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Proceedings of the Maritimes Regional Peer-Review of the Assessment Framework for Southwest Nova Scotia/Bay of Fundy Herring: Part 1 – Review of Data Inputs

Meeting dates: February 5–6, 2019
Location: Dartmouth, Nova Scotia

Chairperson: Kent Smedbol
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Canada

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

A regional peer review of the Southwest Nova Scotia/Bay of Fundy Herring Framework: Part 1 – Data and inputs was held on February 5–6, 2019 at the Northwest Atlantic Fisheries Organization headquarters in Dartmouth, Nova Scotia. As set out in the Terms of Reference (ToR) the focus was to review the data inputs and indices of abundance relevant to the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) spawning component, prior to developing an assessment framework. Participants in this meeting included, Fisheries and Oceans (DFO) Science, DFO Resource Management, DFO Ecosystem Management, DFO Policy, Indigenous communities/ organizations, non-government organizations, fishing industry, and external experts.

This proceedings document includes a summary of the presentations and is a record of the meeting discussions and conclusions. A research document resulting from this meeting will be published on the Fisheries and Oceans Canada Canadian Science Advisory Secretariat CSAS website once it becomes available.

INTRODUCTION

Atlantic Herring is a pelagic fish species found on both sides of the Atlantic Ocean. They first mature and spawn at three or four years of age (23 to 28 cm), and then begin a predictable annual pattern of spawning, overwintering, and summer feeding, that may involve considerable migration and mixing with members of other spawning groups. Herring spawn in discrete locations, to which they are presumed to home. The North Atlantic Fisheries Organization (NAFO) Areas 4VWX management unit contains a number of spawning areas. Spawning areas in close proximity with similar spawning times, and which share a common larval distribution area, are considered part of the same complex. For evaluation and management, the 4VWX Herring fisheries are divided into four stock components:

1. Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) spawning component
2. Offshore Scotian Shelf banks spawning component
3. Coastal (South Shore, Eastern Shore and Cape Breton) Nova Scotia (NS) spawning component
4. Southwest New Brunswick migrant juveniles.

The previous Herring assessment framework conducted in 2011 recommended that the next framework should focus on model improvement and exploration (DFO 2011). This assessment framework focused on the SWNS/BoF spawning component. The last stock assessment for this component was conducted in 2018 (DFO 2018), with stock status updates provided in 2016 (DFO 2016) and 2017 (DFO 2017). The 2018 assessment identified the framework assessment as a priority.

This meeting was the first of a series of Canadian Science Advisory Secretariat (CSAS) peer review processes and addressed the data inputs step in developing an assessment framework for the SWNS/BoF stock component. The objectives were to review the data inputs and indices of abundance relevant for SWNS/BoF Herring as follows:

- Summarize the definition of the SWNS/BoF Herring management unit (growth, morphometrics, movement) provided at the 2006 Framework meetings. Present any relevant new information that might change the definition of the management unit.
- Review SWNS/BoF Herring fishery distribution, landings, age composition, condition, weight/length-at-age, maturity, timing and bycatch.
- Review data that accounts for all fishing mortality and reporting separately, including bait fisheries (since 2016), Silver Hake fishery, NS weirs, gillnets, adult Herring in NB weirs, and purse seine fisheries.
- Review the acoustics data series (1999 to present) including the methods, coverage and turnover biomass estimates (as discussed at the 2018 stock assessment).
- Review the Maritimes Ecosystem Research Vessel (RV) survey age-specific indices of abundance and acoustic data.
- Examine sources of ecosystem information (environmental factors, diet information, unaccounted for sources of mortality, etc.) and identify how this information might be incorporated into the assessment framework.
- Review the ecosystem-based fisheries management (EBFM) framework and identify how it could be incorporated into the assessment framework.

- Provide information on ongoing research related to Herring in academia or other regions of Fisheries and Oceans Canada (DFO).

The Terms of Reference are shown in Appendix A. Participants in this meeting included DFO Science, DFO Ecosystem Management, Province of Nova Scotia, Province of New Brunswick, Indigenous communities / organizations, fishing industry representatives, non-government organizations, and academics (Appendix B). This meeting was held February 5–6, 2019 (Appendix C for the Agenda).

DAY 1: FEBRUARY 5, 2019

The Chair, Kent Smedbol, started the meeting by introducing himself and the reviewers Kim Emond (DFO Science Quebec Region) and Matthew Cieri (Maine Department of Resources). The Chair reviewed the CSAS peer review process and the use of the Scientific Advice for Government Effectiveness (SAGE) Principles and Guidelines. The Terms of Reference with the specific meeting objectives and the Agenda for the two days were also reviewed.

