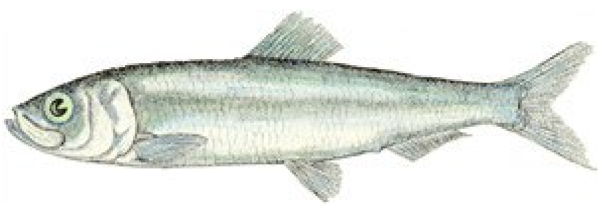
Fisheries and Oceans Canada
Ecosystems and Oceans Science

Pêches et Océans Canada
Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2023/040

APPLICATION OF A NEW MODELLING FRAMEWORK FOR THE ASSESSMENT OF PACIFIC HERRING (*CLUPEA PALLASII*) MAJOR STOCKS AND IMPLEMENTATION IN THE MANAGEMENT STRATEGY EVALUATION PROCESS



*Pacific Herring (*Clupea pallasii*) - credit DFO*
[Pacific Herring]

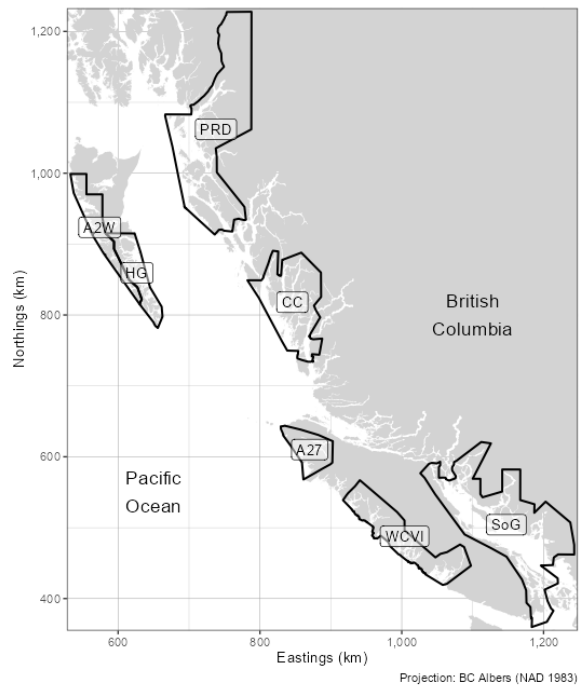


Figure 1. British Columbia Pacific Herring major stock areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), West Coast of Vancouver Island (WCVI), and minor stock areas: Area 2W and Area 27.

Context:

Fisheries and Oceans Canada (DFO) presently uses a management strategy evaluation (MSE) process to collaborate with First Nations, non-governmental organizations and the Herring Industry Advisory Board to develop and implement sustainable harvest strategies for British Columbia (BC) Pacific Herring stocks. The MSE analytical framework uses models to represent key dynamics of herring populations and fisheries, as well as their response to management options. Fisheries and Oceans (DFO) Resource Management requested that DFO Science update and review the data, models, and assumptions that underpin this framework.

*This Science Advisory Report is from the June 26-28, 2023 regional peer review on the Application of a new modelling framework for the assessment of Pacific Herring (*Clupea pallasii*) major stocks and implementation in the management strategy evaluation process. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.*

October 2023

SUMMARY

- A purpose-built statistical catch-at-age model was presented with the following features: flexibility in modelling natural mortality (M), a method for integrating data from surface and dive surveys in estimation of the survey index, representation of timing of all fisheries throughout the year, inclusion of spawn-on-kelp (SOK) fisheries, and an age-composition likelihood function that captures correlation among ages.
- The new model is a spatially integrated statistical catch-at-age herring (SISCAH) model, however the spatial capabilities of the model were not used here. SISCAH was compared to the previous assessment model with a transition analysis, using data through 2022.
- Suitability of SISCAH as an assessment model for the five major Pacific Herring stocks was evaluated using common statistical metrics including goodness of fit, simulation self-tests, retrospective analyses, and sensitivity tests. Trends in biomass, depletion, and recruitment were evaluated for each major stock. Utility of SISCAH as an operating model was evaluated by: i) conditioning on the historical time series (1951-2022), ii) projecting the population over a 15 year time frame, iii) applying example precautionary approach (PA) compliant management procedures to the projected population, and iv) evaluating performance against existing conservation and biomass objectives using closed loop simulations.
- Density-dependent natural mortality was added to represent potential ecosystem impacts (e.g., depensatory predation) on Pacific Herring stocks. Evidence for depensation in natural mortality varied among regions, and was strongest in Haida Gwaii (HG), Central Coast (CC), and West Coast Vancouver Island (WCVI), and weak in Prince Rupert District (PRD) and Strait of Georgia (SOG).
- Model fit was improved by introducing a weighting method for combining surface and dive survey indices within a single year, rather than the previous practice of treating post-1987 surface observations as coming from the dive survey only.
- SISCAH and the previous model show similar time series trends in biomass and recruitment. SISCAH natural mortality estimates match the previous model for HG and WCVI but appears to be constrained at lower levels of natural mortality for PRD, CC and SOG.
- SOK removals were included in the new model, represented as using closed ponding methods although representation using open ponding methods is also possible in future versions. Including these removals had little effect on biomass trends since ponding mortality is generally low, but yield curves were sensitive to allocation of quota among fisheries.
- As an operating model SISCAH reproduced historical population trends and simulated future trends and observational data consistent with the historical observations. Example management procedure evaluations were presented using perfect information simulations.
- Density-dependent natural mortality has stock-specific effects, affecting estimates of long-term average unfished biomass and thus reference points, and consequently the perception of stock status over time. For example, stocks which show stronger evidence of depensation, such as HG, have lower estimates of long-term average unfished biomass which corresponds to lower limit reference points estimates.
- Equilibrium yield curves were produced using 200-year simulations and were the basis for maximum sustainable yield (MSY)-based reference point calculations. These curves were highly sensitive to the allocation of catch between fisheries; an allocation based on the

