Fisheries and Oceans Canada
Canada

Pêches et Océans
Canada

Ecosystems and
Oceans Science

Sciences des écosystèmes
et des océans

Canadian Science Advisory Secretariat (CSAS)

Proceedings Series 2021/044

Pacific Region

Proceedings of the Pacific regional peer review on the Selection and Role of Limit Reference Points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada

February 7-8, 2017
Nanaimo, British Columbia

Chairperson: Linnea Flostrand
Editor: Julia Bradshaw

Fisheries and Oceans Canada
Science Branch
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

January 2022

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
ISBN 978-0-660-40443-1 Cat. No. Fs70-4/2021-044E-PDF

Correct citation for this publication:

DFO. 2022. Proceedings of the Pacific regional peer review on the selection and role of limit reference points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada; February 7-8, 2017. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2021/044.

Aussi disponible en français :

MPO. 2022. Compte rendu de l'examen par les pairs de la région du Pacifique sur la sélection et le rôle des points de référence limites du hareng du Pacifique (Clupea pallasii) en Colombie-Britannique, Canada; 7-8 février 2017. Secr. can. des avis sci. du MPO. Compte rendu. 2021/044.

TABLE OF CONTENTS

SUMMARY

These proceedings summarize the discussions and key conclusions that resulted from a Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting of February 7-8, 2017 held in Nanaimo, British Columbia (BC) to review the Working Paper titled "*The selection and role of limit reference points for Pacific Herring (Clupea pallasii) in British Columbia, Canada*".

In-person and web-based participation included individuals from Fisheries and Oceans Canada (DFO) Science Branch (current and retired employees) and Fisheries Management Branch; individuals representing: First Nations, the Alaska Department of Fish and Game, the commercial fishing sector, academia, and consultants.

The Working Paper presented information pertaining to requirements under the DFO *Decision-Making Framework Incorporating the Precautionary Approach* (DFO 2009) as part of the commitment to renewal of the Pacific Herring management system. Surplus production relationships for the five major stocks of Pacific Herring in relation to spawning stock biomass were evaluated to determine whether there is evidence for stock states that show signs of persistent low production and low biomass that are consistent with signs of possible serious harm. Additionally, a range of theoretical equilibrium reference fishing mortality rates related to the concept of the replacement fishing mortality was investigated along with associated proxies based on maximum sustainable yield, spawning potential ratio and yield-per-recruit. Persistent low production and low biomass states were diagnosed for stocks in the Central Coast (CC), Haida Gwaii (HG), and West Coast (WCVI) major management areas; similar states were not diagnosed for stocks in the Prince Rupert District (PRD) and Strait of Georgia (SOG) management areas. A limit reference point of 0.3 of the unfished spawning biomass ($0.3B_0$) was recommended for stocks in all major management areas based on the upper spawning biomass frontier of the low production, low biomass states for stocks in the CC, HG, and WCVI management areas. This recommendation is conditioned on the assumptions, data, and outputs from current stock assessment models (DFO 2016) and is based on the analysis of production relationships and the policy requirement to position biomass-based limit reference points above states of possible slowly reversible or irreversible serious harm. Limit equilibrium fishing mortality rates based on the concept of replacement fishing mortality could not be recommended because of implausible estimates that were attributed to non-stationarity in natural mortality, changes in observed weight at age, and the relative positions of maturity at age and commercial gear selectivity.

The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report (SAR), and will be used to inform the ongoing renewal of the management framework for BC Pacific Herring. The Science Advisory Report and supporting Research Document will be made publicly available on the Canadian Science Advisory Secretariat (CSAS) website.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR) meeting was held on February 7-8, 2017 at the Pacific Biological Station in Nanaimo to review the Working Paper (WP) titled "*The selection and role of limit reference points for Pacific Herring (Clupea pallasii) in British Columbia, Canada*".

The Terms of Reference (TOR) for the RPR (Appendix A) were developed in response to a request for advice from DFO Fisheries Management. Notification of the RPR meeting and conditions for participation were sent to representatives with the relevant expertise from DFO, First Nations, Alaska Department of Fish and Game, commercial and recreational fishing sectors, environmental non-government organizations, and academia.

The following WP was prepared and made available to meeting participants prior to the meeting (abstract can be found in Appendix B):

> *Kronlund, A.R., Forrest, R.E., Cleary, J.S., and Grinnell, M.H. 2016. The selection and role of limit reference points for Pacific Herring (Clupea pallasii) in British Columbia, Canada. CSAS Working Paper 2016PEL01*.

The meeting Chair, Linnea Flostrand, welcomed participants, reviewed the role of CSAS in the provision of peer-reviewed science advice, and gave a general overview of the CSAS process. The Chair discussed the role of participants, the purpose of the resulting CSAS publications (Science Advisory Report, Proceedings, and Research Document), and the definition and process for achieving consensus around advice. The Chair reviewed the TOR and Agenda (Appendix C) and confirmed that copies of the TOR, WP, and Agenda were distributed to participants prior to the meeting.

In total, 40 people participated in the RPR (Appendix D). Participants were invited to engage fully in the discussion and to contribute knowledge to the process, with the goal of delivering scientifically defensible conclusions and advice. The room was equipped with microphones to allow for remote participation by web-based attendees, and in-person attendees were reminded to address comments and questions so they can be heard online. Participants were informed that Dr. Sherri Dressel (Alaska Wild Fish and Game) and Dr. Doug Swain (DFO, Gulf Region) were asked before the meeting to prepare reviews for written and oral presentation (e.g. Appendices E and F). Both reviewers presented their reviews via webinar with the aid of presentation material. Julia Bradshaw was identified as the rapporteur and Matthew Grinnell was identified as a co-author designated to track information related to WP revision requirements and suggestions.

The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report (SAR) to Fisheries and Aquaculture Management to inform Pacific Herring fishery planning. The SAR and supporting Research Document will be made publicly available on the Canadian Science Advisory Secretariat website.

PRESENTATION OF PACIFIC HERRING RENEWAL

Corey Jackson (Acting Regional Manager, Pelagics, Fisheries Management, DFO, Pacific Region) presented an overview of the multi-year Pacific Herring renewal process, initiated in 2015 (DFO 2015). The goal of the renewal process is to modernize the Pacific Herring fishery management approach by addressing challenges in the assessment and management of the fisheries and improving alignment with DFO policy (e.g., *Decision-Making Framework Incorporating the Precautionary Approach,* DFO 2009). Renewal process elements include:

1. Management Framework: Including identifying specific management objectives that incorporate reference points (e.g., LRPs) and reviewing/updating the current management procedure (data, assessment model and decision rules)
2. Fisheries Management Reform: Including a review of license fees, review of the current pooling and licensing system, potential alternatives to on-grounds management, and fishery monitoring
3. Stock Assessment and Survey Program: Including options to improve the cost-effectiveness and affordability of the current program

Improved alignment with DFO harvest strategy policy (DFO 2009) will include the following elements:

- Specific (measurable) management objectives for Pacific Herring, developed in consultation and collaboration with First Nations, industry, and stakeholders.
- Limit reference points (LRPs) and an upper stock reference (USR). LRPs are one component of the strategic stream to inform on the status of the stock relative to potential conservation thresholds.
- Development of a new management procedure (MP) designed to avoid limits and achieve targets associated with stock and fishery monitoring data; stock assessment efforts, and harvest control rule that outputs a TAC recommendation to inform fisheries planning.

A participant asked how input gets provided into developing management objectives associated with the management strategy evaluation (MSE) process. Mr. Jackson explained there have already been several bilateral meetings to discuss objectives. The renewal process is intended to encourage participation and there will be future opportunities to provide input and feedback (including opportunities for groups/interests that have not been involved to date).

A participant sought clarification as to how objectives will be used and how they relate to identification of LRPs. Mr. Jackson noted there has been some preliminary discussion and consideration of conservation and fishery objectives, both within DFO and with some First Nation and industry. The science advice that comes out of this science review process can provide a basis for conservation objectives, which can include LRPs, levels of certainty and timelines. How LRPs are incorporated into measurable objectives and factor objectives into management decisions will need consideration and discussion after the review. Additional information on this topic to be provided by authors during this RPR.

PRESENTATION OF WORKING PAPER

WORKING PAPER:

Kronlund, A.R., Forrest, R.E., Cleary, J.S., and Grinnell, M.H. 2016. The selection and role of limit reference points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada. CSAS Working Paper 2016PEL01.

Rapporteur: Julia Bradshaw

Presenters: Rob Kronlund, Robyn Forrest and Jaclyn Cleary

Science presentations included an overview of the context and concepts that guided the development of the WP, and a summary of the methods and findings reported in the WP in response to the objectives of the TOR. An overview of some of the key points from the presentation and Working Paper is summarized below.

Rob Kronlund presented information on DFO *Decision-Making Framework Incorporating the Precautionary Approach* (DFO 2009), including describing and differentiating the roles and intent of reference points (limits and targets) and operational control points (OCPs) used in harvest control rules (HCRs). He described best practice recommendations in the context of LRPs and presented information related to the definition and interpretation of slowly reversible or irreversible serious harm, including examples of associated conditions (e.g. stock collapse; compromised recruitment/productivity; genetic selection, and loss of ecosystem function). Results of the surplus production analysis and the diagnosis of persistent low production, low biomass (LP-LB) states for Pacific Herring stocks in the CC, HG, and WCVI management areas were presented. This information was presented in the context of objective 1 of the TOR.

Dr. Robyn Forrest presented information on:

- time-varying processes of natural mortality (M) and observed weight-at-age;
- linking the concept of recruitment overfishing with serious harm and reference points;
- defining equilibrium fishing mortality parameters;
- results of the equilibrium fishing mortality analysis.