BACKGROUND AND STOCK STRUCTURE OF SWNS/BOF HERRING

Rapporteur: Kirsten Clark

Presenter: R. Singh

Information was presented on the life history and stock structure of Herring and identifying the historic and current spawning grounds of the SWNS/BoF spawning component. The results of historic and current tagging projects including work by Ryan Martin and the most recent tagging conducted by the Herring Science Council were reviewed. The presenter noted that a recommendation from the previous Herring framework assessment had been to investigate the affinity of the New Brunswick weir fish to the SWNS/BoF stock but due to the large decline in weir landings, this had not been considered a high priority.

Assessment approaches have varied and a variety of survey indices have been evaluated, used and subsequently rejected, and sometimes reintroduced as inputs into Virtual Population Analysis (VPA) models. A series of larval surveys have been replaced by annual acoustic surveys as the basis for stock evaluation. There is no analytical assessment model and stock status is currently assessed based on several indicators including acoustic survey biomass trends, Industry input, numbers- or proportion-at-age in catch, trends in exploitation rates from survey, and mortality rate trends based on age composition.

Tagging showed some movement of fish tagged in Scots Bay to German Bank and from those tagged on German Bank to the offshore. It was clarified that currently the offshore landings are not included in the reported landings for the SWNS/BoF stock. Some offshore landings may be fish of German Bank origin, but it is not expected that this is a large proportion. There is not a lot of information on the Offshore Scotian Shelf beyond the annual Maritimes Ecosystem RV survey. It was noted by the industry that roe fish were found in the offshore in October 1986 but have not been observed since then.

There was discussion around specific information related to individual spawning components and some of the uncertainties. It was noted that the collapse of Trinity Ledge occurred back in the early 1990s. Industry has been surveying Scots Bay earlier in the year (June) and catching spawning fish. It is uncertain whether these are the same stock or if they are spring spawners. Since fishing activity typically was not occurring in that area at that time of year, it is unknown whether spawning has always occurred at that time or whether this is something new. There is information published on Minas Basin Herring in 1987 as well as further information published in

the 1990s. On German Bank, a lot of the catches are outside the survey box but it is not clear whether they are German Bank spawning Herring. It is known that German Bank is both a feeding and a spawning area. In the Gulf of Maine, spring spawning has been documented as far south as Cape Cod which is relatively new.

Herring larvae are passively held in larval retention areas that were originally documented by Derrick Iles and Michael Sinclair in the 1980s (Iles and Sinclair 1982). The age of larvae when they start to leave these retention areas is unknown but is likely related to their ability to swim out of the prevailing currents.

FISHERY-RELATED INFORMATION – DISTRIBUTION, LANDINGS, AGE

Fisheries in the 4VWX area in recent years have been dominated by purse seine, with lesser catches by weir, and gillnet, and relatively minor landings by shutoff and trap. Currently, most of the landings occur during May–September. A catch-at-age table was constructed using samples from both the commercial fishery and research surveys. Due to ageing inconsistencies, 20% of the samples collected from 1999–2005 have been re-aged and the other 80% removed from the aging database.

It was noted that the fleets have not been fishing in Chedabucto Bay because of the reduced quota and cost of traveling there. Before the reduced fleet activity, biomass in Chedabucto Bay had declined. Fleet activity moved back into the Bay of Fundy because of lower effort. At that time, industry was only permitted three vessels under a scientific license to perform surveys and to collect samples off Halifax in November and in Chedabucto Bay.

A suggestion was made that accounting for stocks from mixed areas to the components of the stock could be done proportionally based on the size of spawning ground. The data are in the tables and can be broken out.

The historical time series indicates that, since 1995, few survive past age 8 and the time series continues to be dominated by ages 2–5. A rapid decline in abundance of year classes in the landings and few older fish imply a high total mortality. Fish of ages 2–4 dominate the fishery (Singh et al. 2020).

Average weight-at-age continues to be below the long-term average. Weights of age 1 and 2 are higher than the long-term averages; however, samples of age 1 fish in the catch are usually small. Lengths-at-age has decreased, except for age 2 fish which have shown an increase. Condition factor has improved for ages 2, 3, and 4, and fluctuated without trend for ages 5–10. Length- and age-at-maturity have both shown a decline through the time series.

The weir and shutoff fisheries catch mainly juvenile Herring (ages 1–3). A sensitivity analysis was undertaken to evaluate the impact of different assumed proportions of United States of America (US) origin Herring on the assessment. Exploratory VPA analyses indicate poor tracking of year classes.

