Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Proceedings Series 2015/006

Pacific Region

Proceedings of the Pacific regional peer review on Stock Assessment and Management Advice for BC Pacific Herring: 2014 Status and 2015 Forecast

September 3-4, 2014
Nanaimo, British Columbia

Chairpersons: Sean MacConnachie and Linnea Flostrand
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March 2015

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1701-1280

Correct citation for this publication:

DFO. 2015. Proceedings of the Pacific regional peer review on Stock Assessment and Management Advice for BC Pacific Herring: 2014 Status and 2015 Forecast; September 3-4, 2014. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2015/006.

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SUMMARY

These proceedings summarize the relevant discussions and key conclusions that resulted from a Fisheries and Oceans Canada (DFO), Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting on September 3rd and 4th 2014 at the Pacific Biological Station in Nanaimo, BC. One working paper was presented for peer review that assessed the current status of the five major and two minor herring stocks in BC in 2014 and forecasted pre-fishery biomass for 2015 by stock area. In following with the request for science advice, the assessment paper:

1) included trends in herring biomass, depletion, and recruitment for each major and minor stock;
2) assessed the current status of Pacific Herring for each of the five major and two minor stocks relative to estimates of unfished spawning biomass (SB_0); and
3) evaluated the consequences of different total allowable catch levels against probabilistic metrics to account for uncertainty in the advice.

The paper also included information to address the request for advice regarding:

1) the application of the historical assessment method and management procedure (pre 2011 assumption of q=1 and use of fixed commercial fishery cutoff) and,
2) a preliminary evaluation of reductions in fishery-independent survey frequency.

A Science Advisory Report was developed to provide science advice (compliant with the DFO fishery decision-making framework) and probabilistic outcomes concerning harvest options for each major and minor herring stock in BC.

Staff from DFO Ecosystems and Oceans Science and Ecosystems and Fisheries Management Sectors, and representatives from First Nations, commercial and recreational fishing sectors, non-governmental organizations, and academia participated in the meeting either in person or remotely via webinar.

The conclusions and guidance resulting from this review was provided in the form of a Science Advisory Report (SAR) to inform the application of the BC herring management framework and the development of the 2015 Integrated Fisheries Management Plan (IFMP). The Science Advisory Report and the Research Document will be made publicly available on the CSAS Science Advisory Schedule.

Compte rendu de la réunion d'examen régionale du Pacifique pour l'Évaluation des stocks et conseils de gestion pour la pêche au hareng du Pacifique en Colombie-Britannique: évaluation de 2014 et prévisions pour 2015

SOMMAIRE

Le présent compte rendu résume l'essentiel des discussions et des conclusions de la réunion régionale de consultation du Secrétariat canadien de consultation scientifique (SCCS) de Pêches et Océans Canada qui a eu lieu les 3 et 4 septembre 2014 à la Station biologique du Pacifique de Nanaimo, en Colombie-Britannique. Un document de travail qui comportait une évaluation de l'état actuel des cinq stocks principaux et des deux stocks secondaires de hareng en Colombie-Britannique en 2014 ainsi que des prévisions de la biomasse avant la pêche pour 2015, par zone de stock, a été présenté aux fins d'examen par les pairs. Pour donner suite à la demande d'avis scientifique, le document d'évaluation :

1) incluait les tendances actuelles en ce qui a trait à la biomasse du hareng, à l'épuisement des stocks et au recrutement pour chaque stock principal et secondaire;
2) présentait une évaluation de l'état actuel du hareng du Pacifique pour chacune des cinq zones principales et des deux zones secondaires du stock concernant les estimations de la biomasse non exploitée du stock reproducteur (BSR_0); et
3) et comportait une évaluation des conséquences de différents niveaux de total autorisé des captures par rapport à des paramètres probabilistes afin de tenir compte de l'incertitude dans l'avis.

Le document fournissait également des renseignements visant à répondre à la demande d'avis concernant :

1) l'application de la méthode d'évaluation et de la procédure de gestion historiques (hypothèse d'avant 2011 selon laquelle q=1 et utilisation d'un seuil fixe pour les pêches commerciales); et
2) une évaluation préliminaire des réductions de la fréquence des relevés indépendants de la pêche.

Un avis scientifique (conforme au Cadre décisionnel pour les pêches du MPO) a été élaboré afin, notamment, de fournir des résultats probabilistes concernant les options de prélèvement pour chaque stock de hareng principal et secondaire en Colombie-Britannique.

Le personnel du Secteur des sciences des écosystèmes et des océans et du Secteur de la gestion des écosystèmes et des pêches du MPO ainsi que des représentants des Premières Nations, des secteurs de la pêche commerciale et récréative, des organisations non gouvernementales et du milieu universitaire ont participé à la réunion soit en personne, soit à distance grâce à un webinaire.

Les conclusions et les conseils découlant de cet examen ont été présentés sous la forme d'un avis scientifique (AS) qui servira à orienter l'application du cadre de gestion du hareng de la C.-B. et l'élaboration du plan de gestion intégrée des pêches (PGIP) pour 2015. L'avis scientifique et le document de recherche à l'appui seront rendus publics dans le calendrier des avis scientifiques du SCCS.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS), Regional Peer Review (RPR) meeting was held on September 3rd and 4th, 2014 at the Pacific Biological Station in Nanaimo to review an assessment of the current status of the five major and two minor Pacific Herring (*Clupea pallasi*) stocks in British Columbia in 2014 and projected spawning biomass for each stock in 2015. Sean MacConnachie was the lead Chair for the meeting, assisted by Linnea Flostrand. Lesley MacDougall helped lead discussion related to developing the SAR.

The Terms of Reference (TOR) for the science review (Appendix A) were developed in response to a request for science advice from DFO Ecosystems and Fisheries Management. Notification of the science review and conditions for participation were sent to representatives with relevant expertise within DFO Pacific Region and First Nations, the Government of British Columbia, commercial and recreational fishing sectors, non-governmental organizations, and academia (Appendix B).

Sean MacConnachie welcomed participants and invited them to introduce themselves and give their affiliation. Sheena Majewski and Linnea Flostrand were identified as rapporteurs and tasked with drafting these proceedings. The Chair reviewed the role of CSAS in the provision of peer-reviewed advice, and gave a general overview of the CSAS process. The Chair discussed the role of participants, the purpose of the various RPR publications (Science Advisory Report, Proceedings, and Research Document), and the definition and process around achieving consensus decisions and advice, noting that the meeting was a science review and not a consultation. The Chair reviewed the Terms of Reference for the meeting and a revised Agenda (Appendix C). It was confirmed that copies of the Terms of Reference, working paper, and a meeting agenda had been distributed to participants prior to the meeting.