Challenges to obtaining plausible estimates of fishing mortality rates and implied spawning biomass reference points were identified. These included violations of equilibrium assumptions associated with estimated time-varying natural mortality and changes in observed weight-at-age, and assessment model structural uncertainty related to the relative positions of the maturity at age schedule and commercial selectivity at age. The authors recommended that LRPs based on replacement fishing mortality or proxies not be considered at this time. This information was presented in the context of objective 2 of the TOR.

Jaclyn Cleary presented information related to forage fish considerations by providing examples from the literature and describing implications for BC Pacific Herring. She reported the current lack of information and application of measureable objectives to provide evidence-based adjustment of a single-stock LRP to meet ecosystem requirements for dependent species. This issue was noted as a topic for future research. This information was presented in the context of objective 3 of the TOR.

Rob Kronlund reviewed the conclusions of Cox et al. 2015 which recommended that theoretical LRPs for BC Pacific Herring should not be based on dynamic reference points that adjust for changes in productivity over time or a historically low biomass level because both choices led to a progressive lowering of the estimated LRP or failed to indicate risk to stocks at low biomass levels. As a preferred alternative, he explained the interpretation of the upper biomass frontier of diagnosed LP-LB states as a threshold for possible slowly reversible or irreversible serious harm. He noted the WP recommendation of $0.3B_0$ is a proxy for the dynamic parameter recommended by Sainsbury (2008) as a best practice and denoted as $0.3B_{\text{unfished}}$. The rationale for an LRP based on B_0 is that it would mitigate against the progressive lowering of conservation thresholds demonstrated for dynamic reference points by Cox et al. (2015). This information was presented in the context of objective 4 of the TOR.

In the context of objective 5 of the TOR, the roles and steps of the strategic stream to develop management objectives and the use of MSE to test management procedures and explore the consequences of reference point choices, including LRPs, were explained. The context in which future analytic work can be done to explore data choices, stock assessment assumptions, and harvest control rules (i.e., management procedures) was also described. This work relies on a simulation-based approach where operating models (OMs) that define alternative hypotheses about the true underlying stock and fishery dynamics can be used to test the robustness of proposed management procedures.

PRESENTATION OF WRITTEN REVIEWS

Dr. Doug Swain (Fisheries Ocean Canada, Gulf Region) and Dr. Sherri Dressel (Alaska Department of Fish and Game) provided reviews of the Working Paper in written and oral presentation formats. Both reviewers reiterated information included in their written reviews and where applicable, responses from authors were noted and are described below.

DR. SWAIN

Dr. Swain described the concept of allee effects (depensation) and recommended that depensation and effects of predation should be included in the WP discussion on serious harm. A strong predation-driven allee effect would decrease stock production at low levels of stock abundance, especially if predator abundance were high. He noted that there is evidence of compensatory responses from low biomass levels with increases in production rates in the early period (1951-1987) but not the latter period (1988-2015) and affirmed that it may be explained in terms of increasing M in the latter period cancelling compensation in stock-recruit dynamics. He acknowledged that there is no strong evidence of this happening with the Strait of Georgia (SOG) stock because it did not decline to very low biomass in the recent period. Authors agreed that it would be worthwhile to include information in the WP discussing depensatory effects and agreed that there would be value in future work efforts of simulating depensation in OMs under the strategic stream to test management procedures.

The reviewer supported the recommendation of a limit reference point of $0.3B_0$ as an interim choice, but noted that if M is increasing 0.3 B_0 may be too low. He reported work of Hutchings (2015) proposing thresholds for impaired species recovery as 10% of observed maximum abundance. He compared that with BC Pacific Herring LP-LB states and depletion estimates (based on visual inspection of figures in the WP), and found that 10% maximum abundance estimates of BC Pacific Herring stocks correspond with depletion estimates for LP-LB states that range from $0.13B_0$ (CC) to $0.22B_0$ (HG).

In agreement with a WP recommendation, the reviewer recommended against time-varying LRPs which can decrease with reductions in stock productivity.

DR. DRESSEL

Dr. Dressel had several comments and questions related to clarifying information reported in the WP. She appreciated the "best practice" definition and context related to developing LRP advice and noted that the WP takes an important step in this direction. She noted that the language of the DFO Harvest Decision-making Framework Incorporating the Precautionary Approach (DFO 2009) on "serious or slowly reversible harm" implies human cause, when LP-LB states could occur in the absence of fishing (e.g., predator driven), a point which could be included in the WP. She recommended that the WP provide more clarification on how the initial and final years of a low-production (LP) state were determined and suggested a specific example be provided as a revision. She also suggested that additional explanation be included in the WP on how and/or where ecosystem considerations fit into Pacific Herring Management system.

Dr. Dressel asked for clarification on how uncertainty associated with a selected LRP gets incorporated into the process and suggested that a description of how that uncertainty is accounted for be included in a WP revision. The authors responded by explaining that aspects of uncertainty come when testing MPs, given management objectives and risks of breaching or reaching a state. At that stage, uncertainty should be captured in the range of the OMs, which should bracket hypotheses of dynamics.

Dr. Dressel questioned why the recommended LRP was within the range of frontiers (maximum depletion values for different stocks and different models), rather than at the extreme (maximum depletion of early and recent years and both models). The authors explained that the reason for not considering the entire time series (1951-2015) to characterize LRPs was in terms of periods having different environmental conditions. The early period had low biomass followed by high productivity; therefore, the depletion estimates for low biomass years from the early period were not included in the current LRP recommendation.

Dr. Dressel questioned whether different LRPs should be considered for different stocks or whether a recommended LRP could be used for stocks in other areas, such as Southeast Alaska. The authors explained that information is not available to describe similarities and differences between stocks in terms of mechanisms driving production. Exploring this would need to be done in a systematic way, such as part of simulation testing. Whether or not any given LRP is appropriate for a stock depends on management objectives structured around LRPs, targets, OM(s) and stock dynamics.

Dr. Dressel asked why the equilibrium reference point analyses were included in the WP if non-stationarity (breech of assumption in equilibrium analyses) would be expected to result in implausible results. She suggested rationale for this be included in WP revision. She also noted that the combination of maturity-at-age determined from past field studies and model based fishery selectivity ogives may be causing problems and suggested revisiting equilibrium reference point analysis after investigating those types of structural uncertainties. The authors responded by stating that they expected results to correspond with the degree to which assumptions of stationarity are violated but the strength of conclusions (to reject findings for use in LRP selection at this time) may not have been drawn unless analysis was done in association with consideration of serious harm. Whether these types of LPRs could be useful in the future depends on outcomes of future research into M and maturity could be investigated. Maturity data were probably collected some time ago and may not be representative.

Dr. Dressel described Southeast Alaska stocks as having relatively small geographic ranges, where age-structured models have been developed for the 4 largest stocks although there have been issues applying them to the 2 less abundant stocks. The two largest stocks (Sitka Sound and Craig) showed increases around 1998 and decreases since approximately 2011, assumed to be from environmental drivers. Estimates of natural mortality (*M*) vary with changes in abundance and are calculated relative to the Pacific Decadal Oscillation in time blocks (different to how estimated for BC stocks). She noted that there appears to be opposing trends in biomass and *M* trends between Southeast Alaska and BC herring stocks that may provide insights into factors affecting productivity. Similar contrasting trends with salmon have also been reported.

DRS. SWAIN AND DRESSEL

Both reviewers commended the thoroughness of the paper and endorsed the production analysis approach of investigating possible serious harm based on persistent LP-LB states.

Both reviewers suggested alternate ways the report could present the vast amount of contextual information to help readers keep track of the diverse issues (e.g., provide a synthesis with conclusions, synopsis, appendix, glossary), and suggested other editorial revisions (e.g. brief description of fishery renewal process, etc).

Both reviewers agreed with authors that equilibrium fishing mortality rate reference points should not be used due to time-varying *M* and possibly confounding with other stock assessment model parameters (maturity at age, fishery selectivity ogives, etc) and that fishing mortality rates estimated in the Working Paper seem implausibly high and suggest a long-term resiliency to a harvest level that is unlikely to exist.

Both reviewers agreed with authors on future work recommendations to investigate assessment parameters (especially the estimation of natural mortality, *M*).

GENERAL DISCUSSION

General discussion was focused on topics related to persistent LP-LB states, possible serious harm, LRPs, the production analysis, and the strategic stream for Pacific Herring renewal. There was also additional discussion regarding how the results of this WP relate to the larger process required to achieve management renewal for BC Pacific Herring.

POSSIBLE SERIOUS HARM AND LIMIT REFERENCE POINTS

It was clearly stated in the WP and by authors that only spawning biomass-based LRPs and fishing morality rate limits were considered and that information related to recommending LRPs related to other types of possible serious harm (e.g., restriction of spatial distribution or genetic diversity) was not investigated in this study. There was general agreement that persistent LP-LB states for the CC, HG, and WCVI stocks are consistent with possible slowly reversible or irreversible serious harm under DFO policy (*Decision-Making Framework Incorporating the Precautionary Approach,* DFO 2009). The authors noted that attempts to predict the occurrence of a persistent LP-LB state were not successful.

There was discussion as to why there was a single LRP recommendation in the presence of two assessment model (AM) configurations. The recommended LRP of $0.3B_0$ is on the threshold of LP-LB states for AM1 and the LP-LB threshold for AM2 is estimated to be lower than AM1. The WP acknowledges that true states are unknown and that each model is a hypothesis about the stock and fishery dynamics. Each model will therefore provide output for an associated set of reference points. The Pacific Herring stock assessment (DFO 2016) does not recommend which of model AM1 or AM2 is preferred.