A participant noted that past assessments had a rationale for excluding small fish from the weirs which was supported by tagging studies. This could be reconsidered, and a fraction of juveniles included. A participant noted that the weirs on Campobello Island, NB, used to catch large Herring and the Russian fishing vessels used to take big adult fish. It is possible that these might be spawning on Grand Manan, NB, or Cutler, Maine, or elsewhere.

A participant commented that the decrease in length- and weight-at-age means that fish are smaller and, therefore, a higher number of fish are taken for the same total allowable catch (TAC). A smaller fish produces fewer offspring and this same phenomenon has been observed in stocks assessed by the International Council for the Exploration of the Sea (ICES) and Pacific Herring and Rockfish. It was suggested that length/weight relationships be included in the

models. Additionally, when conservation objectives are set, age and size changes should be incorporated into management objectives, not just the models.

Estimates of bycatch of incidental species (mainly Spiny Dogfish [*Squalus acanthias*], Silver Hake [*Merluccius bilinearis*] and Atlantic Mackerel [*Scomber scombrus*]) in the Herring fishery are relatively low. There has been a general trend of decreasing amounts of Herring caught as bycatch in commercial bottom trawl fisheries.

There was a question about including bycatch in the Silver Hake fishery because the fishery occurs offshore. Most of the Silver Hake fishery occurs in the two basins but there is some fishing in the area that includes 4X, so only this portion is included.

The bait fishery has been included in Maritimes Fishery Information System (MARFIS) since 2015. Maritimes Region allows three gillnetters under a Herring/Mackerel mixed license. There is mandatory reporting although no reports have been submitted. A delinquent log policy was implemented in 2016. There is a possibility of underreporting but it has improved. Buying bait from commercial fishermen has increased.

It was asked if reported commercial Herring landings sold as Herring bait was of value in an assessment. Although it has been considered, it may not be useful for modelling. As long as Herring is being caught, the end use does not matter. The issue with the bait data held in DFO databases is that it is not accurate. A participant noted that bait data might not be useful for stock assessment but very relevant for seeing how markets change and what external factors are driving demand. A reviewer noted that targeting for bait would impact the selectivity curve, so tracking bait sales is relevant.

It was asked if the decrease in age-at-maturity over 40 years was statistically significant. There have been reductions in weight-at-age and length-at-age but not a lot of change in the spawning and age at first maturity which suggests its more of an age-driven spawning than a length-driven spawning.

There was a research recommendation to review the observed trends in weight and length at age to determine whether the slight increase in ages 1 and 2 might be a sampling artefact.

In the US Herring assessment, New Brunswick weirs are modelled as a separate fleet with their own selectivity curve. Tag returns have not helped in resolving the proportion of Canadian versus US fish because tag returns from the US have been low. It was noted that markets may be affecting landings data. Fish plants have not purchased age 1 Herring for some time and only a few weirs are currently operating.

There was a recommendation to re-assess the 50% age-at-maturity and the proportion mature-at-age.

ACOUSTIC DATA SERIES – METHODS, TURNOVER, INDEX

Spawning stock biomass (SSB) is estimated from the acoustic data collected by industry vessels on the spawning grounds. The minimum estimates of SSB calculated from acoustic survey data between 1999 and 2003 were sufficiently high that substantial population growth and an improvement in age composition were expected; however, these did not occur. Factors causing uncertainties in estimated SSB are acoustic backscatter due to zooplankton, vessel noise, assuming that the surveys are additive, and inter-survey turnover processes.

The turnover method for discounting biomass from previous surveys was described. While, the formula is applied consistently, it sometimes does not make sense. For example, discounting more fish in one day than was observed the previous day. A cap could be applied to the

turnover discount that would be a function of the previous day's biomass; so if the calculated value is larger than the previous survey, the discount applied is by the previous amount.

In the previous year, there was a change in the way the turnover data were calculated. A problem was identified; however, it cannot be fixed quickly. If it is an issue, then it should be considered in the next part of the framework. Consideration could be given to the formula and whether to change it or only apply it in certain cases. There is no approved consensus method on how to change the turnover formula at this time. A standard approach to editing acoustic data and documentation would be a good procedure moving forward. The current analysis methodology is already documented.

It was noted that a standard target strength (TS) is used when there are no Herring samples collected during surveys. It was suggested that with declines in length- and weight-at-age, these should be standardized by the year before, or some other year, because the standard target strength might not remain the same. If a smaller TS is used, it would mean more individuals (a higher number of fish) but not necessarily biomass.

There have been multiple editors since the acoustic index was initiated in 1999. A protocol needs to be developed using prescribed school detection and Echoview noise algorithms to ensure consistency between years and editors. **There was a recommendation to develop a standard protocol.**

A participant asked how Seal Island Herring catches were being treated. These are added to German Bank catches. Spectacle Buoy catches have not been added to German Bank catches in the past. These areas all share the same larval retention and feeding area and appear to be connected.