recent-most 10-years historical average was used in this analysis (excluding years without fishing). Estimated harvest rate at MSY may be used to guide for tuning management procedure evaluations, for compliance with the PA policy reporting requirements, and for evaluation of proposed best practices for forage species.

- A minimum 3 year cycle for management strategy evaluation (MSE) updates is recommended, unless new evidence reveals exceptional circumstances.
- A process for implementing the new assessment and operating model, updates to the MSE, and identification of exceptional circumstances should be developed in a phased approach in consultation with managers, First Nations and stakeholders.
- Environmental variability was modelled implicitly via natural mortality dynamics (i.e., implicit predation), recruitment variability, and inter-annual variability in natural mortality around the depensatory relationship to biomass; however, specific advice on the impacts of climate change and changes to ocean productivity were not addressed in the analysis.
- Future work should include examining alternative parametrizations of density-dependent natural mortality, survey catchabilities, and spatial structure.

INTRODUCTION

Pacific Herring (*Clupea pallasii*) in British Columbia (BC) are currently managed in five major and two minor stock assessment regions (SAR). The major stocks included in this model review are Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), and West Coast of Vancouver Island (WCVI; Figure 1). Pacific Herring are an important species to First Nations, with coastal Indigenous food, social and ceremonial (FSC) fisheries, as well as treaty and Aboriginal commercial fisheries in specific management areas.

Fisheries and Oceans Canada (DFO) uses a management strategy evaluation (MSE) process in collaboration with First Nations, non-governmental organizations and the Herring Industry Advisory Board to develop and implement sustainable harvest strategies for Pacific Herring. The use of the MSE process aligns with DFO's "A Fishery Decision-Making Framework Incorporating the Precautionary Approach" policy (DFO 2009). The process evaluates sustainability of harvest strategies by simulation testing management procedures with operating model scenarios that represent a range of hypotheses about uncertain population and fishery dynamics. Performance of management procedures are measured with conservation and catch objectives for each stock area and fishery (Cox et al. 2019; DFO 2023).

The MSE framework, first implemented in 2018, uses a statistical catch-age model in both the management procedures (annual assessment of BC herring stocks) and to estimate key population parameters used in the operating models (Cleary et al. 2019; DFO 2019; DFO 2020; Benson et al. 2023). Previous scientific reviews, ongoing consultation with First Nations and fishery stakeholders, and increasing survey costs indicate a need for added functionality in the assessment and operating models, including:

1. parameterizing density-dependent natural mortality to better represent potential ecosystem impacts on herring stocks;
2. a method for integrating data from surface and dive surveys in estimation of the survey index;
3. implementing fishing mortality in discrete time steps within a fishing season;
4. inclusion of removals from SOK fisheries; and
5. an age-composition likelihood function that captures correlation among ages.

DFO Resource Management requested that DFO Science update and review the model used for annual assessment of BC Pacific Herring stocks to include elements (1) to (4) and show its utility as an operating model.

ANALYSIS

A new model built in Template Model Builder was presented with the following features: a density-dependent process for natural mortality, explicit representation of SOK fisheries, fisheries with discrete removal events over a short season, a single spawn index that blends dive and surface survey designs, and an age-composition likelihood function that accounts for correlation in residuals among age-classes.

Comparisons with the previous model (ISCAM, Martell et al. 2012) were made. Trends in biomass, recruitment, and natural and fishing mortalities were mostly the same (Figure 2, fishing mortality not shown). Exceptions included natural mortality that seem constrained at lower levels for PRD, CC and SOG, but seemed to match closely for HG and WCVI. Also while trends in biomass were similar, earlier in the time period the magnitude of the biomass appears higher for SISCAH over the previous model. Differences do not indicate unsuitability of either model.