There was discussion on the recommendation of $0.3B_0$ for the Prince Rupert District (PRD) and SOG stocks. For the PRD stock, it was noted that estimates of spawning biomass depletion for both AM1 and AM2 are at levels at or near $0.3B_0$. An argument was made that in the PRD management area no strong evidence for persistent LP-LB states was found although there has been regular fishing there for years (e.g., average harvest rate of 17%) and recruitment appears reasonable. Because of this, it was suggested that more analysis may be required for this stock before a LRP can be recommended for it. In response, it was acknowledged that although stock structure and other factors may be driving PRD stock dynamics and future work can try to understand those factors, it is realistic to prepare and plan for the possibility that the PRD and SOG could transition rapidly into a persistent LP-LB state. The recommendation of $0.3B_0$ for the PRD and SOG stocks is based on the available information for the same species in adjacent management areas and is consistent with a proxy for the Sainsbury (2008) best practice policy recommendation.

Concern was expressed that the recommended LRP of $0.3B_0$ may not be high enough to address ecosystem considerations and facilitate recovery of a stock from relatively high levels of natural mortality and possible spatial scale effects. There was discussion over the Lenfest HCR control points of $0.4B_0$ and multiples of equilibrium fishing mortalities associated with maximum sustainable yield (F_{MSY}). A participant stated there is literature support for $0.4B_0$ as a LRP even though Lenfest linked it to a HCR with an F_{MSY} value of 0.5 and Cox et al. (2015) recommended against using this HCR.

Currently there is no quantitative basis to modify the choice of a LRP based on specific hypotheses of predator or ecosystem needs. No work on Pacific Herring has been done to evaluate the performance of $0.4B_0$ on its own and no LRPs adjusted for forage fish considerations are known to have been implemented. Building management objectives that include explicit objectives for dependent species into an OM would be a starting point into exploring the consequences to management procedure (MP) choices that relate to predator-prey dynamics.

PRODUCTION ANALYSIS

Concern was expressed over the possibility of confounding effects associated with changes in production over time and the changes in survey methodology that occurred between the surface and dive periods. However, it was noted that on close inspection of the time series that the change in productivity preceded the change in survey methodology. Authors believe that a change in survey methodology is unlikely to be responsible for a change in productivity of the magnitude observed for the CC, HG, and WCVI stocks. Furthermore, information from the dive survey period alone characterized the persistent LP-LB states. It was also noted that the dashed line for the average amount for each period may produce a misleading visual impression of an abrupt change in production associated with the change in survey methodology (e.g., WCVI Figure 3 panel b).

There was interest to review the equation used for calculating annual estimates of production to clarify the time interval and sequence of events representing spawning biomass and catch throughout a year. A participant suggested that the year of catch in the equation should be in the time period after year "*t*" spawning. After the meeting, the authors considered the participant's suggestion and agreed that an adjustment was required because, unlike most catch-at-age assessment models, AM1 and AM2 both estimate end of year spawning biomass rather than beginning of year spawning biomass. The analysis was redone with the corrected equation and minor changes to production estimates resulted, which remained consistent with the conclusions and recommendation of the WP about the presence of persistent recent LP-LB states for the WCVI, HG and CC stocks, and the periods determined to be in LP-LB states (Appendix G).

A participant reported that using spawn index estimates to calculate production estimates resulted in different trends in production estimates than the results from using AM1 and AM2 estimates of spawning biomass. The participant stated she supports the approach of using surplus production analysis but does not support results based solely on AM1 and AM2. In response, it was acknowledged that a frontier may appear higher from using spawn index estimates, but the degree of noise is problematic. Spawn index sampling error can't be addressed by taking into account things like growth and natural mortality because the raw spawn index is based on egg deposition observations that have a high degree of noise, which the assessment models smooth out. Furthermore, the calculation of B_0 is impossible without being integrated into an assessment model. Another constraint of using the spawner index that was identified was that the spawner index has a different biomass scale to that of catch because it is a relative index.

Using somatic biomass as the biomass metric instead of spawning biomass was suggested as another alternative method of calculating production. The reason given for this suggestion was that gonad mass and body mass from one year shouldn't be compared with that of the next year, because net productivity changes would be different. This suggestion was made as a consideration for future work. Authors wanted it to be clear that weight at age for fish before spawning was used in the production analysis (i.e., to estimate when gravid), and that spawning biomass estimates for all years represent the same stage and time of year across the time series.

MSE AND THE STRATEGIC STREAM

An author gave a brief description of the MSE process in the context of the strategic stream (i.e., WP page 54). It is an iterative process throughout a seven step cycle. LRPs fit into step one, which is where measurable objectives can be developed that incorporate biological reference points. Hypotheses related to climate change, spatial structure, or predator-prey interactions could be described in OMs used to generate simulated data for evaluating candidate MPs. The goal of an MSE process is to identify MPs that are robust to the uncertainty in stock and fishery dynamics in the sense that they provide acceptable management outcomes related to the measurable objectives.

A WP recommendation is that the consequences of management objectives that incorporate LRPs or other reference points should be evaluated in the context of an MSE process. If candidate MPs fail to perform well during simulation testing, they would likely be rejected from further consideration. There will be opportunities to bring alternative hypotheses for OMs and management procedures into MSE over time to bracket a range of uncertainties. The consequences of reference point choices and performance of candidate MPs will be tested in simulations.

Concern was expressed over possible declines in LRP estimates over time due to possible declines in estimates of B_0 between assessment years. The authors noted that when new assessment data are introduced, or structural changes are made to an assessment model, estimates of model parameters will change but the choice of a long-term fixed equilibrium B_0 rather than a dynamic parameter is intended to mitigate those effects. In a MSE context, how often and to what extent reference points change over time is typically assessed with a suite of OMs to identify the best MPs by their outcomes. The phasing in of strategies can be considered while moving from an operational stream to a strategic stream , such as whether B_0 will change from year to year. Typically, a cycle of the MSE process would result in application of the selected MP for a period of time (e.g., three years) without the requirement to update reference points.

A management-oriented MSE approach is the most promising alternative to the best model approach that has been in place for the last 20-30 years. As stated in the presentation by Mr. Jackson, the renewal of BC Pacific Herring management requires a much broader scope than the current RPR process; requiring further research, collaboration and consultation to ensure the appropriate objectives are identified and the appropriate information and alternative hypotheses are included in process.

ADDITIONAL QUESTIONS AND POINTS OF CLARIFICATION

Additional questions and points of clarifications that came up during science presentations and discussion are summarized below.

A participant asked whether authors can recommend a harvest rate. The authors clarified that no limit fishing mortality rates based on the equilibrium fishing mortality rates were recommended but noted that persistent LP-LB states were diagnosed for the CC, HG, and WCVI stocks when applying an intended harvest rate of 0.2 (or less) in the current HCR.

It was asked what is meant by low productivity, low production and low surplus production and how these relate to incorporating catch. An author clarified that these terms mean the same thing (i.e., when production estimates were negative or near 0).

It was asked why LRP recommendations in the WP were based solely on relative biomass and not measures of production. The WP analysis showed that production can become negative at relatively high spawning biomass levels so it is not clear how a production-based LRP would be set. Recent history suggests that persistent LP-LB states occurred when spawning biomass declined below $0.3B_0$.

It was asked why the WP did not report the estimates of B_0 and the recommended LRP of $0.3B_0$ in absolute values. The response from authors was that focusing on absolute numbers is risky since absolute numbers will change annually as new data is incorporated as well as $0.3B_0$ values will be different for different OMs. The goal is to seek robustness across a range of OM possibilities. The current review is about the process of determining the limits, not the value of the limits themselves (addressed under the heading “MSE and the Strategic Stream”).

In the context of recommending a LRP, clarity was sought on the differences between B_0 and $B_{unfished}$ based on the definition by Sainsbury (2008) for the latter. It was explained that B_0 is a parameter representing an equilibrium state approximating an average. $B_{unfished}$ is a dynamic parameter estimate that characterizes what would be the long-term biomass in the absence of fishing, and as a dynamic parameter it is more sensitive to non-stationarity than B_0. Because of stated differences, authors of the current WP used B_0 in following with recommendations of Cox et al. (2015).

As a possible method to reduce non-stationary effects of weight-at-age estimates, it was asked whether the authors had considered using estimates of unfished equilibrium numbers of spawning fish instead of spawning biomass (i.e., N_0 versus B_0). The authors responded that they did not consider using N_0 and noted that there are no survey observations that are free of requiring age-at-weight estimates because the spawn index calculations use mean weight-at-age to expand the numbers of spawning fish to a biomass-based spawning index.

CONCLUSIONS

The Working Paper was accepted with revisions identified from the review process. The role and format of a Science Advisory Report (SAR) as a product of a peer review process was explained and participants collectively developed summary information related to conclusions, recommendations, sources of uncertainty, and suggestions for figures and tables that should be included. The time lines and steps for drafting, revising and submitting the SAR, Proceedings, and Research Document were also explained.