The following working paper (WP) was prepared and made available to meeting participants prior to the meeting (Appendix D):

> Stock Assessment and Management Advice for British Columbia Pacific Herring Stocks: 2014 Status and 2015 Forecasts by Jaclyn Cleary and Nathan Taylor (CSAP WP2014-PEL02/04);

All participants were invited to join fully in the discussion and to contribute their knowledge to the process, including the development of the SAR on day 2, with the goal of delivering scientifically defensible conclusions and advice. Participants were reminded that everyone at the meeting had equal standing and that they were expected to contribute to the review process, if they had information or questions relevant to the paper being discussed.

A written review of the working paper was provided by Ole Shelton (Appendix E). The goal of soliciting the review was to inform, but not limit, discussion by participants attending the review. Copies of the written review were made available to participants prior to the meeting.

The conclusions and advice resulting from this review will be provided in the form of a SAR, used in the development of the 2015 Integrated Fisheries Management Plan (IFMP) for BC Pacific Herring stocks. The SAR and the supporting Research Document will be made publicly available on the CSAS Science Advisory website.

HERRING MANAGEMENT OVERVIEW

Paul Ryall provided an overview on Pacific Herring fisheries management, which included:

- Role of Fisheries Management (i.e. DFO mandates and polices, science request, consultations on harvest issues, IFMP development, fishery governance)
- Resource Management objectives (i.e. conservation and sustainability, ecosystem processes, harvest opportunities, transparent consultation).
- Harvest planning cycle (annual schedule and order of key meeting and transmission of information)
- How harvest control rule and decision tables relate to science advice.
- Determination of harvest levels. Last year was the first year decision tables were used at P= 50%; metrics of risk tolerance may develop over time; there is a need to develop objectives for evaluating management procedures.
- 2014/2015 Pacific Herring fishery planning and dates (CSAS review, Herring Industry Advisory Board, First Nations meetings, Integrated Herring Harvest Planning Committee, and the development and approval of management plan)

HERRING SCIENCE OVERVIEW

Nathan Taylor presented information on the evolving context around Pacific Herring science, including:

- Background on how stock assessments work, how uncertainty and assumptions can evolve over time,
- Key elements of how stock assessment and management procedures are integrated for decision making,
- Background on the development of the current herring harvest control rule (stemming from work by Hall et al 1988), including goals and assumptions upon which the herring management procedures were originally based (tested on Strait of Georgia but applied to all areas),
- Application of the herring management procedure to date; apparent departures from assumptions associated with this earlier work; the realized proportion of closed years (1986-2013) has been higher than was predicted in initial development of management procedure,
- Unanticipated effects of changes in size and age and natural mortality,
- A rudimentary basis for developing stock assessment parameters and estimates with time series data to demonstrate impacts of changes in size at age and natural mortality on estimates of unfished biomass,
- Reasons why there is a need to evaluate past and future potential management procedures (reduced assessment resources, changes in size at age and natural mortality, objectives),
- Identification of some other herring science activities outside DFO (NSERC Strategic grant, SFU Herring School, Canadian Fisheries Research Network, Ocean Tipping Points, DFO's nascent ecosystem modeling initiative),
- Possible next steps in DFO herring science planning, (Long term - using output from ecosystem models. Medium term – spring herring symposium, spring CSAS, explore candidate limit and target reference points, performance of current and alternative management procedures).

REVIEW OF BC PACIFIC HERRING STOCK ASSESSMENT AND MANAGEMENT ADVICE

Working Paper: Stock Assessment and Management Advice for the British Columbia Herring Stocks: 2014 Assessment and 2015 Forecasts by Jaclyn Cleary and Nathan Taylor. WP2014-PEL02/04

Presenter: Jaclyn Cleary

Formal reviewer: Ole Shelton

Rapporteurs: Sheena Majewski and Linnea Flostrand

PRESENTATION OF WORKING PAPER- BASE MODEL

The lead author briefly reviewed sources of data (commercial catch, biological catch samples and spawn surveys) for the assessment and data issues (resolved and unresolved). The history and structure of the catch-age model was described including: long term evolution and recent updates; modeled phases and steps that occur throughout a model year; a list of model assumptions; model fitting associated with objectives functions, and how uncertainty is captured and propagated to results. Summaries of data trends, spawn survey model fits and assessment model time series results (age 2 recruits, spawning biomass, instantaneous natural mortality and depletion) were presented by major stock area with 2015 biomass projections based on 0 catch. Two 2014 sampling issues associated with data quality were pointed out:

1) an unusually large contribution of CC biological samples from Area 08 that potentially resulted in overly optimistic model estimates of recruitment, and
2) in the last 2 years there has been low biological sampling coverage on the WCVI (four samples in 2014, five in 2013).

The presentation included, but was not limited to the following summary points:

Major stocks:

- Increase in spawn index for SOG (large amount) and WCVI (small amount)
- Decline in spawn index for HG, PRD, CC
- Declining mean weight at age since the 1980s; recent (2-5 years) leveling off
- Decline in model estimates of natural mortality in recent (~10 years) and steeper declines for HG, CC, WCVI (early 2000s-present) relative to other stocks
- Apparent increase in M in recent 3-years as HG stock biomass declines
- Greater uncertainty in most recent years (all major stocks)
- Spawning stock biomass
  - HG, PRD: median estimates of spawning biomass declined from 2013 to 2014
  - CC, SOG, WCVI: median estimates of spawning biomass increased from 2013 to 2014
- Projections
  - HG, PRD: Median estimates of projected spawning biomass in 2015 (given zero catch) are lower than SB_{2014} levels
  - CC, SOG: Median estimates of projected spawning biomass in 2015 (given zero catch) are similar to SB_{2014} levels
  - WCVI: Median estimates of projected spawning biomass in 2015 (given zero catch) are higher than SB_{2014} levels

Minor stocks:

- Area 2W: decrease in spawn index since 2009, median estimate of projected biomass in 2015 (given zero catch) is similar to SB_{2014} levels
- Area 27: slight increase in spawn index from 2013, median estimate of projected biomass in 2015 (given zero catch) is similar to SB_{2014} levels

A description of how to interpret catch stream decision tables was provided.

Following the authors' presentation, points of clarification arose which led to topics for discussion.