The impact of changes in fish condition (fat levels, maturity) is unknown. The size of recruiting SWNS/BoF Herring year-classes is highly variable and there is no index of recruitment. A large fraction of the catch is dependent on recruiting year-classes of uncertain abundances.

Discussion then focused on the assumptions that are used in estimating SSB from the acoustic backscatter. Several recommendations were made including:

- Review turnover "discount" of fish from previous survey day and the next survey day.
- Review relationship of fish TS with size distribution, depth stratification, and fat content. This review may require *in situ* sampling of Herring.
- Review the relationship of acoustic frequencies to biomass.
- Investigate standard procedures for acoustic data processing.

RESEARCH VESSEL (RV) SURVEY – SURVEY INDEX AND SAMPLE AGEING

The annual Maritimes Summer Ecosystem Research Vessel (RV) survey series indicate an increase in abundance of Herring since 2014. The RV survey indicates that Herring are widely distributed in the Bay of Fundy and Scotian Shelf. There is little or no survey coverage, however, on the main spawning areas which are also the main fishing areas (Singh et al. 2020). The RV survey tends to catch larger fish (> 23 cm) and is not consistent in tracking the strong year-classes observed in the fishery. Re-examining the survey samples after the aging problem was solved has not been undertaken, mainly because the RV survey is perceived to be a poor indicator of Herring abundance relative to other indices.

Increases in abundance may be due to changes in Herring behaviour – they are closer to the bottom and this has increased catchability in the RV survey. It was suggested that Herring

catches in the ITQ (Individual Transfer Quota) survey and the Inshore Lobster Trawl Survey be examined because these surveys do sample inshore fishing areas.

LARVAL SURVEYS

Data were presented based on larval surveys conducted from 1972–1998 and in 2009 (Stephenson et al. 1999).

When the 2009 data were compared to the historical series, there was no clear trend in terms of geographic area contracting or expanding. There are no data to determine whether there was a difference in the survivability of spring- and fall-spawned larvae. Only one cruise attempted without success to track a larval cloud through space and time. A participant noted that spring spawning Herring produce larger eggs than fall spawners. The intensity of zooplankton blooms has changed between fall and spring since the papers on Herring larvae have been published.

DAY 2: FEBRUARY 6, 2019

Rapporteurs: Suzuette Soomai and Kirsten Clark

The Chair reviewed the main points and recommendations raised during the first day. The main points related to recommendations for work going forward were:

- Investigate the trends and variations in length-at-age and weight-at-age.
- Investigate turnover of Herring in acoustic surveys from survey to survey.
- Review the acoustic data series and quality control and put a strict protocol in place.
- Protocol for how to use target strength (TS) when there is no associated sample. TS can be affected by depth profile in water as well as fat percentage. More *in situ* sampling is required, such as having a trawler and echosounder active at the same time. Similar data from Herring sampled in weir has been published.
- Two frequencies are being used (38 and 50 kHz) in acoustic surveys. Investigate whether the 50 kHz might be making the biomass estimate higher than expected.

ECOSYSTEM CONSIDERATIONS – PREY, PREDATORS, ENVIRONMENT

The Atlantic Zone Monitoring Program (AZMP) measures a suite of environmental variables across the Scotian Shelf and Gulf of Maine. Environmental variables and indicators that may be relevant to the biology and ecology of Herring include: mixing properties; annual anomaly scorecards for phytoplankton and zooplankton abundance/biomass, microplankton abundance, and copepod indicator species.

Ecosystem modeling studies in the Gulf of Maine provided analogous estimates of predators and prey, although not specific to Herring. Eighty different drivers have been identified and predation intensity from Haddock is important (Bundy et al. 2017).

Large declines in groundfish abundance have changed the suite of predators and their impact on Herring. There are important predator-prey interactions; for example, if Atlantic Cod is in the rebuilding stage, what would be the possible impacts on the future of Herring stocks.

The AZMP data and the larval data should be revisited in developing the new framework to see if they can be incorporated into the assessment framework. A process to develop a maturity index is not available and different ways of using these data could be explored. There may be broader utility besides directly incorporating ecosystem information in the model.

With regard to types of models that can be considered, discussions centered on what models were used in the past. VPA models take a historical approach and move backward in time. The catch-at-age model is more forward-looking. Concerns with refining reference points were raised. The inclusion of environmental data has the potential for helping to refine Herring biomass estimates and to support the development of a Management Strategy Evaluation (MSE).

