discards) using the method described in the stock annex;

1) for category 1 and 2 stocks, in addition to the other relevant model diagnostics, the recommendations and decision tree formulated by WKFORBIAS (see Annex 2 of https://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/Fisheries%20Resources%20Steering%20Group/2020/WKFORBIAS_2019.pdf) should be considered as guidance to determine whether an assessment remains sufficiently robust for providing advice.

2) If the assessment is deemed no longer suitable as basis for advice, consider whether it is possible and feasible to resolve the issue through an inter-benchmark. If this is not possible, consider providing advice using an appropriate Category 2 to 5 approach.;

vi) The state of the stocks against relevant reference points;

Consistent with ACOM's 2020 decision, the basis for Fpa should be Fp.05.

1) 1. Where Fp.05 for the current set of reference points is reported in the relevant benchmark report, replace the value and basis of Fpa with the information relevant for Fp.05

2) 2. Where Fp.05 for the current set of reference points is not reported in the relevant benchmark report, compute the Fp.05 that is consistent with the current set of reference points and use as Fpa. A review/audit of the computations will be organized.

3) 3. Where Fp.05 for the current set of reference points is not reported and cannot be computed, retain the existing basis for Fpa.

vii) Catch scenarios for the year(s) beyond the terminal year of the data for the stocks for which ICES has been requested to provide advice on fishing opportunities;

viii) Historical and analytical performance of the assessment and catch options with a succinct description of associated quality issues. For the analytical performance of category 1 and 2 age-structured assessments, report the mean Mohn's rho (assessment retrospective bias analysis) values for time series of recruitment, spawning stock biomass, and fishing mortality rate. The WG report should include a plot of this retrospective analysis. The values should be calculated in accordance with the "Guidance for completing ToR viii) of the Generic ToRs for Regional and Species Working Groups - Retrospective bias in assessment" and reported using the ICES application for this purpose.

d) Produce a first draft of the advice on the stocks under considerations according to ACOM guidelines.

i. In the section 'Basis for the assessment' under input data match the survey names with the relevant "SurveyCode" listed ICES survey naming convention *(restricted access)* and add the "SurveyCode" to the advice sheet.

e) Review progress on benchmark issues and processes of relevance to the Expert Group.
i) update the benchmark issues lists for the individual stocks in SID;
ii) review progress on benchmark issues and identify potential benchmarks to be initiated in 2023 for conclusion in 2024;
iii) determine the prioritization score for benchmarks proposed for 2023–2024;
iv) as necessary, document generic issues to be addressed by the Benchmark Oversight Group (BOG)

f) Prepare the data calls for the next year's update assessment and for planned data evaluation workshops;

g) Identify research needs of relevance to the work of the Expert Group.

h) Review and update information regarding operational issues and research priorities on the Fisheries Resources Steering Group SharePoint site.

i) If not completed in 2020, complete the audit spread sheet 'Monitor and alert for changes in ecosystem/fisheries productivity' for the new assessments and data used for the stocks. Also note in the benchmark report how productivity, species interactions, habitat and distributional changes, including those related to climate-change, could be considered in the advice.

Information of the stocks to be considered by each Expert Group is available here.

1.3 Reviews of groups or projects important for the WG

HAWG was briefed throughout the meeting about other groups and projects that were of relevance to their work. Some of these briefings and/or groups are described below.

1.3.1 Meeting of the Chairs of Assessment Related Expert Groups (WGCHAIRS)

WGCHAIRS met online in January 2022 in preparation for the new year of advice and science working group activities. This was the second year WGCHAIRS was held remotely. The meeting was held over 4 days. The agenda on day 1 was tailored for new chairs. On day 2 the focus was for assessment groups chaired by ACOM leadership. A joint ACOM/SCICOM session was held on the third day and on the final day the focus was for SCICOM groups.

Under the ICES strategy, activities of advisory working groups such as HAWG are conducted under the umbrella of the Fisheries Resources Steering Group (FRSG) which became operational in 2019. Advisory expert groups maintain their prerogative of "closed groups" in the sense that members will be still nominated at a national level. An FRSG meeting was held on the 27th of January to discuss TAF, the application of WKLIFE methods, stock assessment advances and initiatives as well as challenges groups may encounter related to the COVID disruption.

A number of presentations were given which were relevant to HAWG. The benchmark system and the role of the benchmark oversight group was explained. A benchmark is a peer review of data and methods that requires prior development, analysis, and documentation before it can proceed. Benchmark needs should be identified early, and a prioritization process followed. The benchmark oversight group (BOG) provides support and have an overall coordination role. A benchmark planning checklist has been developed to help groups to prioritize issues and agree a timeline for each issue to be completed. If high priority issues are not completed, then the benchmark may be delayed to allow sufficient time to work on these tasks. The distinction between benchmarks and inter-benchmarks was also discussed.

Given that the use of the transparent assessment framework has slowed down, the benefits and value of TAF was explained and chairs shared their experiences on this. Work is ongoing towards providing ICES advice online. The new developments and the plan for future work was presented.

WGCHAIRS discussed gender equality, diversity, and inclusion in the ICES community. The gender diversity across several aspects of ICES work was presented, including the ASC participation, chairs of working groups, national representatives at ACOM and SCICOM, council delegates and executive committee members. It was highlighted that we should follow the ICES meeting etiquette and we are all accountable. We treat each other with respect, embrace diversity, include equally, communicate thoughtfully, avoid harassment, and promote wellbeing.

1.3.2 Working Group for International Pelagic Surveys (WGIPS)

The Working Group of International Pelagic Surveys (WGIPS) met online on Teams 24th–28th January 2022. Among the core objectives of the Expert Group are combining and reviewing results of annual pelagic ecosystem surveys to provide indices for the stocks of herring, sprat, mackerel, boarfish, and blue whiting in the Northeast Atlantic, Norwegian Sea, North Sea, and Western Baltic; and to coordinate timing, coverage, and methodologies for the upcoming 2022 surveys.

Results of the surveys covered by WGIPS and coordination plans for the 2022 pelagic acoustic surveys are available from the WGIPS report (ICES 2022, WGIPS). The following text refers only to the surveys of relevance to HAWG.

<u>**North Sea, West of Scotland and Malin Shelf summer herring acoustic surveys (HERAS) in 2021:**</u> Six surveys were carried out during late June and July covering most of the continental shelf in the North Sea, West of Scotland, Malin Shelf, West of Ireland and Celtic Sea.

The estimate of **North Sea Autumn Spawning herring** spawning stock biomass is lower than in the previous year at 1.5 million tonnes (2020: 1.7 million tonnes) with a further decrease in the number of mature fish (2020: 8 915 million fish, 2021: 8 170 million fish).

The 2021 estimate of **Western Baltic Spring Spawning herring** 3+ group is 82 000 tonnes and 639 million. Compared to the 2020 estimates of 103 000 tonnes and 667 million fish, this equals a decrease of 20% in biomass.

The **West of Scotland herring** estimate (6.a.N) of SSB in 2021 is 147 000 tonnes and 871 million individuals, which is a ~7% decrease in both biomass and abundance compared to the 158 000 tonnes and 943 million herring estimate in 2020.

The 2021 SSB estimate for **the Malin Shelf area (6.a and 7.b, c combined)** is 278 000 tonnes and 1 827 million individuals. This is higher than the 2020 estimates (226 000 tonnes and 1 435 million herring). There were again low numbers of herring found in the northern strata (to the north of Scotland and east to the 4˚W line) in 2021, which is similar to 2020. There were significant numbers of herring distributed south of 56°N again in 2021, including large numbers of immature herring.

For consistency, the survey results continue to be presented separately for sprat in the North Sea and Skagerrak-Kattegat although these two stocks were combined in a benchmark in 2018 (ICES 2018 WKSPRAT).

The total abundance of **North Sea sprat** (Subarea 4) in 2021 was estimated at 56 200 million individuals and the biomass at 420 000 tonnes. This is a decrease from last year, and around the long-term average of the time series, in terms of both abundance and biomass. The estimate is dominated by 1-year-old sprat (75% in biomass). The estimate includes 0-group sprat (2% in numbers, and 1% in biomass), which only occasionally is observed in the HERAS survey.

For **Div. 3.a,** the sprat abundance in 2021 is estimated at 623 million individuals and the biomass at 6 200 tonnes. This is the second lowest estimate of the time series in terms of biomass, and well below the long-term average both in terms of abundance (70% below) and biomass (76% below). The estimate is dominated by 1- and 2-year-old sprat.

Irish Sea Acoustic Survey: The herring abundance for the Irish Sea and North Channel (7.a.N) during 27th August–11th September 2021 was reported by Northern Ireland. The herring stock estimate in the Irish Sea/North Channel area was estimated to be 99,589 t. The major contribution of ages to the total estimates is from age 1 and age 2 fish by number and weight. The herring were fairly widely distributed within mixed schools at low abundance, with a few distinct high abundance areas. The bulk of 1+ herring in 2020 were observed west of the Isle of Man and off the off the east coast of Northern Ireland, with a fairly scattered lower abundance observed throughout the Irish Sea. The estimate of herring SSB of 64,271t is within the observed range for the time series and the biomass estimate of 98,277t for 1+ ringers for 2021 also remains within the observed range since 2011. Sprat and 0-group herring were distributed around the periphery of the Irish Sea, with the most abundance of 0-group herring in the eastern side and in areas along the northern Irish coast to the west.

Irish Sea spawning acoustic survey: A series of additional acoustic surveys has been conducted since 2007 by Northern Ireland, following the annual pelagic acoustic survey (conducted during the beginning of September). The survey uses a stratified design similar to the Irish Sea Acoustic survey [AC(7.aN)]. Survey methodology, data processing and subsequent analysis is the same as for AC(7.aN) and follows standard protocols for surveys coordinated by WGIPS. The survey is included in the assessment as an SSB index. The major contribution of ages to the total estimates is from ages 0 fish by number and 2 by weight. The herring were distributed within a few distinct high abundance areas to the west and east of the Isle of Man. The estimate of herring SSB of 70,859t for the 2021 acoustic survey is a large increase from 47,933t in 2020. The survey estimates are influenced by the timing of the spawning migration.

Celtic Sea herring acoustic survey (CSHAS): Herring and sprat abundance for the Celtic Sea in October 2021 was reported by the Marine Institute, Ireland. Geographical coverage was comparable to 2020. The core distribution areas were comprehensively covered, and the stock was considered contained within the Celtic Sea survey area.

The 2021 total standing stock estimate is 9,877 t and 310 million individuals (CV 0.44) is an increase on the 2020 estimate (4,717 t and a total abundance of 67,368,000 individuals). The standing stock biomass however still remains in a low state. The stock is dominated by 3-wr fish representing 43% of the total biomass (TSB) and 11% of total abundance (TSN). Immature 0-wr fish accounted for 33% of TSB and 81% of TSN.

The biomass of sprat (TSB) was 12,376 t and the TSN 3,018 mill individuals and an increase on the 2020 estimates (4,717 t and 67.3 mill ind.). The nearshore distribution of sprat likely led to the stock not being fully contained within the survey area.

Pelagic ecosystem survey in Western Channel and eastern Celtic Sea (PELTIC): This survey was conducted by Cefas, UK, in the Western Channel and eastern Celtic Sea in Oct-Nov 2021. For the fifth year, the survey was extended beyond UK waters to also include the French waters of western English Channel and for the second time Cardigan Bay in the southern Irish Sea. The pelagic fish objectives of the survey were successfully completed. In total 2181 nautical miles of acoustic sampling units were collected and supplemented with 41 valid trawls. Sprat were mainly found in Lyme Bay, showing a more offshore distribution than in 2020. The biomass in Lyme Bay, which is the core area sampled since 2013 and is relevant to the stock assessment of sprat in 7de, was 107,355 t which is more than three times higher than the 2020 estimate of 33,798 t and the highest of the time series. This was comprised of 0-gr sprat.

Baltic International Acoustic Survey (BIAS): This survey is conducted throughout the Baltic Sea during the months of September-October with participation of the different Baltic countries. BIAS is coordinated by the Working Group on Baltic International Fish Survey (WGBIFS). Germany is responsible for the survey covering the western Baltic and the Kattegat (SDs 21-24). The results of the **German Autumn Acoustic Survey (GERAS)** are presented to WGIPS and WGBIFS, whereas mainly the herring data are of interest for WGIPS and the sprat data for WGBIFS, respectively. The GERAS-index, which refers only to Western Baltic Spring-spawning herring (WBSSH), is used within the assessment of the Herring stock in Division 3a and subdivisions 22–24 (see Chapter 3). Mixing with the adjacent central Baltic herring stock generally occurs in SD 24 and in 2021 also in SD 21-23. The GERAS-index is routinely adjusted to account for the mixing of the two stocks. The adjustment is based on growth parameters.

The 2021 GERAS-index was estimated to be 0.87 x 10^9 fish or about 31.1 x 10^3 tonnes in subdivisions 21–24. The biomass index in 2021 represents the lowest in the time series.

1.3.3 WGQUALITY, WGBIOP and WGCATCH

Operationalising the outputs from the former PGDATA (final report), now falls within the remit of the ICES working group on the Governance of Quality Management of Data and Advice (WGQuality), which held its first meeting in January 2021. Supporting the objectives of the ICES Advisory Plan, WGQuality work focusses on developing and promoting quality assurance within ICES advisory processes - from data management, data integration, data analysis, and data use, to the process of translating that data into ICES advice. It is affiliated to the Data Science and Technology Steering Group (DSTSG), which is also the parent group for WGBIOP and WGCATCH. These three groups work together to ensure the quality of data going into stock assessments and development of methods for identifying improvements in data quality, or collections of new data, that have the greatest impacts on the quality of advice.

WGBIOP focusses on the quality of biological parameters collected and used in assessments and advice. This includes age and maturity, but also other biological parameters. WGBIOP coordinates the practical implementation of quality assured and statistically sound development of methods, standards, and guidelines for the provision of accurate biological parameters for stock assessment purposes. The overall aim for WGBIOP is to review the status of current issues, achievements and developments of biological parameters and identify future needs in line with ICES requirements and the wider European environmental monitoring and management.

As biological parameters are among the main input data for most stock assessment and mixed fishery modelling, these activities are considered to have a very high priority. The main link between assessment working groups and WGBIOP is through the benchmark process. WGBIOP works in close association with the BSG (ICES benchmark steering group), reviewing all available issue lists, providing information on listed issues, identifying missing issues in relation to specific stocks and guiding the process to get issues related to biological parameters resolved. WGBIOP tries to align its scheduling of age and maturity calibration exchanges and workshops with the newly proposed ICES benchmark prioritization system. WGBIOP has a close working relationship with WGSMART (The Working Group on SmartDots Governance) and in cooperation will further develop the SmartDots tool as a platform for supporting the provision of quality assured data to the end-users.