Consensus was reached on the following conclusions from the RPR process, which will be reflected in the SAR:

- The approach taken to diagnosing possible serious harm for BC Pacific Herring stocks was evidence-based, and conditional on current data and assessment model assumptions AM1 and AM2 (DFO 2016).
- A persistent LP-LB state was interpreted for BC Pacific Herring as being consistent with signs of possible slowly reversible or irreversible serious harm.
- Recent LP-LB states diagnosed for stocks in the CC, HG and WCVI management areas lasted for a period from about one to two Pacific Herring generations (~6-11 years) at spawning biomass levels near or at historical lows. These states were associated with persistent loss of benefits to resource users. Persistent LP-LB states were not diagnosed for stocks in the PRD and SOG management areas.
- The upper spawning biomass frontier of a persistent LP-LB state for the CC, HG and WCVI was considered to be a threshold to a state consistent with signs of possible serious harm.
- Equilibrium fishing mortality reference points associated with the recent analysis are not recommended. Estimates of equilibrium replacement fishing mortality rate (F_{rep}) and proxies were implausibly high due to high long-term average estimates of natural mortality, and the juxtaposition of the maturity and selectivity ogives.
- A spawning biomass-based LRP of $0.3B_0$ is recommended for the CC, HG, and WCVI stocks based on the results of the surplus production analysis and consistency with international best practice recommendations (e.g., Sainsbury 2008).
- A LRP of $0.3B_0$ is recommended for the PRD and SOG stocks as it aligns with international best practice recommendations and because these stocks are geographically adjacent to stocks for which recent low LP-LB states were detected.
- Experience with the current harvest policy since 1986 indicates that persistent LP-LB states can occur when annual total allowable catch recommendations are calculated by applying an intended annual harvest rate of 0.2 or less to the forecasted spawning biomass for stocks in the CC, HG, and WCVI management areas.
- A management strategy evaluation approach is recommended to identify measurable objectives associated with both LRPs and target reference points, develop OMs that represent plausible hypotheses about stock and fishery dynamics, and evaluate the current and alternative management procedures against simulated data produced by the OMs.
  - It is recommended that trade-offs in management outcomes and consequences of reference point choices be evaluated using simulation methods.
  - Under the Pacific Herring renewal process, the development of the strategic stream requires a fulsome statement of conservation, economic, and socio-cultural objectives to define fisheries sustainability.

- Both LRPs and target reference points need to be incorporated into measurable objectives related to achieving desired conservation, economic and socio-cultural management outcomes.
- Continued support for the strategic stream is recommended.

- Ecosystem service requirements of Pacific Herring predators are poorly understood and objectives for predators are not specified. In the absence of quantitative models that represent hypotheses related to dependent species, no adjustment of LRP recommendations for forage fish can be recommended at this time. Future development of operating models within a management strategy evaluation process may include ecosystem dynamics related to predator communities.
- Mechanisms to characterize serious harm to Pacific Herring stock in terms of states related to spatial distribution, stock structure, and genetic diversity are not well understood. Future development of population dynamics models that include spatial dynamics and/or stock structure may lead to candidate LRPs and performance indicators that characterize other definitions of serious harm. Spatial operating models could also inform management options at finer spatial scales than the current major management areas.
- It is recommended that operating and assessment model development should focus on the parameterization of natural mortality, estimates of maturity-at-age, and the effects of prior probability distributions for model parameters on model outcomes.
- The phasing-in of any new management procedure (i.e., changes in data collection, stock assessment and/or harvest control rule) designed to avoid limits and achieve targets is recommended to mitigate short-term consequences to resource users.

SOURCES OF UNCERTAINTY

All surplus production and equilibrium fishing mortality rate results are conditional on stock assessment models AM1 and AM2 informed by data up to 2016 (DFO 2016). These two models differ by parameter uncertainty related to dive survey catchability. In particular, these models do not differ by structural uncertainty related to alternative hypotheses of population dynamics (e.g., parameterization of natural mortality, stock structure assumptions) and fishery dynamics (e.g., fishery timing). Furthermore, productivity in current stock assessment models is fundamentally driven by assumptions about: natural mortality; stock-recruitment relationships and parameters (i.e. steepness); observed changes in size-at-age; the specification of maturity-at-age, and the spawn index. There are possible confounding interactions between these and other model parameters.

If future declines in the abundance of Pacific Herring are experienced, the level and duration of a persistent LP-LB state are uncertain. The location of LP-LB states in both the production and spawning biomass dimensions is not guaranteed to occur at the same location as the recent persistent LP-LB states, nor can the state be expected to persist for the same time period.

Population, ecosystem and fishery dynamics associated with states of possible serious harm related to the spatial distribution, stock structure, and genetic diversity of BC Pacific Herring stocks are not well understood. Future development of population dynamics models that include spatial dynamics and/or stock structure may lead to candidate LRPs and performance indicators that characterize other definitions of serious harm. Spatial operating models could also inform management options at finer spatial scales than the current major management areas. Similarly, future development of operating models that incorporate ecosystem dynamics such as quantified functional relationships between forage species and their predators, could improve understanding of the performance of candidate LRPs with respect to forage fish considerations.

ACKNOWLEDGEMENTS

The Chair thanks the reviewers, Dr. Doug Swain and Dr. Sherri Dressel, for their thorough written reviews and oral presentations and valuable contribution to discussions; to Brigitte Dorner for verifying the intent and accuracy of the production equation and identifying the need for a Working Paper correction for inclusion in the revisions; and to all meeting participants for their constructive input. Julia Bradshaw is appreciated for her work as rapporteur which contributed to these proceedings, and finally to Lesley MacDougall and Lisa Christensen from the Pacific Region CSAS office for their support in planning and coordinating meeting logistics, facilitating remote participation, and assisting in projecting visual information.

REFERENCES CITED

Cox, S.P., Benson, A.J., Cleary, J.S, and Taylor, N.G. 2019. Candidate Limit Reference Points as a Basis for Choosing Among Alternative Harvest Control Rules for Pacific Herring (*Clupea pallasii*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/050. viii + p.

DFO 2009. A Fishery Decision-Making Approach Incorporating the Precautionary Approach. Fisheries and Oceans Canada. (last accessed May 21, 2021).

DFO 2015. Pacific Region Integrated Fisheries Management Plan, Pacific Herring. November 7, 2015 to November 6, 2016. 151 p.

DFO. 2016. Stock Assessment and Management Advice for BC Pacific Herring: 2016 Status and 2017 Forecast. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/052.

Hutchings, J.A. 2015. Thresholds for impaired species recovery. Proc. R. Soc. B 282: 0150654.

Sainsbury, K. 2008. Best Practice Reference Points for Australian Fisheries. Australian Fisheries Management Authority Report R2001/0999.

APPENDIX A: TERMS OF REFERENCE

THE SELECTION AND ROLE OF LIMIT REFERENCE POINTS FOR PACIFIC HERRING (*CLUPEA PALLASII*) IN BRITISH COLUMBIA, CANADA

Regional Peer Review Process – Pacific Region

February 7-8, 2017
Nanaimo, British Columbia

Chairperson: Linnea Flostrand

Context

Pacific Herring (*Clupea pallasii*) in British Columbia (BC) has a long heritage of quantitative stock assessment and management that incorporates comprehensive data collection for stock and fishery monitoring, statistical catch-at-age assessment models, and a harvest control rule (DFO 2015). Stock assessment analysts and fisheries managers have worked closely together to address the challenges posed by the fisheries which are of interest to a diverse array of resource users. In these regards, the current management framework for Pacific Herring already has many of the required elements of the *Fishery Decision-making Framework Incorporating the Precautionary Approach* policy (DFO 2009). Elements yet to be developed include the selection of both limit and target reference points, and an evaluation process to allow the consequences of management choices to be examined in a way that makes trade-offs between conservation, yield and social outcomes explicit.

Limit reference points (LRPs) indicate states that should not be breached (a lower biomass or abundance limit) or exceeded (a fishing mortality limit) due to anticipated undesirable consequences or “serious harm” to the stock such as impaired productivity, genetic restrictions, or stock collapse. Methods appropriate for determining LRPs are not well understood for Pacific Herring fisheries, particularly given the apparent time-varying biological processes related to productivity such as changing natural mortality and weight-at-age. Cox et al. (2015) considered equilibrium limit reference points that remain fixed over time, a dynamic reference point that tracks changes in productivity, a “historical” reference point that defined an LRP in terms of lowest observed biomass, and DFO (2009) policy values of $0.4B_{MSY}$ and F_{MSY}. Advice that resulted from Cox et al. (2015) and international best practices consistent with Canadian policy will be considered when recommending LRPs for Pacific Herring in this review.

Under the current approach for assessment and management of Pacific Herring (“operational stream”), a single model and harvest control rule are used to provide catch recommendations. However, the long-term focus of Science activities related to revising the Pacific Herring management framework is the establishment of a Management Strategy Evaluation (MSE) process to identify a management procedure (i.e., data collection, assessment method, and harvest control rule) that has been simulation tested for robustness to a range of uncertainties regarding stock and fishery dynamics. Therefore, the role of LRPs in the context of the current operational stream and the evolving “strategic stream” guided by the MSE process will be discussed. Strengths and weaknesses of the recommended LRPs will be described relevant to the context in which they would be used.

This Canadian Science Advisory Secretariat (CSAS), Regional Peer Review (RPR) will focus on the concept of serious harm in identifying LRPs for Pacific Herring and evaluate the evidence for identifying states when serious harm might occur. The rationale for recommended status-based and fishing mortality limit reference points for the five major stocks of Pacific Herring will be reviewed. Advice arising from this CSAS RPR will be used to establish LRPs for Pacific Herring in Canada and inform the renewal of the management framework in accordance with Canada's Sustainable Fisheries Framework.

Objectives

The following Working Paper will be reviewed and provide the basis for discussion and advice on the objectives outlined below:

Kronlund, A.R., Forrest, R.E., Cleary, J.S., and Grinnell, M.H. 2017. The selection and role of limit reference points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada. CSAS Working Paper 2016PEL01.

