WORKSHOP ON ESTABLISHING A ROADMAP FOR POSSIBLE CONSERVATION MEASURES FOR HERRING IN THE BALTIC (WKHERBAL)

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Contents

i Executive summary

The Workshop on establishing a roadmap for possible conservation measures for Herring in the Baltic (WKHERBAL) was established in response to a special request from DGMARE. The potential drivers of the observed changes in age and size structure and condition of central Baltic and Gulf of Bothnia herring (*Clupea harengus*) stocks were discussed.

The timing of the observed declines was notably different between the two stocks with the decline in Central Baltic herring starting in the mid-1980s and lasting over a decade to the late 1990s. Whereas the decline in the Gulf of Bothnia started around 1990 and continued until the mid-2000s. Both stocks also show a similar sudden decline in weight-at-age in 2021 followed by a recovery in 2022. The reasons for these changes are likely to be multifactorial and while several possible causes have been suggested the relative contribution of these has not been established.

WKHERBAL identified several actions in the short and long-term to further investigate the potential drivers of the observed changes in age and size structure and condition. These actions can be further elaborated and supported through dedicated scoping and resourcing to transform them into an operational roadmap to address the six evidence needs identified in the request. To implement the proposed actions, effective and sustained cooperation between all relevant Baltic Sea countries is needed.

ii Expert group information

Expert group name	Workshop on establishing a roadmap for possible conservation measures for HERring in the BALtic, (WKHERBAL)
Expert group cycle	1/1
Year cycle started	2023
Reporting year in cycle	Year 1
Chair(s)	Colm Lordan, Ireland
Meeting venue(s) and dates	29-30 November 2023, Online meeting, 15 participants

1 Introduction

The Workshop on establishing a roadmap for possible conservation measures for Herring in the Baltic (WKHERBAL) was established in response to a special request from DGMARE (Section 1.1). The workshop took place online with 15 participants from Sweden, Poland, Finland, Estonia, Germany, Latvia and Denmark, chaired by Colm Lordan (Ireland) (Annex 1). The chair welcomed the participants and introduced the ICES Code of Conduct and Conflict of Interest (CoI). No CoI were declared by participants. On day one of the workshop participants gave a number of informative presentations (see workshop agenda in Annex 2) relevant to the ToRs (Annex 3). Presenters were asked to focus on what, how and why their work was relevant to the ToRs. These contextualised and informed subsequent discussions.

1.1 Request from DGMARE

Over the past years the condition of Bothnian and central Baltic herring has deteriorated, and there are less older and larger herring (i.e. decline in weight-at-age). At the AGRIFISH Council of October 2022 the Commission, Finland, Latvia, Lithuania, Poland and Sweden therefore signed a joint statement expressing their concern about the size and age structure of central Baltic Sea herring and Gulf of Bothnia herring. The Commission committed to request ICES to: (i) conduct scientific analyses of the size and age structure of those stocks, and of the reasons for the observed reduced number of larger-sized herring, and (ii) identify possible measures to address this issue.

In order to identify reasons for reduced number of larger-sized herring and explore possible management measures to improve the condition of these stocks, ICES is requested establish a roadmap for further research needs to feed into potential advice. The objective of the possible management measures is to achieve the objectives of article 2 of the CFP Regulation (EU) 1380/2013, namely to ensure that fishing activities are environmentally sustainable in the long-term and managed so as to achieve economic, environmental and social benefits by exploiting the stocks in such a way that the populations are restored and maintained above levels which can produce MSY.

In view of future provision of ICES advice on possible conservation measures as described in the paragraph above, the roadmap should describe mechanisms for the delivery of data, implementation of a simulation model, or a battery of models, and expertise for the following six potential evidence needs:

1. ***Advice on demographic and individual size structure in medium term future scenarios of total fishing mortality.*** *Simulations of population growth, individual size and age structure of the herring stocks under varying total fishing pressure (F) reductions in the next 10 years, including the option of not to fish at all. A suitable indicator for age/size structure may be chosen or several options may be considered.*
2. ***Advice on spatial (area) closures.*** *The effects of area closures in relation to fishing pressure under the current F_{MSY} framework and show effects on biomass, individual size and age structure, and possible fleet displacements.*
3. ***Advice on temporal closures.*** *The effects of temporal closures such as a closed pre-spawning spring season from 1 January to 30 June, or other suitable time periods, and show effects on biomass, individual size and age structure under the current F_{MSY} framework and management plan.*
4. ***Advice on combined spatial (area) and temporal closures.*** *The effects of combined area closures and temporal closures and the effects of biomass, individual size and age structure in relation to managing the stocks under the current F_{MSY} framework and management plan, and possible fleet displacements.*

5. ***Advice on gear modifications**, including the selectivity of trawls used to catch herring, as an option to improve the individual size and age structure of herring. Also to indicate any potential of the current technical rules to impact the observed change in individual size and condition of the herring stocks.*

6. ***Advice on the coherence of herring fisheries with the objectives of safeguarding food webs, biodiversity and habitat integrity** (as described in the marine strategy framework directive). This should include diversity of sub-populations of herring to the extent feasible and quantify the impact of fishing pressure on these descriptors of the MSFD.*

For all six elements, the data and the analysis should be adequate to support separate scenarios for subdivisions 30-31, and 25-29 and 32 excluding Gulf of Riga. Suggested spatial and temporal closures will be identified through scoping exercises with managers and stakeholders.

Further background and considerations

There are indications that the Baltic herring stocks do not form one population but rather multiple stocks with genetic distinctions and separate spawning and migration patterns. Fishing pressure is one of the likely reasons for the reduced amount of larger herring. The roadmap should chart the available expertise, data and methods to address the six evidence needs. It should document what is currently available, what can be synthesized in the short term and how medium term needs for evidence can be addressed.

The Marine Strategy Framework Directive's (MSFD) objective of good environmental status is of relevance in this context as the CFP has to be coherent with Union environmental legislation. The MSFD's objective relates both to healthy stocks of sufficient total biomass as well as size and age distribution within the stocks (D3). It furthermore relates to food webs (D4) and wider ecosystem components (D1).

Fisheries in the Baltic Sea are currently primarily managed under the MSY framework. Despite this, negative stock trends and a loss of larger/older individuals in the populations are observed. In its advice for 2023 ICES noted that there is considerable uncertainty linked to the current herring stock projections, and e.g. misreporting of herring and sprat is not accounted for in the advice. For the future it should be possible to quantify this uncertainty, at least tentatively, by for example performing sensitivity trials on the models used. The precautionary approach to recruitment variability and biomass levels should be quantifiable targets. Effects of uncertainty should be explored with regards to both F and SSB.

The roadmap should describe different options to address a) spatial (area) -restrictions, b) an reduction in fishing pressure to adjust to the presence of separate populations, c) reductions in vessel size, i.e. limits on fishing mortality per trawling haul.. The roadmap should also address if the evidence is available to indicate any mismatch between the scale of biological and management units.

To demonstrate the stock status in relation to size and age structure, proxies may be used and several options of indicators shown if for example data on size was not available. The MSFD Descriptor 3 criteria are elaborated in the guidance document for MSFD article 8, developed and agreed by the MSCG as part of the MSFD CIS from 2022 (document MSCG_30-2022-04), and in Commission Decision (EU) 2017/848 does not yet lay down methodological standards. ICES is developing a request with DGENV to further develop methodological standards.

The roadmap should ensure that the evidence base provides the level of uncertainty as well as the key elements of that uncertainty such as the understanding of natural mortality, of stock structure and how stock growth parameters influence the projections. Performing sensitivity testing of the models and input data used should show how stock status and projections change if e.g. the catch data is biased and misreporting of sprat as herring or vice versa has an impact or not. An indication of risk or level of precaution with each scenario presented should be indicated.

Finally, roadmap should chart examination of the implication of adjusting mesh sizes. Considering the current fisheries patterns and the fact that the average size of herring has decreased, it is likely that more fish is "selected out" during trawling compared to earlier. This mortality may be a large and growing *cause of overall mortality, either as unknown or as an incorrectly considered part of natural mortality. Poor condition of herring may contribute to even higher mortality.*

1.2 The latest ICES assessments on Central Baltic and Gulf of Bothnia herring.

Central Baltic Herring

The main trends from the latest ICES assessment are shown below in Figure 1.1 taken from (ICES, 2023a). The following discription is for the WGBFAS report (ICES, 2023b).

- State of the adult biomass (SBB): Total spawning biomass of Central Baltic herring has declined from the beginning of the 1960s to a minimum in the beginning 2000s, thereafter it has slightly recovered but it declined again to below B_{lim} in the latest years. SSB has been below B_{MSY} trigger since 1985.
- State of exploitation (F): Fishing mortality is defined as the average F of age classes 3 to 6. F increased in the beginning of 1960s to reach a peak in year 2018. F then decreased to be below F_{MSY} in a few years, increased again to 2018, then to decrease to below F_{MSY} in 2022 ($F/F_{MSY} = 0.91$).
- State of the juveniles (Recr): Large year classes were observed in the 1980s. With the exception of the 2014-year class, recruitment has been low in the last decade. The historical decrease in SSB is believed to be partly caused by a shift in the fishing area from SD 25 and 26 to SD 28.2 and 29 where the average mean weight is lower. Holmgren *et al*. 2012 showed that with the current growth rate and continuous low cod abundance, the herring stock will not reach an equilibrium state until 2030. During the last years, the relative proportion of catches from SD 25 and SD 26 have varied, and since the mean weight-at-age also varies, being higher in SD 25 than in SD 26, the estimation of SSB will consequently be affected.

A major cause for decreasing trends in stock development is the drastic decrease in mean weight (size) at-age during the period of assessment (Figure 1.2). One of the reasons is that slow-growing herring, emanating from the north-eastern parts of the Baltic, has been dominating the catches over the recent years. These fish are also caught - outside the spawning time - in other parts of the Baltic, thereby decreasing the overall mean weights. However, mean weight decreased in all the areas of the Baltic Sea, likely indicating a real change in growth rate. Simultaneously, a decrease in body condition for herring was also observed, which was attributed to a decreased salinity (Möllmann *et al*., 2003; Rönkkönen *et al*., 2004; Casini *et al*., 2010) and increased competition with large sprat stock (Cardinale and Arrhenius, 2000; Casini *et al*., 2006; Casini *et al*., 2010), both factors decreasing the availability of the main prey of herring, the copepod Pseudocalanus spp.

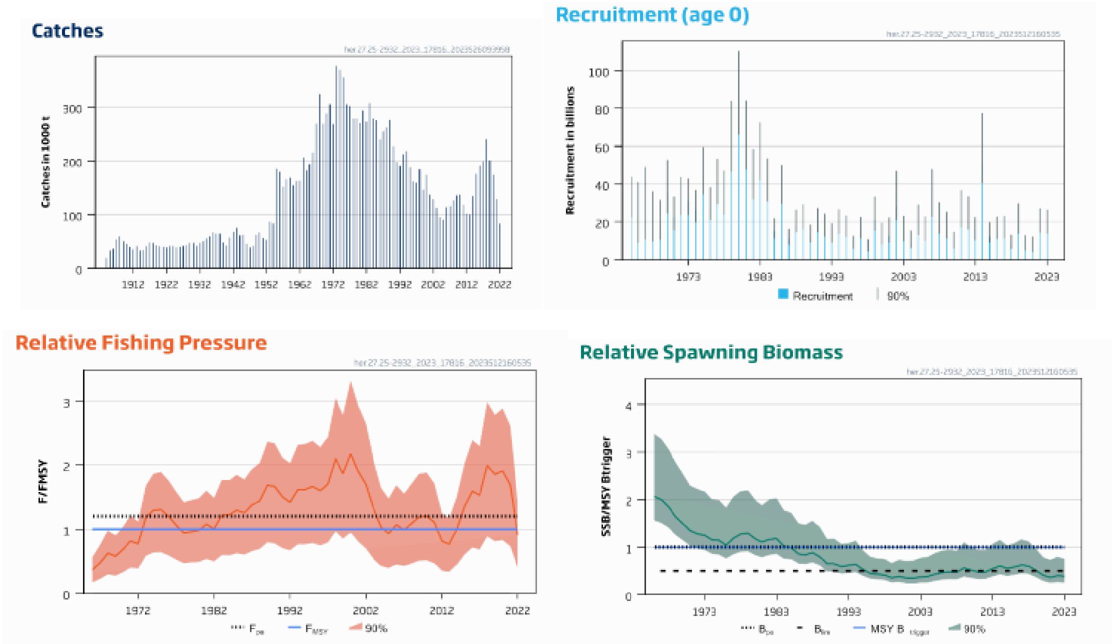

Figure 1.1 Herring in subdivisions 25–29 and 32, excluding the Gulf of Riga. Summary of the stock assessment. The full time series of Recruitment, Fishing Pressure and Spawning Stock Biomass are available in the working group report (Table 4.2.11, ICES, 2023a)

The mean weights-at-age were compiled by subdivision and quarter for 2022 and then combined to give the mean weight-at-age for the whole catch (Table 1.1). Weight-at-age data are only available from 1974 and onwards, and was for 1903-1973 assumed the same as 1973. The marked decrease in mean weights at age that started in the early 1980s ceased around the mid-1990s and remains at this low level. When a particularly strong year class occurs, like 2002, 2007, and 2014, or 2019, there may be density-dependent effects (Figure 1.2). The increased sprat stock size has most likely also contributed to the low herring weight-at-age during the past 25 years. A considerable increase in the mean weight at age in catch was observed in 2022 when compared to 2021. The mean weight at age 1 increased by 84%, while the mean weight at age in the older fish increased by 5-25%, bringing these values close to the 2012-2021 average.