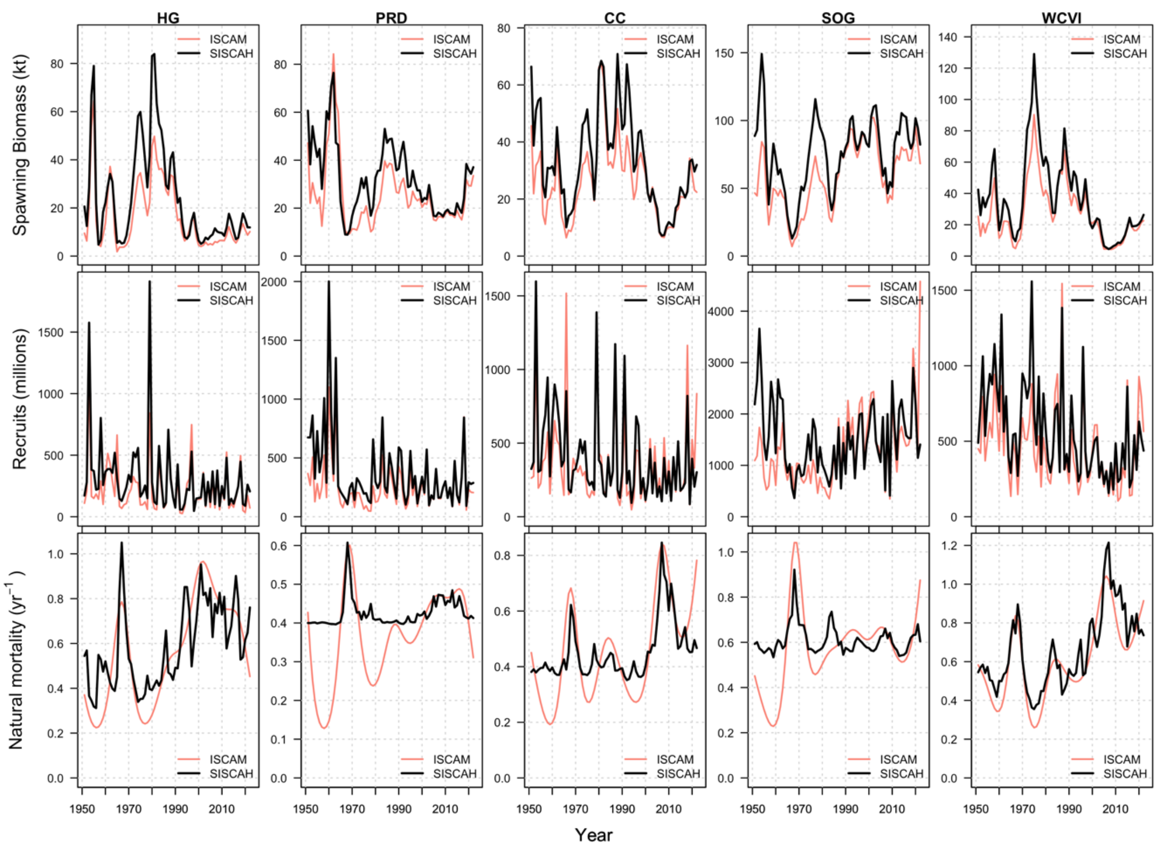


Figure 2. Comparison of biomass, recruitment, and natural mortality estimates between the previous model (ISCAM, pink) and the full SISCAH model (black) for the 5 stock assessment regions: Haida Gwaii, Prince Rupert District, Central Coast, Strait of Georgia, and West Coast Vancouver Island.

Suitability of SISCAH for estimating trends in biomass, depletion, and recruitment for each of the five major Pacific Herring stocks was evaluated via goodness of fit, simulation self-tests, retrospective analysis, and sensitivity tests using 1951-2022 data.

Goodness of fit

Goodness of fit was determined via observation model standard errors (lower is better, and SISCAH had lower values than ISCAM for spawn indices), time-trends in model residuals (minimal time trends), auto-correlation in observation error residuals and process errors (low auto-correlation), and visual inspection of model estimates of biomass, recruitment, and natural mortality for evidence of model artefacts or unexpected behaviour. Model estimates were similar to ISCAM and productivity parameters such as natural mortality and stock-recruit steepness matched expectations.

Simulation self-tests

Simulation self-tests were performed for the CC and SOG SARs. For CC, the level of bias and variation in life-history and survey parameters were determined acceptable because median relative errors were lower than 0.3 in magnitude (except for end effects) and most distributions intersected zero indicating that SISCAH model posteriors generally contained the true parameter values for the CC population.

Spawning biomass depletion and recruitment were unbiased over time, although there was some bias in selectivity parameters when age-composition data are simulated.

Simulating random prior mean values for the rate at which natural mortality increases at low stock sizes (depensation, m_1) increases variance and, in some cases, bias in all life-history parameters. However, process errors tended to compensate for the larger relative errors in the mortality parameters m_1 and M_b (the baseline or minimum natural mortality rate), leaving most time-series estimates somewhat insensitive to the random priors.

For SOG, the variation in the self-tests was also lower than 0.3 in magnitude (excluding end effects). Random priors had a larger effect on the m_1 parameter, which is expected as SOG had few years of low abundance that would help inform the m_1 parameter.

Time-series of relative errors for SOG spawning biomass, depletion, and natural mortality showed similar results as for CC. The main differences were for the Age Data Simulated scenario, where the effects of the positive bias in SB_0 were observed as a small negative bias in spawning biomass depletion estimates and a small negative bias in the M_t series. The latter is caused by the drop in the M_b, parameter, which shifts the mortality rate estimates lower. However, unlike the CC case, the shift in M_b was not modulated as well by mortality process errors because they are so small (standard deviation of 0.06).