- Clarity was sought on whether annual estimates of spawn survey observation error were propagated into model uncertainty. The answer was no.
- It was asked how well the catch is resolved to stock areas for different fisheries. The answer was that efforts have been made to ensure data was resolved to the right areas (based on fish slips etc.) but some uncertainty remains for data during the reduction fishery, although model fits look reasonable. Also, sensitivity cases were ran in an earlier assessment that truncated reduction period and results showed little effect on the most recent biomass estimates.
- It was clarified that the relative size of circles in the plots showing proportion at age from biological samples (1972-2014) are relative to a single sample year, such that sizes of circles are not directly comparable between years. It was asked why there is a break in the confidence interval polygon around 1979 age compositions (HG, PRD). Upon inspection, the answer was that the size of the circles representing age 3 sample compositions was larger than the confidence intervals, thus preventing the interval from being seen.
- The author clarified that the model collectively fits the seine test fishery and commercial seine data as one data set (same gear). It was pointed out that in some years the test fishery samples occur from a wider seasonal time span than commercial seine samples but regardless they are treated as equivalent in model. The author pointed out that, in the past, this has been examined and there was not a big difference in the size or age distribution of the fish between these two types of samples.
- It was asked what age data informs time varying M (natural mortality) when there are no catch sample data (such as years <1972 when no fishery and biological sampling occurred in HG and perhaps other stocks). Authors acknowledged that the paper lacked a description to explain this and stated they will look into and respond later in the meeting.
- A participant asked what annual component of M is used in making biomass projections (related to the mean M of last 5 years). Is it for partial year ending after spawning (i.e. May) or to end of the model year (i.e. June 30)? Authors answered that M used for making projections is for end of the model year.
- It was noted that there are some similar trends between PRD and HG stocks and that movement between stocks may be reflected in M. Concern was also expressed about the validity of having most test fishing samples from outside the PRD areas where most spawning and commercial fishing has been recently occurring. The author pointed out that, in the past, they investigated the effects of splitting PRD samples from the two areas (listed in WP Appendix F).
- The author described the concern with the 2014 CC biological sampling coverage. The CC includes Areas 06, 07 and 08 but in the previous 20 years, on average, only 7% of the samples have been from Area 08 whereas in 2014, 46% of the samples (6 out of 13) were from Area 08 due to additional resources being available in Area 08 to collect samples. The authors were not aware of the anomalous increase in samples from Area 08 until after the assessment was conducted and a CC Fishery Manager pointed out the issue. Area 08

samples had considerably different age compositions than those from Areas 6 and 7: Area 08 samples had 20% age 2 and 27% age 3 compared to Areas 6 and 7 samples that had 9% age 2 and 14% age 3. Also, the average size-at-age of fish from Area 08 was smaller. The inclusion of all Area 8 samples (with equal statistical weighting as other samples) resulted in a higher prediction of recruitment and a larger 2015 biomass projection. The author demonstrated the effect by showing assessment results that omitted Area 08 samples.

FORMAL REVIEW- BASE MODEL

The reviewer concluded that the stock assessment has reasonable assumptions and methods. He reiterated several points made in the written review and stated others. He provided several examples of where biological rationale associated with assumptions would benefit the model description, such as why a random walk of estimating a time series of natural mortality was used (i.e. instead of hierarchical approach), and biological justification for assessing 7 stock areas. He indicated a random walk process would allow M to be influenced by fishing mortality that has not been taken into account. The authors agreed and indicated they can include more rationale for the selection of methods in a revision. Past work could be cited which had bearing on the current use of a random walk approach (i.e. Fu et al. 2004).

The reviewer also suggested the report could include some discussion of how results from the different stocks could be linked and he noted that research to explore questions of stock structure don't always need to rely on tagging data – morphometrics and other indicators could be used. It was recognized that this is a complex question in herring biology that could be discussed at the spring workshop.

The reviewer indicated that the current stock recruitment curves are not informative and may not be the best relationship to use and he suggested that something other than biomass as the predictor (x-axis) be explored (i.e. number of eggs deposited) to increase value of these curves. Authors acknowledged this could be considered in future work.

The reviewer stated that the uncertainty associated with the spawn index sampling should be included to give some indication of how informative the survey data are between years. This led to some discussion on the difficulties of deriving estimates of uncertainty based on spawn survey sampling design (i.e. not a random or systematic design), however, the reviewer thought some type of uncertainty measure could be derived for this purpose, such as an unconventional approach, which there are examples of in the literature. Although the model estimates uncertainty associated with assigning relative weights to data sets, this is not the same as using data to estimate variance and observation error and the reviewer believes data derived estimates need to be explored. There was consensus that future work could investigate possible methods of characterizing spawn survey uncertainty.

The reviewer asked if the spawn coefficient (q) information could be shared between stocks and questioned why estimates of q are estimated separately and why estimates are so different between stocks (i.e. WP Fig E.7). He suggested that if there is rationale for estimating them separately then the paper should include this (based on habitat etc). It was agreed that the authors would provide more background on this in the revisions.

The reviewer inquired about the contribution of the different data components to the model results. For example, what is lost if you drop information regarding age composition data from the stock assessment model? The authors responded with a figure showing different spawning biomass results for WCVI and PRD when age composition is removed from model. Further work to explore the contribution of different data sets was suggested, such as exploring effects on natural mortality estimates when different sets of age composition data are excluded. Results could be presented as predicted versus observed responses in a histogram.

The reviewer suggested including a description of the rationale for the selection of priors for q and wondered whether effects of priors are appropriate. The authors agreed to include a description of this in a revision of the paper and they responded by comparing results for HG and SOG, based on inclusion versus exclusion of q prior information.

The authors clarified the retrospective plots in the WP Figure 25 that show estimates of past spawning biomass (based on the sequential annual removal of data). The reviewer was suggesting that since science advice is forecast based, that a revised paper includes another set of figures showing retrospective changes to subsequent season projections given 0 catch. **The authors agreed to investigate this.**

GENERAL DISCUSSION- BASE MODEL

The selection and use of the fixed maturity schedule across all stocks was discussed. There is currently a lack of information to inform the development of alternative maturity schedules. How would histological samples be collected and used? No archived histological samples are available to study this. Could maturity be linked to weight at age? Sampling bias can confound the reliability of data because most fish sampled are associated with a spawning season (including pre-season migrations). It is difficult to get samples of non-gravid fish. It was also suggested that male to female ratios at spawning time could be examined as a possible influence on biomass. An editorial point was made to remove an obsolete maturity input vector that was identified on page 50 of WP. Authors will delete this from the input file during revision.

There was discussion about what enabled the SOG stock to remain strong for many years compared to other stocks. It was suggested that it may be worthwhile to see if there are other populations in the world that show consistent strong year classes.

It was asked whether increases in Food and Bait samples in the SOG result in immature fish being removed first. The response was that fish size distributions were compared between SOG Food and Bait (seine) samples and roe seine samples and there was no evidence to suggest Food and Bait fish were smaller. Additional work could include comparisons of maturity (relative gonad development) between Food and Bait (i.e. November) and spring samples.