The marked geographical differences in growth patterns are shown in Table 1.1(see also WKBALTPEL report ICES, 2023c). The mean weight is higher in subdivisions 25 and 26 than in the more northern subdivisions. As consequence, the observed variation in average weight (total catches in tonnes/total numbers) could be not only due to a real decrease in growth but also where the larger proportion of herring is caught. As in the years before, the mean weight in the catch was also used as the mean weight in the stock. Weight-at-age in the catch and in the stock generally shows a high correlation for herring (ICES, 2023b).

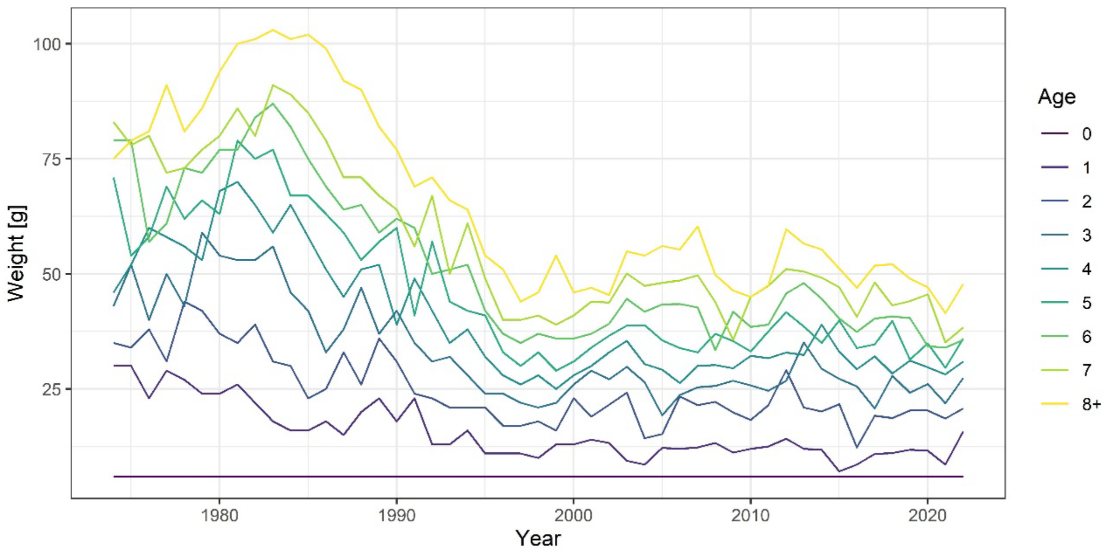

Figure 1.2 Herring in SD 25–29, 32 (excl. GoR). Trends in the mean weights at age (g) in the catch (WE-CA).

Table 1.1 Herring in SD 25–29, 32 (excl. GoR). Mean weight-at-age per SD and quarter in 2022. Mean weight (g).

Quarter:	1						
AGE	Mean	SD 25	SD 26	SD 27	SD 28.2	SD 29	SD 32
0	NA	NA	NA	NA	NA	NA	NA
1	9.5	18.7	13.8	15.6	5.1	5.1	5.4
2	16.8	23.8	33.0	17.0	17.5	12.2	12.5
3	24.3	27.1	35.8	22.1	23.4	19.7	18.3
4	29.0	29.9	35.1	24.2	26.8	23.3	25.0
5	32.7	36.7	41.5	27.1	29.8	24.4	24.2
6	32.1	36.7	44.2	27.8	33.0	28.5	26.2
7	36.6	42.2	45.9	29.1	32.1	27.6	25.3
8	47.3	49.2	48.8	39.7	39.5	37.5	54.6
9	50.9	177.0	60.5	NA	NA	31.0	30.4
10+	48.1	64.0	71.8	NA	49.5	36.1	34.4
Quarter:	**2**						
AGE	Mean	SD 25	SD 26	SD 27	SD 28.2	SD 29	SD 32
0	NA	NA	NA	NA	NA	NA	NA
1	9.6	23.4	15.9	5.7	8.8	5.8	6.4
2	14.9	34.4	21.8	13.0	14.7	13.0	13.3
3	24.1	42.4	36.9	21.2	22.1	18.3	17.7
4	26.2	44.8	35.0	24.8	26.7	23.0	20.6
5	33.0	47.7	40.3	26.8	29.0	27.3	23.5
6	34.1	47.0	39.2	28.3	31.7	28.6	23.3
7	35.0	43.7	43.1	30.0	31.3	34.1	23.5
8	42.8	49.4	47.9	46.1	34.3	49.9	24.4
9	56.8	68.3	62.5	63.0	37.0	NA	NA
10+	45.9	63.1	86.9	69.1	41.8	NA	33.0
Quarter:	**3**						
AGE	Mean	SD 25	SD 26	SD 27	SD 28.2	SD 29	SD 32
0	6.4	NA	18.8	6.0	6.0	6.0	3.9
1	32.0	39.5	31.5	18.5	17.9	14.4	13.8
2	32.3	49.6	42.0	23.3	22.6	18.8	18.7
3	35.1	47.1	44.3	25.4	26.5	21.2	20.7
4	36.9	45.5	40.6	29.7	30.4	24.5	22.8
5	41.4	48.5	44.9	32.6	34.5	25.0	24.5
6	42.5	42.5	46.5	35.7	33.1	NA	24.1
7	46.1	47.4	48.6	43.8	43.8	NA	23.4
8	49.3	60.4	50.7	45.4	35.5	29.2	39.0
9	49.3	48.9	63.0	23.3	23.3	NA	49.0
10+	67.6	62.8	76.5	NA	64.9	NA	46.1
Quarter:	**4**						
AGE	Mean	SD 25	SD 26	SD 27	SD 28.2	SD 29	SD 32
0	5.7	16.0	18.5	6.1	7.4	5.4	5.0
1	24.7	34.7	36.1	18.5	23.9	13.5	13.6
2	25.3	50.7	48.0	22.5	25.8	18.9	19.3
3	32.0	48.0	46.8	27.8	29.9	27.2	23.0
4	34.3	61.1	42.5	29.0	31.7	26.3	25.0
5	42.5	68.1	46.5	41.2	37.1	44.5	27.7
6	41.9	89.4	48.6	32.5	37.1	28.2	30.7
7	45.3	75.4	50.3	35.7	36.9	33.1	30.5
8	52.0	104.4	51.5	39.6	48.3	39.7	44.0
9	43.3	47.6	62.8	30.2	29.8	31.7	39.1
10+	75.3	107.4	75.9	30.3	30.3	30.3	NA

Gulf of Bothnia Herring

The main trends from the latest ICES assessment are shown below in Figure 1.3 taken from (ICES, 2023d). The following discription is for the WGBFAS report (ICES, 2023b).

Spawning stock biomass has an overall decreasing trend since 1994, corresponding to the increasing fishing mortality starting in the beginning in the 1990s and the low level of mean weight at age for the last 20 years (Figure 1.3). The further decrease in SSB in 2021-2023, to levels below $B_{trigger}$, is likely to be related to the downward revision of recruitment and stock numbers in 2021-2022, and the low weight-at-age of the larger herring in particular. Further, body condition of larger herring was record low in 2021. This in combination with lower proportion of older herring in the stock will likely result in remaining low catch rates for larger herring.

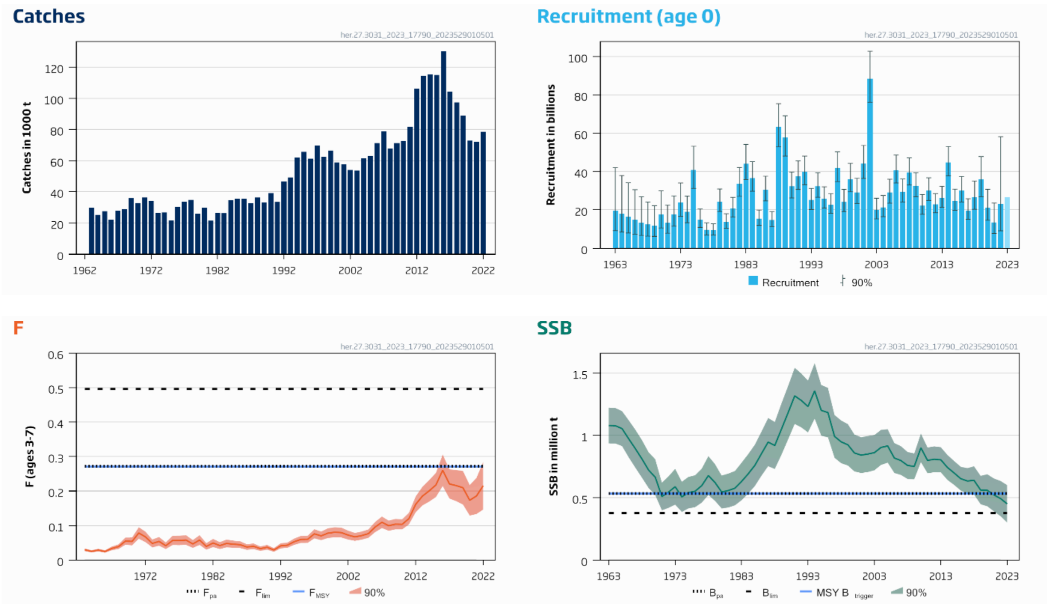

Figure 1.3 Herring in subdivisions 30 and 31. Summary of the stock assessment. The assumed recruitment value for 2023 is shaded in a lighter colour.

Mean weight at age

The average weight at age in age groups 2–10 started to decrease at the end of the 1980s after the large year class of 1988 and along with the regime shifts of the Gulf of Bothnia ecosystem (Figure 1.4; Kuosa *et al*. 2017), i.e. decreasing food resources and in addition, possible physical effects of decreasing salinity on herring. The growth rate of age groups ≤ 9 years of age slowed down at the change of the 1980's and 1990's, as with older herring this took place at the end of the 199's (Figure 1.4.b). Average weight at age was especially low in the first half of the 2000's. In age groups 2–10, average weight started a gradual, low increase In the latter half of the 2000's at the same time with increasing catches, and this increase was seen also in the older age groups in the first half of the 2010's (Figures 1.4a and 1.5). After 2014 weights at age were quite stable for all age-groups, however, in 2021 the mean weights decreased considerably in all age-groups except age 1 and 14. In 2022 the situation improved in many age-groups except in age-groups 2, 4, 9, 12 and 14.

Herring mean weight (age ≥ 5 years) was found to explain most of the variation in the birth rate of grey seal (*Halichoerus grypus*) in 2002–2015 by Kauhala *et al*. (2016), i.e. the best birth rates took place in the years of the highest herring mean weights despite decreasing herring SSB. Similarly, the subcutaneous blubber thickness of grey seals in 2003–2010 correlated positively with the mean weight of 5–6-year old herring. Grey seal blubber thickness correlated negatively with herring catch size, which suggests that herring quality, not quantity, is important for the nutritional status of Baltic grey seals (Kauhala *et al*. 2017).