Retrospective analysis

Retrospective analyses demonstrated some short term sensitivity to new data that eventually settle and become stable. Generally, over-/under-estimation of biomass appeared with equal frequency and biological reference points were stable over time, which – importantly – avoids the need for time-varying reference points.

Sensitivity tests

Sensitivity tests showed that SISCAH estimates of herring biomass and life history parameters were relatively insensitive to specific choices of priors for each SAR. The mean relative difference in estimates between the SISCAH implementation and sensitivity runs with alternative priors was less than 1.4% for all leading life-history parameters.

Operating model suitability

Utility of SISCAH as an operating model was evaluated by: (i) conditioning on the historical time series (1951-2022), (ii) projecting the population over a 15 year time frame, (iii) applying example precautionary approach (PA) compliant management procedures to the projected population, and (iv) evaluating performance against existing conservation and biomass objectives using closed loop simulations. Our purpose was not to complete a full management strategy evaluation but rather to demonstrate the simulation capability of SISCAH as an operating model and to demonstrate initial implications of density-dependent natural mortality under typical DFO PA harvest rate strategies.

We compared the historical data to the projected data and found suitable performance. In particular, (i) the historical and projected process errors for recruitment and natural mortality were similar; (ii) trends in historical and projected time-varying natural mortality had the same 'shape'; (iii) the projected dynamics matched estimated model equilibria; and (iv) simulated data were found to be noisy and not smooth (similar to real data). For all SARs, the population dynamics and observation models for generating simulated data largely matched those defined for the estimation model (Figure 3, example: HG).

SISCAH was found to be acceptable as an operating model because it reproduced historical population trends as well as simulate future trends and observational data consistent with the historical dynamics. Example management procedure evaluations were presented using perfect information and future work will involve management procedure evaluations with stochasticity.

Key findings

Density-dependent natural mortality represents potential ecosystem impacts (e.g., depensatory predation) on Pacific Herring stocks. Evidence for depensation in natural mortality varied among regions, and was strongest in HG, CC, and WCVI, and weak in PRD and SOG (Figure 4). Stocks with low depensation rates (HG, CC, WCVI) show natural mortality increasing over a wide range of biomass levels, whereas stocks with higher depensation rates (PRD, SOG) have more stable trends in natural mortality.

Model fit was improved by introducing a weighting method for combining surface and dive survey indices within a single year, rather than the previous practice of treating post-1987 surface observations as coming from the dive survey only.

Modelling fishery timing more accurately had no measurable effect on model estimates, nor did the addition of SOK removals (represented as closed ponding); however, there were notable differences in yield curves depending on the allocation to the SOK fishery versus a whole herring fishery (e.g., seine roe), which impacts equilibrium reference points. Because the SOK fishery has a lower realized harvest rate due to release of post-spawn adults, estimated U_{MSY} rates were higher for SOK than for other whole herring fisheries. This result occurs because the fishery can capture a much larger fraction of the spawning biomass if most of that biomass is released alive after ponding. For instance, equilibrium yield curves and reference points derived via 200-year constant fishing mortality simulations showed that high allocation to the SOK fishery produced yield curves with higher rates of U_{MSY} than those with higher allocation to other whole herring fisheries (Figure 5, example: PRD).

Estimates of long-term equilibrium unfished spawning biomass (SB_0), current biomass depletion (SB_t/SB_0), and MSY-based reference points (based on recent 10-year average allocation) from SISCAH are presented in Table 1, estimated via both deterministic and stochastic simulation processes. Deterministic estimates of SB_0 are similar to estimates from the previous ISCAM model (Table 2), however MSY-based reference points differ considerably. ISCAM estimates of

U_{MSY} are considerably higher than historical harvest levels, and therefore have not been used in the management of herring fisheries. In contrast, SISCAH U_{MSY} estimates are more in line with historical harvest levels (when effective mortality of SOK fisheries is taken into account), so they can provide an initial reference removal rate from which performance of management procedures consistent with PA policy can be tuned to meet pre-specified objectives. Estimates of SB_0 from deterministic simulations are generally higher than SB_0 from stochastic simulations (i.e., process errors in recruitment and natural mortality), particularly in SARs with low m_1 values. Reference point calculations, including differences between deterministic and stochastic estimates of SB_0, and the sensitivity of yield curves to allocation among Pacific Herring fisheries, merits further investigation.