The objectives of this review are to:

1. Determine whether existing data and assessment model estimates provide evidence for states of "serious harm" or "slowly reversible harm" for Pacific Herring stocks and if so, how these states align with LRPs.
2. Evaluate whether biological reference points derived from estimates of key management parameters are appropriate choices for LRPs in light of evidence for time-varying processes (e.g., estimated time trends in natural mortality and observed trends in weight-at-age for Pacific Herring).
3. Determine if the ecosystem role of Pacific Herring as a forage fish should influence or modify the choice of LRPs.
4. Recommend LRPs for Pacific Herring consistent with the DFO Sustainable Fisheries Framework.
5. Recommend next steps required to develop measurable objectives that include LRPs and subsequently evaluate the effects of LRP choices in the context of the entire management system.

Expected Publications

- CSAS Science Advisory Report
- CSAS Research Document
- CSAS Proceedings

Expected Participation

- DFO (Science, Fisheries Management)
- External reviewers
- First Nations
- Fishing Industry
- Academia

References

Cox, S.P., Benson, A.J., Cleary, J.S., and Taylor, N.G. 2019. Candidate Limit Reference Points as a Basis for Choosing Among Alternative Harvest Control Rules for Pacific Herring (*Clupea pallasii*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/050. viii + 47 p.

DFO 2009. A Fishery Decision-Making Approach Incorporating the Precautionary Approach. Fisheries and Oceans Canada. (last accessed May 21, 2021).

DFO. 2015. Stock Assessment and Management Advice for BC Pacific Herring: 2015 Status and 2016 Forecast. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/038.

APPENDIX B: WORKING PAPER SUMMARY AND TERMINOLOGY GUIDE

SUMMARY

Biological limit and target reference points are commonly used to evaluate the status of fished populations in most management jurisdictions. This paper is focussed on the selection of limit reference points for the five major stocks of British Columbia Pacific Herring (*Clupea pallasii*) in partial fulfillment of requirements under the DFO *Harvest Decision-making Framework Incorporating the Precautionary Approach* and as part of the commitment to renewal of the Pacific Herring management system. The Canadian policy basis for limit reference points is reviewed with respect to the goal of avoiding "serious harm" to a fish stock, and report "best practice" recommendations for limit reference points found internationally. Surplus production relationships for the five major stocks of Pacific Herring in relation to spawning stock biomass is evaluated to determine whether there is evidence for stock states that show signs of persistent low production and low biomass that are consistent with signs of possible serious harm. Additionally, a range of theoretical equilibrium reference fishing mortality rates related to the concept of the replacement fishing mortality is investigated as well as associated proxies based on maximum sustainable yield, spawning potential ratio and yield-per-recruit.

Pacific Herring stocks in the Central Coast, Haida Gwaii, and West Coast Vancouver Island management areas showed recent evidence of persistent low production, low biomass states that began by the mid-2000s and persisted for six to twelve years depending on the stock. These states were preceded by a transition to low production that began as early as the late 1990s from levels of comparatively high spawning biomass. The low spawning stock depletion levels reached during these periods was comparable to the levels estimated during the collapse of all five major stocks in the late 1960s, which was attributed to overharvest rather than loss of production. However, unlike events in the late 1960s, stocks in the Prince Rupert District and Strait of Georgia management areas did not decline to the same extent as the remaining three stocks, and did not change to a persistent low production, low biomass state.

This study suggests that a biomass-based limit reference point of 0.3 of the estimated unfished spawning stock biomass is indicated for the Central Coast, Haida Gwaii and West Coast Vancouver Island stocks. This recommendation is conditioned on the assumptions, data, and outputs from current stock assessment models and is based on the analysis of production relationships and the policy requirement to position biomass-based limit reference points above states of possible serious harm. Limit equilibrium fishing mortality rates based on the concept of replacement fishing mortality could not be recommended due to concern about evidence of non-stationary conditions for natural mortality and size-at-age. Should the introduction of limit reference points be considered for Pacific Herring, a management-oriented simulation approach to evaluating the performance of alternative harvest options for Pacific Herring is recommended. Progress on this evaluation requires stating measurable conservation objectives that define the probability of avoiding limit reference points and a time frame for evaluation. Similarly, target reference points need to be stated in measurable objectives related to achieving desired economic and socio-cultural management outcomes. It is recommended that management procedures designed to avoid breaching limit reference points be phased-in to smooth the transition from existing operational practice.

TERMINOLOGY AND CONCEPT GUIDE (INCLUDES FIGURE 1)

Best Practice. "The 'best' practice concept is based on the best practice that has been demonstrated through use, and recognizes that views of what is 'best' will continuously improve with experience. Best practice is not an absolute or fixed entity, or a guarantee of adequacy. It is based on experience to date and it is expected to evolve over time"(Sainsbury 2008).

Biological Reference Point (BRP). A biomass or fishing mortality level commonly used to evaluate the status of fished populations in most management jurisdictions. Biological reference points are typically derived on theoretical grounds and reflect biological objectives of management related to quantities such as unfished biomass (B_0) or maximum sustainable yield (MSY catch; spawning biomass at MSY, B_{MSY}, or fishing mortality rate at MSY, F_{MSY}). BRPs are generally categorized as limits and targets.

DFO PA Framework. A Fishery Decision-Making Framework Incorporating the Precautionary Approach policy (2009). Canadian policy that defines requirements for limit and upper stock status reference points that delineate Critical, Cautious and Healthy zones and a limit fishing mortality rate.

Harvest Control Rule (HCR). A rule that specifies in advance actions to be taken when specific deviations from operational targets and constraints (e.g., limits) are detected. A HCR typically specifies adjustments to fishing rates in response to perceived changes in stock abundance estimated by a stock assessment model. A HCR may include other management tactics such as gear restrictions, spatial closures, seasonal closures, size-limits, etc.

Limit Reference Point (LRP). Defined by the DFO PA Framework "*… the LRP represents the stock status below which serious harm is occurring to the stock. At this stock status level, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities.*" A LRP is a threshold of last resort positioned prior to biomass or fishing mortality states that cause long-term deleterious outcomes for the fish stock and fishery. A LRP should be avoided with high probability.

Measurable Objective. A fully specified objective that defines an outcome of interest (e.g., avoid spawning biomass levels less than some LRP), the probability of achieving the outcomes (e.g., 95% percent of the time), and a time frame for evaluation of performance (e.g., 20 years). Desires to achieve a *"sustainable fishery*" or "healthy stocks" are goals, not measurable objectives.

Operational Control Point (OCP). A quantity that triggers management action usually chosen based on practical issues of data availability, stock assessment uncertainty error, risk tolerance, and stakeholder preferences. For example, a biomass-based OCP might be the level where fishing mortality is reduced to avoid fishery closures and encourage increased stock abundance.

Serious Harm. Deleterious states for a stock that lead to compromised spawning potential or productivity that results in long-term loss of benefits to resource users. Often difficult to define and diagnose until already quite severe due to limited ability to observe complex population dynamics.

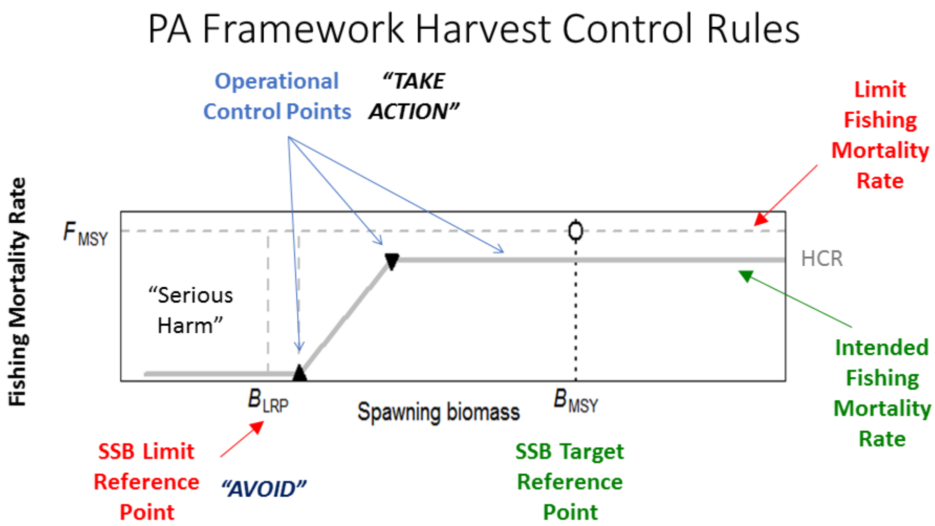

Figure 1. Separation of BRPs and OCPs in the design of a DFO PA Framework HCR. International and domestic fisheries policy state that F_{MSY} is a limit fishing mortality rate and a biomass level of at least B_{MSY} is desirable. Fishing mortality is reduced below a second biomass-based OCP (inverted black triangle) to increase the likelihood of avoiding a fishery closure as B_{LRP} is approached. Note that the reference points B_{LRP} and F_{MSY} are unaffected by changes to the OCPs in the HCR and therefore management objectives do not change (figure modified from Cox et al. 2013).

REFERENCES

Cox, S.P., Kronlund, A.R., and Benson, A.J. 2013. The Roles of Biological Reference Points and Operational Control Points in Management Procedures for the Sablefish (*Anoplopoma fimbria*) Fishery in British Columbia, Canada. Environmental Conservation 40(4): 318-328.

DFO 2009. A Fishery Decision-Making Approach Incorporating the Precautionary Approach. Fisheries and Oceans Canada. (last accessed May 21, 2021).

Sainsbury, K. 2008. Best Practice Reference Points for Australian Fisheries. Australian Fisheries Management Authority Report R2001/0999.