Productivity is not distributed evenly in space and this poses a challenge in developing a spatial assessment model. Local and global productivity need to be determined and a decision has to be made on the management level. The need to collect information across programs, and even in different jurisdictions, in a consistent manner to make recommendations to management was stressed. Work on Herring stomach contents at Saint Andrews Biological Station (SABS) has shown that amphipods predominate in adult Herring diets while juvenile Herring eat more copepods (unpublished DFO data). Herring has many predators among many species of fish, bird, and marine mammals, also invertebrates such as jellyfish that prey on larvae. Predation mortality on eggs is very important, causing up to 90% mortality for Herring eggs. Haddock has been shown to be a big predator of Herring in the Gulf of Maine where predation intensity by Haddock is one of the strongest drivers of SSB. Haddock abundance has been increasing.

Fishing pressure may differ across spawning components and there is uncertainty as to the which particular spawning component a caught fish belong. Some spawning components may be doing well; however, consideration has to be given to how much of an individual spawning components is being harvested to prevent over-harvesting and to prevent collapse.

A DFO national Ecosystem Approach Framework Management (EAFM) Working Group has been formed with participation from Fisheries Management and Science. The Terms of Reference is under development but the scope is to consider how to include broader ecosystem considerations in assessments. Case studies in the regions will be developed as prototypes. There will be a meeting in the Maritimes Region in March 2020 to discuss potential cases and Herring could be a good case study. Under the Aquatic Climate Change Adaptation Services Program (ACCASP), DFO is reviewing all stock assessments to see how ecosystem and climate change considerations can be incorporated.

One of the reviewers commented that including ecological data into an assessment may make it more biologically relevant but less effective for management and that the purpose of the assessment needs to be clear. For example, as a strategic research tool, Ecopath and Ecosim are ecosystem-related models that do not provide management advice. Ecological data can be incorporated into a framework, but not as an assessment model. DFO Science can provide advice but the degree of tolerance to risk is determined by resource managers.

At the present, there is a problem predicting recruitment from biomass and it is not possible for resource managers to make decisions based on recruitment. It was suggested estimates of recruitment be modelled using time varying M and different catchabilities.

RELATED ONGOING RESEARCH

Herring as Seabird Prey

Presenter: Tony Diamond (University of New Brunswick)

Seabird diets can be used as bio-indicators of Atlantic Herring recruitment and stock size. This can be a new tool for ecosystem-based fisheries management. Results from 24 years of seabird diet research on Machias Seal Island, NB, show Herring as a main seabird prey and dominant in the diets of Arctic and Common Terns, Atlantic Puffin, and Razorbill in the 1990s. Seabird colonies are in the midst of Herring spawning grounds and sea birds take Herring pre-recruits.

However, the diet of seabirds are changing, as evidence shows that currently there is less Herring in the diet of Atlantic Puffins (*Fratercula arctica)*. There has been a steep decline since 2000 and a continuing decrease since 2010. Since 2001, Sand Lance (*Ammodytes dubius*)and polychaetes have become more dominant in seabird diet and appear to be a replacement for Herring as prey. Most of the species that have replaced Herring in seabird diets have a lower fat content so the quality of their diet has decreased. The annual survival of adult Atlantic Puffins is positively correlated with Herring landings.

Warming water temperatures appear to be playing an important role in the Gulf of Maine ecosystem based on the Regional Association For Research on the Gulf of Maine (RARGOM) temperature history data. Fish move north and deeper, metabolism increases in warming water, growth accelerates, and swimming burst speed increases making it more difficult for warm-blooded predators. Consequently, this affects the global distribution of seabirds and seals. This is more than just a warming trend and should be taken into account in stock assessment. Ultimately, Atlantic Puffin breeding in the next 20–30 years will be seriously impacted.

Atlantic Puffins and Razorbills (*Alca torda*) will dive 10 to 20 m to get food while Common Terns (*Sterna hirundo*) are surface feeders and will fly up to 40 km, but this was measured only in an unsuccessful breeding season. Generally, flight distance is about 20 km for Atlantic Puffins and 15–18 km for Razorbills. They have been observed feeding around former/perhaps current spawning ground at Cutler.

A participant compared the lack of Herring in seabird diets in the last few years to their own observations of Herring. In the last year, quite a bit of juvenile Herring were observed in that area. There were a lot of juvenile Herring available around Mt. Desert Rock, ME, around that time period.

Seabirds as indicators of Herring recruitment

Presenter: Lauren Scopel (University of New Brunswick)

Seabird feeding characteristics can provide information on the Herring fishery by correlating fishery and seabird data. Data from acoustic surveys and weir landings were compared to chick diets at nine seabird colonies. When Herring abundance is high in parts of the Gulf of Maine, the fishery catches them, but the birds may not because they do not travel as widely. However, Herring abundance in recent bird diets is low.