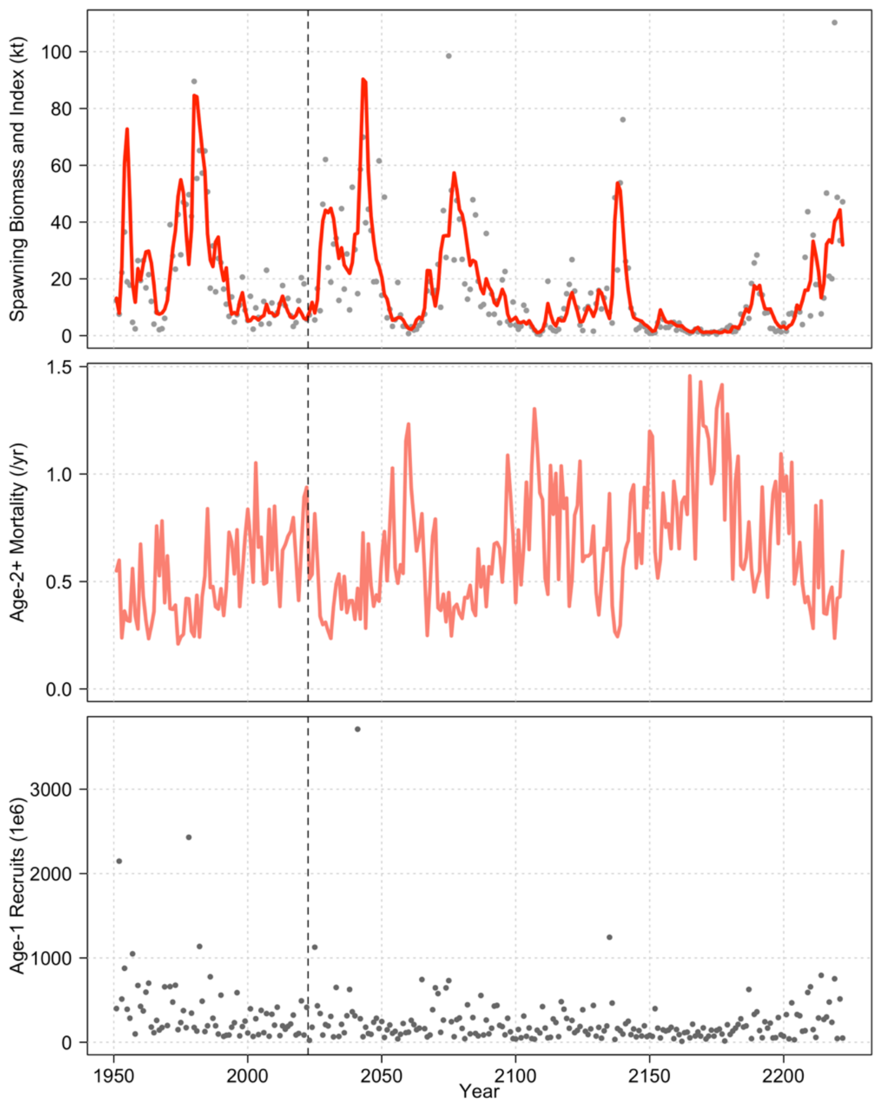


Figure 3. Example simulation replicate derived via the SISCAH operating model under a No Fishing scenario for the Haida Gwaii SAR. Historic trends (1951-2022) include fishery removals, while the simulated 200-year future trends reflect population variability in the absence of fishing. Top panel shows estimated spawning biomass (red line) and blended index (grey points); middle panel shows estimated age-2+ natural mortality (pink line); bottom panel shows estimated age-1 recruits (black points).