The last WGBIOP (October 2021) reviewed the following activities falling within its remit and of interest for HAWG:

- There are no workshop or exchange planned for herring (*Clupea harengus*) and sprat (*Sprattus sprattus)* stocks assessed by HAWG. Prior to the benchmark of Sandeel (*Ammodytes*) 2022 an age reading exchange was conducted.
- A workshop on the identification of clupeid larvae (WKIDCLUP2) was conducted on 30 August – 3 September 2021 in Bremerhaven, Germany, to identify problem areas in clupeid identification. SmartDots was expanded with a fish larvae module specific for this workshop. The module allowed sharing of images of various clupeid larvae of different spawning areas (from the Portuguese coast to the Baltic) and other species co-occurring with the clupeid larvae. Within SmartDots each participant could measure, count myotomes and identify the larvae to species. This first test of the module was promising and will be further developed and used for fish larvae calibration exercises in the future. The results of this short workshop were promising as the agreement in larvae identification was higher compared to the 2014 workshop.

Other clupeid stocks

- An otolith exchange was held for sprat in the Baltic Sea and NEA mackerel, resulting in an overall agreement between readers of 59.0% and 64.7%, respectively.

Planning of future workshops and exchanges

- WGBIOP is planning to organise a workshop in 2023 on the comparison between age reading methods of NSSH using scales and otoliths. WGIPS is requested to collect samples in 2022. The focus is on NSSH but could have implications for NSASH as well.

WGCATCH continues to document national fishery sampling schemes, establish best practice and guidelines on sampling and estimation procedures, and provide advice on other uses of fishery data. The group evaluates how new data collection regulations, or management measures (such as the landings obligation) will alter how data need to be collected and provide guidelines about biases and disruptions this may induce in time-series of commercial data. WGCATCH also develop and promote the use of a range of indicators of fishery data quality for different types of end-users. These include indicators to allow stock assessment and other ICES scientists to decide if data are of sufficient quality to be used, or how different datasets can be weighted in an assessment model according to their relative quality.

WGCATCH 2021 continued to focus on how to communicate relevant information about sampling design and estimation to ICES assessment working groups, how to get a better process around delivering quality catch data for benchmarks. In respect to estimation, the focus was and will be on how to incorporate none-responses in the estimation and estimation of rare event. The first will be explored intersessional and the latter will be explored in an ICES workshop in autumn 2022. In respect to the small-scale fisheries, WGCATCH 2021 updated and refined the risk assessment for transversal data quality methodology and continued to document the sampling effort on biology for this part of the fleet. Further, the group continued the close relation to WGBYC and the RDBES.

1.3.4 WGSAM

The Working Group on Multispecies Assessment Methods WGSAM provides estimates of natural mortality (M) for a number of fish stocks based on estimates from multispecies models. WGSAM provides M estimates for the following HAWG stocks: North Sea herring, North Sea sprat, sandeel SA1 and sandeel SA3. Predation mortality was updated in the 2021 assessment of these stocks based on the 2020 key run of the North Sea SMS model provided by WGSAM (ICES 2021). The 2020 key run is primarily an update of the 2017 key run by extension of the input data and their update when the single species stock assessment input data were revised through benchmarks or inter-benchmarks.

In the SMS model, predators include both assessed species (i.e., cod, haddock, saithe, whiting, mackerel) and species with given input population size (North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, hake, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, and harbour porpoise). The assessed predators are parametrised using a combination of commercial and survey data (i.e., same input as for the single species assessments) except saithe and mackerel which are closely tuned to the ICES stock assessment by using number-at-age from the single species assessment models as input of SMS.

Main changes to input data since the 2017 key run include:

- Update of "single-species data" (catch-at-age numbers, mean weights, proportion mature, survey indices, etc.) with use of the most recent ICES assessment input data. The most important changes are:
    - Whiting benchmark with mean weight at age in the sea derived from survey data, whereas mean weights from the catches were used previously. This gives lower mean weight at ages for the youngest ages and higher mean weights for the oldest ages compared to the 2017 key run
    - Sprat benchmark with inclusion of subdivision 3a in the stock area and re-estimation of historical catch data
    - Mackerel benchmark with new stock size estimate
- Re-estimation of the hake stock within the North Sea
- Re-estimation of horse mackerel and their proportion of the stock within the North Sea

Comparison with previous values of predation mortalities suggest:

- **Herring** - the pattern in M is in general consistent between the two key runs but some differences are estimated in the first and last part of the time series. Differences in most recent years are due to lower stock size of the predators cod and saithe, and by increased predation by whiting and hake.
- **Sprat** - the pattern in M is in general consistent between the two key runs, but the new estimates downscale the absolute values of predations mortality for all ages except age0.
- **Sandeel** – estimates of predation mortality are highly consistent for both the northern and the southern sandeel modelled stocks (i.e., current SMS considers sandeel as two units within the model, approx. corresponding to SA1 and SA3) between the new and previous key runs. Some marginal differences are visible for the southern sandeel with an upscale of M in the last part of the time series for all ages and a downward revision in the first part of the time series for age3+.

Overall, the model structure and main assumptions are consistent with the previous key run. Based on an internal review process, WGSAM considered the new key run appropriate in relation to the purpose of providing predation mortality estimates.

1.3.5 MIK surveys

Down's herring recruitment information

In 2016, WKHERLARS evaluated the North Sea herring larvae surveys (ICES, 2016), and concluded that the current IBTS-MIK recruitment index does not contain information on the Downs spawning component. It was recommended to investigate the possibility to collect data to include information on Down's recruitment. In 2017, the effect of omitting one of the three IHLS surveys, carried out on the Downs component, from the herring assessment was investigated. The omission resulted in a negligible effect, and it was, thus, decided to drop the Dutch IHLS participation in the second half of January. The vessel time and budget of this survey was instead used to conduct a Downs Recruitment Survey (DRS) in April.

The DRS was carried out in April 2018, 2019, 2021 and 2022. Due to COVID-19 measures it was not possible to carry out a DRS in April 2020. As herring larvae need to be caught at the same development stage as the IBTS-MIK, it was not possible to move the survey to a later date in 2020.

The DRS is carried out following the IBTS-MIK protocol, but sampling both day and night, instead of only at night. Comparative fishing trials to check for difference in catchability between day and night were done in 2021 and 2022.

HAWG has a positive view on the continuation of the Downs Recruitment Survey (DRS) but cannot include the survey in the advice based on only two years of a survey. HAWG foresees potential future use of the combined IBTS0-DRS-index for a complete NSAS recruitment index for the advice if the surveys are continued. Thus, HAWG supports the continuation of the exploratory surveys in April and have had a positive response from several laboratories. HAWG recommends that WGSINS investigate calculation of a Downs and combined North Sea herring recruitment index based on the combination of the IBTS-MIK and DRS data.

1.3.6 Stock separation of herring in surveys and catches

The mixing of herring stocks in surveys and catches is an issue in many of the stock assessments carried out in HAWG. Until 2022 only the mixing between North Sea herring and Western Baltic Spring-spawning herring (in the catches, in the HERAS and IBTS surveys) and between Western Baltic Spring-spawning herring and Central Baltic herring (limited to the GERAS survey) were routinely quantified and accounted for in the assessments. In 2022 the 6.a, 7.b-c stocks have been delineated based on the results of genetic stock identification for the first time, thus enabling separate assessments for the 6.a.S, 7.b.c stock and the 6.a.N autumn spawning stock. The development of operational methods to enable estimation of proportion contribution from different stock in catches and survey indices throughout the management areas for herring assessed by HAWG is a topic that HAWG continues to have high on the list of issues to solve to improve upon assessments. Several ICES workshops have been held to progress this topic, most recently WKMIXHER in 2018 and WKSIDAC in 2017. HAWG recommend another meeting of WKSIDAC in 2023. An update on progress of those projects dealing with stock identification and mixing of relevance to HAWG is provided below.

Update on Stock Identification of 6.a, 7.b-c Herring

Atlantic herring west of Scotland and northwest of Ireland comprise at least two reproductively isolated biological populations. The 6.a.N herring spawn off Cape Wrath in northwest Scotland in Autumn (September/October) and the 6.a.S, 7.b-c herring spawn off Donegal in northwest Ireland in winter and early spring (November to March). The stocks are believed to form mixed feeding aggregations west of the Hebrides in summer, where they are targeted by the Malin Shelf Herring Acoustic Survey (MSHAS), conducted annually by the Marine Institute and Marine Scotland. The MSHAS survey index is a primary input into the stock assessments of the two stocks. Up to now it has not been possible to separate the data from the MSHAS into population/stock of origin, therefore only a combined index is available and hence a combined assessment (ICES, 2015). Based on the combined assessment, ICES has provided combined advice for the two areas and stocks since 2015 and has recommended a zero TAC for the last seven years. Scientific samples are obtained during the scientific monitoring fisheries in 6.a.S, 7.b-c and industry surveys in 6.a.N.

In response to the WKWEST (ICES, 2015) report a programme of stock identification research was developed (see summary in ICES HAWG, 2021). The programme initially relied on industry and national institute funding (2016-2018) before the European Commission's Executive Agency for Small and Medium-sized Enterprises (EASME) funded a 36-month project (2018-2020) entitled 'Herring in Divisions 6.a, 7.b and 7.c: Scientific Assessment of the Identity of the Southern and Northern Stocks through Genetic and Morphometric Analysis'. This project comprised an extensive review of the history of the existing stock delineations, comprehensive sampling for both genetics and morphometrics, genetic marker development, genetic screening of samples, the establishment of a genetic protocol for large scale sample screening, morphometric analyses and comparative analyses of both methods (see Farrell et al., 2021). One of the main conclusions of the EASME project was that morphometrics was not suitable to discriminate between mixed herring along the Malin Shelf. Although the use of body and otolith shape showed potential in discriminating between 6.a.N and 6.a.S stocks initially, the method was not powerful enough to discriminate mixed herring samples due to the complex temporal-spatial mixing of these two stocks along the Malin Shelf. The genetic markers and assignment methods constitute a tool that can be used for the assignment of herring caught in mixed survey and commercial catches in Division 6.a into their population of origin with a high level of accuracy (>90%).

The results of this project together with the previous industry and institute funded programme component were compiled into a final project report (Farrell et al., 2021), which was reviewed by the Stock Identification Methods Working Group (SIMWG). The SIMWG concluded that '*the study should serve as an example of good practice for optimal use of existing resources and result reproducibility*', '*the methodology is rigorous throughout*' and '*there is no doubt in SIMWG that the* (genetic) *approaches presented can be used to*':

1. *Distinguish the 6aS late winter spawners from the 6aN autumn spawners;*
2. *Distinguish, more subtly, the spring-spawning contingent in 6aN from 6aS (even though the relatedness between these two is high);*
3. *Confirm essentially the 'North Sea nature' of the 6aN autumn spawners;*
4. *Assess the mixed MSHAS catches (which appear primarily composed of 6aS fish, with the proportion of autumn-spawning fish increasing as one moves north-east towards Cape Wrath and the Orkneys).*

Subsequent to the completion of the EASME funded component of the 6.a stock identification programme and prior to the WKNSCS benchmark it was possible to undertake additional genetic analyses in order to fill any potential data gaps identified during the EASME project. As detailed in the 2021 HAWG report (ICES, 2021) a short-term project extension was developed with the existing project partners. During this extension additional spawning baseline samples were added to the baselines and using the same approaches as specified in Farrell et al. (2021) the 2020 and 2021 MSHAS samples were genetically assigned to their stock of origin. A detailed summary of the genetic approaches underpinning the splitting of the MSHAS data is provided in O'Malley *et al*. (2021), the full stock identification project report in Farrell et al. (2021) and a draft manuscript of the genetic baseline based on the updated baseline in Farrell et al. (in review),

In short, the baseline genetic analyses indicated that herring in ICES Division 6.a comprise at least three distinct populations; 6.a.S herring, 6.a.N autumn spawning herring and 6.a.N spring spawning herring. The 6.a.S herring are primarily a winter spawning population though there is a later spawning component present in the area also. These components are currently inseparable and for the purposes of stock assessment should be combined as 6.a.S herring. No baseline spawning samples could be collected in Divisions 7.b or 7c therefore the relationship between the herring that spawn in this area and those that spawn in 6.a.S is unknown. The 6.a.N spring spawning herring are distinct from the 6.a.N autumn herring and spawn in the Minch in

February and March. This population is not currently subject to stock assessment or specific management measures. There is no historical or contemporary evidence to support the differentiation of 6.a.N autumn spawning herring and North Sea autumn spawning herring. The Downs herring were confirmed to be distinct from the North Sea autumn spawning herring though it could not be reliably discriminated from the Celtic Sea and Irish Sea samples with the current panel of markers. The Celtic Sea herring and Irish Sea herring are distinct from each other and from the populations in ICES Divisions 6.a however the current genetic marker panel is not optimised for their inclusion in the baseline assignment dataset. For the purposes of developing an assignment model only the populations confirmed as being present in Division 6.a were included in the baseline assignment dataset; 6.a.S, 6.a.N autumn and 6.a.N spring.

Across the eight years of MSHAS samples that were genetically assigned (2014-2021), there was a consistent pattern of a higher proportion of 6.a.S herring in the samples than 6.a.N autumn spawning herring. The 6.a.S assigned fish were distributed across the survey area both south and north of the current stock delineation line of 56°N latitude, confirming that this geographic delineator for the collation of survey data is not appropriate. The highest proportions of 6.a.S fish were observed in the hauls closest to the Irish coast. The highest proportions of 6.a.N autumn spawning fish were observed in the most northerly hauls adjacent to the 4°W stock delineator. Potential 6.a.N spring spawning herring comprised a significant proportion of the MSHAS hauls west of the Hebrides.

The assignment of non-baseline putatively mixed samples from Divisions 6.a,7.b-c collected outside of the MSHAS period also provided useful information. Analysis of a subset of the hauls on the Q1 2019 Scottish West Coast International Bottom Trawl Survey (SWC-IBTS) indicated a high degree of mixing of the 6.a populations within the hauls. Analysis of Q3 samples from the 6.a.N. industry acoustic survey indicated that juveniles in the northern Minch area most likely belonged to the 6.a.S or 6.a.N spring populations and samples from the Cape Wrath area were composed of a mix of the 6.a populations.