It was suggested that the paper needs more Bayesian diagnostics to examine convergence or correlations between parameters. Plots of the diagnostics were omitted in WP since they drastically increase file size and have complicated downloading the WP for meeting participants. These diagnostics have been done and all or some (mortality and recruitment etc) can be included in a revised working paper appendix.

In the revised paper, it was suggested to include the rationale on the selection of priors and the use of lognormal versus a normal distribution for M. There was some discussion on whether bounds of a lognormal distribution for M (especially upper bound or tail) versus a normal distribution would make a difference. Another suggestion was to examine the sensitivity of results to different priors. The authors responded that the reason for the selection of current methods was based on past work and that they can include some rationale in their revisions.

To clarify the spawn survey indices, the authors confirmed that some surface survey data (>1988) are adjusted so that the average spawn width estimates are comparable to data from dive surveys (WP p.103 Table B.2). It was suggested that a more detailed explanation about this be included in a revised paper and authors agreed to this**.** Concern was expressed regarding the effects of preprocessing surface spawn data. There was some discussion around alternative modeling which could have two separate spawn indices across the entire time series by stock rather than splitting the time series at 1988. **Recommendation: evaluate the legitimacy of preprocessing surface spawn survey data and having two q's.**

It was asked what alternatives are available to address small sample sizes from the WCVI, (i.e. n=4 in 2014, n=5 in 2013)? The authors showed that averages of historically collected data could be used to represent proportions at age and size.

A participant voiced concern over the validity of a biological sample collected in Area 24 in the WCVI in 2014. This participant advised authors to look into how this sample was collected because this sample may not be representative. The participant also voiced concern that on-the-grounds observations made by fishers and fisheries staff associated with the Nuu-chah-nuth Tribal Council indicated lower levels of spawning compared to assessment model results. Authors stated they would to look into how the Area 24 sample was collected.

There was a question on how informative the prior for q is and the effects of adjusting it. The response was that the prior is very informative and adjusting it could adjust everything (SB, SB_0, mortality etc.).

There was discussion about the assessment's use of estimates of instantaneous natural mortality M, representing the end of a model year, in making projections. The authors acknowledged this would introduce a bias effect in projections since spawning season is before end of model year (June 30) and would cause lower SB projections. The authors acknowledged that the paper lacks a description of what is being done for projections and agreed to improve this in a revision. The authors warned that before trying to fix this in isolation they would want a better understanding of how natural mortality works. There are other and possibly larger issues related to representing natural and fishery mortality throughout a year that have previously been identified, related to modeling fishery and natural mortality simultaneously versus discretely and sequentially throughout a model year. It was also noted that changes to annual mortality are confounded with fish growth and size at age and there are fishery data limitations that would need to be addressed (SOK, FSC, fisheries overlapping in time, reduction period etc). **Recommendation: explore methods of representing mortality that is consistent with how the model applies mortality throughout the time series**. In addition, there could be sequential modeling of fishing mortality (such as using discrete mid or end of year fishing mortality with respect to different fishing gears/ seasons) versus instantaneous rates. Natural mortality could also be partitioned within a year.

The source of biological samples from the CC in 2014 and the possible over-representation of Area 08 was discussed. There was concern that there is not enough known about CC herring to support science and fishery management decisions (uncertainty about mixing/movement and spawning patterns etc). It was asked whether it is useful to include data from Area 08 if the area has not been commercially fished in about 20 years. There was concern that omitting or down weighting Area 08 samples would result in biasing the data. There is a need to consider this case in broader context of sampling design since similar issues occur in other regions and maintaining consistency in the future with reduced funding sources will be difficult. The decision to omit or statistically re-weight sample data should be based on first principles not on results. The authors suggested there are grounds for reducing the 2014 Area 08 sample representation since a distinct change in sampling protocol for other research initiatives did result in the acquisition of a relatively large number of (opportunistic) samples (i.e. Hakai Institute). **Based on the rationale provided by the authors (that a distinct change in CC sampling protocol occurred in 2014) and to be more consistent with past sampling protocols, it was decided that the revised paper will include results based on re-weighting the CC sample data so that Area 08 samples (n=6) represent 7% of the age composition data. It was also recommended that sample protocols are followed to avoid the collection of ad hoc or opportunistic samples.** Future work could include investigating the age structure of samples collected in Area 08 compared to other CC sources.

Discussion focused on age data that informs time varying M. For example, in some years prior to 1972 when no fishery and biological sampling occurred on HG and other stocks, there were

no catch sample data available. The authors explained that prior to 1972 for the HG stock, natural mortality was fit with a cubic spline over several nodes (12) and the number of nodes can be varied. F**urther research is needed to identify causes of the apparent pattern in natural mortality in the post-reduction fishery period. It was also agreed the revised working paper would include a description of the methods undertaken to characterize mortality during the earlier years without age composition data (i.e., cubic spline used to interpolate for years where there is no data).**

As an additional way to track the variability in estimates of natural mortality over time, a request was made to include output showing trends in relative changes across the time series. Authors agreed to consider this when making revisions.

PRESENTATION OF WORKING PAPER- SENSITIVITY CASES

The lead author presented information for sensitivity cases (summaries below). One case compared the results of the base model to a model designed with a fixed spawn index coefficient equal to 1 (q=1), which assumes all spawn is observed and measured (also referred to as the historical procedure). The other sensitivity case compared results of reducing the survey frequency to every two years.

Base model versus historical procedure (q=1, fixed cutoff)

Results (i.e. SB_t, SB_{2015}, SB_0) from both modeling procedures were generated for the major stock areas and 2015 decision tables were also presented and included: performance measures and side by side decision tables associated with stock specific fixed cutoff amounts (defined in 1996), and model specific estimates of $0.25SB_0$, and projected 2015 harvest rates (U'_{2015}). Updated estimates of SB_0 declined over time due to declines in weight-at-age and changes in natural mortality estimates. For all stocks, the base model produced higher estimates of spawning biomass (i.e. SB_t, SB_{2014} and stock status) and higher median estimates of B_0 (except the PRD).

The author clarified that the "historical" management procedures include a fixed q (q=1) and fixed cutoffs in the major stock areas. The current paper does not exactly represent historical cases used for forecasting recruitment (the poor, average and good -PAG categorical method). The historical procedure produced lower estimates of stock status with a narrower range of uncertainty. The Base case produced higher median estimates of B_0 (except for PRD).

In the decision tables from the historic case, projected SB_{2015} for all stocks would be greater than historical fixed cutoffs with at least 50% probability, except for HG. For the same catch level, results of the historical procedure indicate a higher probability of being below the fixed cutoff for all stocks except PRD. For all stock areas the probability of exceeding the target HR (10 or 20%) is consistently higher using the historical procedure.