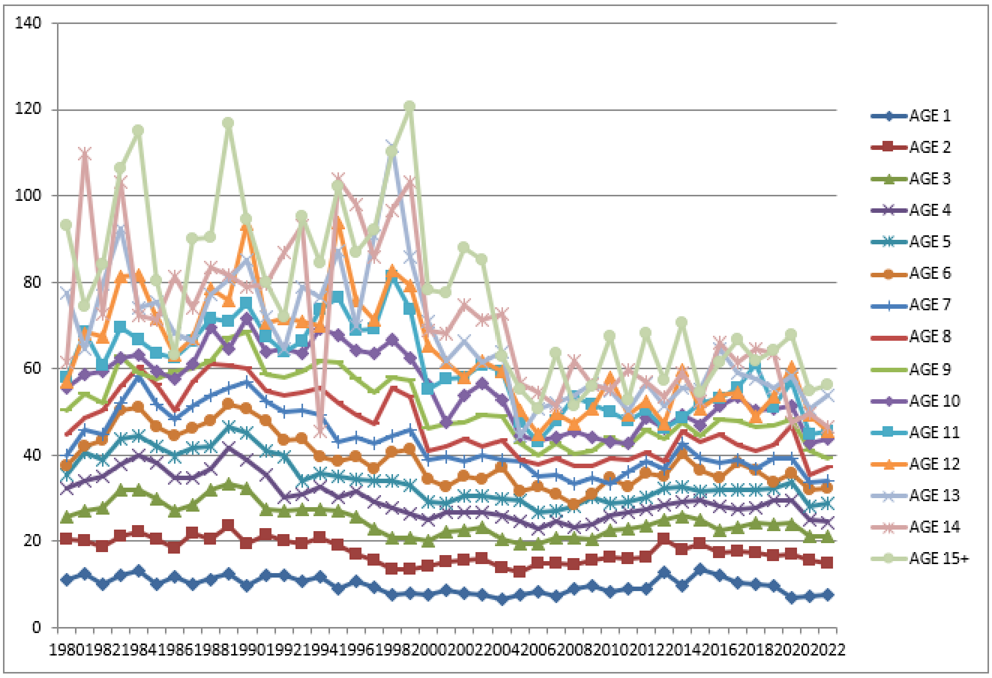

Figure 1.4 Herring in SD's 30 and 31. Mean weights at age in catches

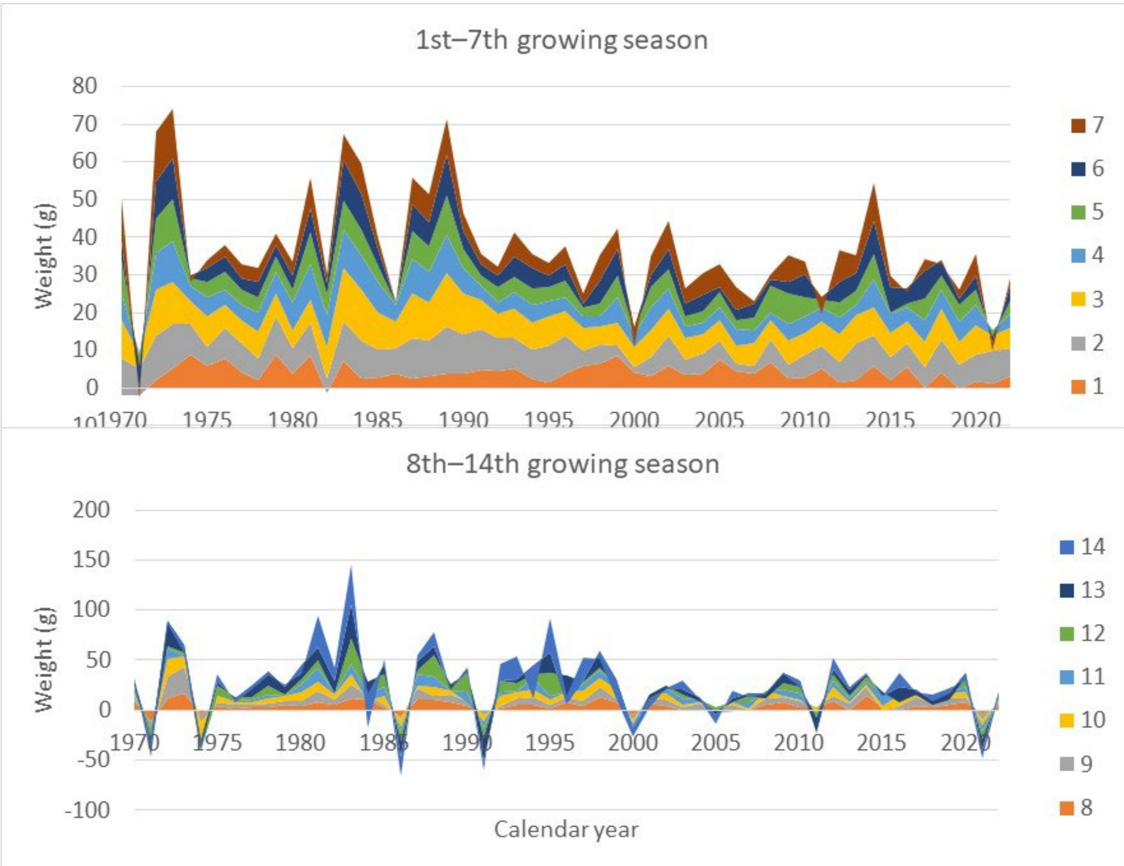

Figure 1.5 Herring in SD's 30 and 31. The mean weight change at age during each growing season.

According to samples from commercial fishery, mean Fulton's condition ($K = W/L^3$) of herring with total length of 9–14 cm in SD 30 was stable, mostly 0.48–0.67 at least from 1998 on until the half of 2010's, when it increased to 0.56–0.69, with highest values above 0.7 in 2022 (Figure 1.6).

In the BIAS trawl samples, condition has gradually increased since 2015 in small herring with total length of 10–12 cm, whereas in length groups 13–14 cm condition has been relatively stable. In larger herring, i.e. length groups 15–20 cm in the sample from 1998–2023 from commercial catches, the condition was especially low in 2004–2006 (data from 2008–2009 missing) and improved in the 2010's in the same time with increasing catches (Figure 1.1 and Figure 1.5). In both commercial and BIAS trawl samples the earlier stable condition decreased from above 0.60 in 2019 to below 0.6 in 2021, when the condition was close to the years 2004–2006. It started to increase again in 2022 (Figure 1.6 and Figure 1.7). According to samples from commercial fishery, the condition has continued to improve since the winter of 2022–2023 and was at the end of 2023 corresponding to the years of 2014–2020, in which the highest condition since 1998 has been observed (Figure 1.5). In data from age groups (not length groups), as low condition as that of 2021 in larger herring size groups has not been observed during the period of 1973–2022. Weight at age decreased from 2019 in almost all age groups, more in old than young herring (Figure 1.4).

The practical starving of larger herring may have been caused by several co-occurring phenomena: large crustaceans that are typical food for herring, amphipods, have not been abundant in recent decades (Henrik Nygård, pers.comm.), and mysids that were commonly seen in herring surveys some years ago and foraged by the herring were seen rarely in the survey of 2021, and they were not abundant in 2022, either. In the survey of 2023, mysids were seen often and were even abundant in some hauls. Improved herring condition from the winter of 2022–2023 on suggests a recovery in the food resources of herring.

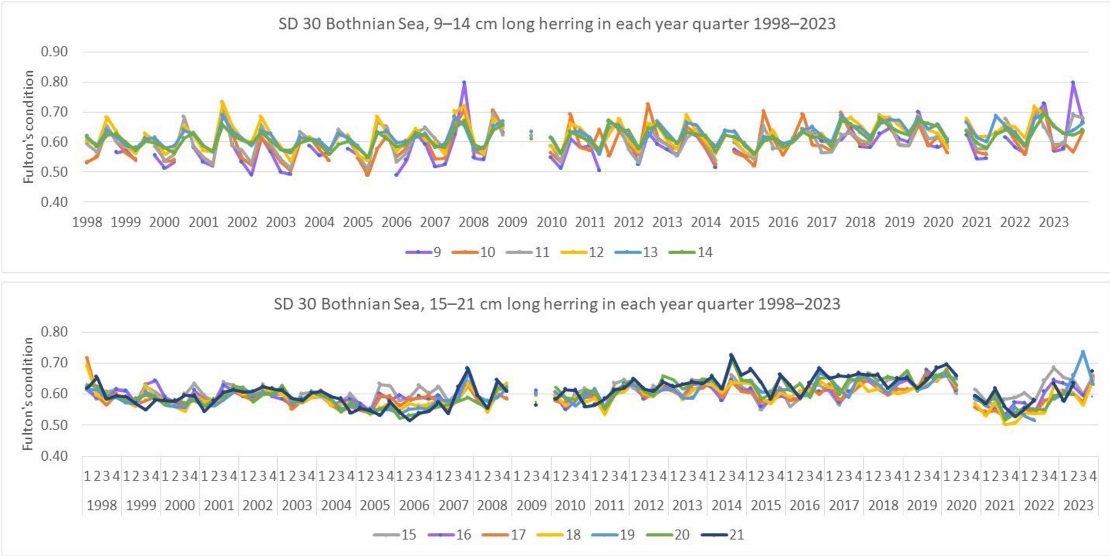

Figure 1.6 Herring in SD's 30 and 31. **Fulton's condition ($K = W/L^3$) of herring by year quarter in different length classes (total length) in commercial catches from SD 30 in 1998–2023.**

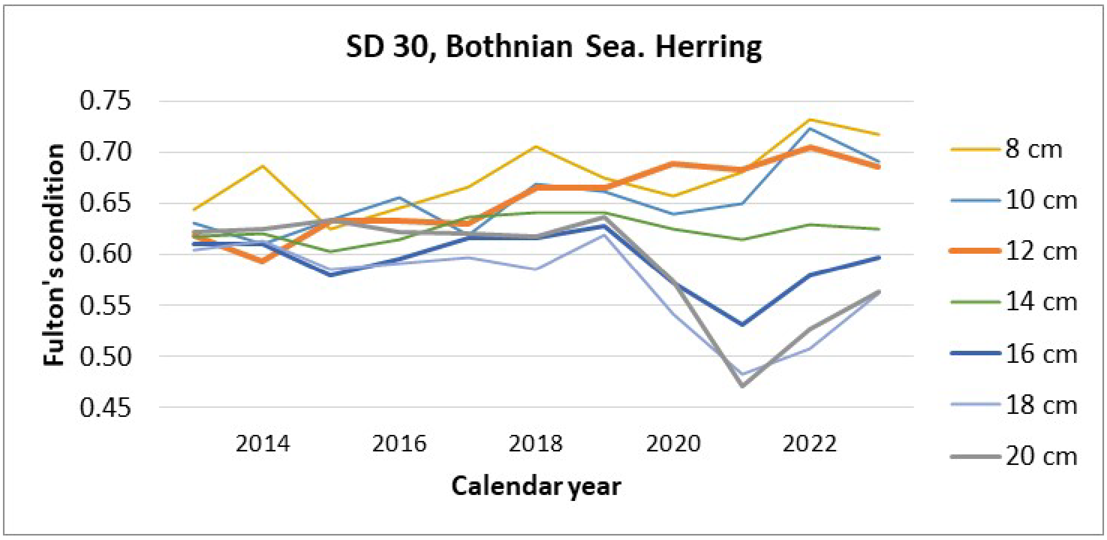

Figure 1.7 Herring in SD's 30 and 31. Fulton's condition (K = W/L3) of herring in different length classes (total length) in BIAS surveys in 2013–2023.*

1.3 Summary of the issue

Both stocks show similar long-term patterns with a significant decline in weight-at-age relative to historic levels. The timing of the decline is notably different between the two stocks with the decline in Central Baltic herring starting in the mid-1980s and lasting over a decade to the late 1990s. Whereas the decline in the Gulf of Bothnia started around 1990 and continued until the mid-2000s. Both stocks also show a similar sudden decline in weight-at-age in 2021 followed by a recovery in 2022. The reasons for these changes are likely to be multifactorial and while several possible causes have been suggested the relative contribution of these has not been established.

* Figure updated with 2023 data after the draft WKHERBAL report was sent for review.

The request requires ICES to develop a roadmap to investigate the cause and to explore possible management measures “to improve the condition of these stocks”.

2 Population structure of Baltic Herring

2.1 Historical perspective

Historically, in total, 9 local spring herring populations have been identified in the Baltic Sea (Ojaveer 1989, Figure 2.1). Five of these are gulf herring populations (of the Gulf of Riga, of the Gulf of Finland, of the Bothnian Bay, of the Bothnian Sea, and the Swedish fjord herring) and four are sea herring populations (of the Swedish east coast, of the east coast of the Northern and Central Baltic, coastal herring of the southern Baltic, and of the western Baltic) (Ojaveer 1989).

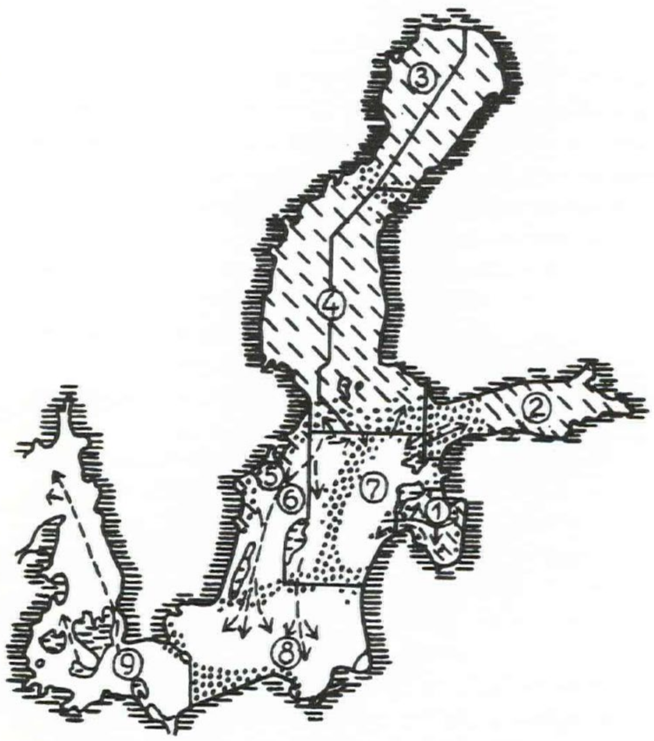

Figure 2. Scheme of areas and chief migrations of Baltic spring herring populations (after Popiel, 1958; Otterlind, 1962; Biester, 1979; Ojaveer *et al.*, 1982; Parmanne and Salmi, 1983). Gulf herring populations: 1 – of the Gulf of Riga; 2 – of the Gulf of Finland; 3 – of the Gulf of Bothnia; 4 – of the Bothnian Sea; 5 – the Swedish fjord herring. Sea herring populations: 6 – of the Swedish east coast; 7 – of the east coast of the Central and Northern Baltic; 8 – coastal herring of the Southern Baltic; 9 – of the Western Baltic. \\\\\ area of the gulf herring populations; ::::: transition zones between the populations; ←— spawning migrations; ← – prolonged feeding migrations; —— borders of herring assessment units of the ICES Working Group on Pelagic Stocks in the Baltic.