Seabird chick diets can indicate abundance information on Herring juvenile before recruitment. Terns are limited to the fish they have access to, as are weirs, while purse seines and Atlantic Puffins and razorbills are mobile. Razorbills have the ability to dive deeper to exploit fish that are moving deeper. Just as seines move, Atlantic Puffins can move further distances for food compared to other birds such as terns. The decline in weir landings may be related to availability; temperature impacts are highest in shallow water and the weirs are stationary.

A participant commented that the temperature effects on Herring distributions have been noticed. Purse seines are fished deeper because the Herring are deeper. With respect to weirs, the fish are deeper but squid tend to drive them inshore. Deeper Herring distributions could also be due to older and larger fish. Exploitation pressures have been associated with marine fish occurring at deeper depths but there needs to be a broader consideration of factors that might be driving fish deeper.

Seabird diets highlight the complexity in stock structure. Length data for Herring can be collected through observations of bird catches. Seabird diet data could be used to determine at what age larval Herring leave the retention area.

University of New Brunswick (UNB) will continue collecting the seabird data contingent on funding. There was discussion on the possibility of the bird team collecting juvenile fish samples for science studies. The US has bottom trawl data for seabird sampling sites. UNB and collaborators in Maine can also share data with the US National Oceanic and Atmospheric Administration (NOAA).

Adaptation to seasonal reproduction and thermal minimum related factors drive fine scale divergence despite gene flow in Atlantic Herring populations

Presenter: Angela Fuentes-Pardo and Daniel Ruzzante (Dalhousie University)

Whole-genome resequencing was conducted to determine the spatial scale and patterns of population structure in Atlantic Herring stocks. The research included 14 locations in Northwest Atlantic-Gulf of Maine (German Bank, Scots Bay, Eastern Shore), Bras d'Or, Seven Island Bay, Northumberland Strait, and Newfoundland.

Spring and fall spawners could be distinguished on basis of single nucleotide polymorphism (SNPs). Based on F_{st} metric, there is relatively low genome wide differentiation among the 14 populations (about 0.04). Maine and German Bank looked different from the rest of the samples based on Principle Component Analyses (PCA). The two axes of differentiation appeared associated with latitude and seasonal reproduction. There was discrimination between spring and fall spawning fish with two exceptions (Seven Islands Bay and Bras d'Or).

Winter sea temperature was the best indicator for the latitudinal genetic pattern observed. Southern locations, German Bank and Musquodoboit, showed an intermediate allele frequency (Scots Bay is just above the north/south line). There are hybrids of spring and fall spawning in the Northumberland Strait. There are latitudinal patterns in genotypes with extreme allele differences between northern-intermediate-southern locations. Scots Bay shows alleles associated with northern stocks while German Bank shows alleles associated with a south stock. Seasonal reproduction mutations would be mostly related to lipid biosynthesis and maturation.

A participant asked if German and Scots Bay Herring could be distinguished genetically. The presenters are analyzing additional samples and hope to be able to do that in the future. Their hypothesis is that selection occurs at the larval stage due to winter sea temperatures. Two locations stood out but these had the lowest sequencing coverage so it was assumed that it was a sampling artefact rather than biologically meaningful. Analyses excluding those two locations were not completed.

A participant remarked that differentiation between German Bank and Scots Bay Herring was reasonable since German Bank Herring spawn in fall while Scots Bay Herring spawn in June through August. It is the initial exposure to cold temperatures that drive the genetic expression. Water temperature data come from an oceanographic model (NEMO) that integrates all temperature data.

Multivariate determination of population health

Presenter: Dan Boyce (Dalhousie University)

A multivariate index was developed using historic datasets, including data used in previous stock assessments, e.g., VPA (1985–2006) and acoustic surveys (1999–2018). The index was used to determine: what factors drive change in Herring productivity; and how and why Herring population state changed in the long-term. This is an alternate approach for looking at Herring well-being by looking at a range of metrics for health. The research uses response and predictor variables and incorporates time-lag effects in the model (Boyce et al. 2019).

Sixteen indicators were identified based on cluster analyses. These were primarily negative after 1980 but low since 2005. Change in several of the indices precede biomass decline and are early warning indicators. Biomass is a very important indicator for assessing the status of the stock but the others might be early warning indicators as to how biomass might change. These included average weight of adult Herring, exploitation (one-year lag), egg predation (especially Haddock), temperature and thermal phenology (seasonal temperatures in larval retention areas).

