INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC–2022–SRB021–00
Last Update: 22 September 2022

21st Session of the IPHC Scientific Review Board (SRB021) – *Compendium of meeting documents*

20-22 September 2022, Seattle, WA, USA

Commissioners

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DISTRIBUTION: IPHC WEBSITE
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INTERNATIONAL PACIFIC HALIBUT COMMISSION

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DRAFT: AGENDA & SCHEDULE FOR THE 21st SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB021)

Date: 20-22 September 2022
Location: Seattle, WA, USA, & Electronic Meeting
Venue: IPHC HQ & Adobe Connect
Time: 12:30-17:00 (20th), 09:00-17:00 (21-22nd) PDT
Chairperson: Dr Sean Cox (Simon Fraser University)
Vice-Chairperson: Nil

1. OPENING OF THE SESSION

2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

- *IPHC-2022-SRB021-01: Agenda & Schedule for the 21st Session of the Scientific Review Board (SRB021)*
- *IPHC-2022-SRB021-02: List of Documents for the 21st Session of the Scientific Review Board (SRB021)*

3. IPHC PROCESS

3.1. SRB annual workflow (D. Wilson)
3.2. Update on the actions arising from the 20th Session of the SRB (SRB020) (D. Wilson)
- *IPHC-2022-SRB021-03: Update on the actions arising from the 21st Session of the SRB (SRB021) (IPHC Secretariat)*

3.3. Outcomes of the 98th Session of the IPHC Annual Meeting (AM098), and 12th Special Session of the IPHC (SS012) (D. Wilson)
- *IPHC-2022-SRB021-04: Outcomes of the 98th Session of the IPHC Annual Meeting (AM098), and 12th Special Session of the IPHC (SS012) (D. Wilson)*

3.4. Observer updates (e.g. Science Advisors)

4. INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED RESEARCH AND MONITORING (2022-26)

- *IPHC-2022-SRB021-05 International Pacific Halibut Commission 5-Year program of integrated research and monitoring (2022-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, B. Hutniczak, & J. Jannot)*

5. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS)

- *IPHC-2022-SRB021-06 2023-25 FISS design evaluation (R. Webster)*

5.1. 2023 FISS design evaluation (R. Webster)
5.2. Updates to space-time modelling (R. Webster)

6. MANAGEMENT STRATEGY EVALUATION: UPDATE

- *IPHC-2022-SRB021-07 IPHC Secretariat MSE Program of Work (2022–2023) and an update on progress (A. Hicks & I. Stewart)*

7. PACIFIC HALIBUT STOCK ASSESSMENT: 2022

- *IPHC-2022-SRB021-08 Development of the 2022 Pacific halibut (Hippoglossus stenolepis) stock assessment (I. Stewart & A. Hicks)*

8. BIOLOGICAL AND ECOSYSTEM SCIENCES – PROJECT UPDATES

- *IPHC-2022-SRB021-09 Report on current and future biological and ecosystem science research activities (J. Planas)*

9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 21st SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB021)

SCHEDULE FOR THE 21st SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB020)

Tuesday, 20 September 2022		
Time	**Agenda item**	**Lead**
12:00-12:30	*Lunch – Meet and greet *Adobe Connect - Participants encouraged to call in and test connection	
12:30-12:35	1. OPENING OF THE SESSION 2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION	S. Cox & D. Wilson
12:35-13:00	3. IPHC PROCESS 3.1 SRB annual workflow (D. Wilson) 3.2 Update on the actions arising from the 20th Session of the SRB (SRB020) 3.3 Outcomes of the 98th Session of the IPHC Annual Meeting (AM098) 3.4 Observer updates (e.g. Science Advisors)	D. Wilson
13:30-14:00	4. INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED RESEARCH AND MONITORING (2022-26): IMPLEMENTATION UPDATE	D. Wilson
14:00-14:45	5. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS) 5.1 2023 FISS design evaluation 5.2 Updates to space-time modelling	R. Webster
14:45-16:30	6. MANAGEMENT STRATEGY EVALUATION: UPDATE	A. Hicks
16:30-17:00	SRB drafting session	SRB members
Wednesday, 21 September 2022		
Time	**Agenda item**	**Lead**
09:00-09:30	Review of Day 1 and discussion of SRB Recommendations from Day 1	Chairperson
09:30-12:30	7. PACIFIC HALIBUT STOCK ASSESSMENT: 2022	I. Stewart

12:30-13:30	Lunch	
13:30-16:00	8. BIOLOGICAL AND ECOSYSTEM SCIENCES – PROJECT UPDATES	J. Planas
16:00-17:00	SRB drafting session	SRB members
Thursday, 22 September 2022		
Time	**Agenda item**	**Lead**
09:00-09:30	Review of Day 2 and discussion of SRB Recommendations from Day 2	Chairperson
09:30-12:30	Revisit any topic for discussion	SRB members
12:30-13:30	Lunch	
13:30-14:30	SRB drafting session	SRB members
14:30-15:30	Secretariat report preparation for adoption	D. Wilson
15:30-17:00	9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 21st SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB021)	S. Cox

Last updated: 19 August 2022

PROVISIONAL: LIST OF DOCUMENTS FOR THE 21st SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB021)

Document	Title	Availability
IPHC-2022-SRB021-01	Agenda & Schedule for the 21st Session of the Scientific Review Board (SRB021)	✓ 22 Jun 2022 ✓ 19 Aug 2022
IPHC-2022-SRB021-02	List of Documents for the 21st Session of the Scientific Review Board (SRB021)	✓ 17 Aug 2022 ✓ 19 Aug 2022
IPHC-2022-SRB021-03	Update on the actions arising from the 20th Session of the SRB (SRB020) (IPHC Secretariat)	✓ 17 Aug 2022
IPHC-2022-SRB021-04	Outcomes of the 98th Session of the IPHC Annual Meeting (AM098), and 12th Special Session of the IPHC (SS012) (D. Wilson)	✓ 17 Aug 2022
IPHC-2022-SRB021-05	International Pacific Halibut Commission 5-Year program of integrated research and monitoring (2022-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, B. Hutniczak, & J. Jannot)	✓ 17 Aug 2022
IPHC-2022-SRB021-06	2023-25 FISS design evaluation (R. Webster)	✓ 19 Aug 2022
IPHC-2022-SRB021-07	IPHC Secretariat MSE Program of Work (2022–2023) and an update on progress (A. Hicks & I. Stewart)	✓ 18 Aug 2022
IPHC-2022-SRB021-08	Development of the 2022 Pacific halibut (*Hippoglossus stenolepis*) stock assessment (I. Stewart & A. Hicks)	✓ 17 Aug 2022
IPHC-2022-SRB021-09	Report on current and future biological and ecosystem science research activities (J. Planas)	✓ 18 Aug 2022
Information papers		
Nil to-date	Nil to-date	-

UPDATE ON THE ACTIONS ARISING FROM THE 20TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB020)

PREPARED BY: IPHC SECRETARIAT (17 AUGUST 2022)

PURPOSE

To provide the Scientific Review Board (SRB) with an opportunity to consider the progress made during the intersessional period, on the recommendations/requests arising from the SRB020.

BACKGROUND

At the SRB020, the members recommended/requested a series of actions to be taken by the IPHC Secretariat, as detailed in the SRB020 meeting report (IPHC-2022-SRB020-R) available from the IPHC website, and as provided in Appendix A.

DISCUSSION

During the 20th Session of the SRB (SRB020), efforts will be made to ensure that any recommendations/requests for action are carefully constructed so that each contains the following elements:

1) a specific action to be undertaken (deliverable);
2) clear responsibility for the action to be undertaken (such as the IPHC Staff or SRB officers);
3) a desired time frame for delivery of the action (such as by the next session of the SRB or by some other specified date).

RECOMMENDATION/S

That the SRB:

1) **NOTE** paper IPHC-2022-SRB021-03, which provided the SRB with an opportunity to consider the progress made during the inter-sessional period, in relation to the consolidated list of recommendations/requests arising from the previous SRB meeting (SRB020).
2) **AGREE** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB021.

APPENDICES

Appendix A: Update on actions arising from the 20th Session of the IPHC Scientific Review Board (SRB020)

APPENDIX A
Update on actions arising from the 20th Session of the IPHC Scientific Review Board (SRB020)

RECOMMENDATIONS

Action No.	Description	Update
SRB020–Rec.01 (para. 11)	***IPHC Fishery-independent setline survey (FISS)*** **NOTING** that the coefficient of variation (CV) for IPHC Regulatory Area 4B exceeded the 15% threshold in 2021 because some stations could not be sampled for logistical reasons (in 2022 the issue is likely to persist due to non-viable bids (economic and logistical reasons)), which may continue into the foreseeable future, the SRB **RECOMMENDED** continuing to investigate potential means to mitigate these effects. For example, by increasing the pool of potential bidders by including vessel using snap-gear.	**In progress** This will occur in late 2022 as we prepare for the 2023 FISS season.
SRB020–Rec.02 (para. 23)	***Pacific halibut stock assessment: 2022*** The SRB **NOTED** that most models within the ensemble produced reasonable and well-constrained estimates of natural mortality (M) and **RECOMMENDED** that estimation of M should be adopted in the short AAF assessment model with consideration in other models as part of the stock assessment research program.	**Completed** This improvement will be retained in the final 2022 assessment. Further investigation will proceed during 2023.
SRB020–Rec.03 (para. 24)	The SRB **NOTED** that the bootstrapping approach to determining maximum samples sizes for age-composition data improved assessment model performance and stability and, therefore, **RECOMMENDED** that the bootstrapping approach be adopted for data-weighting in future assessments.	**Completed** Bootstrapping has now been incorporated in all data processing code for the 2022 and future assessments.
SRB020–Rec.04 (para. 25)	The SRB **NOTED** apparent discrepancies in marine mammal prevalence among anecdotal reports, FISS observations, and preliminary evaluation of logbook data, and therefore **RECOMMENDED** further investigation of methods to better estimate marine mammal prevalence and impacts on the fishery.	**In progress** The Secretariat has continued to explore avenues for better understanding the prevalence of marine mammal depredation in the directed commercial Pacific halibut fishery. More details are provided in IPHC-2022-SRB021-08. Additional data and analyses will be explored during 2023.

Action No.	Description	Update
SRB020–Rec.05 (para. 36)	***International Pacific Halibut Commission 5-year program of integrated research and monitoring (2022-26)*** The SRB **NOTED** the exceptional level of transparency and commitment to the principles of open science represented by the Secretariat's data and code-sharing practices and, therefore, **RECOMMENDED** that the Secretariat consider producing peer-reviewed data report publications, which would (a) enhance outreach to potential external data users and (b) allow for tracking external use of IPHC data and resources.	**In progress**: As time permits, we will work towards meeting this recommendation. We request that this recommended be carried over into the SRB021 report for formal approval by the Commission.