APPENDIX C: AGENDA

The Selection and Role of Limit Reference Points for Pacific Herring in British Columbia, Canada

February 7-8 2017

Pacific Biological Station, Seminar Room

Chair: Linnea Flostrand

Day 1: Tuesday February 7, 2017

Time	Subject	Presenter
0900	CSAS Overview and Procedures Review Terms of Reference and Agenda	Chair
0915	Introductions, sign-in sheet & house keeping	Chair
0930	Overview of the renewal process of Pacific Herring Fishery Management	Corey Jackson
0945	Policy background and concepts	Authors
1015	***Break (*cafeteria will be open)***	
1030	Presentation of Working Paper	Authors
1130	Reviewer overview – Doug Swain	Chair + Reviewer & Authors
1200	***Lunch Break (*cafeteria will be open)***	
1300	Reviewer overview – Sherri Dressel	Chair + Reviewer & Authors
1330	Identification of Key Issues for Group Discussion	RPR Participants
1345	Discussion & Resolution of Technical Issues	RPR Participants
1430	***Break (cafeteria will be closed)***	
1445	Discussion & Resolution of Technical Issues (Continued)	RPR Participants
1700	Adjourn for the Day	

Day 2: Wednesday February 8, 2017

Time	Subject	Presenter
0900	Introductions, sign-in sheet & house keeping Review Agenda Review Status of Day 1	Chair
0915	Discussion & Resolution of Results & Conclusions	RPR Participants
1000	Develop Consensus on Paper Acceptability & Agreed-upon Revisions	RPR Participants
1030	***Break (*cafeteria will be open)***	
1050	*Science Advisory Report (SAR)* Develop consensus on the following for inclusion: • Results & Conclusions • Sources of Uncertainty	RPR Participants
1200	***Lunch Break (*cafeteria will be open)***	
1300	*Science Advisory Report (SAR)* • Continued	RPR Participants
1500	***Break (cafeteria will be closed)***	
1520	*Science Advisory Report (SAR)* • Continued	RPR Participants
1630	Next Steps – Chair to review • SAR review/approval process and timelines • Research Document & Proceedings timelines • Other follow-up or commitments	Chair
1645	Other Business arising from the review	Chair & Participants
1700	***Adjourn meeting***	

APPENDIX D: MEETING PARTICIPANTS

Last Name	First Name	Affiliation
Benchetrit	Jose	DFO Science
Benson	Ashleen	Landmark Fisheries Consultant
Boldt	Jennifer	DFO Science
Bradshaw	Julia	DFO Science
Cass	Al	Herring Conservation and Research Society
Chaves	Lais	Haida Oceans Technical Team
Christensen	Lisa	DFO Science
Cleary	Jaclyn	DFO Science
Dorner	Brigitte	Heiltsuk Nation
Dressel	Sherri	Alaska Department of Fish and Game
Edwards	Andrew	DFO Science
Flostrand	Linnea	DFO Science
Forrest	Robyn	DFO Science
Frederickson	Nicole	Island Marine Aquatic Working Group
Fu	Caihong	DFO Science
Grinnell	Matthew	DFO Science
Hackshaw	Sarah	DFO Science
Hall	Peter	DFO Fisheries Management
Hall	Don	Nuu-chah-nulth Tribal Council
Holmes	John	DFO Science
Holt	Carrie	DFO Science
Holt	Kendra	DFO Science
Jackson	Corey	DFO Fisheries Management
Jones	Russ	Council of Haida Nation - Haida Fisheries Program
Kanno	Roger	DFO Fisheries Management
Kronlund	Rob	DFO Science
MacDougall	Lesley	DFO Science
McGreer	Madeline	Central Coast Indigenous Resource Alliance
Menendez	Claire	Simon Fraser University
Morley	Rob	Canadian Fishing Company
Okamoto	Dan	Simon Fraser University
Ormond	Chad	Q'ul-lhanumutsun Aquatic Resources Society
Rusch	Bryan	DFO Fisheries Management
Rusel	Christa	Atlegay Fisheries Society
Schweigert	Jake	DFO Science
Spence	Brenda	DFO Fisheries Management
Starr	Paul	Herring Conservation and Research Society
Swain	Doug	DFO Science
Tanasichuk	Ron	Lax Kw’alaams Band
Thomas	Greg	Herring Conservation and Research Society and Chair of the Herring Industry Advisory Board

APPENDIX E: WORKING PAPER REVIEW – DOUG SWAIN

Reviewer: Dr. Doug Swain (DFO, Gulf Region, Gulf Fisheries Centre, Moncton, NB)

Working Paper 2016PEL01: The selection and role of limit reference points for Pacific Herring in British Columbia, Canada

SUMMARY

1. Introduction

The authors provide a comprehensive review of the choice, role and estimation of biological reference points for use in fisheries management and of past analyses related to reference points for Pacific Herring. The review is very thorough, but I found it difficult to keep track of the diverse issues and analyses reviewed. A synthesis and conclusion section would be helpful.

SPECIFIC COMMENTS

1.1 Serious Harm and Allee effects (Depensation)

Serious harm is a somewhat vague term and has been the subject of much debate and discussion in relation to reference points. An indisputable indication of serious harm is the emergence of Allee effects or depensation. The population dynamics of fishes and other organisms is generally thought to exhibit negative density dependence, with the per capita rate of population increase increasing as population size decreases. This is expected to occur due to release from density-dependent constraints on production as abundance decreases (Nicholson 1933). Sustainable fisheries are made possible by negative density dependence. Allee effects occur when density dependence becomes positive, with the per capita rate of population increase decreasing as abundance decreases (e.g., (Courchamp et al. 1999).

Allee effects have received scant attention in discussions of PA limit reference points (LRPs). This may be because a number of meta-analyses, focussed primarily on stock-recruit relationships of fish populations, have identified little evidence for depensation in fish stock-recruit relationships (e.g., Myers et al. 1995, Liermann and Hilborn 1997, Hilborn et al. 2014). However, as data on populations at very low abundance becomes increasingly available, the importance of Allee effects is receiving increasing attention (Hutchings and Rangeley 2011, Hutchings 2014, 2015). Although interest in Allee effects has tended to focus on low reproductive success at small population sizes (e.g., Keith and Hutchings 2012), predation is also a potentially important source of Allee effects (Gascoigne and Lipcius 2004). Predation can produce demographic Allee effects (e.g., due to a type II functional response of predators to prey), with predation mortality exerted per predator increasing as prey abundance decreases. It can also result in “emergent” Allee effects, such as increased mortality due to increases in predator abundance that are sustainable when prey are at high abundance but not when prey are depleted (Hutchings and Rangeley 2011, Hutchings 2014).

There is strong evidence of predation-driven Allee effects in many northwest Atlantic groundfish populations (e.g. Swain and Benoît 2015). These populations no longer appear to be viable and, under current conditions, are expected to decline to extirpation even in the absence of fishing (e.g., Swain and Chouinard 2008, Swain and Benoît 2017, Swain et al. 2016). These examples emphasize that LRPs should be set above Allee-effect thresholds and that the consequences of breaching LRPs can be dire. Based on an examination of populations that had declined to very low abundance, Hutchings (2015) identified 10% of Nmax (the maximum observed abundance) as a threshold for impaired recovery of marine fishes (an Allee-effect threshold). Based on visual inspection of Figure 2 and Appendix Figures 1, 3, 5 and 7, this would correspond to Allee-effect thresholds varying between about 0.13 of B_0 (CC) and 0.22 of B_0 (HG) for the stocks considered here.

Also based on visual inspection of the above figures, natural mortality *M* appears to be inversely correlated with spawner biomass *B*. This is consistent with a predation-driven Allee effect, as postulated by Haist et al. (2013). This currently appears to be a "weak" Allee effect (cf. Hutchings 2015), since the production rate generally remains near or above zero. However, if there is an overall increasing trend ln *M* (e.g., due to increasing predator abundance), a strong Allee effect could emerge, as in the case of east coast groundfish, resulting in a high risk of extirpation. This should be a consideration in the choice of LRPs.

1.2 Recruitment overfishing as serious harm

Most candidate LRPs are based on a low probability of strong recruitment, particularly in the case of east coast gadoids (Rivard and Rice 2003). Examples include the SSB at which the expected average recruitment is half of the maximum recruitment predicted by assuming an underlying stock-recruit relationship, and SSB below which the population is unlikely to produce average recruitment under good survival conditions for early life history stages. These LRPs are based on a low probability of good production P rather than a good rate of production (P/B). Stock – recruit relationships are typically assumed to be compensatory, with recruitment rate (R/B) increasing as B declines.

If recruitment variability is the main source of variation in population productivity, these types of LRPs are likely to be conservative. They are aimed at keeping population abundance at a relatively high level that can support a fishery and meet socio-cultural objectives. They are likely to be set at biomass levels well above those where depensatory effects emerge. However, increases in the natural mortality of adult fish can also be a source of serious harm (e.g., Swain and Benoît 2015, Kuparinen and Hutchings 2014). In this case, LRPs based on stock-recruit relationships may not be sufficiently precautionary to avoid serious harm, particularly if emergent Allee effects are occurring.

Minor point1.2.1: The authors state on p.23: ""At low stock sizes, however, most stock-recruit relationships predict a near-linear relationship between spawning biomass and recruits, as compensatory processes break down. In theory, stocks that have been fished down to this level may be considered recruitment overfished as there is no compensatory buffer in juvenile survival." I would argue instead that most stock-recruit relationships (i.e., Ricker, Berverton-Holt) are purely compensatory, with R/SSB increasing as SSB declines, even at low SSB.

Minor point 1.2.2: Why has a Beverton-Holt relationship been assumed when modelling stock-recruit dynamics of Pacific Herring? For the WCVI, CC and HG stocks, the figures cited above provide evidence of decreased recruitment at high levels of spawning biomass B. This is more consistent with a Ricker model, and might be expected for herring if embryo survival is reduced at high B due to thicker spawn beds (i.e., more layers of eggs) and/or larval survival is reduced at high B due to greater cannibalism.