Analysis of the Q4 samples from the 6.a.S monitoring fishery indicated the samples comprised primarily 6.a.S herring. Samples of herring from Lough Foyle were shown to be genetically and biologically 6.a.S herring, though they are currently defined as 6.a.N autumn spawning herring according to the ICES stock delineation. Non-spawning herring caught in Division 7.b assigned genetically to the 6.a.S population.

Updates on tools to split herring populations

Atlantic herring has one of the, to date, best described genomes which has allowed for a genetic inventory of a broad representation of all major stock units in the Northeast Atlantic (Han et al. 2020; Bekkevold et al. *unpublished*). Based on recent work, robust genetic assays to split mixed-stock aggregations have been developed and implemented (Bekkevold et al. *unpublished*; Farrell et al. *in review*). Work has e.g., demonstrated unprecedented accuracy in stock-splitting between North Sea autumn spawning herring, NSAS, her.27.3a47d, and Downs winter spawning herring, her.27.3a47d; between Western Baltic spring spawning herring, WBSSH, her.27.20-24, and NSAS; between WBSS and central Baltic Sea spring spawning herring, CBH (her.27.25-2932); between Faroese autumn spawning herring, FASH, and NSAS; and between Norwegian spring spawning herring, NSS, her.27.1-24a514a, and WBSS (Bekkevold et al. *unpublished*). The work has facilitated the development of a comprehensive genetic database of all main spawning components feeding in areas 4ab and 3a. Genetic splitting of NSAS and WBSS is now fully implemented in data from the Danish and Norwegian commercial catches and their parts of HERAS, and Danish IBTS. Currently, information about additionally occurring stocks in 4ab/3a, such as NSS, Baltic Sea Autumn Spawning herring and Baltic Sea spring spawning herring is not currently used, and these fish has been assigned as either NSAS or WBSS based on previously used methods. Genetic marker-based splitting has thus replaced the methods of vertebral count, otolith shape and microstructure data. Splitting is limited to Danish, Swedish and Norwegian samples from commercial catches and scientific surveys in Skagerrak-Kattegat and the north-eastern North Sea. Applied splitting methods will become consistent between labs and countries as of 2022. The benefit of using genetic methods to identify stock components, in comparison with traditionally implemented phenotyping methods, has been demonstrated for different approaches (Berg et al. 2021; Farrell et al. in review, Bekkevold et al. *unpublished*).

Updates on the analyses of the WKMixHer sample

The 2018 workshop on mixing of western and central Baltic herring stocks (WKMixHer) recommended coordinated sampling of spring spawning herring with the objective to further evaluate mixing of herring stocks in the western-central Baltic and to implement operational methods for separation.

Samples were collected by Sweden, Germany, Poland, and Lithuania during the 2019 and 2020 spawning peak on 7 coastal spawning grounds in the Hanö Bay, Bay of Lübeck, Greifswald Bay, Pomeranian Bay, Kolozbreg, Vistula Lagoon and Klaipéda (Figure 1.2.7.2).

Herring were collected at spawning time from spawning aggregations, resulting in samples from late March till early May as the spawning peak showed a seasonal progression through the region from west to east. Sampling was restricted to ripe and running individuals corresponding to maturity stages 5 to 7. 592 individuals were sampled, covering ages 2-13 winter rings, and stock separation by growth function was applied. Otolith shapes were extracted, and preliminary analyses conducted on 449 of these herring (ages 4-7).

A Canonical Analysis of Principal Coordinates performed on the standardized wavelet coefficients from the otolith shapes showed that herring from the sampled locations group into two well distinct clusters, with a clear geographical longitudinal separation (Figure 1.2.7.3). Samples from part of the Polish coast in SD25 (station "SWI-31" and "ROW") group with the western Baltic cluster.

Among the classifiers tested (both traditional techniques and machine learning algorithms), Random Forest (with k-fold cross validation) provided the best overall accuracy in the discrimination between the two clusters based on otolith shape analysis with overall assignment accuracy of ~70%. When using the growth analysis on the WKMixHer samples (growth is currently used for separating western and central Baltic herring in SD22-24 in the GERAS survey) assignment accuracy to one of the two clusters yield ~97%.

Further work in progress:

- Combine otolith shape and growth analysis when conducting assignments;
- Adding genetic analysis to evaluate the number of components present and validate results from the otolith shape;
- Collect samples of spawning herring from the central part of the Polish coast to evaluate the gradient of differentiation along the southern Baltic coast.

Further information on this is work is available from Valerio Bartolino (valerio.bartolino@slu.se).

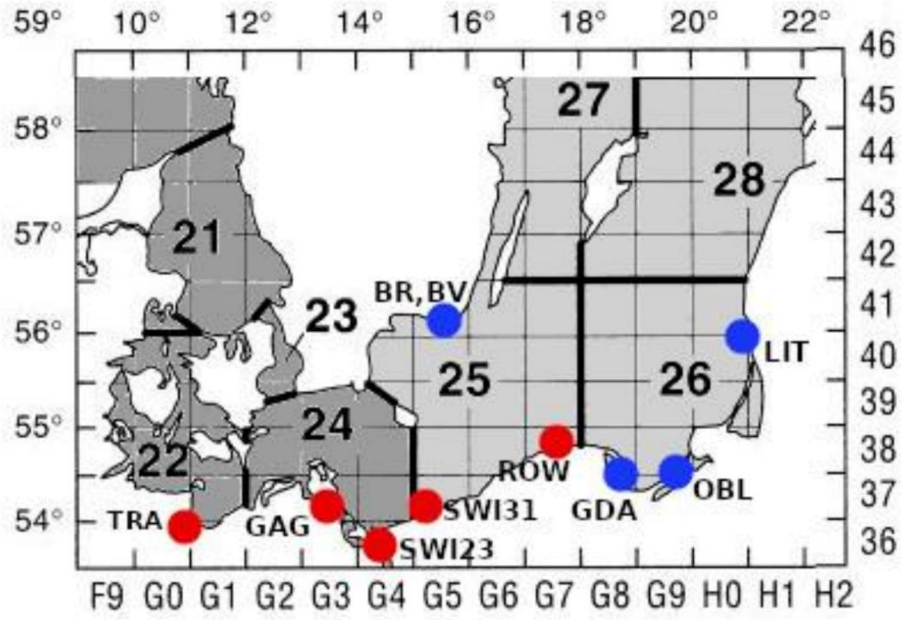

Figure 1.2.7.2. Map with sampling locations of spawning herring during spring 2019-2020. Colours correspond to the two clusters identifies in the Canonical Analysis of Principal Coordinates (See Figure 1.2.7.3).

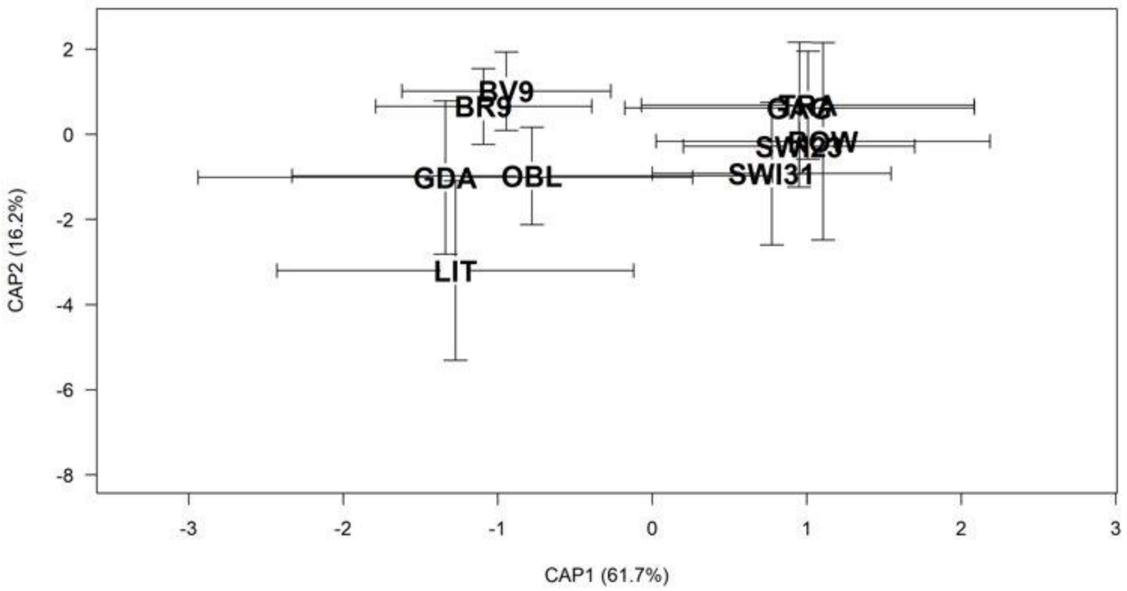

Figure 1.2.7.3. Plot of the first and second Principal Components from the analysis of standardized Wavelet coefficients. The black labels show the centroid for each spawning location. TRA: Bay of Lübeck (GER), GAG: Bay of Greifswald (GER), SWI23: Pomeranian Bay (POL), SWI31: Kolobrzeg (POL), ROW: Rowy (POL), GDA: Gulf of Gdansk (POL), OBL Vistula lagoon (POL), LIT: Klaipėda (LTU), BR9 - BV9: Hanö Bay (SWE).

1.3.7 WKDLSSLS

The Workshop on Data Limited Stocks of Short-Lived Species 3 (WKDLSSLS3) held in 2021 built on the work of the previous two workshops in 2019 (WKDLSSLS) and 2020 (WKDLSSLS2) to further develop methods for stock assessment and catch advice for category 3–4 short-lived species. Work was carried out to evaluate the appropriateness of the management procedures based on direct use of abundance indices (for category 3 stocks). For sprat in 7d,e The effect of seasonal advice schedule (July-June) was investigated. During the stock's inter-benchmark, an annual MSE was not able to investigate within-year processes. A novel intra-annual MSE (Mildenberger et al., 2021) was parameterised for the stock, accounting for seasonal growth and exploitation. The timing and lag between events within the year (e.g., survey observation, implementation of advice, recruitment) affect the performance of Harvest Control Rules (HCR). WKDLSSLS3 concluded that the inter-benchmark decision of 8.57% Constant Harvest Rate (CHR) seems to be appropriate. The group examined the effect of applying an 80% uncertainty cap (UC) to the CHRs. The conclusion from this was an UC resulted in minimal risk reduction for CHR's below the 5% risk threshold. It did reduce risk for CHR's that are too high but could not bring them below the ICES risk threshold. The only significant difference between CHR and CHR+UC was a decrease in interannual variability in the stock. The group found that unconstrained CHRs appear robust to past fishing history, initial stock status and advice schedule but are sensitive to survey catchability. No recommendations from the WKDLSSLS were made in regard to applying a UC to CHR's.

1.3.8 WKNSCS – Benchmark workshop on North Sea and Celtic Sea stocks

The benchmark workshop on North Sea and Celtic Sea stocks (WKNSCS 2022) took place in February 2022 with a data meeting in November 2021. Five stocks were included in this benchmark including herring in 6a, 7b,c. The availability of the genetically split Malin Shelf Acoustic survey data allowed the two stocks to be assessed separately (6aS, 7b,c and 6aN).

For herring in 6aS, 7b,c category 1 assessments were tried using SAM and ASAP. SAM had issues with survey catchability and model convergence as well as with the SSB and F trajectories. ASAP was very sensitive to the assumptions about fishery selectivity. Both models had poor retrospective performance with Mohns Rho values outside acceptable limits. While neither model reached the standard for a category 1 or 2 assessment, significant progress has been made with both approaches showing good promise for the future when more split data (survey and catch) is available. SPiCT was also configured for herring in 6aS, 7b,c but had issues with convergence and poor model diagnostics and was deemed unsuitable to provide category 3 advice.

A SAM assessment was configured for 6aN. The group raised concerns over the catch data and its influence on the assessment presented. Catch data are assumed to be from 6.aN autumn spawning herring, but with a lack of genetic sampling this is not certain. Additionally there are underlying stock identity questions for 6.aN herring relating to the relationship with populations in the North Sea that have not been resolved. The appropriateness of including the IBTS datasets in the SAM model was discussed. The inclusion or exclusion of these indices had an impact on the overall stock trajectory. SPiCT was also tested for 6aN herring. With the short and variable nature of the biomass time series available, this SPiCT model was not considered to be suitable as a category 3 option.

Given that both stocks did not reach the required standard for a category 1 assessment at this benchmark, the new category 3 guidelines from ICES WKLIFEX (2021) were applied. Both stocks applied method 2.2 constant harvest rate. This method uses that uses length, survey and catch data from 2014-2021.

Significant improvements have been made since the last benchmark that have increased the understanding of the stocks and should lay the groundwork for a higher category assessment in the future. Recommendations for future research and data requirements were made for both stocks.

1.3.9 Other activities relevant to HAWG

Ichthyophonus

Ichthyophonus hoferi is a parasite found in fish. It has a low host-specificity, has been observed in more than 80 fish species, mostly marine, and is common in herring, haddock, and plaice. *Ichthyophonus* belong to the Class Mesomycetozoea, a group of micro-organisms residing between the fungi and animals (McVivar and Jones, 2013). Epidemics associated with high mortality have been reported several times for Atlantic herring: in 1991–1994 for herring in the North Sea, Skagerrak, Kattegat, and the Baltic Sea (Mellergaard and Spanggaard, 1997), and in 2008–2010 for Icelandic summer-spawning herring (Óskarsson and Pálsson, 2011). A time-series of the Norwegian data on *Ichthyophonus* was presented at HAWG 2017. The occurrence is usually below 1%, except for the beginning of the 1990s, but high occurrences (22%) were again observed again in the Norwegian IBTSQ1 2017 in the North Sea. Because of the high lethal level of this parasite and episodic outburst, HAWG 2017 decided to continue monitoring the level of *Ichthyophonus* infestation in the following years and Sweden extended the coverage of the sampling to the Skagerrak and Kattegat since IBTSQ3. In the 2018-2021 IBTSQ1 surveys, the occurrences of *Ichthyophonus* in the Norwegian part were again low: 4.4%, <1%, 1.2%, 0.6%, and zero, respectively. In the Kattegat-Skagerrak, the IBTS data suggests levels of incidence generally < 3% but occasionally ICES rectangles with > 20% infestation have been observed in some recent years 2017-2018. The level of infection is generally lower in IBTS Q3 compared to Q1, and it is found to be particularly low in 2021 in both the quarters and among all the ages. Swedish commercial samples from 2021 confirm low levels of infection (≤1%) in both the Kattegat and Skagerrak and throughout all the quarters sampled based on visual inspection. It is relevant that all countries continue to screen herring for *Ichthyophonus* during the IBTS surveys (both Q1 and Q3) and HERAS, as well as for the commercial sampling.