REQUESTS

Action No.	Description	Update
SRB020–Req.01 (para. 14)	***IPHC Fishery-independent setline survey (FISS)*** **NOTING** Table 4 in paper IPHC-2022-SRB020-05 showing that observed CVs for the 2021 O32 WPUE for IPHC Regulatory Areas 2A was 20% higher than expected based on space-time model projections, the SRB **REQUESTED** that the Secretariat examine whether changes in the depth-CPUE relationship could explain extra spatial variation.	**Pending** To be completed for SRB022.
SRB020–Req.02 (para. 18)	***Management Strategy Evaluation: update*** The SRB **NOTED** the Secretariat's plan to further explore migration scenarios in the MSE and therefore **REQUESTED** that the set of migrations scenarios remain within bounds of plausible values identified via the OM development/fitting and previous tagging studies.	**In progress** Scenarios have not been developed at this time, but will be after the core set of simulations are complete.
SRB020–Req.03 (para. 19)	The SRB **REQUESTED** that the ramped implementation bias scenario (Fig. 17 in paper IPHC-2022-SRB020-06 Rev_1) be run under the most aggressive fishing intensity targets to determine the scale of performance sensitivity to that source of implementation variability.	**In progress** The simulations with implementation bias are currently being completed will be presented at SRB021.
SRB020–Req.04 (para. 20)	The SRB **REQUESTED** that the MSE not attempt to implement a Stock Synthesis estimation procedure as part of the management procedure and, instead, to integrate a simpler assessment modelling approach into the management procedure via tuning.	**In progress** No additional work on an SS estimation model has been done. The Secretariat looks

Action No.	Description	Update
		forward to discussing tuning with the SRB.
SRB020–Req.05 (para. 21)	The SRB **REQUESTED** evaluating whether the relative ranking of MPs – defined only by multi-year assessment cycle and size limits - remains similar across the set of proposed distribution scenarios using objectives identified as priorities by the Commission.	**In progress** The differences among distribution procedures will be done when the core set of simulations is complete.
SRB020–Req.06 (para. 26)	***Pacific halibut stock assessment: 2022*** The SRB **NOTED** the proposed new ensemble model weighting scheme using the MASE criterion and **REQUESTED** investigation of predictive skill on additional quantities such as fishery CPUE and mean age in FISS samples.	**Completed** A description of the MASE criterion applied to fishery CPUE is described in document IPHC-2022-SRB021-08, for discussion during SRB021.
SRB020–Req.07 (para. 29)	***Biological and ecosystem sciences – Project updates*** The SRB **NOTED** continued progress toward integration of biological and ecosystem sciences activities with the needs of Stock Assessment (SA) and MSE programs, and **REQUESTED** that future presentations/documents identify (a) the planned statistical analysis of biological data and (b) parameters or structural decisions within SA and MSE to be informed by the results.	**Completed**: The IPHC Secretariat will comply with this request in future presentations/documents.
SRB020–Req.08 (para. 30)	The SRB **NOTED** progress on further developing genomic resources through low-coverage whole genome sequencing and, therefore, **REQUESTED** that the Secretariat provide a detailed plan for bioinformatic interrogation and how data will be used to address IPHC questions related to stock assessment.	**Completed**: Update:The IPHC Secretariat has complied to this request in paper IPHC-2022-SRB021-08.
SRB020–Req.09 (para. 37)	***International Pacific Halibut Commission 5-year program of integrated research and monitoring (2022-26)*** The SRB **REQUESTED** that during the next update of the Plan, the following could be considered: a) revise the Focal Area Objectives for the Stock Assessment and MSE sections; b) revise Measures of Success to: i. Replace "3) Accuracy" and "4) Reduction in uncertainty" with "3) Relevance" and "4)	**Completed**: See paper **IPHC-2022-SRB021-05**

Action No.	Description	Update
	Impact" with the latter two defined by the above Focal Objectives; ii. change "Transparency" to "Accessibility". c) more completely account for external research funding in support of IPHC's mission, for example, by funding students working on stock assessment topics directly related to halibut stock assessment; d) explore genetics-based mark-recapture within the long-term research plan to better inform migration in the MSE operating model.	

INTERNATIONAL PACIFIC HALIBUT COMMISSION

OUTCOMES OF THE 98TH SESSION OF THE IPHC ANNUAL MEETING (AM098), AND THE 12TH SPECIAL SESSION OF THE IPHC (SS012)

PREPARED BY: IPHC SECRETARIAT (D. WILSON, 17 AUGUST 2022)

PURPOSE

To provide the SRB with the outcomes of the 98th Session of the IPHC Annual Meeting (AM098), and the 12th Special Session of the IPHC (SS012), relevant to the mandate of the SRB.

BACKGROUND

The agenda of the Commission's Annual Meeting (AM098) included several agenda items relevant to the SRB:

5. ***STOCK STATUS OF PACIFIC HALIBUT (2021) & HARVEST DECISION TABLE (2022)***
   - *5.1 IPHC Fishery-Independent Setline Survey (FISS) design and implementation in 2021 (K. Ualesi, D. Wilson, C. Jones & R. Rillera)*
   - *5.2 Space-time modelling of survey data (R. Webster)*
   - *5.3 2022-24 FISS designs (R. Webster)*
   - *5.4 Stock Assessment: Data overview and stock assessment (2021), and harvest decision table (2022) (I. Stewart, A. Hicks, R. Webster, D. Wilson, & B. Hutniczak)*
   - *5.5 Pacific halibut mortality projections using the IPHC mortality projection tool (2022) (I. Stewart)*

6. ***IPHC SCIENCE AND RESEARCH***
   - *6.1 IPHC 5-year Biological and Ecosystem Science Research Plan (2017-21): update (J. Planas)*

7. ***MANAGEMENT STRATEGY EVALUATION***
   - *7.1 IPHC Management Strategy Evaluation: update (A. Hicks)*

8. ***PACIFIC HALIBUT FISHERY ECONOMICS – PROJECT REPORT***
   - *8.1 Pacific Halibut Multiregional Economic Impact Assessment (PHMEIA) (B. Hutniczak)*

DISCUSSION

During the course of the 98th Session of the IPHC Annual Meeting (AM098) the Commission made a number of specific recommendations and requests for action regarding the stock assessment, MSE process, and 5-year research program. Relevant sections from the report of the meeting are provided in Appendix A for the SRB's consideration. In addition, the Commission made a number of decisions during a Special Session in 2022 (SS012).

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2022-SRB021-04 which details the outcomes of the 98th Session of the IPHC Annual Meeting (AM098), and the 12th Special Session of the IPHC (SS012), relevant to the mandate of the SRB.

APPENDICES

Appendix A: Excerpts from the 98th Session of the IPHC Annual Meeting (AM098) Report (IPHC-2022-AM098-R), and the 12th Special Session of the IPHC (SS012) (IPHC-2022-SS012-R).

APPENDIX A
Excerpt from the 98th Session of the IPHC Annual Meeting (AM098) Report (IPHC-2022-AM098-R)

RECOMMENDATIONS

Management Strategy Evaluation

AM098–Rec.01 (para. 69) The Commission **RECOMMENDED** that an MSE agenda item be added to the upcoming special session to discuss and provide direction on elements of the MSE workplan, including distribution procedures to incorporate in the management procedures being simulated in 2022 and evaluated at the 99th Session of the IPHC Annual Meeting (AM099).

12th Special Session of the Commission (SS012)

AM098–Rec.02 (para. 116) The Commission **RECOMMENDED** that the 12th Special Session of the Commission be held electronically in late February or early March 2022 and include the following agenda items: 1) FY2023 budget review and adoption; 2) Management Strategy Evaluation; 3) IPHC Fishery Regulations: Daily bag limit in IPHC Regulatory Area 2B (Sect. 28) (IPHC-2022-AM098-PropB4). *[see below for outcomes]*

Length-Weight

AM098–Rec.03 (para. 121) The Commission **RECOMMENDED** the adoption of the updated length-weight relationship as detailed in paper IPHC-2022-AM098-INF07, and its dissemination to the appropriate domestic management agencies.

REQUESTS

Management Strategy Evaluation

AM098–Req.02 (para. 61) The Commission **RECALLED** SS011-Rec.01 and **REQUESTED** that the current size limit (32 inches), a 26 inch size limit, and no size limit be investigated. to understand the long-term effects of a change in the size limit.

AM098–Req.03 (para. 63) The Commission **REQUESTED** that the IPHC Secretariat work with the SRB and others as necessary to identify potential costs and benefits of not conducting an annual stock assessment. This will include a prioritized list of work items that could be accomplished in its place.

AM098–Req.04 (para. 64) The Commission **REQUESTED** that multi-year management procedures include the following concepts:

a) The stock assessment occurs biennially (and possibly triennial if time in 2022 allows) and no changes would occur to the FISS (i.e. remains annual);
b) The TCEY within IPHC Regulatory Areas for non-assessment years:
   i. remains the same as defined in the previous assessment year, or
   ii. changes within IPHC Regulatory Areas using simple empirical rules, to be developed by the IPHC Secretariat, that incorporate FISS data.

AM098–Req.05 (para. 66) The Commission **NOTED** that a distribution procedure is necessary to evaluate the size limit and multi-year assessment management procedures, and **REQUESTED** that a range of distribution procedures be used to highlight potential differences in the performance of size limits and multi-year assessments.

AM098–Req.06 (para. 68) The Commission **REQUESTED** that work continue on methods to evaluate MSE outcomes, including providing new alternative methods to quickly evaluate large sets of management procedures, which may involve ranking them in various ways.

Pacific halibut fishery economics – Project Report

AM098–Req.07 (para. 73) The Commission **AGREED** that it wished to see the Commission improve its knowledge of key inputs into the Pacific halibut stock assessment and Management Strategy Evaluation (MSE) processes, thereby providing the best possible advice for management decision making processes. Accordingly the Commission **REQUESTED** that no additional economic analyses be undertaken and that the Commission instead dedicate its efforts and funds to core areas of responsibility.

RECOMMENDATIONS FROM THE 12TH SPECIAL SESSION OF THE IPHC (SS012)

(25 February 2022)

(IPHC-2022-SS012-R)

RECOMMENDATIONS

Management Strategy Evaluation

SS012-Rec.01 (para. 10) The Commission **RECOMMENDED** the following five distribution procedures to be used in the management strategy evaluation of size limits and multi-year assessments, noting that these distribution procedures are for analytical purposes only and are not endorsed by both parties, thus would be reviewed in the future if the Commission wishes to evaluate them for implementation.

a) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3A, relative harvest rates of 0.75 for IPHC Regulatory Areas 3B-4, and no application of the current interim agreements for 2A and 2B;

b) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3A, relative harvest rates of 0.75 for IPHC Regulatory Areas 3B-4, and current interim agreements for 2A and 2B;

c) Baseline based on recent year O32 FISS results with 1.65 Mlbs to 2A and 20% of the coastwide TCEY to 2B;

d) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3, 4A, and 4CDE, a relative harvest rate of 0.75 for IPHC Regulatory Area 4B, and no agreements for 2A and 2B;

e) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3, 4A, and 4CDE, a relative harvest rate of 0.75 for IPHC Regulatory Area 4B, and current interim agreements for IPHC Regulatory Areas 2A and 2B.

INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED RESEARCH AND MONITORING (2022-26)

PREPARED BY: IPHC SECRETARIAT (D. WILSON, J. PLANAS, I. STEWART, A. HICKS, B. HUTNICZAK, R. WEBSTER, J. JANNOT; 17 AUGUST 2022)

PURPOSE

To provide the SRB with the IPHC 5-year Program of Integrated Research and Monitoring (2022-26).

BACKGROUND

Recalling that:

a) the IPHC Secretariat conducts activities to address key issues identified by the Commission, its subsidiary bodies, the broader stakeholder community, and the IPHC Secretariat;

b) the process of identifying, developing, and implementing the IPHC's science-based activities involves several steps that are circular and iterative in nature, but result in clear project activities and associated deliverables;

c) the process includes developing and proposing projects based on direct input from the Commission, the experience of the IPHC Secretariat given its broad understanding of the resource and its associated fisheries, and concurrent consideration by relevant IPHC subsidiary bodies, and where deemed necessary, including by the Commission, additional external peer review;

d) the IPHC Secretariat commenced implementation of the new Plan in 2022 and will keep the Plan under review on an ongoing basis.

Also recalling that an overarching goal of the IPHC 5-year Program of Integrated Research and Monitoring (2022-26) is to promote integration and synergies among the various research and monitoring activities of the IPHC Secretariat in order to improve knowledge of key inputs into the Pacific halibut stock assessment, and Management Strategy Evaluation (MSE) processes, thereby providing the best possible advice for management decision making processes.

DISCUSSION

The SRB should note that:

a) the intention is to ensure that the new integrated plan is kept as a '*living plan*', and is reviewed and updated annually based on the resources available to undertake the work of the Commission (e.g. internal and external fiscal resources, collaborations, internal expertise);

b) the plan focuses on core responsibilities of the Commission; and any redirection provided by the Commission;

c) each year the SRB may choose to recommend modifications to the current Plan, and that any modifications subsequently made would be documented both in the Plan itself, and through reporting back to the SRB and then the Commission.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2022-SRB021-05 which provides the IPHC 5-year program of Integrated Research and Monitoring (2022-26).

APPENDICES

Appendix A: IPHC 5-Year Program of Integrated Research and Monitoring (2022-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, B. Hutniczak, R. Webster, & J. Jannot)

INTERNATIONAL PACIFIC HALIBUT COMMISSION

5-YEAR PROGRAM OF INTEGRATED RESEARCH AND MONITORING

(2022 - 2026)

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

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BIBLIOGRAPHIC ENTRY

IPHC 2022. International Pacific Halibut Commission 5-Year program of integrated research and monitoring (2022-26). Seattle, WA, U.S.A. *IPHC–2022-5YPIRM, 52 pp.*

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ACRONYMS

AM	Annual Meeting
CB	Conference Board
DMR	Discard Mortality Rate
FAC	Finance and Administration Committee
FISS	Fishery-Independent Setline Survey
FSC	First Nations Food, Social, and Ceremonial [fishery]
IM	Interim Meeting
IPHC	International Pacific Halibut Commission
MSAB	Management Strategy Advisory Board
MSE	Management Strategy Evaluation
OM	Operating Model
PAB	Processor Advisory Board
PDO	Pacific Decadal Oscillation
PHMEIA	Pacific halibut multiregional economic impact assessment [model]
QAQC	Quality assurance/quality control
RAB	Research Advisory Board
SHARC	Subsistence Halibut Registration Certificates
SRB	Scientific Review Board
TCEY	Total Constant Exploitation Yield
U.S.A.	United States of America
WM	Work Meeting

DEFINITIONS

A set of working definitions are provided in the IPHC Glossary of Terms and abbreviations: https://iphc.int/the-commission/glossary-of-terms-and-abbreviations

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EXECUTIVE SUMMARY

An overarching goal of the *IPHC 5-Year Program of Integrated Research and Monitoring (2022-26)* is to promote integration and synergies among the various research and support activities of the IPHC Secretariat in order to improve our knowledge of key inputs into the Pacific halibut stock assessment and Management Strategy Evaluation (MSE) processes, and to provide the best possible advice for management decision-making processes.

Along with the implementation of the short- and medium-term activities contemplated in this *IPHC 5-Year Program of Integrated Research and Monitoring (2022-26)*, and in pursuit of the overarching objective, the IPHC Secretariat will also aim to:

1) undertake cutting-edge research programs in fisheries research in support of Pacific halibut fisheries management;
2) undertake groundbreaking methodological research;
3) undertake applied research;
4) establish new collaborative agreements and interactions with research agencies and academic institutions;
5) promote the international involvement of the IPHC by continued and new participation in international scientific organizations and by leading international science and research collaborations;
6) effectively communicate IPHC research outcomes;
7) incorporate talented students and early researchers in research activities contemplated.

The research and monitoring activities conducted by the IPHC Secretariat are directed towards fulfilling the following four (4) objectives within areas of data collection, biological and ecological research, stock assessment, and Management Strategy Evaluation (MSE). In addition, the IPHC responds to Commission requests for additional inputs to management and policy development which are classified under management support.

The Secretariat's success in implementing the *IPHC 5-Year Program of Integrated Research and Monitoring (2022-26)* will be measured according to the following criteria relevant to the stock assessment, the MSE and for all inputs to IPHC management:

1) Timeliness – was the research conducted, analyzed, published, and provided to the Commission at the appropriate points to be included in annual management decisions?
2) Accessibility – was the research published and presented in such a way that it was available to other scientists, stakeholders, and decision-makers?
3) Relevance – did the research improve the perceived accuracy of the stock assessment, MSE, or decisions made by the Commission?
4) Impact – did the research allow for more precision or a better estimate of the uncertainty associated with information for use in management?
5) Reliability – has research resulted in more consistent information provided to the Commission for decision-making.

1. Introduction

The International Pacific Halibut Commission (IPHC) is a public international organization so designated via Presidential Executive Order 11059 and established by a Convention between Canada and the United States of America. The IPHC Convention was signed on 2 March 1923, ratified on 21 July 1924, and came into effect on 21 October 1924 upon exchange. The Convention has been revised several times since, to extend the Commission's authority and meet new conditions in the fishery. The most recent change occurred in 1979 and involved an amendment to the 1953 Halibut Convention. The 1979 amendment, termed a "protocol", was precipitated in 1976 by Canada and the United States of America extending their jurisdiction over fisheries resources to 200 miles. The 1979 Protocol along with the U.S. legislation that gave effect to the Protocol (Northern Pacific Halibut Act of 1982) has affected the way the fisheries are conducted, and redefined the role of IPHC in the management of the fishery. Canada does not require specific enabling legislation to implement the protocol.

The basic texts of the Commission are available on the IPHC website: https://www.iphc.int/the-commission, and prescribe the mission of the organization as:

*"..... **to develop the stocks of [Pacific] halibut in the Convention waters to those levels which will permit the optimum yield from the fishery and to maintain the stocks at those levels**. ....." IPHC Convention*, Article I, sub-article I, para. 2). The IPHC Convention Area is detailed in Fig. 1.

The IPHC Secretariat, formed in support the Commission's activities, is based in Seattle, WA, U.S.A. As its shared vision, ***the IPHC Secretariat aims to deliver positive economic, environmental, and social outcomes for the Pacific halibut resource for Canada and the U.S.A. through the application of rigorous science, innovation, and the implementation of international best practice.***

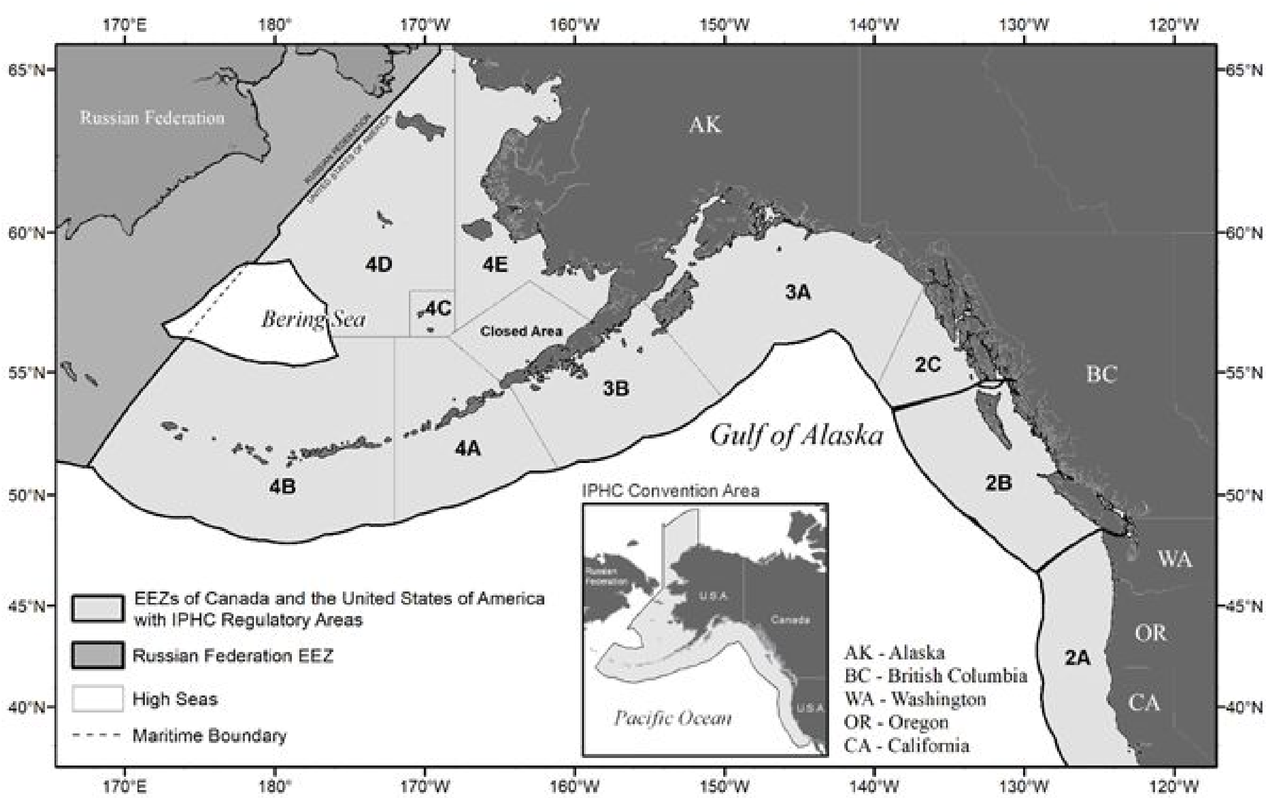

Figure 1. Map of the IPHC Convention Area (map insert) and IPHC Regulatory Areas.

2. Objectives

The IPHC has a long-standing history (since 1923) of collecting data, undertaking research, and stock assessment, devoted to describing and understanding the Pacific halibut (*Hippoglossus stenolepis*) stock and the fisheries that interact with it.