Figure 2.1 Extract from Ojaveer, 1989 and highlighting the 9 local spring herring populations in the Baltic.

Based on morphological features, growth patterns, abundance dynamics, and other characteristics in Baltic autumn herring, seven populations can be discerned - those of the Western Baltic, the Southern Baltic, the western part of the Central and Northern Baltic, the eastern part of the Central and Northern Baltic, the Gulf of Riga, the Gulf of Finland, and the Gulf of Bothnia (Ojaveer 1989).

One possible factor for the long-term changes in mean weight-at-age in Baltic herring could be changes in sub-stock compositions in the population and catches. Most of the historically distinguished herring sub-stock components differ in growth rate and mean weights at age. The gradual change in morphology and biological features is observed, including decreases in growth rates from south-western to north-eastern areas of the Baltic Sea (Ojaveer, 1989, Popiel, 1964). For example, clear differences in growth patterns and parameters of Von Bertalanffy's growth function have been demonstrated between herring northern components dominating in the central Baltic and herring spawning along the southern coast of the Baltic (ICES, 2018). Thus, changes in the percentage contribution of each component in the catches can affect the observed average weight at age.

However, in some herring specimens in the Bothnian Sea, retarding growth was observed during the regime shift at the end of the 1980’s. In a later examination of a small number of stained herring otolith slices from the Bothnian Sea from the beginning of the 1990’s, the growth was observed to have dropped at the end of the 1980’s. In some specimens, growth rate improved again after two years of poor or lacking growth (Figures 1.5, above), in some others, growth remained slow or ceased (Figure 2.2, below). In some aged specimens with already slow growth, no changes were observed. Both in otoliths from the 1980’s with good growth rate and in otoliths from later years with poorer growth, it seems that it has been usual that the specimens have grown some years well, then growth has slowed down or even ended completely (Figure 2.2; Raitaniemi, unpublished).

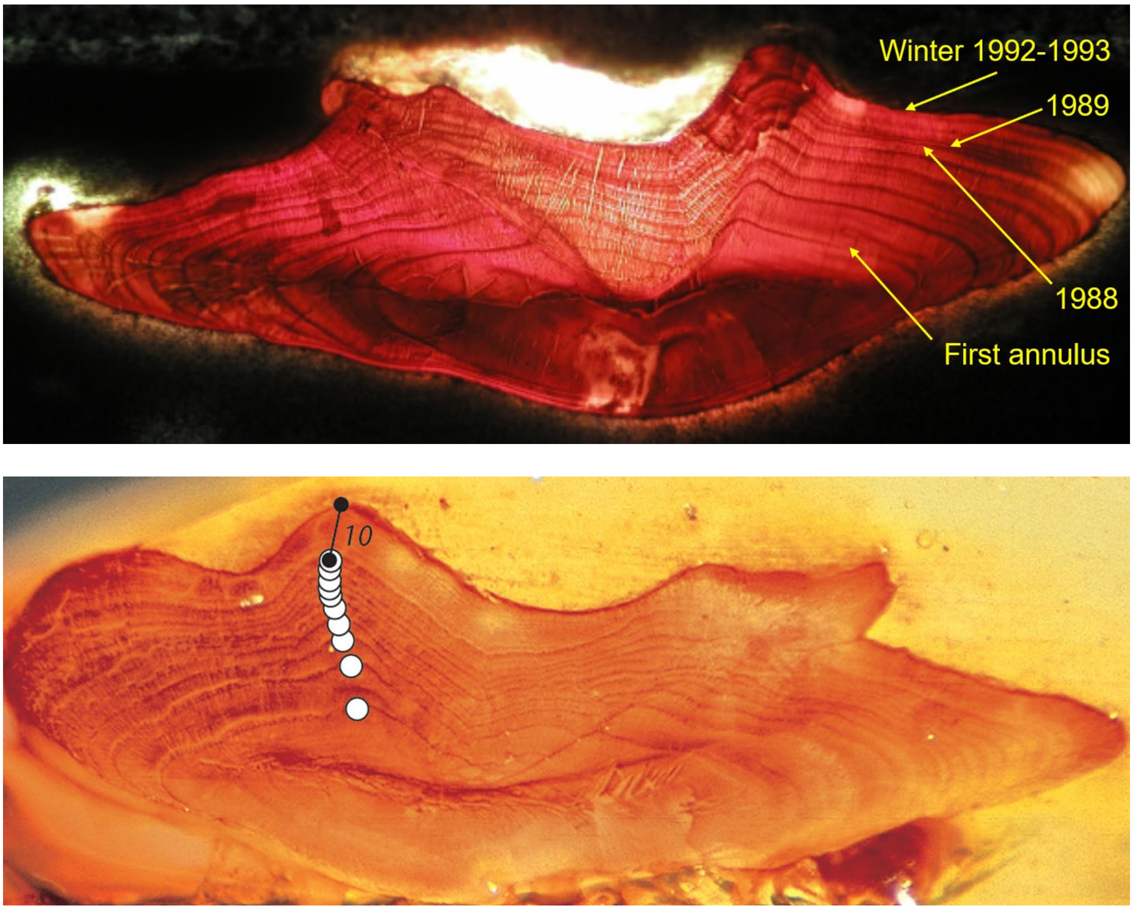

Figure 2.2 Herring in SD30 & 31. Stained otolith sections of herring from SD 30. Above: A specimen caught in the early 1990's. A slowing down of growth was observed afterwards in some examined otoliths in 1988 and 1989, when abundant herring year class appeared. Below: The otolith and determined annual rings of an old herring caught in 1999.

Autumn-spawning herring in the Baltic Sea are presently rare, compared with spring-spawners, and support no directed fisheries. However, they were formerly common or even dominant in the western Baltic–Rügen area, central Baltic Sea, and Gulf of Riga, and historically made an important contribution to the Baltic Sea herring landings (Parmanne *et al*., 1994). For example, they contributed over 90% of the landings from the central Baltic Sea in 1925–1927 (Hessle, 1931). A shift in the population structure of Baltic herring began in the 1960s, and since the early 1970s, spring spawners have dominated the whole Baltic (Rechlin 1991). In the Gulf of Riga herring the estimated exploitation pattern, including the exploitation of juveniles, was unsustainable and led to a sharp stock decline in the 1980s without any signs of recovery yet (MacKenzie and Ojaveer, 2018). Based on a multi-annual ichthyoplankton survey in the southern Baltic Sea (mainly Bornholm Basin) during 2002–2019, it can be concluded that autumn herring larvae were present in all sampled years (Ojaveer *et al*., under review) confirming that autumn herring is still present in the main basin (see also WKBALTPEL report, ICES 2023c).

Specific conservation measures related to the fishing closures in selected areas or periods can be proposed in order to mitigate risks caused by the fishing pressure on certain stock components. For example, reducing the exploitation of autumn spawning herring could be achieved by restricting fishing effort for spring-spawning herring to times and places where the chances of catching autumn-spawning herring are minimal. In addition, autumn spawning herring have been caught together with spring spawning herring, a selection of optimal mesh size used in spring-spawning herring fisheries in some seasons or areas could reduce the catch of juvenile autumn-spawning herring; this would allow more juveniles to survive and reproduce (MacKenzie and Ojaveer, 2018 and references therein).

There is an obvious need to obtain more information on all the sub-stock components of herring, including autumn spawning herring, which due to low numbers in recent years may be at greater risk from fishing pressure and ecosystem changes. Future investigations should include estimation of spatiotemporal dynamics of occurrence of autumn spawners in herring fisheries and identifying autumn herring larvae in ichthyoplankton samples.

2.2 New genetic evidence

Herring stock identification has been transformed in recent years particularly with the application of new genomic techniques in the Baltic Sea but also in the rest of the Northeast Atlantic. Different initiatives took place to identify herring stock components, the data and sampling needed for stock identification, as well as to develop methods for stock split. Some of this work took place via ICES working groups (e.g., HAWG, WGBFAS) and workshops, e.g., WKMIXHER (ICES 2018), WKSIDAC (ICES 2017), and WKSIDAC2 (ICES 2023e).

There is a need for a separate research project with the aim to clarify the stock structure of the central Baltic herring and Gulf of Bothnia herring, validate herring assessment units, and look for operational methods to separate different components in mixed catches. A general concept of the project and sampling design were presented in ICES (2018).

Stock mixing is already considered in the assessment and advice for North Sea autumn-spawner herring and western Baltic spring-spawner herring (ICES 2023f). Prior to 2022 for Denmark and Norway and prior to 2023 for Sweden, the split was following otolith microstructure and vertebrae counts methods. Since, genetics is used to inform stock split, however not all herring populations are considered and assumptions are taken for assigning other stocks (e.g., central Baltic herring, Baltic autumn spawner herring) to these two stocks, with the aim to follow the same assumptions as were used before genetic data was implemented (Berg *et al*. 2023). Stock splitting is also conducted in the Baltic International acoustic survey based on growth estimates to separate western Baltic spring spawner herring and central Baltic herring.

Recent progress has been made in building up a baseline for herring stock identification in the North Sea, West of Scotland, Irish Sea and Celtic Sea (Farrell *et al*. 2022), in the North Sea, and Baltic Sea (Bekkevold *et al*. 2023), in these areas and along the Norwegian coast (ICES 2023e), and along the eastern Swedish coast (Laikre and Johannesson 2023). The single nucleotide polymorphisms (SNPs) considered for each baseline can differ depending on the populations that are considered, but there is an ongoing interest in developing a universal genetic baseline for all the herring stocks and common genetic sampling strategies as the sampling can affect the predicted proportions of stock in the data (ICES 2023f). These aspects would be further discussed and developed at WKSIDAC 3 in June 2024, and at the follow-up workshops WKSIDAC4 2025 and WKSIDAC5 2026. These are described in detail including a roadmap in ICES (2023e). The progress in this regard will depend on resource availability at the national and international levels.

Some discussion currently exists in ICES on developing a database for genetic data. This is still in progress and currently unclear if this would be a separated database or submitted as part of RDBES.

Recent genetic studies have provided additional insightful information on herring genetic structure in the Northeast Atlantic, however it has been noted that in some regions, i.e., the south-east and eastern regions of Baltic Sea the information is incomplete. Further sampling and analyses need to be targeted at spawning populations for the identification and classification (sub)populations in the Baltic Sea. Recent genetic studies around the Swedish coast presented at WKHERBAL have identified the existence of a multitude of distinct populations.

Okamoto et. al 2020 found that spatial variation in exploited metapopulations obscures risk of collapse. In their study focused on Pacific herring they found that unanticipated declines among exploited species have commonly occurred despite harvests that appeared sustainable prior to collapse. This is particularly true in the oceans where spatial scales of management are often mismatched with spatially complex metapopulations. Harvesting metapopulations magnifies spatial variability, which creates discrepancies between regional and local trends while increasing risk of local population collapses. Importantly, Okamoto et. al 2020 show that dynamically optimizing harvest can minimize local risk without sacrificing yield. Thus, multiple nested scales of management may be necessary to avoid cryptic collapses in metapopulations and the ensuing ecological, social, and economic consequences.

Currently we lack the overview of the whole diversity of and spatial-temporal shifts in herring population structure in the Baltic Sea, however, this information is important for understanding the dynamics of the herring stocks. Recognising population diversity is central from a biodiversity perspective, and links to two main aspects: i) to understand how this population diversity plays in relation to the resilience of the species and the stocks, ii) to harmonize stock definitions and operational needs of fisheries management with the high population diversity revealed by the genetics (ICES 2023e). One central issue with moving forward with the work on identification of herring population diversity is the need for sustainable funding of genetic monitoring.

Below is a summary of data and development needs:

1. Improvement of local baselines
2. Extra sampling at spawning locations to inform baseline, notably in the south-east and eastern Baltic Sea
3. Development of a universal common baseline
4. Development of a common genetic sampling strategy
5. Development of an ICES database for genetic data
6. Development of methods to deal with stock split into the assessments.

Timeframe:

- Three WKSIDAC workshops are planned in 2024-2026. The roadmap from WKSIDAC 2 plans to tackle the data and development needs 1, 3-5 by 2026.
- Countries could agree to start collecting samples in the 2024 spring for baseline samples, even though specific countries might not have funding. Genetic samples can be worked up at a later stage when there is funding available, and this would speed up the whole process.
- Development of methods to deal with stock split into the assessments is a longer-term issue notably if the objective is to assess the stock at the (sub)population level as it potentially may involve different expert groups (e.g., HAWG, WGBFAS) and stocks (e.g., North Sea herring, western Baltic herring, central Baltic herring) that need to collaborate to maintain data consistency.
- The timeframe is highly dependent on resource availability, including funding.

Adequate spatiotemporal coverage of genetic sampling and monitoring is crucial for a better understanding of the stock structure and this needs to be an integral part of the data collection framework (DCF).

3 Identification of reasons for reduced condition size and age structure of central Baltic Sea herring and Gulf of Bothnia herring

Both central Baltic herring and Gulf of Bothnia herring show a decrease in condition, and a reduced size and age structure (ICES, 2023b). Changes in the condition (weight), size (length), and age structure may have different sources. The environmental impacts on the growth and age structure of different subcomponents can be different. It is important to note that research on growth factors may not be able to identify impacts if individual groups are not appropriately separated. Each component may, due to a different origin (hatching area) and place of residence later in life, be exposed to different environmental conditions. At the same time, there may be differences in the phenotypic plasticity and response to changes in environmental conditions between different components. These potential differences in the experienced environment and plasticity could potentially prevent or significantly complicate robust estimates of the environmental effects on the changes of biological parameters. For these reasons, discrimination of separate subcomponents of herring and, ideally, gathering information on the historical proportions of certain subcomponents with newly developed or available methods would be an important step forward.