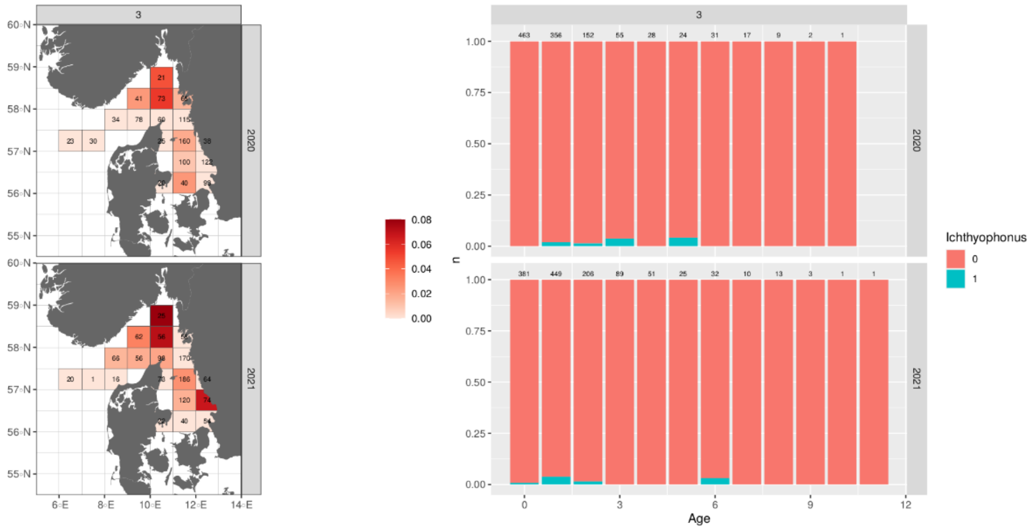

Figure 1.2.14.3 Occurrence of *Ichthyophonus hoferi* in the Kattegat-Skagerrak from Swedish samples collected during the IBTSQ3 2020-2021. Left map with distribution of the proportion of infested herring and number of samples in each rectangle; right distribution of infestation among ages.

Regional Database and Estimation System (RDBES)

The RDBES is still under development, but the part of the data model that stores population data, commercial effort, and landings statistics, are considered ready for production in 2022. The commercial sampling part of the data model is planned to be in production in 2023. In 2022, ICES will launch a data call including commercial effort statistic, landings statistics and sample data for all species.

In 2022, two workshops will be held in relation to the RDBES, WKRDB-INTRO and WKRDBES-RAISE&TAF (Workshop on Raising Data using the RDBES and TAF). The latter will be held in autumn and supports the migrating of present estimation routines to TAF. Furter, an ICES working grouping developing a R package from estimation with the RDBES format, main design-based, was formed in

Further information about the RDBES status and roadmap can be found in ICES (2020). The report from 2021 is still not published by ICES.

1.4 Commercial catch data collation, sampling, and terminology

1.4.1 Commercial catch and sampling: data collation and handling

Input spreadsheet and initial data processing

Since 1999, the Working Group members have used a spreadsheet to provide all necessary landing and sampling data. These data were then further processed with the SALLOC-application (Patterson, 1998). This program gives the required standard outputs on sampling status and biological parameters. It documents any decisions made by the species co-ordinators for filling in missing data and raising the catch information of one nation/quarter/area with information from another dataset.

Since 2015, ICES requested relevant countries within a data call to submit the national catches into InterCatch or to accessions@ices (via the standard exchange files). National catch data submission was due by 7th March 2022. Not all countries delivered their data in due time.

"InterCatch is a web-based system for handling fish stock assessment data. National fish stock catches are imported to InterCatch. Stock coordinators then allocate sampled catches to unsampled catches, aggregate to stock level and download the output. The InterCatch stock output can then be used as input for the assessment models". Stock coordinators used InterCatch for the first time at the 2007 Herring Assessment Working Group. However, InterCatch does not provide the output as needed for the assessment of NSAS and WBSS. Both data collation methods are, therefore, still used in parallel.

Excel was used to allocate samples to catches for 6.a following the same procedure outlined in WD01 to HAWG 2017.

More information on data handling transparency, data archiving and the current methods for compiling fisheries assessment data are given in the Stock Annex for each stock. Figure 1.5.1 shows the separation of areas as applied to the data in the archive.

1.4.2 Sampling

Quality of sampling for the whole area

The level of catch sampling by area is given in the table below for all herring stocks covered by HAWG (in terms of fraction of catch sampled and number of age readings per 1000 tonnes catch). There is considerable variation between areas. Further details of the sampling quality and the level of samples can be found by stock in the respective sections in the report and the stock annexes.

Area	Working Group Catch	Sampled Catch	Age Readings	Age Readings per 1000t
4.a(E)	88253	88740	2338	26
4.a(W)	181445	143883	4618	25
4.b	58826	39199	1074	18
4.c	9188	5805	196	21
7.d	26902	17509	305	11
7.a(N)	7208	6329	1680	233
3.a	13318	11520	2551	192
SD22-24	1601	1360	2683	1675
7g, 7.j, 7aS	745	745	1094	1468
6.aN	1115	671	43	39
6.aS, 7.b and 7.c	1821	1821	2037	1119

Given the diversity of the fleets harvesting most stocks assessed by HAWG, an appropriate spread of sampling effort over the different métiers is more important to the quality of catch-at-age data than a sufficient overall sampling level. The WG therefore recommends that all métiers with substantial catch should be sampled (including bycatches in the industrial fisheries), that catches landed abroad should be sampled, and information on these samples should be made available to the national laboratories and incorporated into the national InterCatch upload.

1.4.3 Terminology

The WG noted that for herring the use of "age", "winter rings", "rings" and "ringers" still causes confusion outside the group (and sometimes even among WG members). The WG tries to avoid this by consequently using "rings", "ringers", "winter ringers" or "wr" instead of "age" throughout the report. However, if the word "age" is used it is qualified in brackets with one of the ring designations. It should be observed that, for autumn and winter spawning stocks, there is a difference of one year between "age" and "rings". Further elaboration on the rationale behind this, specific to each stock, can be found in the individual Stock Annexes. It is the responsibility of any user of age-based data for any of these herring stocks to consult the relevant annex and if in doubt consult a relevant member of the Working Group.

1.5 Methods Used

1.5.1 SAM

The Spate-space stock Assessment Model SAM described in described in Nielsen and Berg (2014) is currently used to assess several of the HAWG stocks. This model has the standard exponential decay equations to carry forth the Ns (with appropriate treatment of the plus-group), and the Baranov catch equation to calculate catch-at-age based on the Fs. The additional components of SAM are the introduction of process error down the cohort (additional error term in the exponential decay equations), and the random walk on Fs. The steps (or deviations) in the random walk process are treated as random effects that are "integrated out", so are not viewed as estimable parameters. The sigma parameter controls how large the random walk deviations are, and this parameter is estimated. SAM provides the option of correlated errors across ages for the random walks on F, where the correlation is an additional parameter estimated to be estimated. The current implementation of SAM is an R-package based on Template Model Builder (TMB) (Kristensen *et al.*, 2016) and is maintained and available at https://github.com/fishfollower/SAM. At WKPELA 2018 a multi-fleet version of SAM was presented (ICES, 2018) and it is currently used for the assessment and forecasts of Western Baltic Spring-spawning herring, and to provide fleet specific selection patterns for short and medium-term forecasts for the North Sea herring.

SAM is currently run by HAWG via both the web browser at www.stockassessment.org and within the FLR (Fisheries Library in R) system (www.flr-project.org) which is an attempt to implement a framework for modelling integrated fisheries systems including population dynamics, fleet behaviour, stock assessment and management objectives. The stock assessment tools in FLR can also be used on their own in the WG context. The combination of the statistical and graphical tools in R with the stock assessment aids the exploration of input data and results.

1.5.2 ASAP

The ASAP 3 (http://nft.nefsc.noaa.gov) model has been used for Celtic Sea herring. ASAP (A Stock Assessment Program) is an age-structured stock assessment modelling program (Legault and Restrepo, 1998). ASAP is a variant of a statistical catch-at-age model that can integrate annual catches and associated age compositions (by fleet), abundance indices and associated age compositions, annual maturity, fecundity, weight, and natural mortality-at-age. It is a forward projecting model that assumes separability of fishing mortality into year and age components but allows specification of various selectivity time blocks. It is also possible to include a Beverton-Holt stock-recruit relationship and flexible enough to handle data poor stocks without age data (dynamic pool models) or with only new and post-recruit age or size groups.

1.5.3 SMS

SMS is a stochastic multispecies assessment model, including seasonality, used for sandeel in Division 3.a and Subarea 4, for sprat in the North Sea and 3.a. The model is run in single species mode for these stock assessments. Major difference with the other stock assessment models used by HAWG is the ability to assess in seasonal time-steps, necessary to distinguish the fishing season and off-season for both the sandeel and sprat stocks. Furthermore, it integrates catches, effort time-series, maturity, weight, and natural mortality-at-age. The model allows to set separate selectivity year blocks to account for changes in the fishing fleet.

1.5.4 Short-term predictions

Short-term predictions for the North Sea used a code developed in R. The method was developed in 2009 and intensively compared to the MFDP approach. Celtic Sea herring and Irish Sea herring forecast used the standard projection routines developed under FLR package FLCore (version 2.6.0.20170228). For sprat in the North Sea, a forecast using the FLR framework is in use. North Sea herring is assessed using a fleet-wise projection method using native R and FLR routines (some maintenance of the code has been done this year mainly to improve readability and documentation).

The Western Baltic Spring-spawning herring uses an R-based multifleet forecast routine available at www.stockassessment.org.

1.5.5 Reference Points

The eqsim software (https://github.com/ices-tools-prod/msy) was used in recent benchmarks to estimate MSY reference points for herring stocks of HAWG.

For sprat in the North Sea (Division 4) and sandeel in management area 1–4, the ICES guide for setting management reference points for category 1 stocks is used to find B_{lim}. MSY $B_{escapement}$ is equal to B_{pa} and is calculated as $B_{lim} \times e^{\sigma \times 1.645}$. An upper level on the fishing mortality is implemented (F_{cap}) if the difference between B_{lim} and MSY $B_{escapement}$ is not compatible with the ICES F_{MSY} criteria (i.e., that the average probability in the long-term of getting below B_{lim} should be no more than 5% per year). F_{cap} is calculated/optimized using a management strategy evaluation framework (MSE).

The 2018 benchmark (WKPELA 2018) of the North Sea herring, Western Baltic herring and Celtic Sea herring presented considerable challenges in the estimation of reference points and their calculation remains at times still controversial. An overview and critical discussion of those main challenges are provided in last year's report (ICES 2018, Section 1.2.6) and maintain their validity in the ongoing discussion on reference points.

New reference points were calculated for North Sea Herring during the 2021 inter-benchmark meeting (ICES, 2021). This resulted in a downward revision of the estimate of B_{lim} and $MSYB_{trigger}$ and an upward revision of the estimate of F_{msy}. Sensitivity testing revealed that the derivation of reference points for herring in the North Sea is very sensitive to the choice of time periods and stock–recruitment models used.

F_{pa} is defined as the exploitation rate reference point below which exploitation is considered to be sustainable, having accounted for assessment uncertainty. In 2020 a decision was made by ACOM to standardize the basis for F_{pa} whereby it is equal to the fishing mortality including the advice rule that, if applied as a target in the ICES MSY advice rule (AR) would lead to SSB ≥ B_{lim} with a 95% probability (also known as Fp05). The derivation of F_{pa} should include the expected stochastic variability in biology and fishery, as well as advice error.

Proxy reference points were derived for the category 3 stocks - herring in 6aS, 7b,c and 6aN at the benchmark in 2022 (ICES, 2022). $F_{proxyMSY}$ for both stocks was calculated using data from 2014-2021. This will be updated annually as new data becomes available. MSY $B_{trigger}$ is derived from the split acoustic survey biomass index and is 1.4*I_{loss} where I_{loss} is the lowest observed index value.

1.5.6 Repository setup for HAWG

To increase the efficiency and verifiability of the data and code used to perform the assessments as well as the short-term forecasts within HAWG a repository system was set up in 2009. Within this repository, all stocks own a subfolder where they store their data and code used to run the assessments presented in this report and used as base for the advice. At the same time, there is one common folder, used by all assessments, that ensures that the FLR libraries used are identical for all stocks, as well as the output generated to evaluate the performance of the assessment.

The repository was moved from google code to github in 2016 and is now available as a branch of the ICES github site. https://github.com/ICES-dk/wg_HAWG. Contributing to the repository is not possible for outsiders as a password is required. Downloading data and code is possible to the public. The repository is maintained by members of the WG and the ICES Secretariat.

1.6 Ecosystem overview and considerations

General ecosystem overviews for the areas relevant to herring, sprat and sandeel stocks covered by the Herring Assessment Working Group for herring stocks south of 62°N (HAWG) are given for the Greater North Sea and Celtic Seas Ecoregions (ICES, 2020e, f).

A more detailed account specific to herring is documented in ICES HAWG (2015). A number of topics are covered in this section including the use of single species assessment and management, the use of ecosystem drivers, factors affecting early life-history stages, the effects of gravel extraction, variability of the biology and ecology of species and populations (including biological and environmental drivers), and disease.

It should be pointed out that while numerous studies have greatly improved our understanding on the effects of environmental forcing on the herring stock productivity and dynamics, further work is still required to move beyond simple correlative understanding and elucidate the underlying mechanisms. One specific case is the persistent decrease in mean weight-at-age for many of the herring stocks in the region (Figure 1.7.6). Furthermore, mechanisms to incorporate this understanding into the provision of management advice are limited. ICES could therefore benefit greatly from developments that unify these two aspects of its community.

ICES is reviewing the level of inclusion of ecosystem information into the single-species assessments that provide the base for the current advices to evaluate progresses toward ecosystem-based fisheries management. The intent is to quantify whether and how the ICES assessments incorporated broader system-level considerations, from the inclusion of technical interactions among fisheries (i.e., catch and bycatch of target and non-target species) to interactions with the physical environment (i.e., environmentally-driven recruitment, climate), and biological components (i.e. density-dependency, predation).