The IPHC Secretariat conducts activities to address key issues identified by the Commission, its subsidiary bodies, the broader stakeholder community, and of course, the IPHC Secretariat itself. The process of identifying, developing, and implementing our science-based activities involves several steps that are circular in nature, but result in clear research activities and associated deliverables. The process includes developing and proposing projects based on direct input from the Commission, the experience of the IPHC Secretariat given our broad understanding of the resource and its associated fisheries, and concurrent consideration by relevant IPHC subsidiary bodies, and where deemed necessary, additional external peer review.

Over the last five years (2017-2021), the research conducted by the IPHC Secretariat has been guided by a 5-Year Biological and Ecosystem Science Research Plan (IPHC–2019–BESRP-5YP) that aimed at improving knowledge on the biology of Pacific halibut in order to improve the accuracy of the stock assessment and in the management strategy evaluation (MSE) process. The IPHC-2019-BESRP-5YP contemplated research activities in five focal areas, namely Migration and Distribution, Reproduction, Growth and Physiological Condition, Discard Mortality Rates and Survival, and Genetics and Genomics. Research activities were highly integrated with the needs of stock assessment and MSE by their careful alignment with biological uncertainties and parameters, and the resulting prioritization (Appendix I). The outcomes of the IPHC-2019-BESRP-5YP have provided key inputs into stock assessment and the MSE process and, importantly, have provided foundational information for the successful pursuit of continuing and novel objectives within the new 5-Year Program of Integrated Research and Monitoring (2022-2026) (5YPIRM) (Appendix I).

The 2nd Performance Review of the IPHC (IPHC-2019-PRIPHC02-R), carried out over the course of 2019, also provided a range of recommendations to the Commission on ways in which it could continue to improve on the quality of scientific advice being provided to the Commission. There were nine (9) specific recommendations as provided below:

Science: Status of living marine resources

PRIPHC02–Rec.03 (para. 44) The PRIPHC02 ***RECOMMENDED*** *that opportunities to engage with western Pacific halibut science and management agencies be sought, to strengthen science links and data exchange. Specifically, consider options to investigate pan-Pacific stock structure and migration of Pacific halibut.*

PRIPHC02–Rec.04 (para. 45) The PRIPHC02 ***RECOMMENDED*** *that:*

a) further efforts be made to lead and collaborate on research to assess the ecosystem impacts of Pacific halibut fisheries on incidentally caught species (retained and/or discarded);
b) where feasible, this research be incorporated within the IPHC's 5-Year Research Plan (https://www.iphc.int/uploads/pdf/besrp/2019/iphc-2019-besrp-5yp.pdf);
c) findings from the IPHC Secretariat research and that of the Contracting Parties be readily accessible via the IPHC website.

Science: Quality and provision of scientific advice

PRIPHC02–Rec.05 (para. 63) The PRIPHC02 ***RECOMMENDED*** *that simplified materials be developed for RAB and especially MSAB use, including training/induction materials.*

PRIPHC02–Rec.06 (para. 64) The PRIPHC02 ***RECOMMENDED*** *that consideration be given to amending the Rules of Procedure to include appropriate fixed terms of service to ensure SRB peer review remains independent and fresh; a fixed term of three years seems appropriate, with no more than one renewal.*

PRIPHC02–Rec.07 (para. 65) The PRIPHC02 ***RECOMMENDED*** *that the peer review process be strengthened through expanded subject specific independent reviews including data quality and standards, the FISS, MSE, and biological/ecological research; as well as conversion of "grey literature" to primary literature publications. The latter considered important to ongoing information outreach efforts given the cutting-edge nature of the Commission's scientific work.*

PRIPHC02–Rec.08 (para. 66) The PRIPHC02 ***RECOMMENDED*** *that the IPHC Secretariat develop options for simple graphical summaries (i.e. phase plot equivalents) of fishing intensity and spawning stock biomass for provision to the Commission.*

Conservation and Management: Data collection and sharing

PRIPHC02–Rec.09 (para. 73) The PRIPHC02 ***RECOMMENDED*** *that observer coverage be adjusted to be commensurate with the level of fishing intensity in each IPHC Regulatory Area.*

Conservation and Management: Consistency between scientific advice and fishery Regulations adopted

PRIPHC02–Rec.10 (para. 82) The PRIPHC02 ***RECOMMENDED*** *that the development of MSE to underpin multi-year (strategic) decision-making be continued, and as multi-year decision making is implemented, current Secretariat capacity usage for annual stock assessments should be refocused on research to investigate MSE operating model development (including consideration of biological and fishery uncertainties) for future MSE iterations and regularised multi-year stock assessments.*

PRIPHC02–Rec.11 (para. 83) The PRIPHC02 ***RECOMMENDED*** *that ongoing work on the MSE process be prioritised to ensure there is a management framework/procedure with minimal room for ambiguous interpretation, and robust pre-agreed mortality limit setting frameworks.*

The work outlined in this document builds on the previous a 5-Year Biological and Ecosystem Science Research Plan (IPHC–2019–BESRP-5YP), closing completed projects, extending efforts where needed, and adding new avenues in response to new information. Appendix I provides a detailed summary of the previous plan and the status of the work specifically undertaken. Key highlights relevant to the stock assessment and MSE include:

- Completion of the genetic assay for determining sex from tissue samples, processing of commercial fishery samples collected during 2017-2020, inclusion of this information in the 2019 and subsequent stock assessments, and transfer of this effort from research to ongoing monitoring.
- Incremental progress toward population-level sampling and analysis of maturity and fecundity.
- Continued development of the understanding of physiological and environmental mechanisms determining growth for future field application.
- Published estimates of discard mortality rates for use in data processing and management accounting.
- Collection of genetic samples and genome sequencing to provide a basis for ongoing evaluation of stock structure at population-level and finer scales.

All previously described research areas continue to represent critical areas of uncertainty in the stock assessment and thus are closely linked to management performance. The previous 5-year plan was successful in either providing direct new information to the stock assessment or building the foundation for the collection/analysis of such information in this updated plan. As noted below, some new priorities have emerged, and others have evolved based on the work completed to date. The incorporation of research objectives in the 5YPIRM that address climate change as a factor influencing Pacific halibut biology and ecology as well as fishery performance and dynamics constitutes a timely and relevant contribution towards advancing IPHC-led research to the forefront of fisheries science.

An **overarching goal** of the *IPHC 5-Year Program of integrated research and monitoring (2022-26)* is therefore to promote integration and synergies among the various research and support activities of the IPHC Secretariat in order to improve our knowledge of key inputs into the Pacific halibut stock assessment and MSE processes, in order to provide the best possible advice for management decision-making processes.

Along with the implementation of the short- and medium-term activities contemplated in this *IPHC 5-Year Program of Integrated Research and monitoring (2022-26)*, and in pursuit of the overarching objective, the IPHC Secretariat will also aim to:

1) undertake cutting-edge research programs in fisheries research in support of fisheries management of Pacific halibut;
2) undertake groundbreaking methodological research;
3) undertake applied research;
4) establish new collaborative agreements and interactions with research agencies and academic institutions;
5) promote the international involvement of the IPHC by continued and new participation in international scientific organizations and by leading international science and research collaborations.
6) effectively communicate IPHC research outcomes
7) incorporate talented students and early researchers in research activities contemplated.

The research and monitoring activities conducted by the IPHC Secretariat are directed towards fulfilling the following four (4) **objectives** within areas of data collection, biological and ecological research, stock assessment, and MSE. In addition, the IPHC responds to Commission requests for additional inputs to management and policy development which are classified under management support. The overall aim is to provide a program of integrated research and monitoring (Fig 2):

Research

1) **Stock assessment**: apply the resulting knowledge to improve the accuracy and reliability of the current stock assessment and the characterization of uncertainty in the resultant stock management advice provided to the Commission;
2) **Management Strategy Evaluation (MSE)**: to develop an accurate, reliable, and informative MSE process to appropriately characterize uncertainty and provide for the robust evaluation of the consequences of alternative management options, known as harvest strategies, using defined conservation and fishery objectives;
3) **Biology and Ecology**: identify and assess critical knowledge gaps in the biology and ecology of Pacific halibut within its known range, including the influence of environmental conditions on population and fishery dynamics;

Monitoring

4) **Monitoring**: collect representative fishery dependent and fishery-independent data on the distribution, abundance, biology, and demographics of Pacific halibut through ongoing monitoring activities;

Integrated management support

5) **Additional inputs**: respond to Commission requests for any additional information supporting management and policy development.

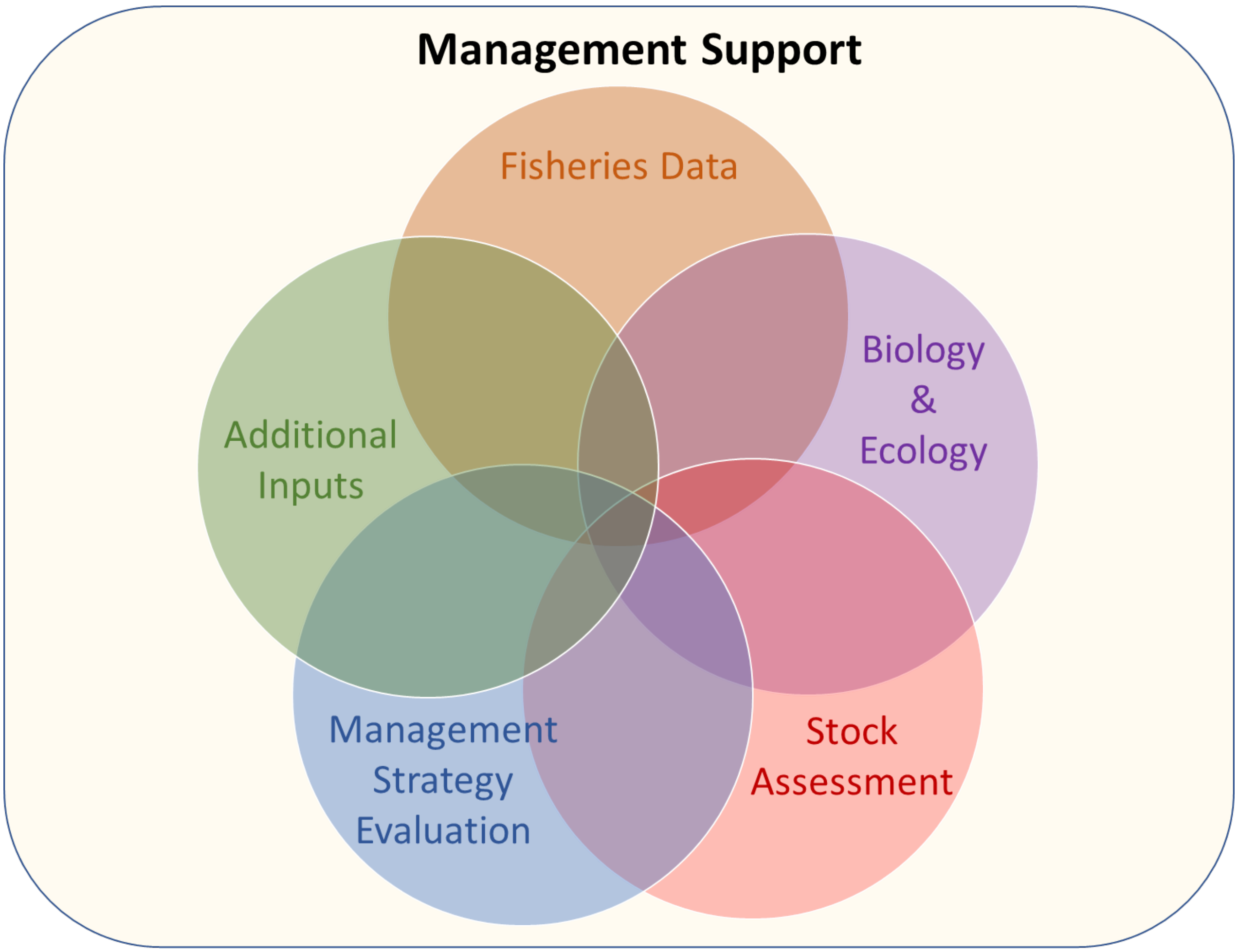

Figure 2. Core areas of the IPHC's program of integrated research and monitoring providing management support.