The presenter summarized that multiple indicators can provide valuable information of how Herring populations are changing and complement existing assessment approaches. Interpretation of reference points is also better when a long-term perspective is used in placing the contemporary population dynamics in context. Uncertainty with regard to biomass levels is high and the additional information is useful to determine SSB. The change in some indices can be used as early warning indicators for changing biomass. Results show that the spatial domain of adults spans the entire Scotian Shelf, while the larval and the juvenile domains are spatially restricted in the Bay of Fundy. There is a negative effect of temperature on larvae and adults.

A question was asked about the different time periods associated with the indices. A mixed model was used and surveys were standardized to the mean. Several sensitivity checks were run restricting analyses to a common time and little effect was observed.

A participant remarked on the development of a causal model from the 88 input variables. Almost all pressures identified were temperature related. The preliminary conclusion from this would be that temperature is one of the major drivers. One of steps to get from 88 variables to a causal model required some interpolation to fill in gaps which meant that a lot of the plankton data, for example, had to be excluded because of frequent data gaps. This is a good approach because when looking at predictors both the time series of Herring and time series of temperature need to be considered together. An objective approach would be to identify health indicators *a priori* and then conduct the assessment.

ECOSYSTEM CONSIDERATIONS WRAP UP

The department has requested that all assessment frameworks include ecosystem considerations. Meeting participants were asked to put on record what kinds of information should be considered moving forward.

A participant advised that we should be considering the framework in which we evaluate Herring. There have been changes over time and the perspective of what makes up an ecosystem approach is evolving. The present objectives are to collect data on the timing of spawning, and abundance on the spawning grounds but an ecosystem approach includes productivity, habitat and will evolve to include social and economic components.

Missing data are sources that may illuminate future climate change and predator-prey relationships. For instance, including long time series of spatial data in Herring assessments, such as remote sensing and AZMP data, Copepod preferences of Herring, prey availability, links to fat levels in Herring, and Herring predators at different life stages. This task is made more difficult by changes in species composition and the possible relationships between sea surface temperature and predators.

Other data sources mentioned were trends in bird populations and links to Herring populations as additional signals as part of a broad ecosystem response. Thresholds related to the environment are also important considerations; for example, when does the temperature threshold become problematic for Herring. Remote sensing data could also be included in the

assessment. Herring migrate between the Bay of Fundy and elsewhere in the Gulf of Maine and as a result they may be subject to harvesting in the other jurisdictions.

Management objectives moving forward were also discussed. The Integrated Fishing Management Plan (IFMP) is under revision and there will be discussions with industry similar to those conducted for Mackerel. Science will be asked what information can be provided to support management objectives. The Advisory Committee working group brings in other stakeholders. The same people are working on the IFMP and the assessment framework and these will inform each other.

DISCUSSION AND WRAP-UP

The participants were asked to consider the data sources presented and whether they should be included or not excluded for the next phase of the framework. Meeting participants were urged to agree on which data inputs were useful for the modeling process.

A research recommendation was that fishery data be reviewed for trends in length- and weight-at-age as well as fishery catch-at-age, and maturity indices.

- A caveat was recommended to be added to work planning noting the concerns about the quality of data, that is, inclusion of catches not related to BoF stocks (Offshore Banks, Little Hope); also, how the collection of samples that were weighted by sample weight vs the catch weight might affect the quality of data.

Acoustic indices

- Review turnover formula for fish between surveys, target strength, acoustic frequencies 38 vs 50 kHz, and standardize procedures for acoustic data processing. The turnover formula should be investigated prior to Part 2 of the framework.
- A participant raised a concern that bias occurs in the acoustic biomass estimates due to zooplankton presence and vessel noise and that the assessment team review these prior to the next step. Vessel noise is edited out and only an issue when noise mixed with schools. A participant recommended that only schools be included in the estimates. Another participant stated that noise is only a problem with some vessels, and these could be examined separately. It was agreed that, if an issue is identified based on the review of the acoustic data, the group will be informed.

RV survey and acoustics

- These data were considered good for spatial coverage. No aging has been conducted since 2005 and would require a lot of work. RV survey trends could be included and tuned with environmental covariates back to 1999 for comparison with industry data. There was a recommendation to update the aging of otoliths collected on the RV survey.

Tagging data

- Review Industry and other tagging data sources

Seabird Data

- There was uncertainty on how the seabird data can be used as an abundance index, but its usefulness can be explored during the next year. This would be more of a strategic indicator over 20 years.

AZMP

- Data from the AZMP will be included where appropriate.

Genetics

- An important tool for understanding the management unit. Included if university colleagues can make it available.

Other factors

- Update current rates of predation by processing stomachs collected on the RV survey.