Reduced data frequency

The reduced data frequency scenarios explored the question: "What would have happened last year (in the assessment results) without the 2013 spawn index?" Estimates of SB_{2013} and 1-yr projections of SB_{2014} with and without the 2013 survey data (spawn index) were compared. In the CC, SOG, and WCVI areas, the survey index was greater in 2013 than in 2012. Removal of the 2013 survey index resulted in 52%, 38% and 28% reduction in median estimates of SB_{2013} for CC, SOG, and WCVI, respectively. The median estimate of SB_{2013} was marginally greater for HG and 24% lower for PRD. This analysis sheds some light on relative consequences of reductions in survey frequency for rebuilding stocks, such as HG, CC, WCVI, which have been closed for majority of past 10-yrs. Predictions would have been less optimistic for these stocks in 2014 without the 2013 data. Limitations were identified:

- there is no predictive information about directionality (increases or decreases) of biomass projections 'with' and 'without' the most recent year of survey data (retrospective errors don't occur in a consistent direction each year),
- the 'decision making behaviour' made in the absence of survey data cannot be captured,
- using an assessment model to assess the average performance of a management procedure is not a useful approach. Closed-loop feedback simulations are needed for this.

Another part of the reduced data frequency scenarios was to explore the effect of having biennial spawn survey coverage during the last 10 years, encompassing two abrupt changes detected by annual surveys: 2005 to 2006 (large decrease), and 2012 to 2013 (large increase). General trends in the results included systematic under-estimation in spawning biomass when there was an "increasing trend" in the survey index and systematic over-estimation in spawning biomass when there was a "decreasing trend" in the survey index. Authors acknowledge this analysis may be limited by the intentional selection of segments of time series with "abrupt changes". Limitations identified included:

- it is not known how different historical decisions, given a 'non-survey year', would have affected the stock (i.e. upward or downward adjustments of quota in response to + or – retrospective biases)
- using an assessment model to characterize retrospective biases for predictive purposes is risky because errors can reverse without warning. Closed-loop feedback simulations should be used instead.

FORMAL REVIEW AND DISCUSSION- SENSITIVITY CASES

Base model versus historical procedure (q=1, fixed cutoff)

There was discussion regarding what q actually represents and how it relates to spawn indices. It was explained there are regular meetings with contract dive teams and managers so they are aware of spawns that may be been missed. This is usually mitigated with surface surveys, but that information is not used to inform q.

The rationale for comparing the base case with the historical procedure was discussed. This work was included to demonstrate the consequences of assessment model changes in 2011. The best way to estimate q and its use in annual stock assessments was discussed. There has been general agreement that q should not be 1 and one suggestion was that perhaps management can consider this in the risk tolerance and decision tables. FAM noted that field observations do not reflect assessment results. Science advice from multiple models is not uncommon (i.e. past herring escapement model, halibut). It was noted that perhaps the overlap between results of the historical and base case distributions could be of interest when comparing harvest metrics. In the revised paper, the authors were asked to clarify that the historical procedure was a variant of what was done (i.e. Poor, Average, Good recruitment forecasting categories were not represented in sensitivity cases). There was general agreement that the intention of the work was not to go back to the historical methods and past cutoffs but that comparisons are useful for fishery managers.

Reduced data frequency

The reviewer expressed concern with reducing data frequency for short lived species and advises against it if possible. He stated that a sensitivity case that drops out more years over a longer time series is more informative than dropping out years known to be associated with large (extreme) changes in observed biomass. If the question is how best to quantify how much worse the predictions will be by removing data, there are others ways of doing this than treating the results of the full time series as "true". Model performance can be shown by retrospective plots (i.e. such as used for CC reduced data frequency work over longer time period) and

sequential predictions are useful. Projections, predictive distributions for biomass, and age structure etc. can be used to see what happens if you use data up to a given year and have to project beyond one year (i.e. up to 2004 to predict to 2006).

There was some discussion on whether closed loop simulation work is required to properly evaluate the effects on advice of reducing sampling frequency. If there is an evaluation of the loss of yield over time, then there is a case for applying closed loop simulations. The reviewer voiced concern, however, since closed-loop simulations would rely on the belief that the base generating-model is correct, so limitations of this approach should be considered and compared with alternative approaches.

The biennial survey work done for the CC only showed effects of removing spawn survey data. There was a sense that this work (i.e. on one stock and one data set) didn't provide enough guidance to managers to evaluate the effect of reducing the frequency data acquisition. One suggestion was that the SOG would be a good candidate to continue this work since there is more data. Future work also could consider unfished areas to see whether this results in contradictory advice. Decision tables could be created to compare different risk thresholds.

Given concerns of reductions in resources for data acquisition, there was consensus that further discussion and planning is required to examine less expensive ways of acquiring data annually.

CONCLUSIONS

A template for developing the SAR was prepared and projected for all to see. The main sections of the template were briefly described in terms of format and purpose. Concern was expressed that participation at the meeting and the definition of consensus could have legal implications. It was clarified that does not mean that every participant is assumed to agree fully with everything discussed or with the conclusions and recommendations derived from the meeting. The Chair reviewed the process of capturing advice in the SAR as it relates to sources of uncertainty, recommended future work, working paper caveats or changes.

Fishery managers would like other performance metric output associated with other ranges in catch streams that they had yet to identify for the authors. Since this would not entail model changes the group endorsed this.

It was asked whether decision tables from the sensitivity cases should be included in the SAR. A suggestion was made to exclude the decision tables from sensitivity cases in the SAR but to include text describing the sensitivity cases, their trends and their association with uncertainty, conclusions and recommendations etc. This would be done to minimize the sets of results presented to avoid a lengthy and cumbersome SAR. There was consensus on this point and it was decided that this would be done and decision tables included in the SAR would only be from base model results, which would include results from re-weighting 2014 CC biological data.

It was recommended that the IFMP include the same decision tables if possible for consistency.

It was suggested that context and results associated with both types of sensitivity cases (historical versus base and reduced sample data frequency versus base) be drafted by authors for inclusion in draft SAR.

It was requested that the SAR capture information about discrepancies and uncertainties associated with comparing historical procedure output (q=1) and its management procedure (1996-2010 cutoffs) versus base case output.

It was proposed and decided that the authors would help draft a list of future work recommendations based on what they included in the WP and what was recommended during the current review, to be circulated in a draft SAR.

It was determined that the revised working paper and the SAR require wording describing the context of the HCR so that readers are more informed on the selection of operational reference points referred to in the documents, including background on how the harvest control rule was developed and current concerns with its use (type of model used in its development, violated assumptions, SOG simulations and performance over time, etc.).