3. Strategy

The IPHC Secretariat has five (5) enduring strategic goals in executing our mission, including our overarching goal and associated science and research objectives, as articulated in our Strategic Plan (IPHC Strategic Plan (2019-23)): 1) To operate in accordance with international best practice; 2) Be a world leader in scientific excellence and science-based decision making; 3) To foster collaboration (within Contracting Parties and internationally) to enhance our science and management advice; 4) Create a vibrant IPHC culture; and 5) Set the standard for fisheries commissions globally.

Although priorities and tasking will change over time in response to events and developments, the Strategic Plan provides a framework to standardise our approach when revising or setting new priorities and tasking. The Strategic goals as they apply to the science and research activities of the IPHC Secretariat, will be operationalised through a multi-year tactical activity matrix at the organisational and management unit (Branch) level (Fig. 3). The tactical activity matrix is described in the sections below and has been developed based on the core needs of the Commission, in developing and implementing robust, scientifically-based management decisions on an annual, and multi-year level. Relevant IPHC subsidiary bodies will be involved in project development and ongoing review.

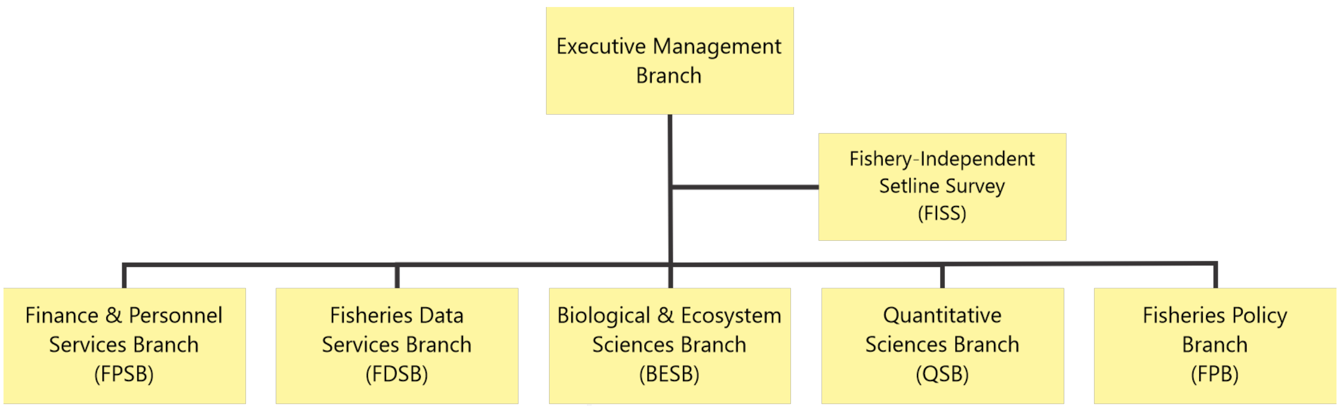

Figure 3. IPHC Secretariat organisation chart (2022).

4. *Measures of Success*

The Secretariat's success in implementing the *IPHC 5-Year Program of Integrated Research and Monitoring (2022-26)* will be measured according to the following criteria relevant to the stock assessment, the MSE and for all inputs to IPHC management:

1) Timeliness – was the research conducted, analyzed, published, and provided to the Commission at the appropriate points to be included in annual management decisions?
2) Accessibility – was the research published and presented in such a way that it was available to other scientists, stakeholders, and decision-makers?
3) Relevance - did the research improve the perceived accuracy of the stock assessment, MSE or decisions made by the commission?
4) Impact – did the research allow for more precision or a better estimate of the uncertainty associated with information for use in management?
5) Reliability - has research resulted in more consistent information provided to the Commission for decision-making.

4.1 *Delivery of specified products*

Each project line item will contain specific deliverables that constitute useful inputs into the stock assessment and the management strategy evaluation process, as well as support their implementation in the decision-making process at the level of the Commission.

4.2 Communication

The IPHC Secretariat will disseminate information about the activities contemplated in the IPHC 5-Year Program of Integrated Research and Monitoring (2022-2026) and the resulting products to Contracting Parties, stakeholders, the scientific community, and the general public through a variety of channels:

1) IPHC website (www.iphc.int);
2) Formal documentation provided for IPHC meetings (Interim and Annual Meetings, Subsidiary Body meetings, etc.);
3) Presentations at national and international scientific conferences;
4) Published reports and peer-reviewed publications (section 4.4);
5) Outreach events;
6) Social media outlets (e.g. Facebook, Twitter, LinkedIn, etc.);
7) Informal presentations and interactions with partners, stakeholders, and decision-makers at varied times and venues when needed.

4.3 External research funding

The Secretariat has set a funding goal of at least 20% of the funds for this program to be sourced from external funding bodies on an annual basis. Continuing the successful funding-recruitment strategy adopted during the previous 5-yr research plan (IPHC–2019–BESRP-5YP) (Appendix I), the Secretariat will identify and select external funding opportunities that are timely and that aim at addressing key research objectives (as outlined in Appendix II) that have important implications for stock assessment and the MSE process. The IPHC Secretariat has the necessary expertise to propose novel and important research questions to funding agencies and to recruit external collaborators from research agencies and universities as deemed necessary. The IPHC Secretariat will continue to capitalize on the strong analytical contributions of quantitative scientists to the development of biological research questions within the framework of research projects funded by external as well as internal funding sources.

4.4 Peer-reviewed journal publication

Publication of research outcomes in peer-reviewed journals will be clearly documented and monitored as a measure of success. This may include single publications at the completion of a particular project, or a series of publications throughout the project as well as at its completion. Each sub-project shall be published in a timely manner and shall be submitted no later than 12 months after the end of the research. In the sections that follow, the expected publications from each research stream and cross-stream are defined.

5. Core focal areas – Background

The goals of the main activities of the *5-Year program of integrated research and monitoring (2022-26)* are integrated across the organisation, involving 1) monitoring (fisheries-dependent and –independent data collection), and 2) research (biological, ecological), modelling (FISS and stock assessment), and MSE, as outlined in the following sub-sections. These components are closely linked to one another, and all feed into management decision-making (Fig. 4). Additionally, management-supporting information constitute a range of additional decision-making drivers within and beyond IPHC's current research and monitoring programs. The current program builds on the outcomes and experiences of the Commission arising from the implementation of the 2017-21 5-Year Biological and Ecosystem Science Research Plan (IPHC–2019–BESRP-5YP), and which is summarized in Appendix I.

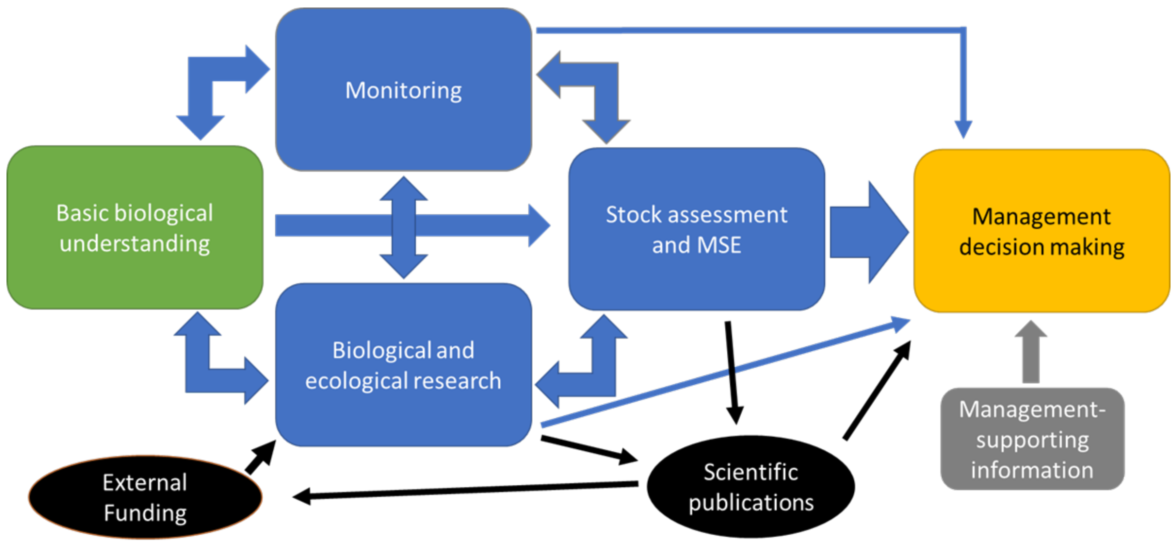

Figure 4. Flow of information from basic biological understanding of the Pacific halibut resource, through IPHC research components (monitoring, biological and ecological research, stock assessment, and MSE) to management decision-making. Management-supporting information (grey) constitute a range of additional decision-making drivers within and beyond IPHC's current research and monitoring programs. Arrows indicate the strength (size of the arrow) and direction of information exchange. Also identified (in black) are the external links from funding and scientific publications which supplement the IPHC's internal process.

5.1 Research

5.1.1 Stock Assessment

Focal Area Objective	To improve accuracy and reliability of the current stock assessment and the characterization of uncertainty in the resultant stock management advice provided to the Commission.
IPHC Website portal	https://www.iphc.int/management/science-and-research/stock-assessment

The IPHC conducts an annual stock assessment, using data from the fishery-independent setline survey (FISS), the commercial Pacific halibut and other fisheries, as well biological information from its research program. The assessment includes the Pacific halibut resource in the IPHC Convention Area, covering the Exclusive Economic Zones of Canada and the United States of America. Data sources are updated each year to reflect the most recent scientific information available for use in management decision-making.

The 2021 stock assessment relied on an ensemble of four population dynamics models to estimate the probability distributions describing the current stock size, trend, and demographics. The ensemble is designed to capture both uncertainty related to the data and stock dynamics (due to estimation) as well as uncertainty related to our understanding of the way in which the Pacific halibut stock functions and is best approximated by a statistical model (structural uncertainty).