Sprat and herring, two clupeid fish species, dominate the fish assemblage in the Baltic Sea (Margonski *et al*. 2010). The relatively simple food web of the Baltic, with a limited number of species, reinforces interspecific interactions between these two dominant species that are located at a similar trophic level. Consequently, competition between sprat and herring for scarce food resources (primarily zooplanktonic *Pseudocalanus* spp.) was thought to be one of the primary factors influencing herring growth (Cardinale and Arrhenius 2000; Rönkkönen *et al*. 2004; Casini *et al*. 2010; Lindegren *et al*. 2011). Furthermore, prior research has also demonstrated the importance of abiotic factors, such as temperature and salinity, for herring growth and population dynamics (Cardinale and Arrhenius 2000; Kornilovs *et al*. 2001; Casini *et al*. 2006; Margonski *et al*. 2010; Bartolino *et al*. 2014; Smoliński 2019a). For example, otolith biochronology developed based on the archival otoliths revealed that the interspecific competition between sprat and herring had a major impact on the growth of the northern component of the central Baltic herring (Smoliński 2019b). Also, it has been shown that specific regional precipitation patterns and hydrological conditions play a secondary role in these processes. However, as mentioned previously, the responses of herring to changes in environmental conditions probably differ between stocks and their components. Thus, further research should be encouraged aiming at distinguishing herring stock components and subsequently evaluating their specific responses to the environment.

WKHERBAL discussed the following knowledge and data gaps:

- Possible negative feedback loops of the fishery closures on the herring growth - through the increase in sprat abundance.
- Changes in the proportions of the sub-components as possible mechanisms in the observed alterations in growth/age structure.
- Zooplankton distribution and availability play an important role in the condition of herring. Zooplankton data should be included in further investigations.
- Data resources are available at the different institutes (short-term) should be investigated.

- Further, monitoring should be conducted on a regular basis (pilot projects could be used to investigate and design surveys).
- Research on diet preferences should be redone regularly.
- The feasibility of large-scale fat content measurements (by fish fatmeter) should be assessed.
- Interactions with sticklebacks that are potential prey for large herring and predators on herring eggs (Kotterba *et al.*, 2014; Olin *et al.*, 2022; Olsson *et al.*, 2019).

Table 3.1 Summary of factors affecting condition size and age structure of central Baltic Sea herring and Gulf of Bothnia herring

	Gulf of Bothnia herring	Central Baltic herring
Altered age structure	increased F in the early 2010s	-effects of fishing pressure -changes in the proportions of populations in the stock
Reduced size	- regime shift at the end of the 1980s (ages 1-3) - decreasing size of phytoplankton and zooplankton species - changes in zooplankton community due to lower salinity - density dependence (ages 1-4)	-changes in the proportions of populations in the stock and/or changes in the proportions of fast and slow-growing individuals within the same population (Rosa Lee effect) - competition with sprat -food availability (including Mysidae and *Pseudocalanus*) - abiotic factors
Variations in condition	- food availability, specifically the large bodied *Limnocalanus macrurus*, Mysidae and *Pseudocalanus*. Missing mysids likely explain the drop observed in 2021, on ages 3 and older - density dependence (ages 1-5 in the 2010s, ages 6 and older in the 1990s)	- competition with sprat -food availability (including Mysidae and *Pseudocalanus*) - abiotic factors

Importance of Mysidae monitoring

A decrease in herring condition has been observed to follow the collapse of mysids on some occasions in both SD 30 (2021–2022), and SD 29 and SD 32 (at the beginning of the 1990s). The changed mysid densities could explain some of the sudden changes in herring condition. *Mysis mixta* has been monitored for a limited time period in the southern Baltic Sea (Margonski and Maciejewska, 1999). In the Bothnian Sea and northernmost SD 29 and SD32, an index level monitoring of mysids (index 0–4) in BIAS surveys from each haul sample was started in 2022. Experiments to assess the numbers with acoustic equipment during the same surveys have been started. There is a need to go further with these experiments and implement regular monitoring.

Available data:

- Commercial catches (including information from scientific sampling)
- Metadata on zooplankton (University of Tartu)
- Acoustic estimates of the sprat and herring abundance (limited spatially and temporal) including biotic fish information (BIAS survey)
- Abiotic and biotic (phyto- and zooplankton, benthic animals) data from sampling stations in the Gulf of Bothnia (The Finnish Environment Institute)

Necessary data:

- genetic assignment of herring populations in survey and commercial catches
- parallel tests of other (non-genetic) methods' applicability to discriminate certain herring stock components (ICES 2018, WKMIXHER report: Table 2.1)
- establishing regular monitoring of mysids in the Baltic Sea
- stomach content of herring and the analysis of diet preference, food selectivity. etc.
- monitoring of herring fat content (depending on feasibility) and analysis of its temporal, spatial and age-specific variability
- information on the spatial and temporal distribution pattern and abundance of stickle-backs.

Ongoing analysis:

- changes in weight-at-age (Smolinski *et al*., in prep and WKPALTBEL Report (ICES 2023c))
- changes in growth (SLU, Masnadi *et al*., in prep)
- the prey of herring in SD 30 (Luke and University of Turku 2023–2024).

Necessary analysis:

- spatio-temporal modeling of overlap between sprat and herring as well as stickleback and herring at different age groups start as descriptive analysis.
- broad analysis of food availability and utilization by herring at different age groups.

4 National Research initiatives relevant to the roadmap

Swedish Research Project based on a government commission

The project is part of a Swedish government commission to the Swedish Agency for Marine and Water Management (SwAM) and will be conducted between 2022 and 2027. The commission involves to conduct a fixed-term scientific project that corresponds to a relocation of the trawl border for vessels that fish for pelagic species in the Baltic Sea, with for the purpose of evaluating the effects on the biomass of the Baltic herring population, as well as its size, population and age structure. The project will evaluate how development of the herring is affected by other environmental factors, as well as predation from fish, birds and seals and investigate how closures may have effects on other parts of the ecosystem. Socioeconomics effects on the fishery and processing industry will also be analysed.

The project is to be carried out in several areas within the management areas for herring in the central Baltic Sea and the Gulf of Bothnia. The project should include those vessels, regardless of flag, that have fishing rights in the areas. Consultation on which areas shall be closed is about to take place with relevant EU member states (primarily Finland and Denmark), the EU Commission and relevant stakeholders. Within each trial area, the authority may allow some professional fishing to be conducted for trial activities, small-scale fishing and fishing that is conducted with local and regional importance and fish for use as food. However, only under the condition that the purpose of the scientific project is not opposed.

A draft plan including monitoring, data analyses and modelling has been suggested by SLU Aqua to follow up on potential effects of closed areas. The program includes 6 work packages (wp) of monitoring and analyses:

1. Abiotic information

In this wp analyses of the extent to which the development of the herring is affected by abiotic vs biotic factors will be conducted.

2. Pelagic fish (herring, sprat and stickleback)

This work package aims at monitoring spatiotemporal changes in the abundance, size and age distribution, body growth, condition, diet, and maturity of herring, sprat and stickleback during spawning, wintering and pre-spawning, inside and outside the extended trawl border and new closed areas.

3. Genetics and otolith chemistry

The combination of genetics and otolith chemistry is an approach that gives the opportunity to study population structure at one point in time (genetics) and also migration patterns and habitat choice over an extended period of time (otolith chemistry). Together, the methods have the potential to describe and explain stock structure, which is crucial background information for designing fisheries regulations.

4. Pelagic fisheries

A change in the spatial fishing patterns will, most likely lead to a shift in fishing effort so that other areas will be more heavily exploited than they used to be. This could imply that the fishery would be associated with other types and volumes of bycatches, exploit different size classes and other subpopulations of herring compared to the case with business-as-usual fishing patterns. In this wp we will monitor all major fisheries in the management area with a high spatial and temporal resolution.

5. Seals and cormorants

The purpose of this wp is to assess responses in top predator ecology, as a consequence of reduced fishing pressure and to estimate fish removal by seals and cormorants in fishery-regulated areas.

6. Other ecosystem effects

To evaluate ecosystem effects of an extension of the trawl border, we suggest three different studies, one focusing on the coastal ecosystem, one on the offshore ecosystem and one connecting these. The coastal ecosystem study involves a large field survey, combined with statistical modelling to estimate the indirect effects on coastal predatory fish and growth of filamentous algae. The offshore ecosystem study will assess changes in the ecosystem over longer time scales and potential drivers in an integrated trend analysis of already existing data. Finally, we suggest applying a coupled coastal-open sea ecosystem model to study the effects of a lower fishing pressure on herring in the Bothnian Sea.

All these three studies would be performed in collaboration with ongoing projects, thus benefiting from existing data collection and compilation efforts, as well as ongoing development of modelling methods.

Project PopHerr – Population composition of the herring stock in the southern Baltic Sea (Poland)

This project is led by Prof. Magdalena Podolska and is taking place from 2022-2024. The aim of the project was to collect the data for research on the population composition of herrings and to determine this composition using statistical methods (growth parameters, morphometry, otolith shape), genetic, and chemical methods (protein and fat content, microchemistry). Results of the pilot study showed the applicability of otolith NIR spectroscopy in distinguishing between CBSC and CBNC. Compilation and analysis of data on otolith morphology (Fourier analysis) and body morphology (landmarks geometric morphometry) is in progress.

5 The development of a simulation model(s) to analyse the impact of different conservation measures.

The requirements specified in the request would likely involve modelling and simulations using a number of different tools. An indicative list of models and their suitability to address the requirements outlined in the roadmap are provided in Table 5.1. The expert knowledge of several of the models was lacking at the meeting further scoping would be needed with relevant experts. WKHERBAL concluded that there would be trade-offs across multiple dimensions including; time required to set up, complexity of the models, input data requirements, assumptions needed, expert resources need, understanding/acceptance of the outputs. These are discussed further below.

Table 5.1 Simulation models available and their suitability to address the requirements identified in the roadmap.

Simulation Models	F Scenarios	Spatial closures	Temporal closures	Combined spatial (area) and temporal closures	MFSD descriptors	Advice on gear modifications
SS3 Simulations	✔	✗	✗	✗	(✓)	✔
Stock based –– Spaito temporal models	✔	✓	✓	✓	(✓)	✓
Displace MSE	✓	✔	✔	✔	(✓)	✔
Mixed fisheries models	✓	(✓)	(✓)	(✓)	(✓)	✓
Multispecies SMS	✔	✗	✗	✗	✓	✗
Ecopath with Ecosim and Ecospace (EwE)	✓	✓	✓	✓	✔	(✓)
Atlantis	✔	?	?	?	✔	?

✔ – Very suitable

✓ – Suitable with some adaptation

(✓) – Suitable with major adaptation

? – Unknow suitability

✗ - Probably not suitable

SS3 Simulations

The current assessment model can be used to test changes in levels of fishing mortality. Changes in fishery selection can also be simulated assuming that these can be estimated and parameterised in the model. The main developmental work involves using the current age-based SS3 assessment model for the Gulf of Bothnia herring (ICES 2023d), SLU Aqua has performed a preliminary analysis of (*i*) the historical development, and (*ii*) the effects of future different exploitation (F) levels on the age-structure of the stock. Historically, the proportion of age-5+ number of individuals and biomass in the stock has varied considerably, due to for example the influence of particularly strong year classes. The mean proportion for the last 8 years however, has been significantly lower compared to the mean of the previous years of the time-series (Figure 5.1), in part likely explained by a period of high fishing mortality starting around 5 years earlier (ICES 2023b). Further, the analysis shows a clear effect of future different exploitation levels on the age-structure of the stock at equilibrium, given the assumptions of the forward projections (e.g., a constant environment, constant maturity- and weight-at-age and a BH stock-recruitment relationship). Increased fishing mortality results in decreased future proportion of age-5+ number of individuals and biomass in the stock, whereas decreased fishing mortality shows the opposite pattern (Figure 5.1).