It was pointed out that performance metrics for catch streams are dependent on fishery allocation. If fishery managers are considering different allocation schemes, the model would need to be run to reflect this, which would produce different sets of performance output. It was determined that this point needs to be explained in the SAR and the revised working paper and that each set of decision table output needs to stipulate what allocation scheme is being represented (in a caption or heading), including that SOK allocation and harvest is assumed constant where applicable. A recommendation was also made to include SOK allocation in the preparation of future sets of assessment decision tables.

Wording in the SAR and revised working paper should indicate that the current set of decision tables represent allocations that are status quo examples. By endorsing the working paper, the group concluded that they should not need to review other sets of decision tables resulting from assessment related to other allocation schemes.

It was concluded that for the SAR, wording in the section on “Sources of Uncertainty” should include information identified in the working paper, such as in section 2.5 (unresolved problems/ issues with data) and section 3.4 (unresolved problems/ issues with the assessment model).

Other sources of uncertainty discussed at the meeting to be included in the SAR are:

- Lack of accounting for SOK fishery in assessment methods and results,
- Representativeness of the small WCVI age composition sample size, including the validity of the sample collected in Area 24 in 2014,
- Use of a long term average for q that enables estimates to vary between assessment years with no accounting for sampling uncertainty.

Recruitment and natural mortality are considered to be the most important processes determining the productivity of BC Pacific Herring stocks. Factors driving age-3 recruitment to the spawning biomass, forecasted by the assessment model, are not fully understood. Median (model) estimates of instantaneous natural mortality (*M*) appear to be decreasing in all of the major and minor stock areas, except HG and Area 2W. The reasons for these changes are not clear at present, but are under investigation as natural mortality is an important parameter in the stock assessment model because it affects current stock biomass and also the estimate of the unfished biomass. Long term declines in body size (weight at age) have been observed for all BC herring stocks and some Alaska herring stocks, from the early 1980s-2010 with a levelling off at the low end of the range in most recent year(s) however factors causing these changes are poorly understood. Because of the uncertainty in *M*, stock performance evaluated against a historical biomass level (SB0) that is based on a different value for *M* will also be highly uncertain.

Modelling results reflect only the structural assumptions specified in the model and weights assigned to the various data components, representing a minimum estimate of uncertainty. While uncertainty in the estimated parameters and derived quantities is explicitly addressed using a Bayesian approach alternative model and stock structure assumptions, including alternative forecasting methods, would illustrate greater levels of uncertainty. Moreover, small sample sizes of age-composition samples are a concern in recent years.

There was consensus to accept the working paper with the inclusion of key revisions identified during the review.

It was agreed that the working paper authors and the Chairs will draft a SAR for circulation. The Chairs and rapporteurs will develop proceedings for circulation. These steps will be done as early as possible.

RECOMMENDATIONS AND ADVICE

There was consensus to endorse the results for the 2014 spawning biomass estimates and 2015 forecasts of spawning biomass from the updated herring integrated statistical catch-at-age model (ISCAM).

There was consensus that advice for each Pacific Herring stock be presented in probabilistic decision tables showing predicted status in 2015 given a range of constant catches relative to target harvest rates and performance metrics relating directly to the previously used herring harvest control rule (HCR).

The following future work is recommended:

- Develop survey and sampling protocols to meet current assessment objectives given future potential budgetary constraints. Evaluating alternative program structures and the effects of changes in the monitoring and assessment frequency should be a priority.
- Explore ways to characterize the uncertainty associated with the spawn index data.
- Evaluate the legitimacy of preprocessing surface spawn survey data and having two q's for two separate spawn index time series.
- Identify the cause of the apparent pattern in M during the post reduction fishery period (pre-1972 in Haida Gwaii and in other areas).
- Model the fishing year sequentially from food fishery to the spawning fisheries rather than assuming that all fishing and natural mortality occur simultaneously throughout the year.
- Incorporate sources of fishing mortality not currently captured in ISCAM and explore effects from varying spawn on kelp (SOK) mortality estimates, ideally in association with acquiring accurate SOK fishery data.
- Investigate alternative formulations for reference points that are independent of the biological variations that appear to have occurred in this species so that management strategies can be more easily evaluated.
- Develop closed loop models for feedback simulations and sensitivity cases to test the effectiveness of existing and alternative management strategies.

ACKNOWLEGEMENTS

The Chairs thank the reviewer, Ole Shelton for his expertise and valuable review of the working paper and all of the participants for their constructive engagement in the science review process at this meeting. Sheena Majewski is thanked for being a rapporteur. Lesley MacDougall's assistance in helping lead discussion on information to include in the SAR is greatly appreciated as is Ann Mariscak's assistance in providing meeting logistics support.

REFERENCES

Fu, C., Schweigert, J., and Wood, C.C. 2004. An evaluation of alternative age-structured models for risk assessment of Pacific herring stocks in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/011. ii + 55 p. (Accessed February 16, 2015)

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APPENDIX A: TERMS OF REFERENCE

Stock Assessment and Management Advice for BC Pacific Herring: 2014 Status and 2015 Forecast

Regional Peer Review – Pacific Region

September 3-4, 2014
Nanaimo, BC

Chairperson: Sean MacConnachie

Context

Pacific herring is a pelagic species inhabiting inshore and offshore waters of the North Pacific from California to the Beaufort Sea. Herring annually migrate between feeding and spawning areas. Commercial fishing for British Columbia herring stocks is managed based on five major and two minor stock management areas consisting of Haida Gwaii (Area 2E), Prince Rupert District, Central Coast, Strait of Georgia, and West Coast of Vancouver Island (WCVI). The two minor herring stock management areas are Haida Gwaii Area 2W and WCVI Area 27.

The assessment of current Pacific herring abundance and forecasts has been generated annually since the late-1980s, for each of the five major and two minor stocks in British Columbia, utilizing a statistical catch–age-model since 2006. The model is fitted to commercial catch, proportions-at-age and fishery-independent survey data (spawn index) to estimate biomass and recruitment and generate 1-year forecasts of spawning biomass (Martell et al, 2012; DFO 2013).

Fishery-independent survey (spawn index) and biological sampling has been conducted annually since 1951. Recent adjustments in the structure and available funding for these programs have raised concern that these changes could have impacts on the model outputs and the quality of stock assessment advice.

Fisheries and Oceans Canada (DFO) Pacific Fisheries Management Branch has requested that DFO Pacific Science Branch assess the status of B.C. herring stocks in 2014, and provide projections of potential herring abundance in 2015 and the consequences of a range of potential harvests to inform the development of the 2015 Integrated Fisheries Management Plan (IFMP).