Stock assessment results are used as inputs for harvest strategy calculations, including mortality projection tables for the upcoming year that reflect the IPHC's harvest strategy policy and other considerations, as well as the harvest decision table which provides a direct tool for the management process. The harvest decision table uses the probability distributions from short-term (three year) assessment projections to evaluate the trade-offs between alternative levels of potential yield (catch) and the associated risks to the stock and fishery.

The stock assessment research priorities have been subdivided into four categories:

1) Assessment data collection and processing;
2) technical development;
3) biological inputs; and
4) fishery yield.

It is important to note that ongoing monitoring, including the annual FISS and directed commercial landings sampling programs is not considered research and is therefore not included in this research priority list despite the critical importance of these collections. These are described in the sections below.

5.1.2 Management Strategy Evaluation (MSE)

Focal Area Objective	To develop an accurate, reliable, and informative MSE process to appropriately characterize uncertainty and provide for the robust evaluation of the consequences of alternative management options, known as harvest strategies, using defined conservation and fishery objectives.
IPHC Website portal	https://www.iphc.int/management/science-and-research/management-strategy-evaluation

Management Strategy Evaluation (MSE) is a process to evaluate the consequences of alternative management options, known as harvest strategies. MSE uses a simulation tool to determine how alternative harvest strategies perform given a set of pre-defined fishery and conservation objectives, taking into account the uncertainties in the system and how likely candidate harvest strategies are to achieve the chosen management objectives.

MSE is a simulation technique based on modelling each part of a management cycle. The MSE uses an operating model to simulate the entire population and all fisheries, factoring in management decisions, the monitoring program, the estimation model, and potential ecosystem effects using a closed-loop simulation.

Undertaking an MSE has the advantage of being able to reveal the trade-offs among a range of possible management decisions. Specifically, to provide the information on which to base a rational decision, given harvest strategies, preferences, and attitudes to risk. The MSE is an essential part of the process of developing, evaluating and agreeing to a harvest strategy.

The MSE process involves:

- Defining fishery and conservation objectives with the involvement of stakeholders and managers;
- Identifying harvest strategies (a.k.a. management procedures) to evaluate;
- Simulating a Pacific halibut population using those harvest strategies;
- Evaluating and presenting the results in a way that examines trade-offs between objectives;
- Applying a chosen harvest strategy for the management of Pacific halibut;
- Repeating this process in the future in case of changes in objectives, assumptions, or expectations.

There are many tasks that would continue to improve the MSE framework and the presentation of future results to the Commission. The tasks can be divided into five general categories, which are common to MSE in general:

1. **Objectives**: The goals and objectives that are used in the evaluation.
2. **Management Procedures (MPs)**: Specific, well-defined management procedures that can be coded in the MSE framework to produce simulated Total Constant Exploitation Yields (TCEY) for each IPHC Regulatory Area.
3. **Framework**: The specifications and computer code for the closed-loop simulations including the operating model and how it interacts with the MP.
4. **Evaluation**: The performance metrics and presentation of results. This includes how the performance metrics are evaluated (e.g. tables, figures, and rankings), presented to the Commission and its subsidiary bodies, and disseminated for outreach.
5. **Application**: Specifications of how an MP may be applied in practice and re-evaluated in the future, including responses to exceptional circumstances.

All these categories provide inputs and outputs of the MSE process, but the Framework category benefits most from the integration of biological and ecosystem research because the operating model, the simulation of the monitoring program, the estimation model, and potential ecosystem effects are determined from this knowledge.

Outcomes of the MSE process will not only inform the Commission on trade-offs between harvest strategies and assist in choosing an optimal strategy for management of the Pacific halibut resource but will inform the prioritization of research activities related to fisheries monitoring, biological and ecological research, stock assessment, and fishery socioeconomics.

5.1.3 Biology and Ecology

Focal Area Objective	To identify and assess critical knowledge gaps in the biology and ecology of Pacific halibut within its known range, including the influence of environmental conditions on population and fishery dynamics.
IPHC Website portal	https://www.iphc.int/management/science-and-research/biological-and-ecosystem-science-research-program-bandesrp

Since its inception, the IPHC has had a long history of research activities devoted to describe and understand the biology of the Pacific halibut. At present, the main objectives of the Biological and Ecosystem Science Research Program at IPHC are to: 1) identify and assess critical knowledge gaps in the biology of the Pacific halibut; 2) understand the influence of environmental conditions in the biology of the Pacific halibut and its fishery; and 3) apply the resulting knowledge to reduce uncertainty in current stock assessment models.

The primary biological research activities at the IPHC that follow Commission objectives and that are selected for their important management implications are identified and described in the proposed 5-Year Research Plan for the period 2022-2026. An overarching goal of the 5-Year Research Plan is to promote integration and synergies among the various research activities led by the IPHC to improve our knowledge of key biological inputs that feed into the stock assessment and MSE process. The goals of the main research activities of the 5-Year Research Plan are therefore aligned and integrated with the IPHC stock assessment and MSE processes. The IPHC Secretariat conducts research activities to address key biological issues based on the IPHC Secretariat's own input as well as input from the IPHC Commissioners, stakeholders and particularly from specific subsidiary bodies to the IPHC, including the Scientific Review Board (SRB) and the Research Advisory Board (RAB).

The biological research activities contemplated in the 5-Year Research Plan and their specific aims are detailed in Section 6. Overall, the biological research activities at the IPHC aim to provide information on 1) factors that influence the biomass of the Pacific halibut population (e.g. distribution and movement of fish among IPHC Regulatory Areas, growth patterns and environmental influences on growth in larval, juvenile and adult fish, drivers of changes in size-at-age); 2) the spawning (female) population (e.g. reproductive maturity, skipped spawning, reproductive migrations); and 3) resulting changes in population dynamics. Furthermore, the research activities of IPHC also aim to provide information on the survival of regulatory-discarded Pacific halibut in the directed fisheries with the objective to refine current estimates of discard mortality rates and develop best handling practices, and reduce whale depredation and Pacific halibut bycatch through gear modifications and through a better understanding of behavioral and physiological responses of Pacific halibut to fishing gear.

5.2 *Monitoring*

Focal Area Objective	To collect fishery-dependent and fishery-independent data on the distribution, abundance, and demographics of Pacific halibut, as well as other key biological data, through ongoing monitoring activities.
IPHC Website portal	***Fishery-dependent data:*** • https://www.iphc.int/datatest/commercial-fisheries • https://www.iphc.int/data/datatest/non-directed-commercial-discard-mortality-fisheries • https://www.iphc.int/data/datatest/pacific-halibut-recreational-fisheries-data • https://www.iphc.int/datatest/subsistence-fisheries • https://www.iphc.int/data/time-series-datasets ***Fishery-independent data:*** • https://www.iphc.int/management/science-and-research/fishery-independent-setline-survey-fiss • https://www.iphc.int/data/datatest/fishery-independent-setline-survey-fiss • https://www.iphc.int/datatest/data/water-column-profiler-data

5.2.1 *Fishery-dependent data*

The IPHC estimates all Pacific halibut removals taken in the IPHC Convention Area and uses this information in its yearly stock assessment and other analyses. The data are compiled by the IPHC Secretariat and include data from Federal and State agencies of each Contracting Party. Specific activities in this area are described below.

5.2.1.1 *Directed commercial fisheries data*

The IPHC Secretariat collects logbooks, otoliths, tissue samples, and associated sex-length-weight data from directed commercial landings coastwide (Fig. 5). A sampling rate is determined for each port by IPHC Regulatory Area. The applicable rate is calculated from the current year's mortality limits and estimated percentages of weight of fish landed, and estimated percentages of weight sampled in that port to allow for collection of the target number of biological samples by IPHC Regulatory Area. An example of the data collected and the methods used are provided in the annually updated directed commercial sampling manual (e.g. IPHC Directed Commercial Landings Sampling Manual 2022). Directed commercial fishery landings are recorded by the Federal and State agencies of each Contracting Party and summarized each year by the IPHC. Discard mortality for the directed commercial fishery is currently estimated using a combination of research survey (U.S.A.) and observer data (Canada).

5.2.1.2 Non-directed commercial discard mortality data

The IPHC accounts for non-directed commercial discard mortality by IPHC Regulatory Area and sector. Non-directed commercial discard mortality estimates are provided by State and Federal agencies of each Contracting Party and compiled annually for use in the stock assessment and other analyses. https://www.iphc.int/data/datatest/non-directed-commercial-discard-mortality-fisheries.

Non-directed commercial discard mortality of Pacific halibut is estimated because not all fisheries have 100% monitoring and not all Pacific halibut that are discarded are assumed to die. The IPHC relies upon information supplied by observer programs run by Contracting Party agencies for non-directed commercial discard mortality estimates in most fisheries. Non-IPHC research survey information or other sources are used to generate estimates of non-directed commercial discard mortality in the few cases where fishery observations are unavailable. Non-directed fisheries off Canada British Columbia are monitored and discard mortality information is provided to IPHC by DFO. NOAA Fisheries operates observer programs off the USA West Coast and Alaska, which monitor the major groundfish fisheries. Data collected by those programs are used to estimate non-directed commercial discard mortality.

5.2.1.3 Subsistence fisheries data

Subsistence fisheries are non-commercial, customary, and traditional use of Pacific halibut for direct personal, family, or community consumption or sharing as food, or customary trade. The primary subsistence fisheries are the treaty Indian Ceremonial and Subsistence fishery in IPHC Regulatory Area 2A off northwest Washington State (USA), the First Nations Food, Social, and Ceremonial (FSC) fishery in British Columbia (Canada), and the subsistence fishery by rural residents and federally recognized native tribes in Alaska (USA) documented via Subsistence Halibut Registration Certificates (SHARC). Subsistence fishery removals of Pacific halibut, including estimated subsistence discard mortality, are provided by State and Federal agencies of each Contracting Party, estimated, and compiled annually for use in the stock assessment and other analysis. https://www.iphc.int/datatest/subsistence-fisheries.

5.2.1.4 Recreational fisheries data

Recreational removals of Pacific halibut, including estimated recreational discard mortality, are provided by National/State agencies of each Contracting Party, estimated, and compiled annually for use in the stock assessment and other analysis. https://www.iphc.int/data/datatest/pacific-halibut-recreational-fisheries-data.