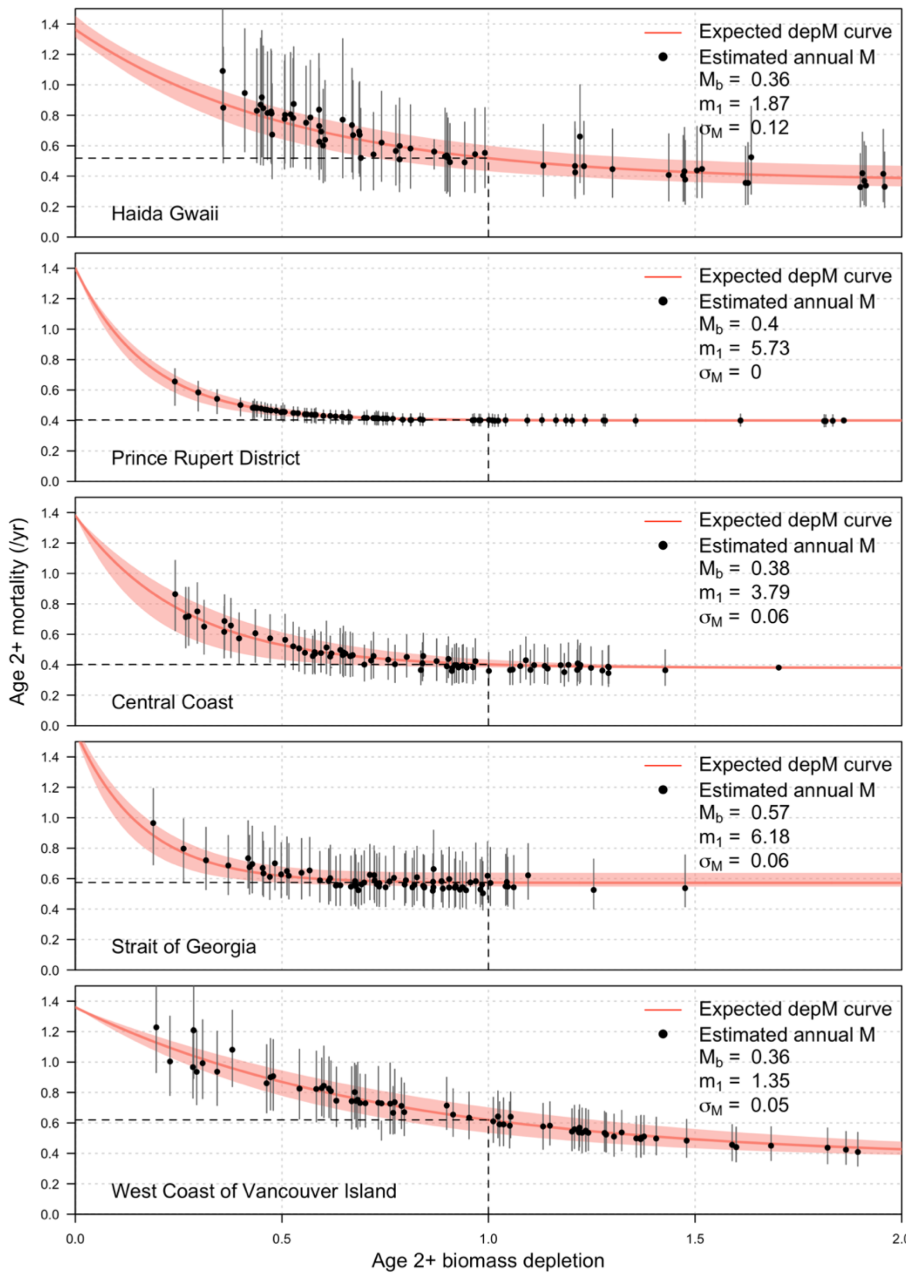


Figure 4. SISCAH model posterior estimate of the density-dependent relationship between age-2+ biomass depletion and age-2+ natural mortality. The median relationship is shown by a thick pink line, with the posterior 95% credibility range shown by the pink shaded region. Individual points show the annual posterior median natural mortality estimates with standard errors reported as σ_M. Other parameters are: m_1 = depensation rate, M_b = asymptotic lower limit of density-dependent mortality.