In addition, Fisheries Management and Science Branch has requested an evaluation of the consequences of reduced fishery-independent surveys (spawn index) and biological sampling to inform future stock assessment program planning. Reviewing possible approaches to respond to this need, it has been determined that a comprehensive simulation approach to this evaluation would be ideal. However, for this RPR there are only resources and time to prepare a preliminary evaluation.

Objectives

Guided by the DFO Fishery Decision-making Framework Incorporating the Precautionary Approach (DFO 2009) under the Sustainable Fisheries Framework, RPR participants will review the following working paper to provide the basis for discussion and advice on the specific objectives outlined below.

> Cleary J. and N. Taylor. Status of B.C. Pacific Herring (*Clupea pallasii*) stocks in 2014 and forecasts for 2015. CSAP Working Paper 2014-15/ PEL02+PEL04. (final authorship TBC).

1. Present trends in herring biomass, depletion, and recruitment for each major and minor stocks;

2. Assess the current status of Pacific Herring for each of the five major and two minor stocks relative to historical control points (25% B_0), including a sensitivity case using pre 2011 methods (i.e. fixed cut-off levels and q=1);
3. Evaluate the consequences (including potential risk of exceeding harvest rates prescribed by the current harvest control rules) of different total allowable catch levels for 2015 against probabilistic metrics to accommodate uncertainty in the advice. Results will be presented in the form of decision tables.
4. Conduct a preliminary evaluation of the consequences of reduced fishery-independent surveys (spawn index) and biological sampling frequency on the precision of herring biomass, depletion, and recruitment estimates for each of the five major stock areas. This preliminary evaluation will be based on the following analyses:
    a. Estimating the 2013 Pacific Herring biomass for each of the major stocks relative to 25% B_0 with and without the inclusion of the 2013 spawn and biosampling data.
    b. Comparing the probabilistic metrics of different total allowable catch levels produced in 2013 (for 2014) using and excluding 2013 data.
    c. A retrospective analysis for one stock area (Central Coast), leaving out every second year of data for a 10-year period.

Expected publications

- CSAS Proceedings (1)
- CSAS Science Advisory Report (1)
- CSAS Research Document (1)

Participation

- DFO Science Branch
- DFO Fisheries Management Branch
- BC Provincial government representation
- Commercial and recreational fishing interests
- First Nations organizations
- Non-government organizations
- Academia

References Cited and Additional Information

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach.

DFO. 2012a. A review of the Pacific herring assessment framework and stock assessment and management advice for Pacific herring 2011 status and 2012 forecasts, September 7-9, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser.2011/062.

DFO 2012. Proceedings on the Regional Peer Review of the Evaluation of Data and Model Assumptions on the Calculation of Management Parameters using the Pacific Herring Assessment Model (ISCAM); June 27 & 28, 2012. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2012/043.

DFO 2013. Proceedings of the Regional Peer Review Meeting of the Stock Assessment and Management Advice for the British Columbia Pacific Herring Stocks: 2012 Status and 2013 Forecasts; September 5 and 6, 2012. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2013/009.

Martell, S.J., Schweigert, J.F., Haist, V., and Cleary, J.S. 2012. Moving towards the sustainable fisheries framework for Pacific herring: data, models, and alternative assumptions; Stock Assessment and Management Advice for the British Columbia Pacific Herring Stocks: 2011 Assessment and 2012 Forecasts. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/136. xii + 151 p.

APPENDIX B: ATTENDEES

Last Name	First Name	Affiliation
Boldt	Jennifer	DFO, Science
Boutillier	Jim	DFO, Science
Brown	Gus	Heiltsuk Tribal Council/GRS Board Member
Cangardel	Agathe	Haida Fisheries Program
Chalmers	Dennis	BC Ministry of Fisheries
Cleary	Jaclyn	DFO, Science
Cox	Sean	Simon Fraser University
Evanson	Melissa	DFO, FAM
Kotyk	Mel	DFO, North Coast
Flostrand	Linnea	DFO, Science
Fort	Charles	DFO, Science
Fu	Caihong	DFO, Science
Gladstone	Keith	Heiltsuk
Goruk	Andrea	DFO, FAM
Hall	Peter	Fisheries Management
Hall	Don	Nuu-chah-nulth Tribal Council
Hay	Doug	DFO Scientist Emeritus
Jones	Russ	Council of Haida Nation - Haida Fisheries Program
Kanno	Roger	Fisheries Management
Kulchyski	Tim	Cowichan Tribes
Kumar	Rajeev	UBC
Lane	Jim	Nuu-chah-nulth Tribal Council
MacConnachie	Sean	DFO, Science
Majewski	Sheena	DFO, Science
McCarter	Bruce	DFO, Science
Mijacika	Lisa	Fisheries Management
Morley	Rob	Canadian Fishing Company
Olson	Andy	Tseshaht First Nation
Ormond	Chad	Q'ul-lhanumutsun Aquatic Resources Society
Rusch	Bryan	DFO, FAM
Rusel	Christa	Atlegay Fisheries Society
Ryall	Paul	Fisheries Management
Safarik	Ed	Herring Conservation and Research Society (HCRS)
Newman	Earl	Heiltsuk First Nation
Schweigert	Jake	DFO, Science
Shelton	Ole	NOAA
Sloan	Norm	Parks Canada
Spence	Brenda	Fisheries Management
Starr	Paul	Herring Conservation and Research Society (HCRS)
Taylor	Nathan	DFO, Science
Thomas	Greg	Exec. Dir. HCRS and Chair of the Herring Industry Advisory Board
Thompson	Matthew	DFO, Science
White	Penny	Central Coast Indigenous Resource Alliance

APPENDIX C: AGENDA

REGIONAL PEER REVIEW MEETING (RPR)

Centre for Science Advice Pacific

Stock Assessment and Management Advice for BC Pacific Herring: 2014 Status and 2015 Forecast

September 3 & 4, 2014

Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC, V9T 6N7

Chairperson: Sean MacConnachie

Agenda		
Wednesday September 3 – Day 1		
09:00	Welcome and Introductions and Housekeeping Items	Sean MacConnachie
09:10	CSAS Overview and Meeting Procedures	Sean MacConnachie
09:20	Terms of Reference	Sean MacConnachie
09:30	Herring management – current status	Paul Ryall
10:00	Current state of science	Nathan Taylor
10:30	***Break***	
10:50	Status of BC Pacific Herring in 2014 and forecasts for 2015 – presentation of working paper key points/highlights • BASE assessment results	Jaclyn Cleary
12:00	***Lunch***	
13:00	Reviewer comments • BASE assessment results	Reviewer: Ole Shelton
13:15	General discussion • BASE assessment results	All Participants
14:00	Presentation of sensitivity analysis • Sensitivity analysis BASE vs Historic MP	Jaclyn Cleary
14:15	Reviewer comments • Sensitivity analysis BASE vs Historic MP	Reviewer: Ole Shelton
14:30	General discussion • Sensitivity analysis BASE vs Historic MP	All Participants
15:00	***Break***	