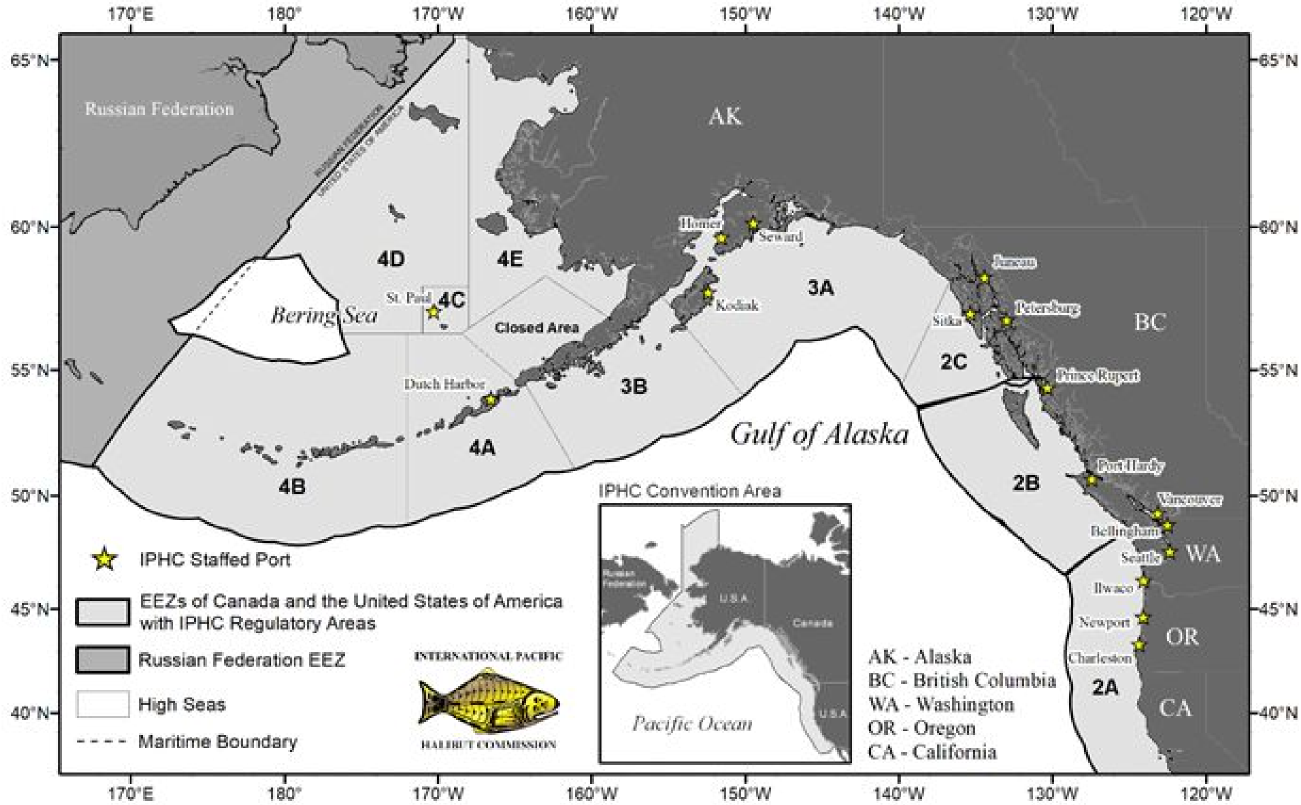

Figure 5. Ports where the IPHC has sampled directed commercial landings throughout the fishing period in recent years (note: ports sampled may change from year-to-year for operational reasons).

5.2.2 Fishery-independent data.

Data collection and monitoring activities aimed at providing a standardised time-series of biological and ecological data that is independent of the fishing fleet.

5.2.2.1 Fishery-independent setline survey (FISS)

The IPHC Fishery-Independent Setline Survey (FISS) provides catch-rate information and biological data on Pacific halibut that are independent of the fishery. These data, collected using standardized methods, bait, and gear, are used to estimate the primary index of population abundance used in the stock assessment. The FISS is restricted to the summer months but encompasses the commercial fishing grounds in the Pacific halibut fishery, and almost all known Pacific halibut habitat in Convention waters outside the Bering Sea. The standard FISS grid totals 1,890 stations (Fig. 6). Biological data collected on the FISS (e.g. the length, weight, age, and sex of Pacific halibut) are used to monitor changes in biomass, growth, and mortality. In addition, records of non-target species caught during FISS operations provide insight into bait competition, and serve as an index of abundance over time, making them valuable to the potential management and avoidance of non-target species. Environmental data are also collected including water column temperature, salinity, dissolved oxygen, pH, and chlorophyll concentration to help identify the conditions in which the fish were caught, and these data can serve as co-variates in space-time modeling used in the stock assessment. An example of the data collected and the methods used are provided in the annually updated FISS sampling manual (e.g. IPHC FISS Sampling Manual 2022).

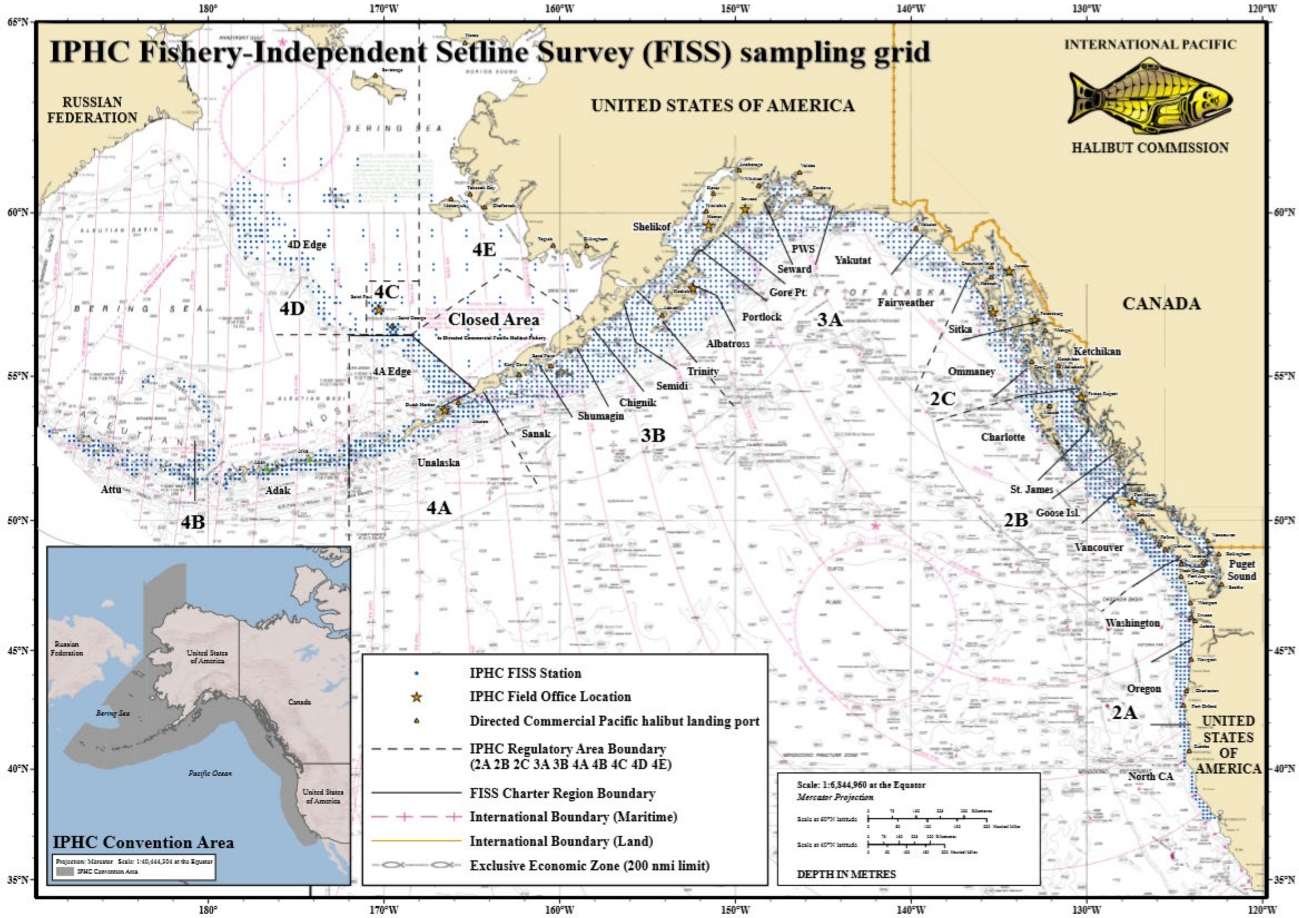

Figure 6. IPHC Fishery-Independent Setline Survey (FISS) with full sampling grid shown.

Quality control and sampling rate estimations: Following a program of planned FISS expansions from 2014-19, a process of rationialisation of the FISS was undertaken. The goal was to ensure that, given constraints on resources available for implementing the FISS, station selection was such that density indices would be estimated with high precision and low potential for bias. An annual design review process has been developed during which potential FISS designs for the subsequent three years are evaluated according to precision and bias criteria. The resulting proposed designs and their evaluation are presented for review at the June Scientific Review Board (SRB) meetings and potentially modified following SRB input before presentation to the Commissioners at the Work Meeting and Interim Meeting. Annual biological sampling rates for each IPHC Regulatory Area are calculated based on the previous year's catch rates and an annual target of 2000 sampled fish (with 100 additional archive samples).

5.2.2.2 Fishery-independent Trawl Survey (FITS)

The IPHC has participated routinely in the NOAA Fisheries trawl surveys operating in the Bering Sea (Fig. 7, annually since 1998), Aleutian Islands (intermittently since 1997) and Gulf of Alaska (since 1996). The information collected from Pacific halibut caught on these surveys, together with data from the IPHC Fishery-Independent Setline Survey (FISS) and commercial Pacific halibut data, are used directly in estimating indices of abundance and in the stock assessment and to monitor population trends, growth/size, and to supplement understanding of recruitment, distribution, and age composition of young Pacific halibut.

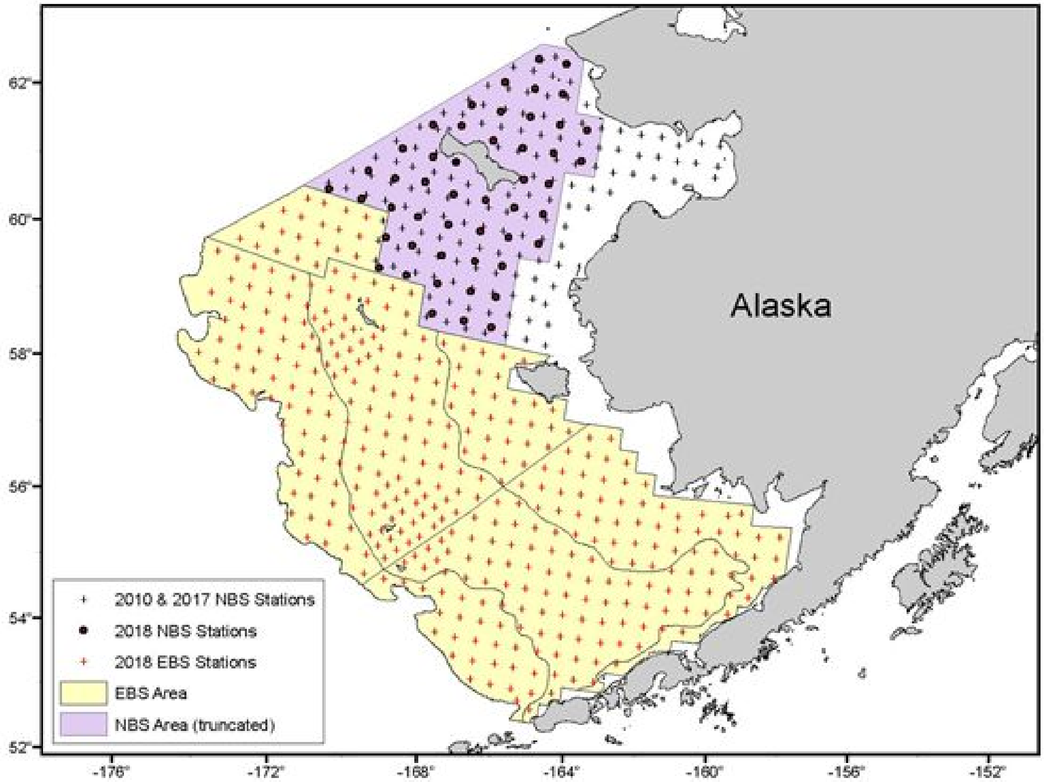

Figure 7. Sampling station design for the 2018 NOAA Bering Sea bottom trawl survey. Black dots are stations sampled in the 2018 "rapid-response" Northern Bering Sea trawl survey and black plus signs are stations sampled in standardized Northern Bering Sea trawl survey.