Following the ACOM request (March 2019), HAWG collected information and has updated this on where and how change in ecosystem productivity (either annually or over time-periods) is incorporated in its fish stock assessments, MSE operating models and management advice products for the following six categories (relevant variables in parentheses) below:

1. Stock assessments (weight-at-age [in stock or catch], length distribution, maturity, sex ratio)
2. Forecasts (recruitment over recent years – reflecting productivity changes, recent weight-at-age, maturity, natural mortality)
3. Natural mortality (predation, diseases, parasites) assessed and included as variable by year (including smoothed)
4. Stock distribution (changes caused by year class strength, predators, prey, habitat suitability/quality)
5. Mixed fisheries (catch and bycatch of target/non-target species)
6. Climate change (is this considered and how?)

Because the inclusion of system-level information may span from the use of qualitative background considerations to inclusion of quantitative information into analytical assessments, the following scoring system recently proposed by Marshall *et al*. (2019) has been applied:

- Score 0 – information unavailable / not used.
- Score 1 (Background) – productivity is mentioned in the report and/or considered in the output as background information.
- Score 2 (Qualitative) – applicable in two cases: i) when quantitative data/information on productivity change were included in the report, but not used in any analyses/models, or ii) explicit link between the productivity change and assessment parameters or output was established. *For example, including numerical data from diet studies on the target species would receive a score of 2, as would discussing a link between sea surface temperature and recruitment predictions.*
- Score 3 (Quantitative) – productivity-related data were explicitly included in the assessment model through data inputs or estimated parameters.

Stock code	Stock assessment					Short-term forecast				
	variable w@a	length dis-tribution	variable mat@a	estimated variable nat mort	estimated variable sex ratio	environ. driven recruitment	truncating recruitment time-series	recent or trend weight@a	recent or trend mat@a	recent or trend nat mort
her.27.20-24	3	2	3	3	0	1	3	3	3	3
her.27.3a47d	3	2	0	3	0	1	3	3	0	3
her.27.6aS7bc	2	3	2	2	0	0	0	0	0	0
her.27.6aN	2	3	2	2	0	0	0	0	0	0
her.27.irls	3	2	1	2	0	0	3	3	0	0
her.27.nirs	3	2	3	2	0	0	3	3	3	2
san.sa.1r	3	0	1	3	0	0	1	3	1	3
san.sa.2r	3	0	1	1	0	0	3	3	1	1
san.sa.3r	3	0	1	3	0	0	1	3	1	3
san.sa.4	3	0	1	1	0	0	3	3	1	1
san.sa.5r	0	0	0	0	0	0	0	0	0	0
san.sa.6	0	0	0	0	0	0	0	0	0	0
san.sa.7r	0	0	0	0	0	0	0	0	0	0
San.27.6a	0	0	0	0	0	0	0	0	0	0
spr.27.3a4	3	0	1	3	0	0	3	3	1	3
spr.27.67a-cf-k	3	0	0	0	0	0	0	0	0	0
spr.27.7de	3	0	0	0	0	0	0	0	0	0

1.7 Summary of relevant Mixed fisheries overview and considerations, species interaction effects and ecosystem drivers, Ecosystem effects of fisheries, and Effects of regulatory changes on the assessment or projections for all stocks.

Brief summaries are given here; more detailed information can be found in the relevant stock summaries.

North Sea Autumn spawning herring (her.27.3a47d):

The North Sea herring fishery is a multinational fishery that seasonally targets herring in the North Sea and English Channel. An industrial fishery, which catches juvenile herring as a bycatch operates in the Skagerrak, Kattegat and in the central North Sea. Most fleets that execute the fishery on adult herring target other fish at other times of the year, both within and beyond the North Sea (e.g., mackerel *Scomber scombrus*, horse mackerel *Trachurus trachurus* and blue whiting *Micromestistius poutasou*). In addition, Western Baltic Spring spawners are also caught in this fishery at a certain time of the year in the northern North Sea to the west of the Norwegian coast. The fishery for human consumption has mostly single species catches, although some mixed herring and mackerel catches occur in the northern North Sea. The bycatch of sea mammals and birds is also very low, i.e., undetectable using observer programmes. There is less information readily available to assess the impact of the industrial fisheries that bycatch juvenile herring. The pelagic fisheries on herring and mackerel claim to be some of the "cleanest" fisheries in terms of bycatch, disturbance of the seabed and discarding. Herring like other pelagic forage fish has a central ecological role in the North Sea ecosystem, directly interacting with zooplankton, demersal fish, and other predators (sea mammals, elasmobranchs, and seabirds). Thus, a fishery on pelagic fish may impact on these other components via second order interactions. There is a paucity of knowledge of these interactions, and the inherent complexity in the system makes quantifying the impact of fisheries very difficult.

Another potential impact of the North Sea herring fishery is the removal of fish that could provide other "ecosystem services". The North Sea ecosystem needs a biomass of herring to graze the plankton and act as prey for other organisms. If herring biomass is very low other species, such as sandeel, may replace its role or the system may shift in a more dramatic way. Likewise, large numbers of herring can have a predatory impact on species with pelagic egg and larval stages.

The populations of herring constitute some of the highest biomass of forage fish in the North Sea and are thus an integral and important part of the ecosystem, particularly the pelagic components. North Sea herring has a complex sub-stock structure with different spawning components, producing offspring with different morphometric and physiological characteristics, different growth patterns and differing migration routes. Productivity of the spawning components varies. The three northern components (Autumn spawners) show similar recruitment trends and differ from the Downs component (Winter spawners), which appears to be influenced by different environmental drivers. Having their spawning and nursery areas near the coasts, means herring are particularly sensitive and vulnerable to anthropogenic impacts. The most serious of these is the ever-increasing pressure for marine sand and gravel extraction and the development of wind farms. Climate models predict a future increase in air and water temperature and a change in wind, cloud cover and precipitation. Analysis of early life stages' habitats and trends over time suggests that the projected changes in temperature may not widely affect the potential habitats but may influence the productivity of the stock. Relatively major changes in wind patterns may affect the distribution of larvae and early stage of herring.

Western Baltic Spring-spawning herring (her.27.20-24):

The Western Baltic herring fishery is a multinational fishery that seasonally targets herring in the eastern parts of the North Sea (Eastern 4.a and 4.b), the Skagerrak and Kattegat (Division 3.a) and Western Baltic (SD 22–24). The fishery for human consumption has mostly single-species catches, although in recent years some mackerel by-catch occurred in the trawl fishery for herring. In addition, North Sea herring are also caught within Division 3.a. The bycatch of sea mammals and birds is low enough to be below detection levels based on observer programmes. At present, there is a very limited and progressively decreasing industrial fishery in Division 3.a and hence a limited by-catch of juvenile herring. The pelagic fisheries on herring claim to be some of the “cleanest” fisheries in terms of by-catch, disturbance of the seabed and discarding. Pelagic fish interact with other components of the ecosystem, including demersal fish, zooplankton, and predators (sea mammals, elasmobranchs, and seabirds). Another potential impact of the Western Baltic herring fishery is the removal of fish that could provide other “ecosystem services.” There is, however, no recent research on multispecies or ecosystem interactions in which the WBSS interact. Although a fishery on pelagic fish may affect these other components via second order interactions.

Dominant drivers of larval survival and year-class strength of recruitment are considered to be linked to oceanographic dispersal, sea temperatures and food availability in the critical phase when larvae start feeding actively. However, research on larval herring survival dynamics indicates that driving variables might not only vary at the population level and by region of spawning but also by larval developmental stage. Since WBSS herring relies on inshore, transitional waters for spawning and larval retention, the suit of environmental variables driving reproduction success potentially differs from other North Atlantic stocks recruiting from coastal shelf spawning areas.

Herring in the Celtic Sea and 7.j (her.27.irls):

There are few documented reports of bycatch in the Celtic Sea herring fishery. Small quantities of non-target whitefish species were caught in the nets. Of the non-target species caught whiting was most frequent followed by mackerel and haddock. The only marine mammals recorded were grey seals (*Halichoerus grypus*). The seals were observed on a number of occasions feeding on herring when the net was being hauled and during towing. They appear to be able to avoid becoming entangled in the nets. Occasional entanglement of cetaceans may occur, but overall incidental catches are thought to be minimal.

Temperatures in this area have been increasing over the last number of decades. There are indications that salinity is also increasing. Herring are found to be more abundant when the water is cooler while pilchards favour warmer water and tend to extend further east under these conditions. However, studies have been unable to demonstrate that changes in the environmental regime in the Celtic Sea have had any effect on productivity of this stock. Herring larval drift occurs between the Celtic Sea and the Irish Sea. The larvae remain in the Irish Sea for a period as juveniles before returning to the Celtic Sea. Catches of herring in the Irish Sea may therefore impact on recruitment into the Celtic Sea stock. The residence of Celtic Sea fish in the Irish Sea may have an influence on growth and maturity rates.

The spawning grounds for herring in the Celtic Sea are well known and are located inshore close to the coast. Spawning grounds tend to be vulnerable to anthropogenic influences such as dredging and sand and gravel extraction. Herring are an important component of the Celtic sea ecosystem. There is little information on the specific diet of this stock. Herring form part of the food source for larger gadoids such as hake. Recent research showed that fin whales *Balaenoptera* *physalus* are an important component of the Celtic Sea ecosystem, with a high re-sighting rate indicating fidelity to the area. There is the suggestion that the peak in fin whale sightings in November may coincide with the inshore spawning migration of herring.

Herring in 6.a North (her.26.6aN):

Herring are an important prey species in the ecosystem and also one of the dominant planktivorous fish. Herring fisheries tend to be clean with little bycatch of other fish. Herring represent an important prey item for many predators including cod and other large gadoids, dogfish and sharks, marine mammals and seabirds. Because of the trophic importance of herring puts its stocks under immense pressure from constant exploitation**.**

The benthic spawning behaviour of herring makes this species vulnerable to anthropogenic activity such as offshore oil and gas industries, gravel extraction and the construction of wind farms. There are many hypotheses as to the cause of the irregular cycles shown in the productivity of herring stocks (weights-at-age and recruitment), but in most cases it is thought that the environment plays a key role (through prey, predation and transport). The 6.aN herring stock has shown a marked decline in productivity during the late 1970s and has remained at a low level since then.

Herring in 6.a South and 7.b and 7.c (her.27.6aS7bc):

Sea surface temperature**s** from Malin head on the North coast of Ireland since 1958 indicate that since 1990 sea surface temperatures have displayed a sustained increasing trend, with winter temperatures > 6°C and higher summer temperatures. Environmental conditions can cause significant fluctuations in abundance in a variety of marine species including fish. Oceanographic variation associated with temperature and salinity fluctuations appears to affect herring in the first year of life, probably during winter larval drift.

Productivity in this region is reasonably high on the shelf but drops rapidly west of the shelf break. This area is important for many pelagic fish species. The shelf edge is a spawning area for mackerel *Scomber scombrus* and blue whiting *Micromesistius potassou*. Preliminary examination of productivity shows that overall productivity in this area is currently lower than it was in the 1980s.

The spawning grounds for herring along the northwest coast are located in inshore areas close to the coast and tend to be vulnerable to anthropogenic influences such as dredging and sand and gravel extraction.

Herring in the Irish Sea (her.27.nirs):

The targeted fishery for herring in the Irish Sea is considered to have limited bycatch of other species. Herring are preyed upon by many species but at present the extent of this is not quantified. The main fish predators on herring in the Irish Sea include spurdog (*Squalus acanthias*), whiting (*Merlangius merlangus*) (mainly 0–1 ring) and hake (*Merluccius merluccius*) (all age classes). Small clupeids are an important source of food for piscivorous seabirds and marine mammals which can occur seasonally in areas where herring aggregate. While small juvenile herring occur throughout the coastal waters of the western and eastern Irish Sea, their distribution overlaps extensively with sprat (*Sprattus sprattus*).

Stock discrimination techniques, tagging, and otolith microstructure and shape show that juveniles originating in the Celtic Sea are present in the Irish Sea. The majority of mixing between these populations occurs at winter rings 1–2. Over the period 2006 to 2010 interannual variation in the proportion of mixing was large, with between 15% and 60% observed in the wintering 1+ biomass estimate during the study period. Further work on stock identity is ongoing. There are irregular cycles in the productivity of herring stocks which are probably caused by changes in the environment (e.g., transport, prey, and predation).

North Sea and 3a sprat (spr.27.3a4):

Sprat is a short-lived forage fish that is predated by a wide range of marine organisms, from predatory gadoids, through birds to marine mammals. Therefore, the dynamics of sprat populations are affected by the dynamics of other species through annually varying natural mortality rates. Because sprat interacts with many other components of the ecosystem (fish, zooplankton, and predators) the fishery may impact on these other components via these food web interactions. It is uncertain how many sprat migrate into and out of adjacent management areas, i.e. the English Channel (7.d and 7.e) and the western Baltic and the Sound (SD22–24), or how this may vary annually. Uncertain is also the boundary with local populations occurring along the Scandinavian Skagerrak coasts. While genetic information has supported the exclusion of sprat along the Norwegian coasts from the current assessment unit, similar information was insufficient for the Swedish coasts despite the fact that local populations likely exist. Young herring as a bycatch is acknowledged for this fishery with bycatch regulations in force. The bycatch of marine mammals and birds is considered to be very low (undetectable using observer programs).

Sprat in the English Channel (7.d and 7.e) (spr.27.7de):

The fishery considered here is primarily in Lyme Bay with small trawlers targeting sprat with very little to no bycatch of other species. The relationship of the sprat in this area to the sprat stock or population in the adjacent areas is unknown: Sprat larvae most likely drift away from the main spawning area in Lyme Bay, but to which extent they expand westward into the Celtic Sea or eastern deep into the Eastern English Channel and the North Sea is unknown. The potential for mixed fisheries, if the fisheries are expanded to cover the whole of the English Channel, is unknown at present. It is acknowledged that sprat is prey for many species, and these will affect the natural mortality, however, this has not been quantified in this area. In addition, changes in the size of the sprat population through fishing will affect the available prey for a number of commercially exploited species.

Sprat in the Celtic Seas ecoregion (6 and 7 (excluding 7.d and 7.e)) (spr.27.67a-cf-k):

This ecoregion currently has fisheries in the Celtic Sea, northwest of Ireland and a variety of Scottish Sea lochs with the possibility of fisheries being revived in the Clyde. Generally, mixed fisheries are not an issue as sprat are targeted with very little to no other species caught as a bycatch. If a fishery was to be prosecuted in the Clyde and Irish Sea, then bycatch of young herring may become an issue due to the overlap in distribution between young herring and sprat. It is acknowledged that sprat are prey for many species and these will affect the natural mortality, however, this has not been quantified in this area. Since sprat preys on e.g., zooplankton and is preyed upon by many species fisheries for sprat can have effects on the ecosystem dynamics.