Agenda		
15:15	Status of BC Pacific Herring in 2014 and forecasts for 2015 – Continued • Survey Frequency Sensitivity Analysis	Jaclyn Cleary
15:30	Reviewer comments • Survey Frequency Sensitivity Analysis	Reviewer: Ole Shelton
15:45	General discussion • Survey Frequency Sensitivity Analysis	All Participants
16:30	***Adjourn***	
Thursday September 4 – Day 2		
09:00	Introductions & Housekeeping	Sean MacConnachie
09:10	Review Day 1 and Agenda for Day 2	Sean MacConnachie
09:30	Continue discussion from Day 1 (if required) Issues • Data • BASE assessment results • Sensitivity analysis BASE vs. historic MP • Survey Frequency • Research recommendations • Unknowns/other considerations	All Participants
10:30	***Break***	
10:45	Continue and wrap-up discussion	All Participants
12:00	***Lunch***	
13:00	Science Advisory Report - Develop Consensus on: • Key results, conclusions and recommendations • Uncertainties • Science Advice • Other	All Participants
14:30	***Break***	
14:45	Science Advisory Report Discussion Continued	All Participants
16:15	Wrap-up, next steps, other business	All Participants
16:30	***Adjournment***	

APPENDIX D: SUMMARY OF THE WORKING PAPER

BC PACIFIC HERRING STOCK ASSESSMENT AND MANAGEMENT ADVICE

Herring stock abundance in BC waters was assessed for 2014 and forecasts were made for 2015 using the integrated statistical catch-age model (ISCAM). BC herring stocks are managed as five major and two minor stock areas and science advice is provided on the same scale. Commercial catch and survey information collected in each area and all biological data on spawn deposition, size and age composition of spawning stocks were used to determine current abundance and forecast future abundance levels. This working paper provides a summary of current stock status in 2014 and forecasts of abundance in 2015 for each stock area as well as probabilistic management advice on harvest options using performance metrics based on the existing herring Harvest Control Rule (HCR). The paper includes information on two types of sensitivity cases that were done. One was to compare the results of the base model to results from a model representing a historical method (q=1, fixed cutoff). The other sensitivity case explored in the paper was to compare results from reducing the frequency of time series input data.

A number of unresolved data and modeling issues, major uncertainties, and research needs are also summarized in the report.

APPENDIX E: WRITTEN REVIEW

Date: August 29, 2014

Reviewer: Andrew Olaf (Ole) Shelton, NOAA, NWFSC, Seattle, WA

CSAS Working Paper: 2014/15

Working Paper Title: Status of B.C. Pacific Herring (*Clupea pallasi*) in 2014 and forecasts for 2015

The main purpose of this working paper is threefold: 1) to update the 2013 stock assessment model for 5 major and two minor herring stocks in British Columbia waters using data from 2014 and make predictions for 2015; 2) assess and compare the current stock assessment methodology and assumptions with historical assumptions about the relationship between the spawn survey index and the true, unobserved spawning biomass (i.e. assumptions about the parameter *q*); and 3) explore the consequences of changing the frequency of survey data collection for assessing current stock status and predicting future stock abundance.

In general, the stock assessment provides a scientific basis for management of herring in BC based on reasonable assumptions and methods. I break my review into four components – 1) addressing the methods in the base assessment 2) comparing current and historical stock assessment methods, 3) comments on the frequency of surveys, and 4) suggesting some future research recommendations**.**

Base model vs. historical assumptions:

This seems like a reasonable assessment of the role assumptions about *q* play in determining both current spawning biomass and historical reference points. It illustrates the complexity of trying to estimate stock depletion when current biomass and unfished biomass are both estimated quantities.

Small comment – I would like some clarification on the explanation of historical vs. base case assessment. Table 11 suggests that *q* is still estimated for the pre-dive survey years but the description on page 29 and 30 seems to suggest q = 1 for the entire series.

Survey Frequency

The assessment of survey frequency seems reasonable in general approach. Given that herring are short lived species with populations strongly driven by recruitment variability, one of the main consequences of not performing annual surveys will be to mis-estimate the number of newly recruiting individuals. In years with a large recruit class, this will lead to underestimating biomass, while in years with a small recruit class, the biomass will be underestimated. Generally, I would guess that reducing survey frequency would result in predictions that next year being more similar to the predictions this year, which seems to be borne out by the results in Fig. 24. However, these two scenarios represent years in which large, unexpected changes happened to the observed data and so should yield large contrasts between data frequency scenarios.

There are a number of formal methods for assessing the predictive accuracy of models. Generally, these use scoring metrics to assess the quality of model predictions. Rather than asking if models that use different frequency of survey data make different median predictions (Fig. 24), it should be possible to formally compare the predictions and observed data from stock assessments that use different sampling frequencies. For example, one could use data from the start of the time series to 2005 to predict 2006 and compare this to a model that uses all data pre-2000 but only biennial surveys after, say, 2000 to predict 2006. This could be repeated for 2007, 2008, etc. to provide a perspective on the predictive quality of each survey

data frequency and the characteristics of assessments under each data type. This would be a fairly complex undertaking that may better be classified under future research.

I would appreciate a more thorough description of the results in Fig. 25. The colors clearly represent assessments that include different ranges of years as data inputs, but I was unclear what is being compared. For example, are the residuals referred to in the text comparing the output from the most recent assessment (2014) to the prediction of stock size in 2005 from the 2004 assessment (see bottom of line 33 and top of page 34)? I think this could be clarified with a sentence or two. It could also be useful to include a figure of the residuals through time in addition to figure 25 to illustrate the magnitude and direction of residuals.

Suggested Research Needs

While it is always possible to improve assessments, the complexity and quantitative nature of the assessment process requires a gradual improvement in methods. I agree with the authors that using management feedback simulations is a reasonable approach. The authors mention both time-varying growth and time-varying mortality. Spatial and/or temporal variation in maturity could confound estimates of both growth and maturity. I would suggest investigations of maturity as a valuable primary point of research.

As noted above, I think evaluating the potential risk associated with moving to biennial surveys is very important as well. I support the inclusion of all estimates of herring mortality from all documented sources (e.g. SOK) in the stock assessment.