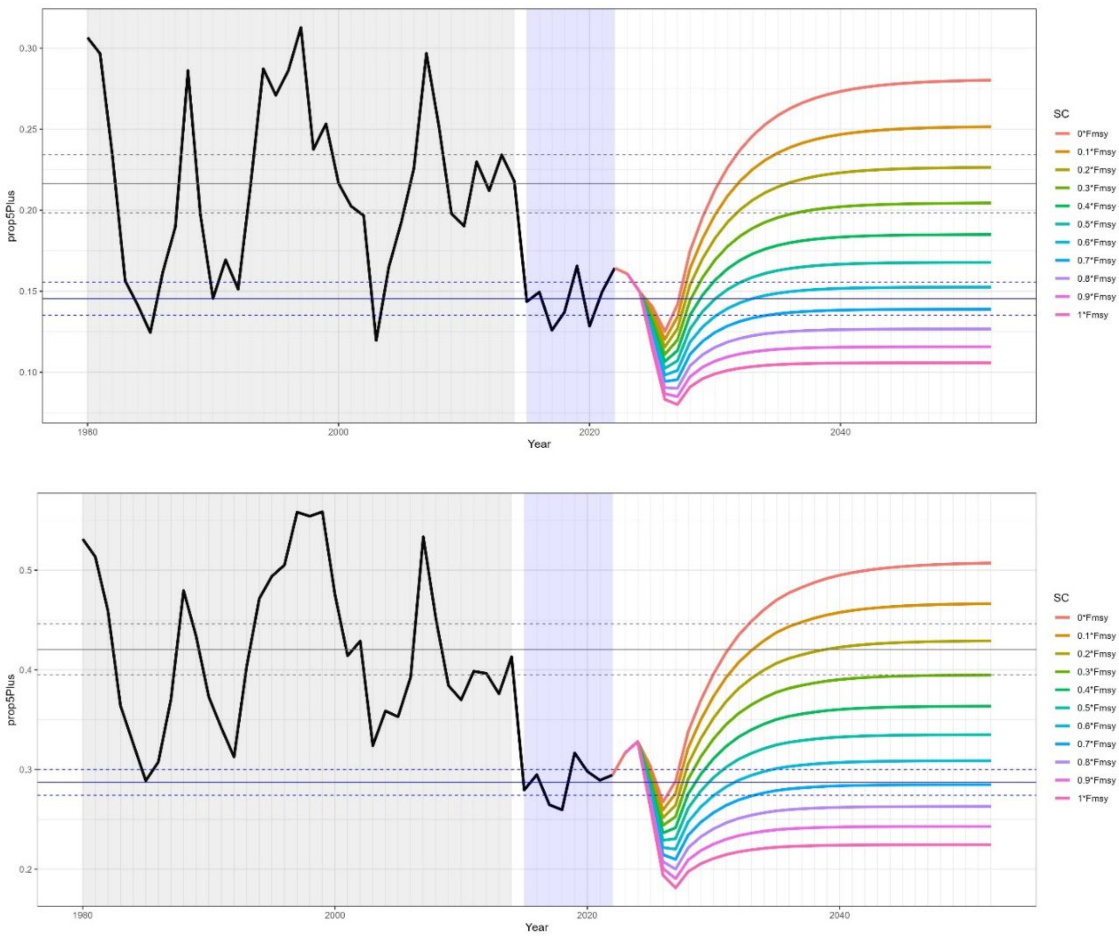

Figure 5.1 Changes in the proportion of numbers (upper panel) and biomass (lower panel) of age 5+ individuals in the her.27.30-31 stock over time, historically (black line; years 1980-2022) and at different future fishing mortalities (fractions of F_{MSY}, coloured lines; years 2023-2052). Shaded areas with corresponding horizontal lines highlight two historical periods with significantly different mean proportions (grey high; blue low; solid and dashed horizontal lines showing

means and 95% CIs). Proportions are based on assessment model estimates of the number of individuals and biomass per age-class and year.

The SLU Aqua analysis briefly described above is only investigating age-structural changes in the stock, as the current GoB herring assessment model is age-based. To investigate questions regarding size-structure (including analyses of, e.g., effects of different future exploitation levels or other conservation measures on the biomass of fish larger than 18 cm, or changes in the mean length of the 5% largest individuals [$L_{max5\%}$]), the current assessment model would have to be extended to also include length-at-age and weight-at-length data. This type of data is available; it has however not been collated into a single data set having the format required by the SS3 modelling framework. Once the age-length-weight data is collated and reformatted, the SS3 assessment model can be extended (and benchmarked) to an age- and length-based model where modelled number of individuals belong to both an age- and a length-class, and periods of different herring growth are represented by time-blocks with different growth parameters.

Similar adaptations could be made to the extended EqSIM tool developed for WKREBUILD2 but given that the assessment modelling framework is already suitable to carry out F and selectivity simulations WKHERBAL concluded that there was little value in exploring this option further.

Stock based - Spatio temporal models

An emerging goal from the last benchmark meeting for Central Baltic herring was to develop a spatially structured length- and age-based stock assessment model (See section 2.7 of ICES, 2023c). The roadmap for future work on the stock assessment model is closely connected and potentially synergistic with the roadmap required to answer this special request. If developed the assessment model could be extended to include spatial and temporal simulations of different management measures. The timeframe for development of this model is around 4 years at current resourcing levels. WKHERBAL concluded that if sufficient underpinning spatial data needed could be provided, this type of approach could lead to the most informative stock specific simulation tool.

Species Distribution Models and Displace MSE

The DISPLACE model developed by Bastardie *et al* 2014 is a dynamic, individual-based model for spatial fishing planning and effort displacement integrating underlying fish population models. Rufener *et al.* (2023) recently applied a Species Distribution Model (SDM) to Western Baltic Cod integrating commercial fishery and research survey data on a 15-year time series to design multiple alternative spatial closures, all based on identifying persistent essential fish habitats (i.e., nursery, spawning, and feeding grounds). They further used the spatial-explicit Management Strategy Evaluation (MSE) tool DISPLACE to contrast the outcomes of these fishing closures, and identify which provided the optimal balance between socio-economic and biological demands and sustainability. The analysis included changes in size composition of the population in year 5 and 10 of the simulation. This approach could be potentially be developed and used to test the proposed spatial and temporal closures for Baltic herring stocks. It may require a dedicated project and resourcing as was the case for the cod study.

Mixed fisheries

WKHERBAL considered the current Fcube mixed fisheries model would likely not be that informative to test the various management measures suggested in the Roadmap but other mixed fish could be developed (e.g. FLBEIA).

Multispecies SMS

The Multispecies SMS model is an established and reviewed model that has previously been applied in the Baltic Sea to provide inputs for assessments of commercially exploited stocks including Baltic sprat and herring (ICES, 2023b). The modelling framework is described in Lewy and Vinther (2004). A full description of the model inputs, outputs and review of the latest key run is available in ICES 2023f. It could be possible to extend this modelling framework to simulate multispecies stock dynamics under a range of F scenarios and this could in turn inform MFSD foodweb descriptors.

Gadget (Baltic Sea; Gulf of Bothnia)

Gadget is a platform to run statistical models of marine ecosystems consisting of a limited number of species, accounting for biological processes, such as maturation, growth, predation, etc. (see Bauer *et al* 2019). The Gadget implementation in the Baltic is a multispecies and multifleet model. Trophic interactions are represented by cod feeding on both herring and sprat, as well as on benthic prey. The model is age-length structured with quarterly time steps running from 1974 to 2013. WKHERBAL were aware that a Gadget models have been developed for both the Baltic Sea and Gulf of Bothnia but did not have further details on it applicability to the management questions in the roadmap, The utility of this framework should be explored further in the roadmap.

Ecopath with Ecosim and Ecospace (EwE)

Keramidas *et al.* (2023) reviewed of Ecopath with Ecosim models in European marine ecosystems including the Baltic. Ecopath with Ecosim (EwE: Polovina, 1984; Christensen and Walters, 2004a) is the most widely used software tool for modelling marine food webs. It is suitable for examining the impacts of human and environmental stressors on the food web. It is based on three main componets: i) the static depiction of a food web in a mass-balanced state over a specific time period (Ecopath), ii) uses differential equations for time simulations (Ecosim: Walters *et al.*, 1997) and iii) spatially resolved Ecospace (Walters *et al*. 1999) with Spatio-Temporal simulations (Steenbeek *et al.* 2013). Several EwE models have been developed in this area for different time periods and spatial scales, including i) Ecopath for Baltic and costal Baltic ecosystems (Sandberg *et al.*, 2000; Tomczak *et al.*, 2009), ii) Ecosim (Harvey *et al.*, 2003; Tomczak *et al.*, 2012;) and been used to investigate food-web dynamics questions (Österblom *et al.*, 2007, Tomczak *et al.*, 2013); Niiranen *et al.*, 2013; Costalago *et al.*, 2019) . Spatial dynamic model Ecospace was developed by (Bauer *et al.*, 2018; Bauer *et al.*, 2019). The model developed by Bauer *et al*. (2018 and 2019) focuses on the combined impact of fishing, eutrophication and climate change on the food webs. Bauer *et al*. (2019) developed numerical simulations of potential future ecological states of the Baltic Sea ecosystem at the end of century under five Share Socioecological Pathways using a spatial food web (Ecospace) model, forced by a downscaled physical–biogeochemical RCO-SCOBI model. Korpinen *et al* (2022) reviewed and assess the current status of food web indicators and food web models, and discuss whether the models can help addressing current shortcomings of indicator-based food web assessments for the MSFD, using the Baltic Sea as an example region, suggesting EwE models as a useful tool. Current development of the Central Baltic EwE model by Bauer at al. (2018) is further developed at SLU-Aqua under Future Mares EU project and focuses on testing Natural-based solutions as i.e Marine Protected Areas and Fishing closures under fishing and eutrophication management regimes with climate change. Model for Baltic Sea covering whole Baltic Sea (SD 22-32 ex GoR) to address cumulative pressures and MSFD are under development (Tomczak, Kulatsa *et al*. in prep). Recently, EwE model for Kattegat (Spatio-dynamic Ecospace) was developed by Dr. Tomczak and used to investigate management scenarios (Olsen *et al.*, 2023) and MSFD D4 and OSPAR FW9 indices under climate, eutrophication and fishing scenarios (Tomczak *et al*, in prep). Regional EwE model of the western Baltic Sea was constructed to assess the impact that alternative fisheries management strategies have on the status of commercial stocks, diversity of top predators and fishing yield (Scotti *et al.*, 2022a). That study found that the EBFM scenario (fishing at 50% of F_{MSY} for forage fish) allows rebuilding of the harbour porpoise population and the recovery of all stocks except flatfish, with strongly increased catches well above the present levels for cod and herring.

Because EwE approach is applied more often in the policy, advice and management frameworks (Karp *et al*., 2023) i.e in fisheries (Howell *et al*. 2021, Chagaris *et al*., 2020) or environmental management (Piroddi *et al*. 2021) ecosystem models as EwE requires model validation together with analyses of model uncertainties. Introduction of Ecosampler module (Steenbeek *et al*., 2013) allow to measure the impact of input parameter sensitivity on EwE results. Niiranen *et al*. (2012) carried out a simplified model uncertainty and sensitivity analysis on an Ecopath with Ecosim food-web model of the Central Baltic Sea (Tomczak *et al*., 2012) and found the model sensitive to both variations in the input data of pre-identified key groups and environmental forcing. Recently Bentley at al. (2024) present good practice of calibrating of EwE if applied in the operational capacity and advice framework. This suggest the substantial development in operational use of complex ecosystem models and availability or relevant tools at the Baltic sea, but still there is a need for careful development, testing and applied for good practise of such models if applied for advice framework.

Atlantis

Bossier *et al.* 2018 developed a calibrated Baltic Atlantis model and an integrated end-to-end modelling framework to examine ecosystem-wide responses under scenarios of human-induced changes in the Kattegat, Western Baltic Sea and southern Baltic proper regions with a focus on eutrophication, nutrient load reductions, and sensitivity to fishing pressure and climate factors. This model has the potential to address the MSFD descriptors and impacts of change of fishing pressures on different functional groups. The model also includes a spatial structure that might be able to test spatial management scenarios. As with other end-to-end ecosystem models Atlantis is complex and would require extensive calibration and testing before relevant results for the roadmap could be derived.

Selectivity changes

WKHERBAL discussed in detail the impacts gear modifications on pelagic fisheries in the Baltic and the request to "indicate any potential of the current technical rules to impact the observed change in individual size and condition of the herring stocks". On one hand STECF EWG 15-01 consider that the use of gear based technical measures for the size selection of small pelagic species are unlikely to offer an effective means of adjusting the exploitation pattern. This is on the basis that there is some doubt whether many of the fish escaping from trawls through selectivity devices survive (Suuronen *et al*. 1996. Tenningen *et al*. 2021). Therefore, the use of size selective gears may simply transfer fishing mortality from the discard fraction to the escapee fraction. Another important aspect is that this hidden mortality is also a fish welfare issue that calls for more scientific and management focus (Anders *et al*. 2019). Thus, like the conclusion by STECF 15-05 and based on the apparent high rates of post escape mortality, WKERBAL concluded that it was probably not a high priority to explore this further unless a more detailed review of the role of technical measures in pelagic fisheries is available.

6 RoadMap

WKHERBAL identified several short-term actions that were either ongoing or could be carried out within one year of the roadmap by setting up mechanisms for the collection and delivery of data. Some of these actions will need resourcing but the expertise is generally available. The medium-term actions will likely require some scoping, project development and dedicated resourcing to achieve them.