1.3 Estimating reference points when there is non-stationarity in productivity

This issue arises several times in the introductory review. It is sometimes suggested that reference points should be adjusted when there are changes in productivity attributed to regime shifts or other factors that are not expected to reverse in the short or medium term. On the Canadian east coast, this issue arose when the productivity of many groundfish stocks declined in the 1990s and 2000s and it was suggested that biological reference points (i.e., the LRP) should consequently be reduced (e.g., Duplisea and Cadigan 2011). The current review notes that Cox et al.(2015) did not recommend this approach based on simulation analyses. This approach progressively lowers conservation thresholds as the stock declines. I strongly agree that that this approach is inadvisable. It is not consistent with avoiding low-productivity states which represent “serious harm”. This is particularly true when the decline in productivity is coincident with a decline in population size. In this case, the reduced productivity could reflect an Allee effect (e.g., increased predation mortality at low prey abundance), a clear case of “serious harm”. In this latter case, I would argue that the LRP may need to be increased rather than decreased because serious harm may have already occurred at the previously established LRP.

2. Methodology and Results

2.1 Equilibrium Limit Reference Points

A range of fishing mortality reference points was calculated for each stock. The calculated fishing mortality values were implausibly high. As noted by the authors, there are a number of issues with this analysis. Calculation of reference levels for fishing mortality (e.g., F_{MSY}) is problematic when there is time-varying *M* (Legault and Palmer 2016). When *M* is increasing, the estimated F_{MSY} will increase based on short term yield per recruit considerations (e.g., a high *F* is needed to catch fish before they die due to high *M*). On the other hand, longer term yield considerations would favour a lower *F* to avoid losses in future yield as R and B decline due to high total mortality. I agree with the authors that these estimates should not be used to determine reference points for Pacific Herring, though simulations may resolve some of the issues.

2.2 Production Analyses

In my view, these are the key analyses in this work. They clearly indicate that there has been an important change in the productivity of these stocks. Early in the time series (1951-1987) the relationship between production rate P/B and biomass B was strongly compensatory, with P/B increasing to high levels as B decreases to low levels. In the recent time period (1988 – 2016), P/B has been very low at all levels of B and there is no indication of compensation at low B. This may reflect a strong depensatory relationship between M and B, as suggested by model estimates. This suggests that there already has been serious harm to the productivity of these stocks. This change in production relationships is strongest for the WCVI, CC and HG stocks but is also evident for the PRD stock. It is not evident for the SOG stock, but this stock has not experienced strong depletion in the recent period.

3. Conclusions

I agree with the conclusions of the authors that

1. dynamic LRPs should not be used in response to time-varying productivity, with one caveat. In the event of an emergent predation-driven Allee effect, the LRP may need to be set at an increasingly high level to avoid serious harm as predator abundance increases.
2. the *F*-based reference points calculated here should not be used in this case due to the estimated time-varying *M*.
3. the observed changes in productivity appear to be driven by changes in the natural mortality of adults rather than recruitment dynamics.
4. historical low biomass levels from which a stock has previously recovered may not be a reliable choice for the LRP due to changing ecosystem conditions. An example is provided by the Atlantic cod stock in the southern Gulf of St. Lawrence, which has declined to a level estimated to be 20% of the SSB from which it recovered in the 1970s, and is expected to decline further (Swain et al. 2015).

The authors propose setting the LRP at $0.3B_0$ for all 5 stocks. The rationale is that this level is at (HG) or above (WCVI, CC) the minimum depletion observed in the recent Low Production – Low Biomass states experienced by these stocks. In my view, this is a reasonable argument for choosing this LRP. It is also above the Allee-effect threshold proposed by Hutchings (2015).

However, the production analysis suggests that these stocks have already experienced serious harm to their productivity. In the 1951-1987 period, the relationship between P/B and B was compensatory, with P/B increasing at low B. In the later period, P/B was very low at all B and there was no compensatory increase in P/B at low B. This change may reflect increasing adult *M*. If this is the case, a higher biomass level for the LRP may be required. I cannot recommend what this level should be, but I think that research on this question should be a priority, perhaps involving simulation testing under different assumptions about time-varying M and its relationship to stock biomass.

A key feature of the population dynamics of these stocks appears to be increasing *M* and an apparent depensatory relationship between *M* and stock biomass. Information is not available in this document to evaluate the strength of the evidence for these patterns in *M*, an issue which is presumably beyond the scope of this review. Nonetheless, I think that research on estimating the patterns in adult *M* in these stocks and on the causes of these patterns should be a priority, particularly given the state of many east coast groundfish stocks which are predicted to decline to extirpation at their current levels of adult *M*.

LITERATURE CITED

Courchamp F., Clutton-Brock T., Grenfell B. 1999. Inverse density dependence and the Allee effect. Trends Ecol Evol 14: 405−410.

Duplisea D.E. Cadigan N. 2011. Proceedings of the workshop for Technical Expertise in Stock Assessment (TESA): Maximum Sustainable Yield (MSY) Reference Points and the Precautionary Approach when Productivity Varies; December 13-15. 2011. CSAS Proceedings Series 2012/055.

Gascoigne JC, Lipcius RN (2004) Allee effects driven by predation. J Appl Ecol 41: 801−810.

Hilborn, R., Hively, D. J., Jensen, O. P., and Branch, T. A. 2014. The dynamics of fish populations at low abundance and prospects for rebuilding and recovery. ICES J Mar Sci 71: 2141–2151.

Hutchings JA.2014 Renaissance of a caveat: Allee effects in marine fish. ICES J Mar Sci 71: 2152–2157.

Hutchings JA. 2015 Thresholds for impaired species recovery. Proc. R. Soc. B 282: 0150654.

Hutchings JA, Rangeley RW (2011) Correlates of recovery for Canadian Atlantic cod. Can J Zool 89: 386−400.

Keith, D. M., and Hutchings, J. A. 2012. Population dynamics of marine fishes at low abundance. Can J Fish Aquat Sci 69: 1150–1163.

Kuparinen A., and Hutchings J.A. 2014 Increased natural mortality at low abundance can generate a demographic Allee effect. R. Soc. Open Sci. 1, 140075. (doi:10.1098/rsos.140075)

Legault CM, Palmer MC. 2016. In what direction should the fishing mortality target change when natural mortality increases within an assessment? Can J Fish Aquat Sci 73: 349-357.

Liermann, M., and Hilborn, R. 1997. Depensation in fish stocks: a hierarchic Bayesian meta-analysis. Can J Fish Aquat Sci 54: 1976–1984.

Myers, R. A., Barrowman, N. J., Hutchings, J. A., and Rosenberg, A. A. 1995.Population dynamics of exploited fish stocks at low population levels. Science, 269: 1106–1108.

Nicholson A.J. 1933 The balance of animal populations. J Anim Ecol 2: 131−178.

Rivard D. and Rice J. 2002. National workshop on reference points for gadoids. CSAS Proceedings Series 2002/033.

Swain, D.P. & Benoît, H.P. 2015. Extreme increases in natural mortality prevent recovery of collapsed fish populations in a Northwest Atlantic ecosystem. Mar Ecol Progr Ser 519, 165-182.

Swain, D.P., and Benoît, H.P. 2017. Recovery potential assessment of the Gulf of St. Lawrence Designatable Unit of Winter Skate (*Leucoraja ocellata* Mitchill), January 2016. DFO Can. Sci. Adv. Sec. Res. Doc. 2016/119. xviii + 134 p.

Swain, D. P., and G. A. Chouinard. 2008. Predicted extirpation of the dominant demersal fish in a large marine ecosystem: Atlantic cod (Gadus morhua) in the southern Gulf of St. Lawrence. Can J Fish Aquat Sci 65: 2315-2319.

Swain, D.P., Savoie, L., Cox, S.P., and Aubry, E. 2015. Assessment of the southern Gulf of St. Lawrence Atlantic cod (*Gadus morhua*) stock of NAFO Div. 4T and 4Vn (November to April), March 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/080. xiv + 137 p.

Swain, D.P., Savoie, L., and Cox, S.P. 2016. Recovery potential assessment of the Southern Gulf of St. Lawrence Designatable Unit of White Hake (*Urophycis tenuis* Mitchill), January 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/045. vii + 109 p.

APPENDIX F: WORKING PAPER REVIEW – SHERRI DRESSEL

Reviewer: Dr. Sherri Dressel (Statewide Herring Fisheries Scientist, Alaska Department of Fish and Game, Juneau, Alaska)

Commercial Fisheries Division Headquarters

Working Paper 2016PEL01: The selection and role of limit reference points for Pacific Herring in British Columbia, Canada

The selection and role of limit reference point for Pacific herring (Clupea pallasii) in British Columbia, Canada contains a wealth of information on Limit Reference Points (LRPs), the role of and need for LRPs in management, the broad diversity of approaches to establishing reference points for herring stocks worldwide, the history of historical reference points and Operational Control Points (OCPs) in BC, the renewal process of the herring management system in DFO, and considerations for the role of herring as a forage fish in herring management.