Sandeel in the North Sea ecoregion (san.sa.1r-7r)

A mosaic of sandeel fishing grounds occur throughout different areas of the North Sea ecoregion. The grounds present different degrees of larval connectivity which has supported the division of sandeel in the North Sea into a number of more or less reproductively isolated subpopulations. Whereas the fishing grounds are assumed to remain relatively constant over time, the actual distribution of the fishery varies greatly from year to year in response to both changes in the availability of sandeel and changes in management between areas.

Sandeel is targeted by a highly seasonal industrial fishery which has experienced a progressive change towards fewer larger vessels owing most of the quota since the introduction of ITQ in 2004. Time and area restrictions and bycatch limits represent the main management measures.

Although the fishery has little bycatch of protected species, competition with other predators is a central aspect of the sandeel management within an ecosystem approach.

Sandeel play in fact an important role in the North Sea food web as they are a high quality, lipid-rich food resource for many predatory fish, seabirds, and marine mammals. Concerns of local depletion exist, especially for those sandeel aggregations occurring at less than 100 km from seabird colonies as some bird species (i.e., black-legged kittiwake and sandwich tern) may be particularly affected whereas more mobile marine mammals and fish are likely to be less vulnerable to local sandeel depletion.

1.8 Stock overview

The WG was able to perform analytical assessments for 9 of the 17 stocks investigated. Results of the assessments are presented in the subsequent sections of the report and are summarized below and in figures 1.7.2–1.7.5.

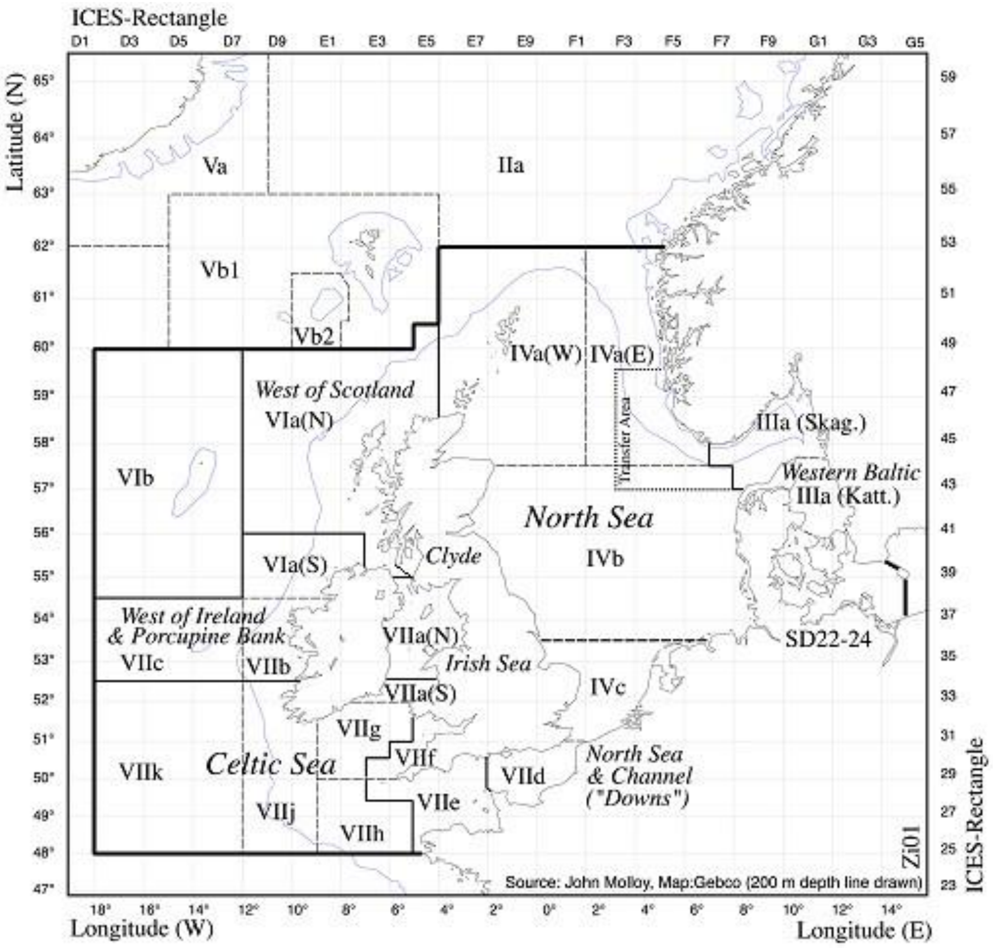

Figure 1.7.1 ICES areas as used for the assessment of herring stocks south of 62°N. Area names in italics indicate the area separation applied to the commercial catch and sampling data kept in long term storage. "Transfer area" refers to the transfer of Western Baltic Spring Spawners caught in the North Sea to the Baltic Assessment.

North Sea autumn spawning herring (her.27.3a47d) is the largest stock assessed by HAWG. The spawning-stock biomass was low in the late 1970s and the fishery was closed for a number of years. This stock began to recover until the mid-1990s when it appeared to decrease again. A management scheme was adopted to halt this decline. Based on the WG assessment the stock was classified as being at full reproductive capacity and harvested sustainably at F_{MSY} and under the management plan target for several years. Since 2019, no management plan is in place for North Sea Herring.

Western Baltic Spring Spawners (her.27.20-24) are distributed in the eastern part of the North Sea, the Skagerrak, the Kattegat and the subdivisions 22, 23 and 24. In the eastern part of North Sea and Division 3.a, the stock is considered to mix with North Sea autumn spawners and mixing with Central Baltic herring stock has been taken into account in the GERAS survey indices. Recent genetic work shows high mixing in the whole management units with other herring populations that is not currently taken into account in the assessment. The stock has decreased consistently since the late 2000s. The 2019 SSB (54 388 t) and 2020 recruitment (550 822 thousand) are record low. The estimate of SSB in 2021 (62 765 t) is considered low, below both B_{pa} and B_{lim}. Fishing mortality ($F_{3–6}$) was reduced from 0.58 in 2008 to 0.31 in 2011. It had then remained above F_{MSY} (0.31) until 2015 (0.34-0.43) but showed an increase in 2016-2018 with an estimated F_{3-6} above 0.49. $F_{3–6}$ then decreased since 2019 below F_{MSY} from 0.30 to 0.15 in 2021, which is the lowest $F_{3–6}$ on records. The 2023 advised catch of WBSS is 0 t, which if applied by managers, will result in an increase in SSB from 71 011 t in 2022 to 80 978 t in 2023. The zero catch will not allow the stock to rebuild above B_{lim} (120 000 t) by 2024 (95 882 t). A medium-term forecast to 2025 showed that SSB can increased to 111 989 t if F=0 in 2023-2024 but will still remain below B_{lim}.

Herring in the Celtic Sea and 7.j (her.27.irls): The herring fisheries to the south of Ireland in the Celtic Sea and in Division 7.j have been considered to exploit the same stock. For the purpose of stock assessment and management, these areas have been combined since 1982. The stock has fluctuated over time. Low stock size was observed from the mid-70s to the early 80s. The SSB increased again before declining in the late 90s. From 2005 the stock increased when several strong cohorts (2004, 2008, 2009, 2010 and 2013) entered the fishery and as they gained weight, they maintained the stock at a high level. The SSB has decreased since its peak in 2011 and is estimated to be 11 680 t in 2020, which is well below B_{pa} (at 54 000 t) and B_{lim} (34 000 t). Recruitment has been below average since 2013. An increase in recruitment can be seen in 2021 however the assessment is highly uncertain, and recruitment has been consistently overestimated in recent years. Fishing mortality ($F_{2–5}$) declined between 2003 and 2009 but started to rise again in 2010 due to increased catches. F decreased in 2020 in line with greatly reduced catches and is slightly higher in 2021. This year's assessment estimates a fishing mortality, $F_{2–5}$ = 0.069 in 2021 which is well below all reference points (F_{MSY} is 0.26 and F_{lim} is 0.45). Short-term projections predict SSB to increase to 19 349 t in 2022.

Herring in 6.aN (her.27.6aN): Off the west of Scotland, the herring stock is composed of two groups - one spawning during spring (February until April) in the Minch and the other during autumn (late August until October) off Cape Wrath. Fisheries have historically targeted both groups, and their relative contribution is believed to have varied over time. These stocks were assessed together with herring in 6.a.S, 7.b.c during 2015-2021. The development of a genetically split acoustic survey index for the Malin Shelf Herring Acoustic Survey (MSHAS) from 2014-2021 into the component stocks means that separate advice for 6.aN autumn spawners and 6.a.S, 7.b.c is now possible. 6.aN spring spawners are not fully resolved by the present method and are not assessed. The Malin Shelf herring estimate of SSB for autumn spawning herring in 6.aN in 2021 is 43 886 tonnes. Although estimates appear to be improving from the minimum value in 2019, it should be noted that numbers of herring to the West of Scotland are very low compared to historical estimates prior to the genetic split (ICES 2021a). Fishing pressure on the stock is at or below $F_{MSY\ proxy}$ (0.335) and the stock size index is above MSY $B_{trigger\ proxy}$ (14 711 t).

There is little information on terminal year recruitment in the catch-at-age data and there are as yet no recruitment indices from the surveys.

Herring in 6aS, 7b,c (her.27.6aS7bc): Herring to the northwest and west of Ireland in ICES Divisions 6.a.S, 7.b,c are primarily a winter spawning (Nov-Jan) stock, though later spawning in spring (Feb-Apr) also occurs. This stock was assessed together with herring in 6aN from 2015-2021. Following a benchmark which took place in 2022 these two stocks are now assessed separately. This was made possible by the development of a genetically split acoustic survey index. The ability to split the summer acoustic survey (MSHAS) from 2014-2021 into the component stocks means that separate advice is now possible. The survey index for herring in 6aS, 7b,c has been increasing since the lowest point in 2016 (36,707 t) and in 2021 was estimated to be 189,856 t, which is the second highest point in the current time series. Recent catches are among the lowest in the time series. Fishing pressure on the stock is at or below $F_{MSY\ proxy}$ (0.034) and the stock size index is above MSY $B_{trigger\ proxy}$ (51 390 t). There is little information on terminal year recruitment in the catch-at-age data and there are as yet no recruitment indices from the surveys. Recruitment of the 2018 year-class was good and this year class is now 3 winter ring and accounted for 58% of the catch numbers at age in 2021.

Herring in the Irish Sea (her.27.nirs): comprises two spawning groups (Manx and Mourne). This stock complex experienced a decline during the 1970s. In the mid-1980s the introduction of quotas resulted in a temporary increase, but the stock continued its decline from the late 1980s up to the early 2000s. During this time period the contribution of the Mourne spawning component declined. An increase in activity on the Mourne spawning area has been observed since 2006. In the past decade there have been problems in assessing the stock, partly as a consequence of the variability of spawning migrations and mixing with the Celtic Sea stock. A benchmark in 2017 resulted in a substantial revision of SSB perception leading to an increased SSB in the most recent period compared to pre-benchmark perceptions. In 2021, SSB and recruitment have been estimated at 30 792 t and 196 418 thousand respectively. $F_{4\text{–}6}$ is estimated at 0.21 in 2021 with estimates of F stable since 2009. Under the MSY approach the stock is expected to show a decrease to 23 076 t in 2023.

North Sea and 3a sprat (spr.27.3a4): The catches are dominated by age 1–2 fish. Due to the short life cycle and early maturation, most of the stock consists of mature fish. To undertake the assessment and fit with the natural life cycle of sprat the assessment model is shifted by six months so that an assessment year and advice runs from 1 July to 30 June each year, and thus provide in-year advice. Since the last benchmark (ICES 2018), sprat in Division 3.a and Subarea 4 are combined into a single assessment unit. The advice is based on the MSY escapement strategy with an additional precautionary F_{cap}. The F_{cap} of 0.69 is used to ensure that after the fishery has been conducted, escapement biomass is preserved above B_{lim} with high probability. The estimates for 2022 show an SSB of 100 000 t which is below B_{pa} (125 000 t). The ICES advise for the period 1 July 2022–30 June 2023 is that catches of sprat should not exceed 68 690 t which represents a 36% decrease on the last year advice. The reduction is due to the decrease in stock size following the low recruitment observed in 2021.

Sprat in the English Channel (7.d and 7.e) (spr.27.7de): Consists of a small midwater trawl fleet targeting sprat primarily in the vicinity of Lyme Bay, western English Channel. The stock identity of sprat in the English Channel relative to sprat in the North Sea and Celtic Sea is unknown. This year, ICES has provided catch advice for sprat in divisions 7.d and 7.e (primarily in the vicinity of Lyme Bay) based on criteria for data limited stocks. Data available are catches, a time-series of LPUE (1988–2016) and one acoustic survey that has been carried out since 2013 in the area where the fishery occurs and further offshore, also including the waters north off the Cornish Peninsula and, from 2017, the French part of the Western English Channel. The 2021 survey also extended into Cardigan Bay. The advice provided is based on the application of a constant harvest rate of 8.57%

to the 2021 acoustic survey biomass estimate. The advised catch of 9 200 t for 2023 is 217.6% higher compared to last year. Since sprat is a short-lived species and given the timing of the survey (October), an advice period, valid from 1 July to 30 June in the following year, has been adopted for this stock starting in 2022. This will mitigate the problem of the lag between the survey information and the advice year which occurred previously. This has also been extended to the TAC which will also run from 1 July to 30 June. The fishing season for sprat runs from August to February.

Sprat in the Celtic Seas (spr.27.67a-cf-k): The stock structure of sprat populations in this ecoregion (subareas 6 and 7 (excluding 7.d and 7.e)) is not clear, and further work for the identification of management units for sprat is required. Most sprat in the Celtic Seas ecoregion are caught by small pelagic vessels that also target herring, mainly Irish and Scottish vessels. The quality of information available for sprat is heterogeneous across this composite area. There is evidence from different survey sources of significant interannual variation in sprat abundance. Landed biomass, but not biological information on the catch, is available from 1970s in some areas (i.e., 6.a and 7.a), while Irish acoustic surveys started in 1991, with some gaps in the time-series provide sprat estimates but their validity to provide a reliable sprat index is questionable because they do not always cover the core of sprat distribution in the area. Acoustic estimates in the Irish Sea are more reliable. The state of the stock of sprat in the Celtic Seas ecoregion is uncertain. ICES advice a catch of no more than 2240 tonnes for 2022 and 2023 in this ecoregion based on the precautionary approach.