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APPENDIX A: TERMS OF REFERENCE

Assessment Framework for Southwest Nova Scotia/Bay of Fundy Herring: Part 1 – Review of Data Inputs

Regional Peer Review – Maritimes Region
February 5–6, 2019
Halifax, Nova Scotia

Chairperson: Kent Smedbol

Context

Atlantic Herring (*Clupea harengus*) is a pelagic species found on both sides of the North Atlantic. Herring spawn in discrete locations, to which they are presumed to home. Herring first mature and spawn at three or four years of age (23 to 28 cm or 9 to 11 in), then begin a predictable annual pattern of spawning, overwintering, and summer feeding, which often involves considerable migration and mixing with members of other spawning groups. The Northwest Atlantic Fisheries Organization (NAFO) Areas 4VWX management unit contains a number of spawning areas. Spawning areas in close proximity with similar spawning times, and which share a larval distribution area, are considered part of the same complex. For evaluation and management, the 4VWX Herring fisheries are divided into four components:

1. SW (Southwest) Nova Scotia/Bay of Fundy spawning component
2. Offshore Scotian Shelf banks spawning component
3. Coastal (South Shore, Eastern Shore and Cape Breton) Nova Scotia spawning component
4. SW New Brunswick migrant juveniles.

The last assessment framework conducted in 2011 recommended that the next framework should focus on model improvement and exploration (DFO 2011). This assessment framework will focus on the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) spawning component. The last stock assessment for this component was conducted in 2018 (DFO 2018), with stock status updates provided in 2016 (DFO 2016) and 2017 (DFO 2017). The 2018 assessment identified the framework assessment as a priority.

This meeting is the first of two, and will address the data inputs step in developing an assessment framework for the SWNS/BoF component.

Objectives

The objective of this first meeting is to review the data inputs and indices of abundance relevant for SWNS/BoF Herring.

- Summarize the definition of the SWNS/BoF Herring management unit (growth, morphometrics, movement) provided at the 2006 Framework meetings. Present any relevant new information that might change the definition of the management unit.
- Review SWNS/BoF Herring fishery distribution, landings, age composition, condition, weight/length at age, maturity, timing and bycatch.
- Review data that accounts for all fishing mortality and reporting separately. Including bait fisheries (since 2016), silver hake fishery, Nova Scotia weirs, gillnets, adult herring in New Brunswick weirs and purse seine fisheries.
- Review the acoustics data series (1999 to present) including the methods, coverage and turnover biomass estimates (as discussed at the 2018 stock assessment).

- Review the groundfish research vessel survey age-specific indices of abundance and acoustic data.
- Examine sources of ecosystem information (environmental factors, diet information, unaccounted for sources of mortality, etc.) and identify how this information might be incorporated into the assessment framework.
- Review Ecosystem-Based Fisheries Management (EBFM) framework and identify how it could be incorporated into the assessment framework.
- Provide information on ongoing research related to Herring in academia or other regions of DFO.

Expected Publications

- Proceedings
- Research Document

Expected Participation

- Fisheries and Oceans Canada (DFO) (Science, Ecosystem Management, and Fisheries and Aquaculture Management)
- Provinces of Nova Scotia and New Brunswick
- Academics
- Indigenous communities/organizations
- Fishing industry
- Other invited experts

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APPENDIX B: LIST OF PARTICIPANTS

Name	Affiliation
Allard, Karel	Environment and Climate Change Canada / Canadian Wildlife Service
Baker, Lori	Eastern Shore Fisherman's Protective Assn. (ESFPA)
Bartlett, Mike	Woodstock First Nation
Benson, Ashleen	Landmark Fisheries
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APPENDIX C: AGENDA

2019 Southwest Nova Scotia/Bay of Fundy Atlantic Herring Framework:
Part 1: Data and Inputs

Regional Peer Review – Maritimes Region

February 5–6, 2019

Chairperson: Kent Smedbol

DAY 1 (Tuesday, February 5, 2019)

Time	Topic
9:00 - 9:15	Welcome and Introductions
9:15 - 10:15	Background and Stock Structure of SWNS/BoF Herring
10:15 - 10:30	Break
10:30 - 12:00	Fishery-related information – distribution, landings, age
12:00 - 1:00	Lunch Break
1:00 - 2:30	Acoustic data series – methods, turnover, index
2:30 - 2:45	Break
2:45 – 4:15	Research vessel survey – index, age
4:15 - 4:30	Wrap up

DAY 2 (Wednesday, February 6, 2019)

Time	Topic
9:00 - 9:15	Recap of Day 1
9:15 - 10:15	Larval Survey information
10:15 - 10:30	Break
10:30 - 12:00	Ecosystem considerations – prey, predators, environment
12:00 - 1:00	Lunch Break
1:00 - 2:30	Related ongoing research
2:30 - 2:45	Break
2:45 - 4:30	Discussion and Wrap - Up