Short-term actions (Year 1)

- Population Simulations with varying F scenario reductions (evidence need 1) could be carried out within a year using modified SS3 stochastic projection. There are no specific additional data needs and the expertise is readily available.
- The roadmap to develop a spatially structured length- and age-based stock assessment model for Central Baltic Herring as set out in section 2.7 of WKBBALTPEL report (ICES, 2023c). To be progressed higher spatial resolution sampling data is needed. This could become available through the RDBES see below. The expertise is readily available, but some resourcing would be required to get this done within 1 year.
- Stock coordinators are transitioning towards using the RDBES for data compilation and analysis since this will have increased spatial and temporal resolution of sampling, catch and effort data. While the expertise is available this need to be adequately resourced.
- A modelling framework to address evidence needs 2-4 around spatial and temporal simulation models needs to be scoped out and decided. Based on WKHERBAL investigations the DISPLACE MSE looks like a promising method. The relevant expertise was not available at WKHERBAL to scope this out further and dedicated resources would be required to plan and execute a project around this.
- Similarly, it was only possible to identifying the possible ecosystem models relevant to address evidence need 2,3,4 and 6. Further work is needed to describe the data resourcing requirements and to identify the most appropriate models. This could be done in year one within a dedicated Workshop.
- Section 2.2 above sets how new genetic information should be collected. In year one WKHERBAL recommends the establishment of a coordinated herring genetic sampling to identify sub-stock structure in catches and surveys across the entire area.
- Analysis of changes in weight-at-age were carried out a part of the recent benchmark (Smolinski *et al.*, in prep and WKBBALTPEL Report (ICES 2023c). This work should be continued and the expertise is available.
- Similarly changes in growth have been investigated by SLU (Masnadi *et al.*, in prep). This work should be continued and the expertise is available.
- Work is ongoing on the prey of herring in SD 30 (Luke and University of Turku 2023–2024). This work should be continued and the expertise is available.
- An update of the Baltic Ecosystem overview is planned by ICES for 2024. This work should be continued and the expertise is available.

Medium-term actions (1-3 years)

- DISPLACE model or similar models to investigate potential spatio-temporal closures would need to be co-developed with managers and stakeholders. For this to happen a dedicated project with funding and clear timelines could be developed. The outputs from such a project could feed into ICES review and advisory process.
- Appling ecosystem models such as EwE, GADGET, Atlantis etc. (or an ensemble of models) should be developed to investigate MSFD indicators. For example, applying spatio-

temporal modelling (EwE) of overlap between sprat and herring as well as stickleback and herring at different size groups to be carried out to investigate intraspecies competition. Apply Spatio-temporal modeling (EwE) investigate food-web effect of potential spatio-temporal closures to be co-developed with managers and stakeholders.

- A regular mysids sampling throughout the survey area should be initiated.
- New monitoring data on stomach content of herring, together with the analysis of diet preference and food selectivity should also be carried out.
- The feasibility of large-scale fat content measurements (by fish fatmeter) should be assessed.
- Monitoring of spatiotemporal changes in the abundance, size and age distribution, body growth, condition, diet, and maturity of herring, sprat and stickleback during spawning, wintering and pre-spawning, inside and outside the extended trawl border and new closed areas in Sweden.
- Monitor all major fisheries in the Swedish management area with a high spatial and temporal resolution.
- The roadmap from WKSIDAC 2 plans to tackle the data and development needs 1, 3-5 by 2026.

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Annex 2: Agenda WKHERBAL

09:30 (CET) – 17:00 on the 29th and 30th

Wed 29th

9:30 Welcome, Code of Conduct and Conflict of Interest, round table.

10:00 – 11:15 – Size and condition changes

- Including older fish in fisheries management: A new age-based indicator and reference point for exploited fish stocks (Max Cardinale)
- Drivers affecting abundance and individual growth of age-1 Gulf of Riga spring herring (Henn Ojaveer)
- Gulf of Bothnia herring; Survey Results, condition and food web changes since the 1980s (Jari Raitaniemi)
- The effects of different fishing pressure on herring age-structure in the Gulf of Bothnia (David Gilljam)

11:15-11:30 Break

11:30-12:20 Stock Structure

- Latest results from our analyses on genetic differentiation in Baltic Sea herring (Lovisa Wennerström)
- Short summary of the Report of the workshop on the mixing of western and central Baltic herring stocks (WKMixHER). Szymon Smoliński
- Findings from WKSIDAC2 on the population structure of Baltic herring stocks (Florian Berg) florian.berg@hi.no

12:20-13:00 The Spatial Dimension

- Latest results from our government commission on effects of closed areas on herring. (Mikaela Bergenius Nord)
- Catch composition in relation to area from Danish vessels. (Claus Reedtz Sparrevohn)

13:00-14:00 Lunch

14:00 Mixed fisheries

- Technical interactions in the pelagic and demersal fisheries in Baltic Sea. Kristiina Hommik

14:30 Refresh on ToRs and Request

Road Maps ToC

Interactive Discussion Session

15:45 -16:00 Break

16:00 – 17:00 Discussion, Recap and Plan for Day 2

Annex 3: Terms of Reference

2023/WK/FRSG The **Workshop on establishing a roadmap for possible conservation measures for HERring in the BALtic, (WKHERBAL),** chaired by Colm Lordan* (Ireland), will meet online on 29 and 30 November 2023 to:

a) Agree on the relevance and feasibility of, and time frames needed for:
   - the development of a simulation model(s) to analyse the impact of different conservation measures*
   - the identification of reasons for reduced condition size and age structure of central Baltic Sea herring and Gulf of Bothnia herring
   - the analysis of the compatibility of herring fisheries with the objectives of safeguarding food webs, biodiversity and habitat integrity.

b) Prioritize the tasks needed to answer ToR(a) and describe resource, data and methodological limitations that currently prevent their development;

c) Consider ongoing research at national institutes on Baltic herring stock identification and food web structure and describe additional research needed within the roadmap to develop adequate conservation measures for herring in the Baltic;

d) Review current work under WKD3C3scope, WKD3C3thresholds, WKD3C3SIM, WKSIDAC2, WGMIXFISH-advice, WKREBUILD2 and relevant literature that can contribute to the development of such roadmap.

WKHERBAL will report by 24 January 2024 to the attention of the FRSG and ACOM.

*different exploitation levels, spatial closures, temporal closures, spatio-temporal closures and gear modifications.

Supporting information

Priority	The workshop is directly linked to a high-priority special request for advice from DGMARE.
Scientific justification	Body condition of larger herring was reported as low for the Gulf of Bothnia stock. The reasons for reduced number of larger-sized herring should be investigated. Furthermore, the development of a simulation model or battery of models to evaluate the impact of five conservation measures is also requested: 1. Fishing mortality scenarios and its impact in demographic and individual size structure in medium term projections. 2. Spatial (area) closures 3. Temporal closures 4. Combined spatial (area) and temporal closures For spatio and/or temporal closures its effect on biomass, individual size and age structure, and possible fleet displacements should be investigated. 5. Gear modifications including the selectivity of trawls used to catch herring, as an option to improve the individual size and age structure of herring. Furthermore, the possible impact that the current

	technical measures could have had on the condition and individual size of individuals should be also investigated. 6. The coherence of herring fisheries with the objectives of safeguarding food webs, biodiversity and habitat integrity should be investigated. Defining a roadmap for possible conservation measures will prioritize research on the impact of fishing on the ecosystem and, particularly, on the population structure of herring in the long term. The outcomes of the workshop could inform future benchmarks of the assessments of the relevant stocks. This workshop can scope for the relevance and feasibility of additional technical management measures.
Resource requirements	None, beyond the funding for the workshops to be provided by DGMARE.
Participants	The workshop will be attended by up to 20 experts on the biology, ecology and fisheries of small pelagic fish in the Baltic and adjacent areas.
Secretariat facilities	SharePoint access and Secretariat support.
Financial	Financed through specific budget linked to a special request for ICES advice.
Linkages to advisory committees	ACOM, SCICOM.
Linkages to other committee or groups	FRSG, WGBFAS, HAWG.
Linkages to other organizations	HELCOM.

Annex 4: Reviewers' Reports

Review by Aaron Adamack

This review represents my personal views and does not represent the views of Fisheries and Oceans Canada, nor the Canadian government.

I am unsure as to whether the document I reviewed is supposed to be significantly revised or not. I found the structure of the document haphazard and occasionally hard to follow with a number of typos and incomplete sentences throughout. Some things like MSFD, BIAS, and the impact of sticklebacks on herring were introduced before or without explanation which made the sections a bit difficult to follow. I was not always able to read the figures fully due to poor image quality and sometimes very small font size.

The Terms of Reference for the workshop asked the participants to agree on the relevance and feasibility of and time frames needed for three main tasks, prioritize those tasks, identify potential limitations to achieving those tasks, review ongoing research and work that might help to address those tasks. I believe that the workshop participants have largely addressed the terms of reference, though I think there are areas where topics could have been explored in greater detail (discussed below), but I largely think that the Terms of Reference were for the most part addressed. One area where the terms of reference might not have been fully addressed is term "b" Prioritize the tasks needed to answer ToR(a) and describe resource, data, and methodological limitations that currently prevent their development. I am not entirely sure that the workshop participants actually prioritized the tasks. I am also a bit puzzled as to why a meeting that was seemingly focused on the development of data for a future simulation model apparently lacked the participation of relevant modeling experts with the requisite expertise with the proposed models e.g. pg 22.

Reading the request from DGMARE, I was immediately struck by the text referring to a decline in the weight-at-age of herring. This same issue has been raised at recent assessments for several Canadian Atlantic herring stocks (e.g. DFO 2022ABCD) and I wonder if the workshop should be considering additional abiotic or global factors such as temperature, climate or perhaps changes in phenology where Atlantic herring over a broad spatial range are experiencing declines in weight-at-age and perhaps stock size over a similar time frame. There are several papers suggesting that a decrease in size may be an effect of climate change on fish, among them: Sheridan and Bickford 2011, Audzijonyte et al. 2020, Huang et al. 2021. Further, Moyano et al. 2020 appears to have found a link between warm water and poor growth of early life stages of Western Baltic Spring-Spawning herring. It may also be useful to broaden the literature review to North American Atlantic herring stocks and possibly Pacific herring stocks where there are some similarities. A possible starting point could be Trochta et al. 2020. On a related note, it may be worthwhile to investigate the potential interaction between age at maturity and size at age in addition to the other factors being considered.

In section 1.1 and elsewhere, interactions with and misreporting catches with sprat are discussed. It is noted that the effects of misreporting of herring and sprat is not accounted for in the advice. Where there are a number of analyses proposed to examine interactions between sprat and herring it may be useful as a part of this work to try and achieve a better understanding of how the misreporting of herring and sprat is affecting stock projections. It was unclear from the report, could catches of sprat being misreported as herring be driving some of the trends being seen in the figures shown in the report? Or is the problem in the opposite direction (e.g. herring being reported as sprat)? Which subdivisions are most prone to the misreporting of catches?

I generally liked section 2.2. New genetic evidence. I thought that the work here was well mapped out with a clear recognition of the important role of funding, given the often high cost of genetic work. This section might be strengthened by spending a bit more time discussing operational methods of identifying source stocks for fish from mixed catches and the need for good spatial-temporal coverage of samples from commercial catches. Genetic work is expensive, and it would likely be beneficial to try and develop cheaper means of identifying the origin of fish being caught throughout the region. If it is financially viable to examine samples from a broader selection of commercial catches, the distribution of a stock over the course of a year should become clearer. Perhaps more sampling of commercial catches would have the side benefit of aiding the investigation of the pattern of misreported catches.

My comments on section 3 overlap to some extent with my comments on the request from DGMARE. It may be useful to be more specific on what type of zooplankton data is needed to understand changes in herring condition. In my limited experience with sampling zooplankton, quite different methodologies are needed for sampling Pseudocalanus spp. and mysids and I would argue it would be better to make it clear that there isn't a need for generic zooplankton, but specific types of zooplankton. I was puzzled by the explicit focus on the need to use a fish fat meter to measure fat content of herring. It was suggested as a topic that needed further investigation, but it was never really explained why this would be superior to existing condition measurements. I can see why sticklebacks are being included in the discussion, but it seemed like their role in the ecology of herring was a bit overly brief. A section similar to "Importance of Mysidae monitoring" may be needed for sticklebacks.

In section 5, the proposed modeling approaches may not be ideal for the work being requested as a part of the terms of reference with respect to the MSFD. As noted in Section 3, the environmental impacts on the growth and age structure of different stock components may themselves be different, which may be difficult to implement in Ecopath with Ecosim and Ecospace (EwE) and Atlantis. It would seem like some parts of the model would need to be left vague in order to leave space in the models to include fine details that in part define the differences between the different stock components. Additionally, the model development time for both can be somewhat lengthy. Simpler modeling approaches such as bioenergetics modeling (Kitchell et al. 1977) or growth rate potential models (Brandt et al. 1992) may be faster to implement and more readily capable of examining the potential impacts of different combinations of temperature, salinity, and prey availability on the growth of herring from different components of the stock. Additionally, these models may be possible to implement using data that might already be in hand, or could be run using assumed or theoretical values for some or all parameters.

I thought the Roadmap presented in Section 6 was generally reasonable. It might be improved with a bit more structure and perhaps a prioritized listing of activities.

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Review by Aril Slotte, Institute of Marine Research, Bergen, Norway, 14 February 2024

General Comments

Drawing on my expertise as a herring specialist, I approached the report with the intention of assessing its accessibility for both experts and those unfamiliar with the Baltic Sea herring dynamics.

I noticed that the structure of the report does not follow the ToRs of the ICES WKHERBAL workshop, put into Appendix 3. However, it does comprehensively cover the requested topics from DGMARE, from which the ToRs are based on.

Overall, it lacks some clarity, and the structure could have been changed to give a better flow of issues building up to the roadmap of conservation measures for the herring in the Baltic. In some parts it is challenging for outsiders to evaluate the without exploring external literature.