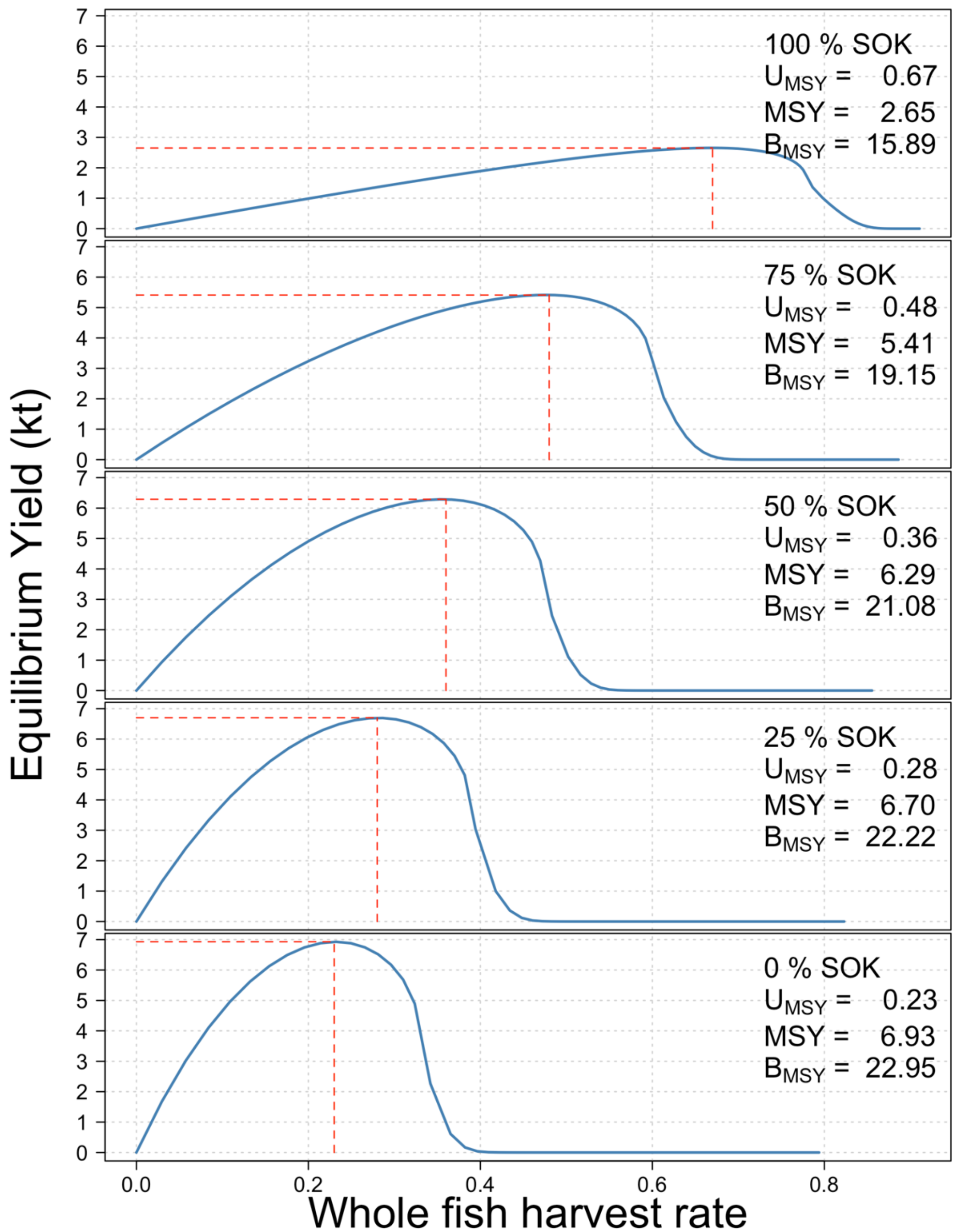


Figure 5. Example equilibrium yield curves and reference points derived via 200-year constant fishing mortality simulations, using SISCAH model life-history and fishery parameters estimates for the Prince Rupert District SAR. Yield curves shown here differ based on allocation between spawn-on-kelp (SOK) and seine roe fisheries. The top panel shows full whole herring quota allocation to SOK and the bottom panel shows full allocation to seine roe. For yield curves where % SOK is greater than 0, the whole fish harvest rate for SOK reflects the adult mortality associated with ponding and handling. U_{MSY} is the estimated harvest rate at maximum sustainable yield (MSY) and B_{MSY} is the estimated biomass at MSY. Harvest rate is calculated as catch divided by catch plus spawning biomass.

Table 1. SISCAH estimates of deterministic (Det) and stochastic (Stoch) equilibrium unfished spawning biomass (SB_0, kt) and depletion (SB_t/SB_0), as well as estimates of maximum sustainable yield (MSY, kt), biomass at MSY (B_{MSY}, kt), and the harvest rate associated with MSY (U_{MSY}). Values are Bayes posterior median estimates with half the inter-quartile range reported in parentheses.

	Unfished SB_0		Depletion SB_{2022}/SB_0		MSY reference points		
	Det	Stoch	Det	Stoch	B_{MSY}	U_{MSY}	MSY
HG	24.14	12.93	0.46	0.86	5.23	0.26	0.30
PRD	49.02	46.41	0.75	0.78	19.33	0.37	3.65
CC	53.61	46.67	0.59	0.68	20.37	0.31	1.95
SOG	124.07	119.11	0.65	0.68	41.83	0.35	22.66
WCVI	41.32	38.06	0.62	0.68	10.30	0.35	2.42

Table 2. ISCAM estimates of long-term equilibrium unfished spawning biomass (SB_0, kt), depletion (SB_t/SB_0), and equilibrium reference points: maximum sustainable yield (MSY, kt), biomass (B_{MSY}, kt), and the associated harvest rate at MSY (U_{MSY}).

	SB_0	SB_t/SB_0	B_{MSY}	U_{MSY}	MSY
HG	21.82	0.47	4.03	0.592	5.84
PRD	55.48	0.6	9.88	0.396	6.48
CC	49.63	0.45	3.61	0.691	8.06
SOG	133.57	0.51	15.25	0.652	28.62
WCVI	43.29	0.52	4.07	0.708	9.85

Sources of Uncertainty

This model is set up on a Bayesian framework, meaning that both the data as well as the prior distributions on model parameters have some amount of influence on the model outputs, and both encapsulate some amount of uncertainty.

Sources of uncertainty pertaining to the data include abundance indices, age and weight compositions, as well as some harvest estimates (e.g., spawn-on-kelp).

Sources of uncertainty around prior distributions should be a balance between allowing priors to be uninformative enough so that the parameter estimates are primarily informed by the data, but not so uninformative that parameters have difficulty converging on their estimates. As such there may be differences around prior specification as the balance these two goals is often an individual choice (i.e., informative priors help improve convergence, but may also bias results or artificially reduce uncertainty). Many of the SISCAH model priors have been built on understanding from previous herring models, including ISCAM, which have their own uncertainties. Further work on the development of priors for the density dependent parameters was recommended by the review process.

Other sources of uncertainty include how model specification affects parameters and reference point estimates. The review process highlighted two specifications to examine in future work: (i) parametrizations of density-dependent natural mortality that includes both depensatory and compensatory options, and (ii) how survey catchabilities are quantified. For survey catchabilities, a paired study could be used to find the relationship between modern day surface surveys and dive surveys, so that only one catchability coefficient would need to be specified.

Other model specifications that may add uncertainty to the model include the weight and type of constraints put on the model, including things such as the Jefferies prior on unfished biomass and the lower bounds of natural mortality. Such specifications can also be improved via sensitivity analyses.

Alternative parameterizations can change model output and reference point estimates.