Sandeel in 4 (san-nsea): A decline in the sandeel population in recent years concurrent with a marked change in distribution has increased the concern about local depletion, of which there has been some evidence. Since 2010 this has been accounted for by dividing the North Sea into 7 management areas. Denmark and Norway are responsible for most of the fishery of sandeel in the North Sea. The catches are largely represented by age 1 fish. Analytical assessments are performed in four of the management areas (A1r–4) where most of the fishery takes place and data are available. Note that a benchmark in 2016 revised most of the area definitions.

A1: SSB has been above B_{pa} (145 000 t) in 2016-2018 and dropped to 71 000 t in 2019, 61 000 t in 2020, and 127 000 t in 2021. The forecasting indicates that SSB will increase to a level above B_{lim} (110 000 t), but below B_{pa}, in 2022. Recruitment in 2021 was below the geometric mean of the time-series, and lower than in 2020. Fishing mortality (F) has fluctuated, showing a declining trend since the mid-2000s followed by an increase in 2017 to approximately the long-term average where it remained relatively stable till 2020 for the last four years (~ 0.5) but dropped in 2021.

A2: SSB has been below B_{lim} (56 000 t) since 2004, with few exceptions. SSB increased in 2018 above B_{pa} as the result of the exceptionally high 2016-year class and decreased again in 2019. SSB in 2021 is estimated at 35 000 t The 2021 year class is estimated to be high above the long-term average.

A3: The stock has increased from the record low SSB in 2004 when it was half of B_{lim} (80 000 t) to above B_{pa} (129 000 t). SSB had a peak of more than 440 000 t in 2018 and is estimated to 375 000 t in 2021. The recruitments in 2016 and 2019 were among the five highest on record. Forecast indicates an SSB in 2022 of 210 000 t. Fishing mortality (F) declined in the early 2000s and has been low until 2018. F has been increasing in the last couple of years.

A4: Fishing mortality (F) has been low since 2005 but increased in 2018 before decreasing again in 2019-2020 before increasing to a close-to record high level in 2021. SSB has fluctuated above precautionary reference points (B_{lim}) since 2011 with the exception of 2015 and 2020. Recruitment was low in 2018, high in 2019 and around the long-term average in 2020. Recruitment in 2021 is expected to be slightly lower than in 2020.

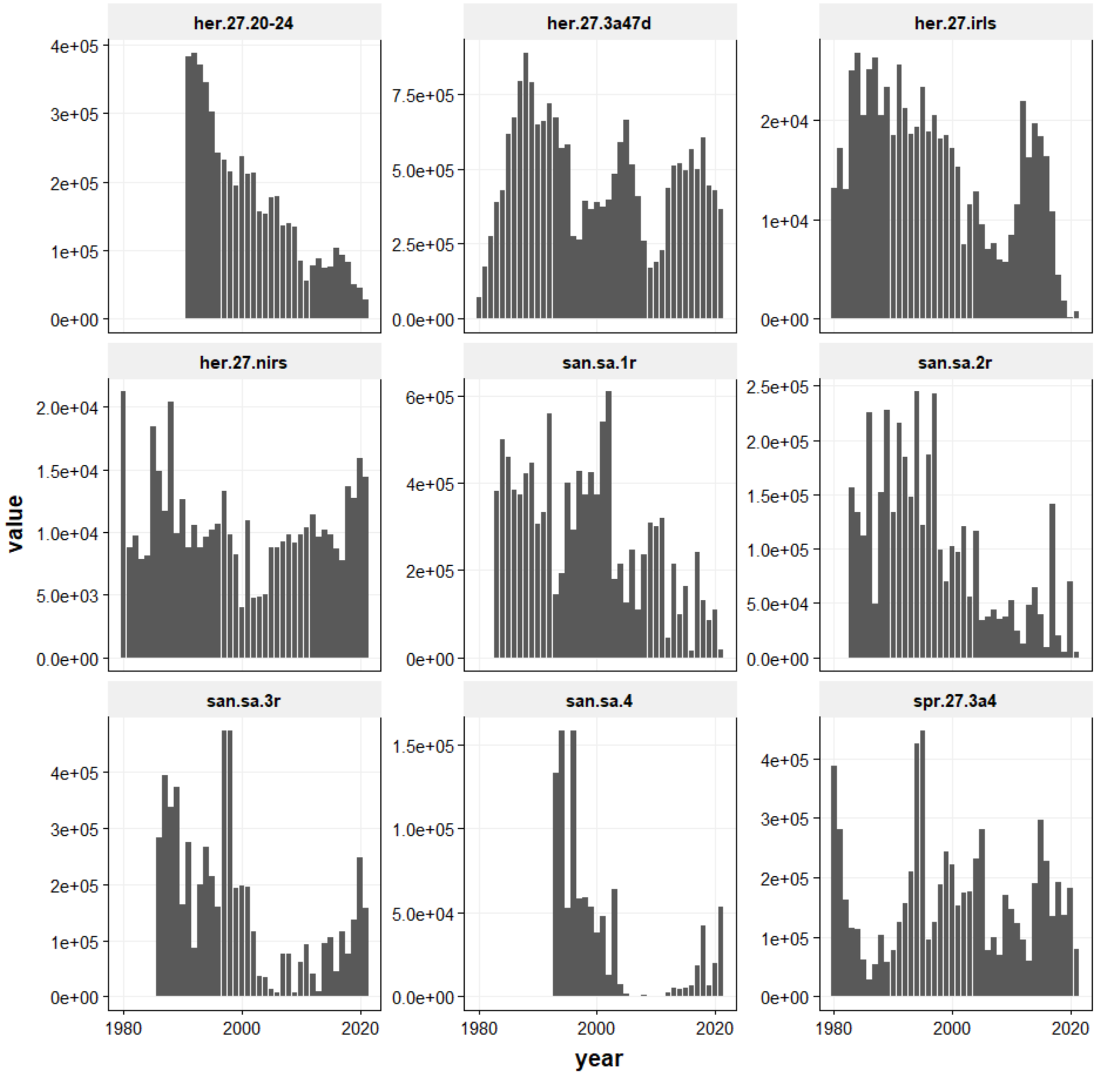

Figure 1.7.2 WG estimates of catch/landings (yield) of the category 1 herring, sprat and sandeel stocks presented in HAWG 2022

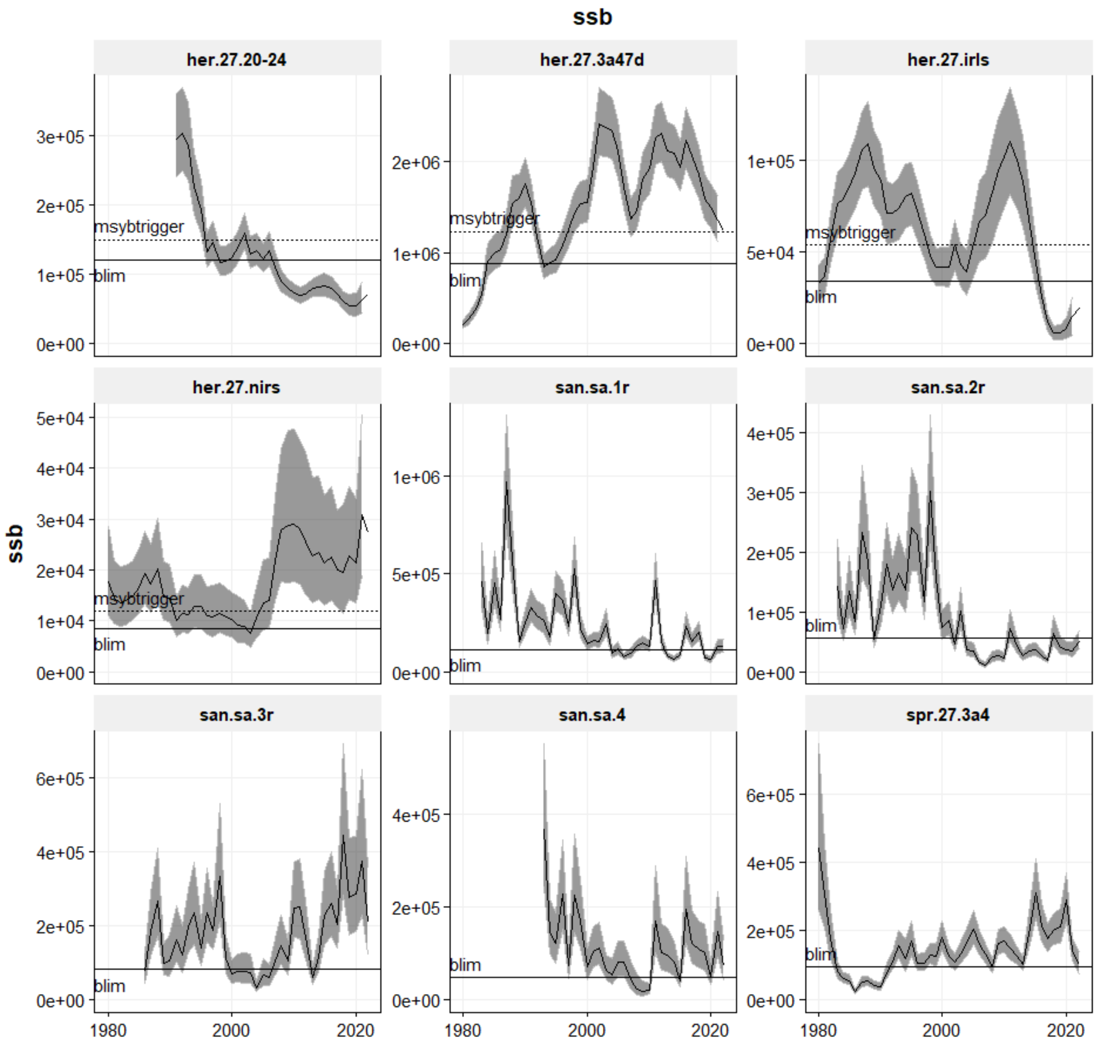

Figure 1.7.3 Spawning-stock biomass estimates for the category 1 sprat, herring and sandeel stocks assessed at HAWG 2022.

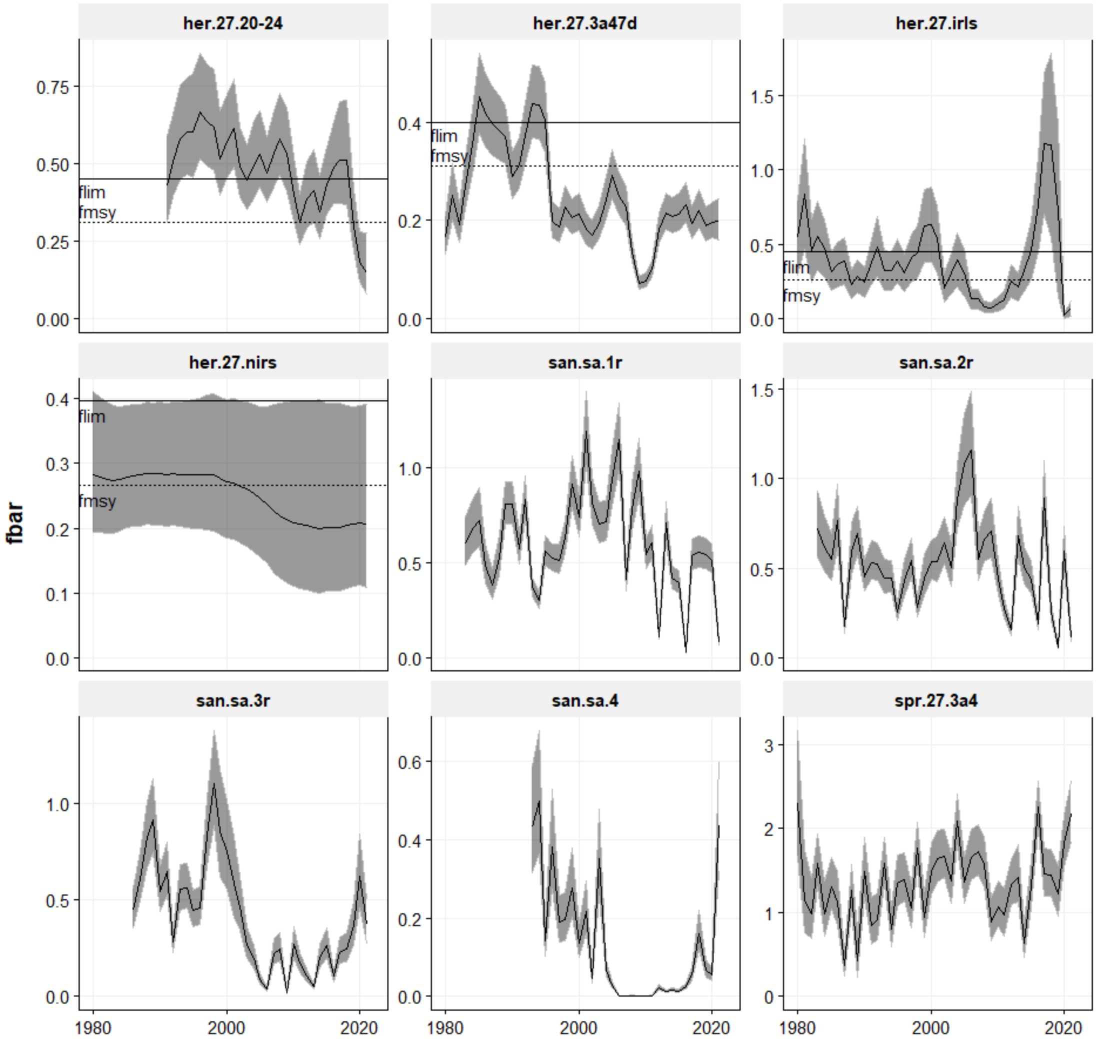

Figure 1.7.4 Estimates of mean F for the category 1 sprat, herring and sandeel stocks assessed at HAWG 2022.