Additionally, the absence of more defined plans suggested for international collaboration including new monitoring surveys or improvement of the existing ones raises some concerns. There are several national initiatives for projects and some ongoing research relevant for the topics. However, given the intricate stock structure and spatiotemporal distribution in the Baltic region one would expect a strong demand for joined forces across the nations to collect and analyse the necessary data for a better understanding of the dynamics in the area.

On the other hand, the plans for using model tools to test conservation measures looks promising.

The final roadmap of short- and medium-term actions is not ordered according to priorities. It is difficult to grasp what the workshop finds to be most urgent issues. Also, I missed some longer-term actions, which links to my concern about more clear plans for international cooperations to improve the monitoring and data foundation for future stock assessment and management.

I personally do not have a good overview of what has been done recently elsewhere in similar situations with severe stock declines, issues with growth and conditions, potentially linked to regime shifts. I missed a bit a small chapter on the potential success of introducing conservation measures in other stocks that might be relevant to the situation in the Baltic Sea, if there are such success stories one can refer to.

Chapter 1. Introduction

The report starts with DGMARE requests, whereas ToRs for the workshop are listed at the end of the report under Appendix 3. Based on this, it was a bit difficult to follow up on structure and how the different objectives were answered. I would have suggested to have the actual ToRs at the start instead, answered these accordingly, and added DGMARE requests as an appendix.

The report continues with an overview of the recent stock assessments of Central Baltic and Gulf of Botnia herring, directly describing the latest ICES advice sheets. As an outsider not familiar with the herring dynamics within the Baltic Sea it would have been helpful with a small introductory chapter prior to the stock assessments where the Baltic Sea system and its herring populations, the fishery and monitoring surveys were described. This would prepare the reader a bit before going deeper into stock trends including issues with growth and condition. Hereunder I miss an introduction map of management areas addressed throughout the report. The historical aspects of the stock structure description could have been presented under this intro chapter, and leaving details and actions related to the new genetic development and future sampling regimes required under the "Stock structure" chapter.

Regarding the stock assessments, I missed info about the age structure itself. It was not clear to me if there was a significant empirical evidence of age truncation from the stock assessment. Hereunder if mortalities appeared to differ with age, both the natural and fishing mortalities. This is info that would have been valuable here, with relevant figures.

Under the "Stock assessment" chapter there is a heading "Mean weight at age" also containing data on condition factor, which is something else. Relatedly, I really missed data on actual body growth in length. The reduced weight at age includes both reduced length and condition, and when presenting such important background information for this kind of report digging further into the issues behind stock declines, they should be split. It could have been an own chapter focussing more on the trends in growth and condition, closer to standards expected for a per-review article, as this seems to be of critical importance for the actions required under the future roadmap.

For instance, I presume data presented on size at age, condition etc from fisheries vary within management areas according to catch season, in addition to the spatial variation. Such a figure was shown for areas 30-31, not for the others. It was pointed out that fisheries have shifted to areas with smaller herring, which could influence the size and size at age data. But little effort was put on comparing seasons. It is of critical importance if weight at age and condition is measured before, during or after the growth season. I such I think it was a bit difficult to evaluate the details on growth and condition, when not being sure about what they represented. However, I am confident that the overall ceasing trends demonstrated represent nature.

BIAS trawl samples are described with no reference. I had to search internet to read more about this survey. I found some local national reports, and more aggregated data in the ICES WGBIFS report. If this is an autumn survey covering the full distribution of all herring stocks within the Baltic Sea, this should to me be the unique reference to the growth success/pre-winter condition of herring. This is an acoustic survey where such parameters could be estimated properly weighted by the abundance within management areas and at exact stock levels (ref the later discussions on use of newest genetic tools). If the natural mortality is influenced by the condition before the winter, then this is where action also should be put into measuring fat levels, which was pointed out as one the future goals.

The title "A summary of the issue", is a short summary of weight decline/reduced condition, not about stock assessment. I found this a bit odd. Not sure if this small summary is needed, at least not as it stands now.

Chapter 2. Population structure of Baltic herring

Here we can first read about the historical perspective of population structure. As mentioned above, I would have liked to have this presented at the start of the report, before reading more about stock assessment and the issues with growth and condition.

The important issue with population structure not forwarded clearly in the ToRs of WKHERBAL, but it is shortly mentioned under the requests from DGMARE. In contrast to that, the report does put a lot of effort into this, which I agree is essential for any future roadmap of conservation measures for the Baltic herring. The report now contains a good description about the new development and future potential to monitor stock identity at the individual level. This is something that needs prioritization. The problem is that this will involve considerable costs for the nations involved in sampling of landings and surveys, but it will be a definite requirement and nations should invest accordingly. Given the large-scale spatiotemporal differences in the Baltic Sea and potential mixed fisheries, any future conservation measures would demand correct stock identification during monitoring.

Chapter 3. Identification of reasons for reduced condition size and age structure

This chapter about the reasons for reduced condition, size and age structure of central Baltic Sea herring and Gulf of Bothnia herring could have been placed directly after a chapter on growth and condition. Here there is one line addressing truncated age structure. This is an important point, as mentioned above I missed info on for instance age specific exploitation patters and natural mortalities under the stock assessment chapter. One thing is that the fish grows slower, and condition is reduced. But if there in addition are fewer old fish, this points additional increased mortalities. From the info in this chapter, it is difficult to grasp if the authors think the age truncation is due to fishery or other natural causes.

There is a good description of relevant research on the potential causes of reduced condition and size, but here I would have liked to see a few figures on actual trends in relevant influencing factors to support the text.

There is listed a lot of data-gaps and suggested work that needs to be done. I miss a bit some more clear priorities here, and how this can be planned as international cooperations. It is not so easy to see how the further roadmap will be put into action. For instance, a plan is lacking on how to best monitor this. There is mentioned the need for pilot surveys. But will this develop to a new international survey like BIAS, only more focussed on ecology and run earlier in the season? It is mentioned about the importance of mysids as prey, and that this should be properly monitored, with new development inside BIAS surveys as example. I think the way forward here is to have these internationally coordinated surveys to secure proper monitoring.

When it comes to diet, which is pointed out as important to monitor, there has been a development in methodology over the recent decade. Now genetics, fatty acids and stable isotopes, other methods than simple snapshots of what is inside a stomach at time of sampling, is becoming more used. In a plan to monitor diet and consumption, this is something to look further into.

Chapter 4. National Research initiatives relevant to the roadmap

The chapter describes well the national initiatives, no special comments here. Except I would rather have hoped to read about really designated international initiatives, which finally would be required to reach a better understanding and solve issues relevant for conservation.

Chapter 5. The development of a simulation model to test conservation measures

The chapter on potential ways to study the impact of conservation measures with various model tools is informative, with a nice overview table of the suitability of the models to address the requirements of the roadmap.

I especially find the plan for a spatially structured length- and age-based stock assessment model interesting. Given the spatiotemporal dynamics in herring stocks inside the Baltic Sea and the future development in genetic tools to estimate catch and acoustic abundance down to exact stock, a natural follow up will be to include spatial and temporal simulations of different management measures as suggested. If such a model could be developed over next 4 years, I think this will be the way forward on the long run.

I notice, however, that WKHERBAL suggests the spatial-explicit Management Strategy Evaluation (MSE) tool DISPLACE as a starting point. Using the individual based model tool is a bit different direction than developing a new spatially structured stock assessment tool. I acknowledge that DISPLACE already has been used with success on cod in the area and there can be adjusted to herring and put into work relatively quickly, but still hope the development of the stock assessment model can progress as a more long-term action.

I can understand the need to also address ecosystem changes with large scale ecosystem models fitted to the system. Here the potential tools are well described in the report. But I still think a more designated international cooperative effort to monitor and collect data from the relevant spatiotemporal dynamics of the ecosystem at different levels would be a necessity for progress in the understanding of herring dynamics.

Chapter 6 Roadmap

The final roadmap outlines short and medium-term actions comprehensively but could benefit from a more systematic approach with clarification on the order of priorities. A clearly defined long-term plan, especially focusing on international collaboration for sustained monitoring programs, is essential. Addressing the need for international cooperation and streamlining the roadmap for more effective implementation would strengthen the report's overall impact.

Annex 5: A summary of Growth Rate Potential modeling and potential application to Baltic Sea herring (Aaron Adamack, Fisheries and Ocean Canada)

A bioenergetics models (e.g. Kitchell et al. 1977) are (often) simple models that are used to model the energy budgets of an organism. Measures of food consumption are turned into estimates of energy intake. The energy taken in is partitioned between energy retained for growth or reproduction and energy lost to respiration, excretion and egestion. In the case of fish, we can often model the change in weight over time per unit weight of a fish as:

$$\frac{dB}{B\,dt} = C - (R + F + U)$$

Where B is the biomass of a fish, C is the amount of food consumed, R is respiration, F is egestion, and U is excretion. If consumption exceeds the combined losses from respiration, egestion, and excretion, the fish gains weight, if it is less than the combined losses, a fish loses weight, and if it is equal to the combined losses then weight is stable. Consumption and respiration are often treated as being affected by temperature, with metabolic rates generally being faster in warmer conditions. Consumption and respiration are also affected by body size. In it's simplest form, you can give a bioenergetics model the initial size of an individual, an assumed consumption rate, and some constant water temperature or a time varying water temperature and use this to model the growth of an individual over time.

Growth rate potential models (e.g. Brandt et al. 1992) are essentially a spatially-explicit version of a bioenergetics model. Instead of modeling growth of an individual at one location, you can model their growth rate potential at many locations. In the Brandt et al. (1992) version of a growth rate potential model, the authors collected high resolution data on prey density and water temperature across a cross-section of Chesapeake Bay in May and July. I believe the data were then partitioned into cells that were ~0.5 m in the vertical dimension and 25 m in the horizontal dimension. They then used the data on prey density and water temperature to estimate the expected growth rate of a 1.9 kg striped bass if it was living/growing in each cell. Doing this they were able to compare the amount of habitat that would produce positive growth between May and July, average growth rates by month and other statistics. Several similar studies have been conducted for other regions. One that I thought might be of interest is Zhang et al. 2014 which used the growth rate potential modeling approach and extended the bioenergetics model to also include an oxygen effect on growth. For the Baltic, I wonder if it might be feasible to similarly include a salinity effect in the bioenergetics model.

An approach I took, Adamack et al. 2012, was to use a bioenergetics model that had been developed using a Bayesian approach to investigate the potential effects of freshwater diversions in coastal Louisiana, USA on brown shrimp growth and production. In this approach, the concept of space is a bit more abstract as I was modeling different locations within a coastal salt marsh by assuming different initial salinities. High salinity sites would be typical of sites closest to the ocean, while low salinity sites would be more typical of inland sites near the edge of the area that is tidally influenced.

Based on my very limited understanding of the situation in the Baltic, it seems like an approach in line with Brandt et al. 1992 and Zhang et al. 2014 or an approach similar to Adamack et al. 2012 could be taken. In both cases, a basic bioenergetics model for Atlantic herring would need to be developed. A brief scan of the literature suggests that there are a number of potential starting points with modeling work done by Bachiller et al. (2018), Jones (2014), and Megrey et al. (2007). For the Brandt et al. and Zhang et al. approaches, depending on the frequencies of the acoustic transducers being used on the acoustic surveys, it may be feasible to generate spatial maps of the zooplankton prey fields for herring across the survey areas. If CTD casts are performed, water column temperature and salinity profiles could be taken from the CTD casts combined with kriging or similar methods to fill in conditions between CTD casts. Alternatively, it might be possible to generate water temperature and salinity maps by extracting data from physical models for the Baltic. For the prey fields, if it is possible to distinguish between copepods and mysids, it would be possible to consider prey switching between copepods and mysids by herring using functions similar to those used in Adamack et al. 2017 or Kolesar et al. 2017. For the Adamack et al. (2012) approach, rather than using acoustics to drive predation, ideally, point source data on temperature, salinity and zooplankton densities by species could be used to force the model. If location specific zooplankton data were not available, it could be feasible to use existing data to determine the range of possible concentrations for copepods and mysids and test all combinations (or even a subset of combinations) of copepod and mysid concentrations in combination with water temperatures and salinities that are reflective of different regions of the Baltic (the simulations are quite fast to run – probably seconds to hours depending on how many different combinations of scenarios are being run). For both approaches, I would suggest running the simulations for a range of herring sizes/ages (e.g. ages 1 to some maximum age, perhaps 8 or 12 years?) given that there are some hypotheses in the report that the problem for older/bigger herring is that there may not be enough mysids for the older fish to survive/grow.

I think the design of simulations might look like:

Sites: N; Each site would have a temperature and salinity value. Perhaps multiple values if you wanted to also look at multiple points within a year.

Prey concentrations: A grid of all possible combinations of copepods and mysid concentrations. Grid size could be reduced by developing location specific ranges to avoid simulating unrealistic values.

Ages simulated: 1 to 8 or 12 or whatever is reasonable

The total number of simulations would be: Sites * number of copepod concentration intervals * number of mysid concentration intervals * number of ages simulated (* seasons?).

It should be feasible for a post-doc with prior modeling experience to complete this work in ~1 to 2 years, with 2 being a bit safer assumption. It would depend in part as to how complex the bioenergetics model ends up being (e.g. is it worth modeling the uncertainty?; would something like a dynamic energy budget model be useful? is there a desire to collect new paired data or can they use existing data? etc.).

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