The authors do a nice job of outlining what they will cover and the flow of this paper at the end of their background section. However, for me, the multiple sections that follow in the introduction meant that I had lost the vision for what the paper is going to cover by the time I reached the end of the introduction. While all of the information in the introduction is pertinent and extremely helpful, it also distracts from the primary goal of the paper. I have two potential suggestions:

1. One way to keep the focus and flow in this paper without losing the valuable information contained in the introduction would be to cover the management renewal strategy in DFO, the history of reference points in Canada, the review of global reference points and management strategies, and a review of how forage fish have been considered in management in separate documents and then reference them in this paper. This would likely be the best way to keep the focus in this paper, but it would require that this is possible within the DFO reporting process. This could possibly also be done by including those sections as appendices and then only referring directly to parts that lead directly into the focus of the paper.
2. A second way would be to keep all this information in the paper, but include summary sentences at the end of each section to draw relevant conclusions and to clarify how the information will be used in, or how it applies to, the current paper. In addition, at the end of the introduction, a paragraph that brings the reader back to the focus of this paper would be extremely helpful.

The production analysis presented by the authors provides evidence for states of low productivity and low biomass (LP-LB) and, using the definition that states of low productivity and low biomass define states of serious or slowly reversible harm, the authors have also provided evidence for states of serious or slowly reversible harm. Given the current model and analysis, I support the authors' decision to use production analysis to define LPRs.

- I had difficulty interpreting how the initial and final years of the LP-LB time-period was determined. Additional clarification or walking through an example might be helpful.
- Can you describe a bit more how you chose 0.3B0? For example, why did you choose a value within the range of the frontiers, rather than at the extreme? Also, the introduction emphasized that it is important to include variability when setting LRPs. Can you speak to how the selected LRP does that? Finally, the introduction mentioned that there are different population dynamics between the stocks and different LRPs may be useful. Given that, can you explain why you think it is acceptable to apply 0.3B0 to PRD and SOG?

Given that the determination of equilibrium reference points depends on estimated model parameters, I support not using equilibrium reference points for setting LRPs at this time and support the authors' recommendation that model development should focus on the parameterization of natural mortality, estimates of maturity at age, and the effects of prior probability distributions for steepness and survey catchability on model outcomes. The estimates of F_{MSY} reported here and in Cox et al. (2015[1]) seem unusually high. Authors indeed mention that they were among the highest produced for herring species world-wide (note that the Table 5 referred to in the text appears to be missing) and that that is partly due to the high value of *M* used in the analysis (long-term average of the time series of *M*), and partly due to the juxtaposition of the maturity and selectivity-at-age schedules. One important piece of information that would likely be important to include in the paper is that the current estimates of maturity are based on field study results and held constant across stocks, whereas selectivity is estimated by the model. It is possible that maturity might differ among stocks (model estimates suggest it does in southeast Alaska) and could partially explain why values for HG are different from other areas. Estimating both maturity and selectivity by the model may provide a better representation of the relationship between these two parameters and might lead to different estimates of F_{MSY}. The use of equilibrium reference points might be a viable option after additional work is conducted on the model structure, and would be worth revisiting.

It would be worth clarifying in the paper why equilibrium reference points were not selected – was it because of non-stationarity in natural mortality and growth, which violates an assumption of the equilibrium analysis (this was known ahead of doing the analysis, so it might beg the question of why the analysis was conducted) or was it because of the results of the analysis?

There is much discussion in the paper about the role of herring as a forage fish and whether it should influence the choice of LRPs. It wasn't completely clear to me as a reader where consideration of herring as a forage fish should be made within the renewal of the Pacific Herring management system.

APPENDIX G: PRODUCTION EQUATION REVISIONS TO WORKING PAPER[1]

The analyses described in the Working Paper utilize the outputs of the 2016 Pacific Herring stock assessment model. During the second day of the meeting, a participant questioned the authors on the accuracy of Equation P1, citing the timing of spawning relative to catch. The equation described surplus production on p.22 of the Working Paper as:

(P1) $P_t = B_{t+1} - B_t + C_t$

where P_t is the surplus spawning biomass production for year t, B is spawning biomass and C is catch. This equation was cited from its original source (Hilborn 2001) and applied in the production analyses in the Working Paper.

The participant suggested the equation should be re-written as:

(P5 [2]) $P_t = B_{t+1} - B_t + C_{t+1}$

to account for the assessment model assumption that spawning occurs after the catch is taken. The participant supplied a spreadsheet to show the calculation, although the authors did not receive it until after the meeting due to webmail being unavailable all day.

Eq. P5 is a fairly subtle adjustment to Eq. P1 that requires careful consideration of when spawning occurs, and when spawning biomass is observed relative to the catch. The authors were not able to give the suggestion full consideration during the meeting, and discussion moved to other topics.

The day after the meeting, the authors gave the participant's comment thorough consideration. This required examination of the assessment model computer code to determine the timing of catch relative to the timing of spawning biomass implemented in the model. The authors determined that an adjustment is required because unlike most catch-at-age assessment models, the Pacific Herring model estimates end of year spawning biomass rather than beginning of year spawning biomass. This means that Eq. P5 is more correct given spawn timing.

The correction results in minor changes to production estimates (Figure 1; Table 1; Tables in Appendices 1a and 1b) and does not change the conclusions of the Working Paper about the presence of persistent recent low production, low biomass (LP-LB) states for the WCVI, HG and CC stocks, or the periods determined to be in LP-LB states (Table 1; dark grey shaded rows in Tables in Appendices 1a and 1b). These states are interpreted as being consistent with signs of "serious harm" as described by the DFO Decision-making Framework Incorporating the Precautionary Approach policy. Conclusions for PRD and SOG stocks are also unchanged.

The authors have confirmed that the revised analysis supports the Working Paper recommendation with respect to the choice of a limit reference point of 0.3 of the unfished

---

[1] The working paper has been updated to include this new Eq. P5, with accompanying text: "However, unlike most assessment models the Pacific Herring model (Martell et al. 2012) estimates end of year spawning biomass rather than beginning of year spawning biomass. In addition, the assumption is made that spawning biomass is observed after the catch is taken. Therefore, an adjustment to Eq. P1 is required that considers when spawning biomass is observed relative to the catch that arose from spawning biomass in year *t* given by Eq. P5.

spawning biomass**. Given the minor changes in the production estimates all recommendations remain the same as reached at the CSAS peer review.**

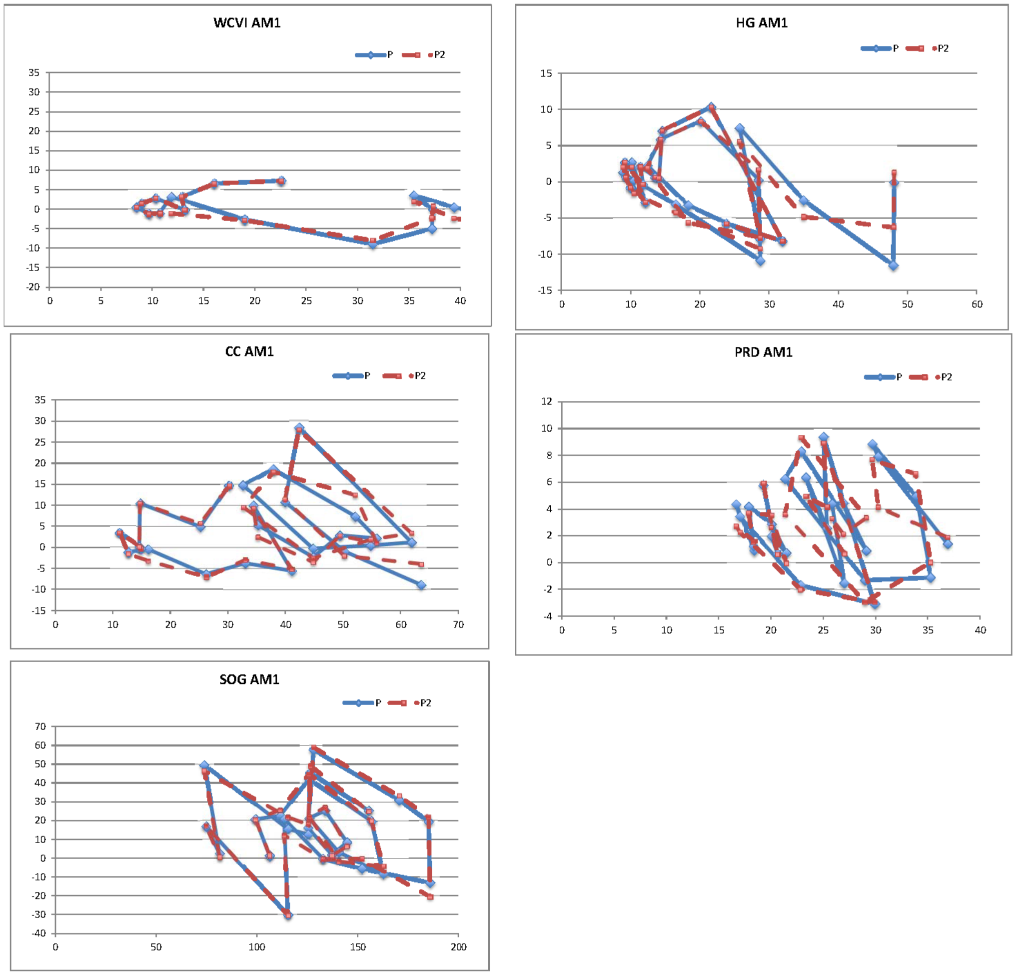

Figure 2. Phase plots of spawning stock biomass (SSB) production against SSB for model AM1 for all five major stocks for the Dive Survey (recent) time period. Blue series show values from the Working Paper (Production calculated using Eq. P1). Red series show values where Production was calculated using Eq. P5).

REFERENCES

Hilborn, R. 2001. Calculation of biomass trend, exploitation rate, and surplus production from survey and catch data. Can. J. Fish. Aquat. Sci. 58: 579-584.

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. Res. Doc. 2011/136. xxi + 151 p.