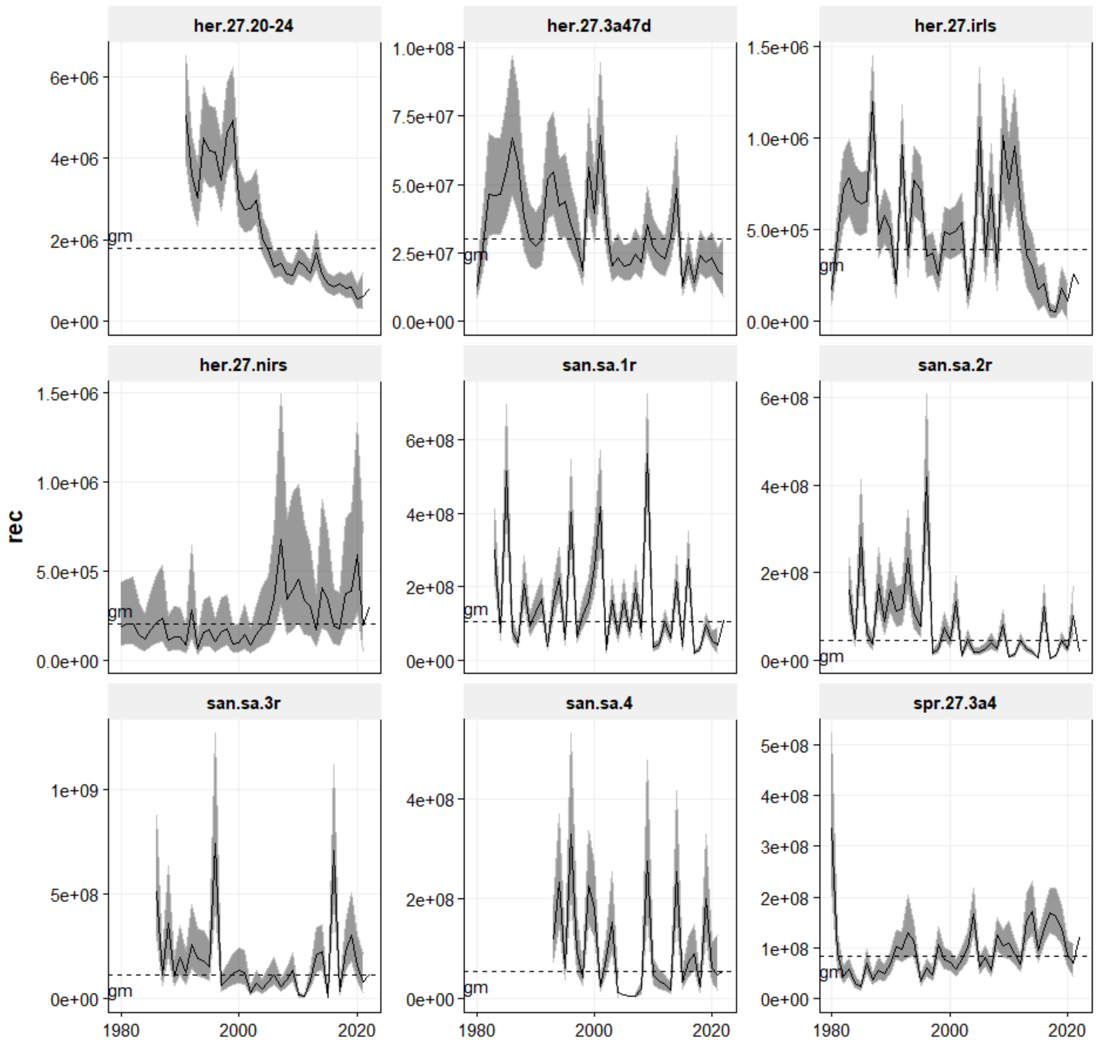

Figure 1.7.5 Estimates of recruitment for the category 1 sprat, herring and sandeel stocks assessed at HAWG 2022.

Given the marked decrease in the weight-at-age of several of the herring stocks assessed by HAWG, the time-series of the relative weight change are presented for comparative reasons (Figure 1.7.6).

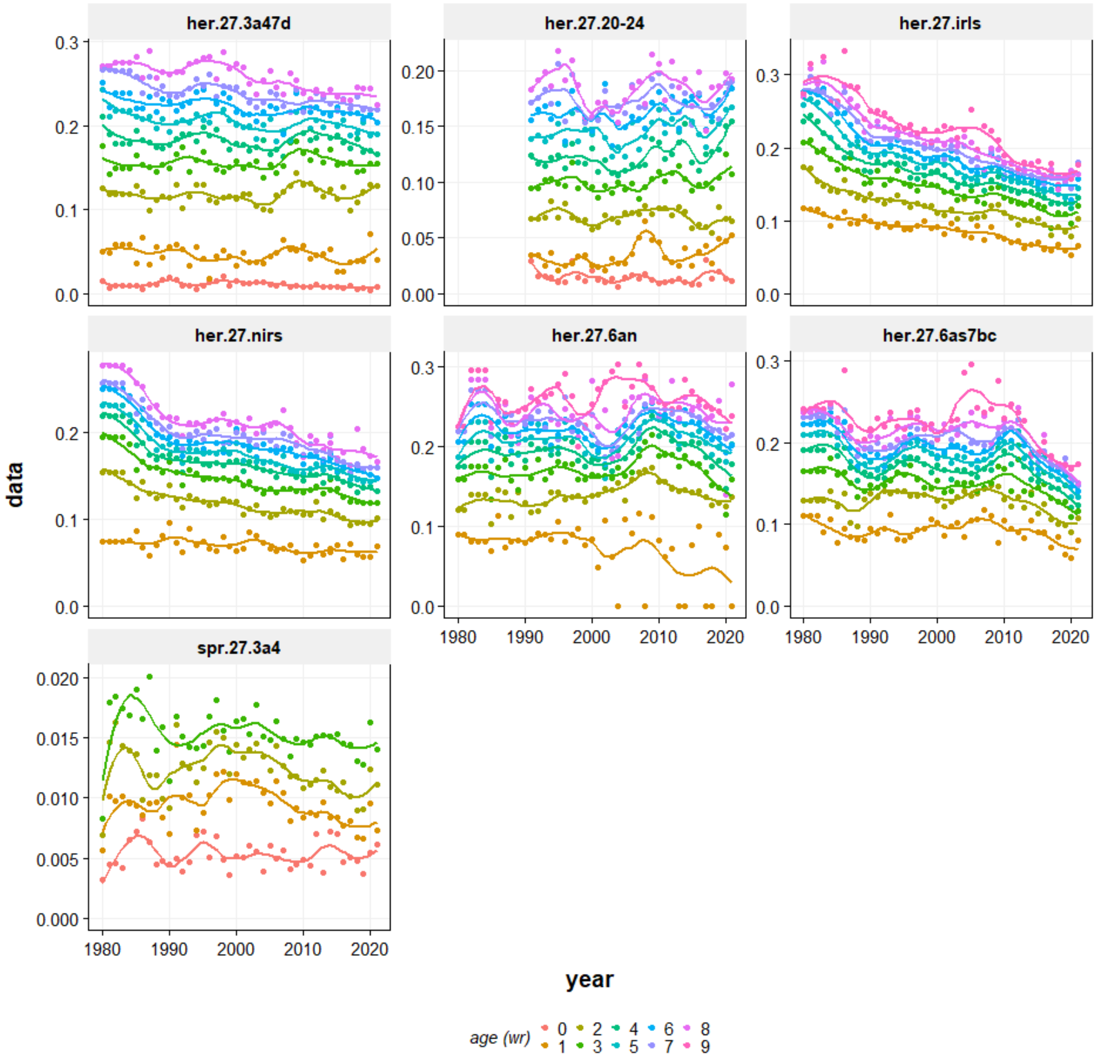

Figure 1.7.6 Time-series of herring mean individual weight in the catch.

1.9 Mohn’s rho and retrospective patterns in the assessments

The analysis of retrospective patterns is one of the core diagnostics of the analytical assessments performed by ICES working groups, including HAWG. Mohn’s rho (ϱ) is the metric which is currently used to quantify retrospective patterns.

Mohn’s rho (ϱ) is calculated as the relative difference between an estimate from an assessment with a truncated time-series and an estimate of the same quantity from an assessment using the exact same methodology over the full time-series. The average of the relative change over a series of years is calculated as[1]:

$$\rho_n = \frac{1}{n}\sum_{i=1}^{n}\frac{X_{y=T-i,dd=T-i}-X_{y=T-i,dd=T}}{X_{y=T-i,=T}}$$

where $X_{y,d}$ is the assessment quantity, e.g. SSB or F_{bar}, for year *y* from the assessment with terminal year *d*, T is the terminal year of the most recent assessment (the year of the most recent catch-at-age data), and n is the number of retrospective assessments used to calculate rho.

The two-year subscripts for quantity X refer to the year for the quantity and the terminal year of the assessment from which the quantity was derived. For example, for an assessment WG in 2018, using catch-at-age up to 2017, the relevant quantities for the first retrospective ($i = 1$) calculation are: $X_{y=T-i,d=T} = X_{y=2016,dd=2017}$ which corresponds to the assessment quantity for 2016(T-i) derived from the assessment using the full time-series with terminal year 2017 (T); and $X_{y=T-i,=T-i} = X_{y=2016,dd=2016}$ which is the estimate of the assessment quantity for the same year T-i = 2016) estimated from an assessment where the data are truncated to have terminal year 2016 (T-i).

Mohn’s rho values have been uploaded at https://community.ices.dk/ExpertGroups/Lists/Retrobias/overview.aspx and they are included in this report in Table 1.8.1.

[1] From ICES guidelines

Table 1.8.1 Mohn's rho value calculated by HAWG on category 1 and 2 stocks with age-based fish stock assessments.

Stock code	Terminal year of catch data	Number of retrospective assessments used (n)	F_{bar} rho value	SSB rho: was the inter- mediate year used as the terminal year?	SSB rho value	Recruitment rho: was the intermediate year used as the terminal year?	Recruitment rho value
her.27.20-24	2021	5	-0.140	No	0.208	No	0.111
her.27.3a47d*	2021	5	-9.498	No	7.305	No	-10.269
her.27.irls	2021	5	-0.41	No	1.34	No	3.02
her.27.nirs	2021	5	-0.159	No	0.093	No	-0.309
san.sa.1r	2021	5	-0.10	No	0.43	No	0.87
san.sa.2r	2021	5	-0.13	No	0.55	No	0.37
san.sa.3r	2021	5	0.20	No	-0.12	No	0.01
san.sa.4	2021	5	-0.16	No	0.54	No	1.12
spr.27.3a4	2021	5	-0.05	Yes	0.25	No	0.27

1.10 Transparent Assessment Framework (TAF)

TAF (https://taf.ices.dk) is a framework to organize all ICES stock assessments. Using a standard sequence of R scripts, it makes the data, analysis, and results available online, and documents how the data were pre-processed. Among the key benefits of this structured and open approach are improved quality assurance and peer review of ICES stock assessments. Furthermore, a fully scripted TAF assessment is easy to update and rerun later, with a new year of data.

The following HAWG scripts are now available on TAF (https://taf.ices.dk/app/stock#!/):

7. North Sea herring (her.27.3a47d) update single-fleet SAM assessment, multi-fleet model run required for the forecast, and the forecast analysis (Update in progress 2021)
8. Herring west of Scotland (her.27.6aN) WKLIFE method 2.2 chr (prepared at the benchmark in 2022)
9. Herring west of Scotland and Ireland (her.27.6aS7bc) WKLIFE method 2.2 chr (prepared at the benchmark in 2022)
10. Herring south of 52°30'N Irish Sea, Celtic Sea, and southwest of Ireland (her.27.irls) ASAP assessment (Update in progress 2022)
11. Sprat in 7d, e Category 3, biomass trends (Last updated 2018)
12. Sandeel in area 1r (san.sa.1r) SMS assessment (Last updated 2019)
13. Sandeel in area 5r (san.sa.5r) category 5.4 analysis (Last updated 2019)
14. Sandeel in area 6 (san.sa.6) category 5.2 analysis (Last updated 2019)
15. Sandeel in area 7r (san.sa.7r) category 5.3 analysis (Last updated 2019)

A draft TAF workflow is currently being tested by HAWG members. This involves checking the code and providing feedback. A score will be given which reflects the cleanliness, readability and if the code is easy to understand.

WKREPTAF

The TAF Reporting Workshop (WKREPTAF) met in January 2021 and explored the reporting process for ICES expert groups (with special focus on stock assessment groups) and how this could become simpler, less time consuming, and of better quality. The workshop focussed on how to expand TAF to facilitate the reporting process within working groups. The workshop concluded that 1. Script-based reports (i.e. markdown) would allow stock assessment groups to automate the process of inserting and formatting tables and figures in the report. 2. The data to be held within TAF can be documented within the report sections of the current ICES report in a standardized manner. With more data becoming available in TAF, there is the opportunity to more easily link ecosystem considerations and mixed fisheries considerations within stock specific chapters. 3. The transition from conventional reporting to script-based reports would benefit from agreeing on standardized stock assessment inputs for TAF. 4. The script-based reports open up the opportunity to directly incorporate information from the regional database (RDBES), DATRAS, Stock Information Database and Stock Assessment Graph database (SAG). 5. Training in TAF and markdown reporting are essential for the ICES community (ICES, 2021, WKREPTAF).

1.11 Benchmark process

HAWG has made some strategic decisions regarding the future benchmarking of its stocks listed in the table below.

Stock	Assessment category	Latest benchmark	Benchmark or Interbechmark in the next 12 months	Further planning	Comments
NSAS herring	1	2018 Interbenchmark 2021	No	Exploration of M scaling methodologies, model configuration, new M values	Issue list available
WBSS herring	1.2	2018	Perhaps	Revise fleet definition in the 3.a catches, make the assumption on Winter spawners consistent between Danish and Swedish catches, revise the mean weight at age in the transfer area	Issue list and roadmap for next benchmark available, likely need for a benchmark in 2024 or 2025
6aN herring	3	2022	No	Continue genetic sampling on the acoustic survey. Start genetic sampling of the catches. Further investigate additional survey indices. Explore stock identity issues. Further work on model development.	Issue list in prep
6.aS, 7.bc herring	3	2022	No	Continue genetic sampling on the survey. Start genetic sampling the catch. Further investigate survey indices. Further work on model development.	Issue list in prep
Celtic Sea herring	1	2015 Interbenchmark 2018	No	Mixing with Irish Sea herring, recruitment signal	Issue list available
7.aN herring	1	2017	No	Explore stock mixing, recruitment signal and F in the assessment	Issue list available
Sprat NS.3a	1	2018	No	Consider stock component, local components in 3a, boundary with the Baltic	Issue list available
Sprat 7.de	3	2018 Interbenchmark 2021	No	Consider stock components, review advice guidance for short lived species	Issue list available
Sprat Celtic	5	2013	No	Research roadmap to review and plan sprat work in 2022	Issue list available
Sandeel areas 1r–4	1	2016	Yes	Update reference points for sandeel area 3 based on the new M estimates	Issue list available