CONCLUSIONS AND ADVICE

- Structural assumptions of SISCAH, such as density-dependent natural mortality, can affect estimates of the long-term average unfished biomass, biological reference points, and, consequently our understanding of stock status over time. For example, stocks with stronger evidence of depensatory natural mortality, like HG, show lower estimates of long-term average unfished biomass and have lower corresponding limit reference point estimates.
- Equilibrium yield curves are produced using 200-year simulations and are the basis for MSY-based reference point calculations. Like many multi-sector fisheries, yield curves are sensitive to the allocation of catch among fisheries and the lower effective fishing mortality for SOK affects BC herring yield curves when this fishery is included. Future work should define a preference for how harvest rates are defined. For the present simulations, allocation among sectors in projections matched the historical average relative catch levels for the most recent 10-years with fishery openings (years with zero catch were skipped). Estimated harvest rates at MSY may be used to guide tuning management procedure evaluations, for compliance with the PA policy reporting requirements, and for evaluation of proposed best practices for forage species.
- A minimum 3-year cycle for MSE updates is recommended, unless new evidence reveals exceptional circumstances.
- A process for implementing the new assessment and operating model, updates to the MSE, and identification of exceptional circumstances should be developed in a phased approach in consultation with managers, First Nations and other stakeholders.

OTHER CONSIDERATIONS

Environmental variability was modelled implicitly via natural mortality (e.g., implied predation impacts), recruitment process variability, and natural mortality process variability around the average depensatory relationship; however, specific advice on the impacts of climate change and changes to ocean productivity were not addressed in the analysis.

Future work should include examining other parametrizations of density-dependent natural mortality, survey catchabilities, and spatial structure.

LIST OF MEETING PARTICIPANTS

Last Name	First Name	Affiliation
Benson	Ashleen	Landmark Fisheries Research
Boldt	Jennifer	DFO Science
Bruce	Kevin	DFO Fisheries Management
Burridge	Christina	BC Seafood Alliance
Cahill	Chris	Michigan State University
Cleary	Jaclyn	DFO Science
Cox	Sean	Simon Fraser University / Landmark Fisheries Research
Curkan	Curtis	DFO Fisheries Management
Dorner	Brigitte	Heiltsuk First Nation
Driscoll	John	Pacific Marine Conservation Caucus / David Suzuki Foundation
Forrest	Robyn	DFO Science
Frederickson	Nicole	Island Marine Aquatic Working Group
Hawkshaw	Sarah	DFO Science
Johnson	Sam	Landmark Fisheries Research
Jones	Russ	Council of the Haida Nation
Keefe	Marisa	DFO Fisheries Management
Lane	Jim	Nuu-chah-nulth Tribal Council
Mazur	Mackenzie	DFO Science
Miyagi	Eamon	DFO Fisheries Management
Muirhead-Vert	Yvonne	DFO Centre for Science Advice Pacific
Nowosad	Damon	Q’ul-Ihanumutsun Aquatic Resources Society
O	Miriam	DFO Centre for Science Advice Pacific
Olmstead	Melissa	DFO Science
Postlethwaite	Victoria	DFO Fisheries Management
Power	Sarah	DFO Science
Romanin	Kevin	Province of British Columbia
Rooper	Chris	DFO Science
Rusch	Bryan	DFO Fisheries Management
Schut	Steve	DFO Science
Starr	Paul	Herring Industry Advisory Board
Tai	Travis	DFO Science
Van Beveren	Elisabeth	DFO Science
White	Penny	Lax Kw'alaams Band

SOURCES OF INFORMATION

This Science Advisory Report is from the June 26-28, 2023 regional peer review on the Application of a new modelling framework for the assessment of Pacific Herring (*Clupea pallasii*) major stocks and implementation in the management strategy evaluation. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Benson, A.J., Cleary, J.S., Cox, S.P., Johnson, S., and Grinnell, M.H. 2023. Performance of management procedures for British Columbia Pacific Herring (*Clupea pallasii*) in the presence of model uncertainty: closing the gap between precautionary fisheries theory and practice. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/048. viii + 70 p.

Cleary, J.S., Hawkshaw, S., Grinnell, M.H., and Grandin, C. 2019. Status of B.C. Pacific Herring (*Clupea pallasii*) in 2017 and forecasts for 2018. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/028. v + 285 p.

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 framework incorporating the precautionary approach.

DFO. 2019. Evaluation of Management Procedures for Pacific Herring (*Clupea pallasii*) in the Strait of Georgia and the West Coast of Vancouver Island Management Areas of British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/001.

DFO. 2020. Proceedings of the Pacific regional peer review of the Evaluation of Management Procedures for Pacific Herring (*Clupea pallasii*) in the Strait of Georgia and the West Coast of Vancouver Island Management Areas of British Columbia; July 25-26, 2018. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2020/027.

DFO. 2023. Management Strategy Evaluation Update and Evaluation of Upper Stock Reference Point Options for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Sci. Resp. 2023/002.

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.

THIS REPORT IS AVAILABLE FROM THE:

Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

E-Mail: DFO.PacificCSA-CASPacifique.MPO@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-68097-2 N° cat. Fs70-6/2023-040E-PDF

Correct Citation for this Publication:

DFO. 2023. Application of a new modelling framework for the assessment of Pacific Herring (*Clupea pallasii*) major stocks and implementation in the management strategy evaluation process. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/040.

Aussi disponible en français :

*MPO. 2023. Application d'un nouveau cadre de modélisation pour l'évaluation des grands stocks de hareng du Pacifique (*Clupea pallasii*) et mise en œuvre dans le processus d'évaluation des stratégies de gestion. Secr. can. des avis. sci. du MPO. Avis sci. 2023/040.*