5.3 Management-supporting information

Successful fisheries management requires rigorous application of the scientific method of problem solving in the development of strategic alternatives and their evaluation on the basis of objectives that integrate ecosystem and human dynamics across space and time into management decision-making (Lane and Stephenson, 1995). This points to the importance of understanding a broad range of factors to deliver on the Commission's objective to develop the stocks of Pacific halibut to the levels that permit the optimum yield from the fishery over time. Management-supporting information beyond IPHC's current research and monitoring programs relate to, among others, socioeconomic considerations, community development, political constraints, and operational limitations.

Responding to the Commission's "*desire for more comprehensive economic information to support the overall management of the Pacific halibut resource in fulfillment of its mandate*" (economic study terms of reference adopted at FAC095 and endorsed at AM095 in 2019), between 2019 and 2021 the IPHC conducted a socioeconomic study. The study's core product, Pacific halibut multiregional economic impact assessment (PHMEIA) model, describes economic interdependencies between sectors and regions to bring a better understanding of the role and importance of the Pacific halibut resource to regional economies of Canada and the United States of America (see project report). The model details the within-region production structure of the Pacific halibut sectors (fishing, processing, charter) and cross-regional flows of economic benefits. The model also accounts for economic activity generated through sectors that supply fishing vessels, processing plants, and charter businesses with inputs to production, by embedding Pacific halibut sectors into the model of the entire economy of Canada and the USA. The PHMEIA model fosters stakeholders' better understanding of a broad scope of regional impacts of the Pacific halibut resource. The results highlight that the harvest stage accounts for only a fraction of economic activity that would be forgone if the resource was not available to fishers in the Pacific Northwest. Moreover, the study informs on the vulnerability of communities to changes in the state of the Pacific halibut stock throughout its range, highlighting regions particularly dependent on economic activities that rely on Pacific halibut. Leveraging multiple sources of socioeconomic data, the project provides complementary input for designing policies with desired effects depending on regulators' priorities which may involve balancing multiple conflicting objectives. A good understanding of the localized effects is pivotal to policymakers who are often concerned about community impacts, particularly in terms of impact on employment opportunities and households' welfare.

The economic impact assessment is supplemented by an analysis of the formation of the price paid for Pacific halibut products by final consumers (end-users) that is intended to provide a better picture of Pacific halibut contribution to the gross domestic product (GDP) along the entire value chain, from the hook-to-plate. This supplemental material is available in IPHC's Pacific halibut market analysis.

6. Core focal areas – Planned and opportunistic activities (2022-2026)

Research at IPHC can be classified as "use-inspired basic research" (Stokes 1997) which combines knowledge building with the application of existing and emerging knowledge to provide for the management of Pacific halibut. The four core focal areas: stock assessment, management strategy evaluation, management supporting information, and biology & ecology, all interact with each other as well as with fisheries monitoring activities in the IPHC program of integrated research and monitoring. Progress and knowledge building in one focal area influences and informs application in other core focal areas, also providing insight into future research priorities. The circular feedback loop is similar to the scientific method of observing a problem, creating a hypothesis, testing that hypothesis through research and analysis, drawing conclusions, and refining the hypothesis.

The IPHC Secretariat has been working with IPHC advisory bodies, such as the Scientific Review Board (SRB), and the Commission to conduct scientific research in a way that utilizes the scientific method. Problems are often identified by an advisory body or Commission and hypotheses are developed by the IPHC Secretariat. Research is reviewed by the SRB and refined hypotheses are presented to advisory bodies and the Commission. This process occurs via an annual schedule of meetings, as shown in Fig. 8. In May, an MSE informational session may be held if there is significant progress in the MSE such that it would be useful to prepare stakeholders for the Management Strategy Advisory Board (MSAB) meeting in October. Recommendations related to the MSE, and development of a harvest strategy directed to the Commission are a result of the MSAB meeting. The SRB holds two meetings each year: one in June where requests are typically directed to IPHC Secretariat, and one in September where recommendations are made to the Commission. The June SRB meeting has a focus on research; the September meeting represents a final check of science products to be presented to the Commission for use in management. The Research Advisory Board (RAB) meets in November to discuss ongoing research, provide guidance and recommend new research projects. The Work Meeting (WM) is held in September and is a working session with IPHC Secretariat and the Commission to prepare for the Interim Meeting (IM) held in November and the Annual Meeting (AM) held in January. Outcomes from the AM include mortality limits (coastwide and by IPHC Regulatory Area), directed fishery season dates, domestic regulations, and requests and recommendations for the IPHC Secretariat. In conjunction with the AM are meetings of the Finance and Administration Committee (FAC), the Conference Board (CB), and the Processor Advisory Board (PAB). The Commission may also hold Special Sessions (SS) throughout the year to take up and make decisions on specific topics.

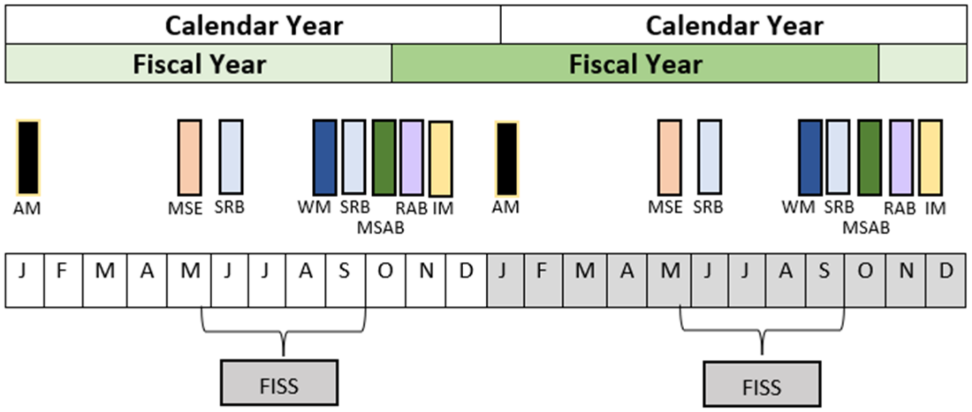

Figure 8. The typical IPHC annual meeting schedule with the calendar year and fiscal year shown. The meetings, shown in the middle row are: Annual Meeting where the Commission makes many final decisions for that year (AM), an MSE informational session (MSE), Scientific Review Board meetings (SRB), the Commission Work Meeting (WM), the Management Strategy Advisory Board meeting (MSAB), the Research Advisory Board Meeting (RAB), and the Interim Meeting (IM). The annual FISS schedule is also shown.

In addition to the annual meeting process at IPHC, individual core focal areas of research may identify and prioritize research for other core focal areas. For example, stock assessment research often identifies gaps in the knowledge of Pacific halibut biology and ecology, which then identifies priority research for the Biology and Ecology core area. Vice versa, basic biological and ecological research can identify concepts that could be better understood and result in improved implementation in any of the core areas. Furthermore, Management Strategy Evaluation can often be used to identify priority research topics for any core areas by simulation testing to identify research that may have the largest benefit to improving the management of Pacific halibut.

The top priorities of research for various categories in each of the core focal areas are provided below. The top priorities are a subset of the potential research topics in each core focal area. More exhaustive and up-to-date lists of research topics, that may extend beyond a five-year timeframe, can be found in recent meeting documents related to each core focal area.

6.1 Research

6.1.1 Stock Assessment

Within the four assessment research categories, the following topics have been identified as top priorities in order to focus attention on their importance for the stock assessment and management of Pacific halibut. A brief narrative is provided here to highlight the specific use of products from these studies in the stock assessment.

6.1.1.1 Stock Assessment data collection and processing

6.1.1.1.1 Commercial fishery sex-ratio-at-age via genetics

Commercial fishery sex-ratio information has been found to be closely correlated with the absolute scale of the population estimates in the stock assessment and has been identified as the greatest source of uncertainty since 2013. With only four years (2017-20) of commercial sex-ratio-at-age information available for the 2021 stock assessment, the annual genetic assay of fin clips sampled from the landings remains critically important. When the time series grows longer, it may be advantageous to determine the ideal frequency at which these assays need to be conducted. Development of approaches to use archived otoliths, scales or other samples to derive historical estimates (if possible) could provide valuable information on earlier time-periods (with differing fishery and biological properties), and therefore potentially reconcile some of the considerable historical uncertainty in the present stock assessment. This assessment priority directly informs *6.1.3.2 Reproduction* as described below.

6.1.1.1.2 Whale depredation accounting and tools for avoidance

Whale depredation currently represents a source of unobserved and unaccounted-for mortality in the assessment and management of Pacific halibut. A logbook program has been phased in over the last several years, in order to record whale interactions observed by commercial harvesters. Estimation of depredation mortality, from logbook records and supplemented with more detailed data and analysis from the FISS represents a first step in accounting for this source of mortality; however, such estimates will likely come with considerable uncertainty. Reduction of depredation mortality through improved fishery avoidance and/or catch protection would be a preferable extension and/or solution to basic estimation. As such, research to provide the fishery with tools to reduce depredation is considered a closely-related high priority. This assessment priority directly informs *6.1.3.4 Mortality and Survival Assessment* as described below.

6.1.1.2 Stock Assessment technical development

6.1.1.2.1 Maintaining coordination with the MSE

The stock assessment and MSE operating models have been developed in close coordination, in order to identify plausible hypotheses regarding the processes governing Pacific halibut population dynamics. Important aspects of Pacific halibut dynamics include recruitment (possibly related to extrinsic environmental factors in addition to spawning biomass), size-at-age, movement/migration and spatial patterns in fishery catchability and selectivity. Many approaches developed as part of the tactical stock assessment have been explored in the MSE operating model, and conversely, the MSE operating model has highlighted areas of data uncertainty or alternative hypotheses for exploration in the assessment (e.g. movement rates). Although these two modelling efforts target differing objectives (tactical vs. strategic) continued coordination is essential to ensure that the stock assessment and the MSE represent the Pacific halibut similarly and provide consistent and useful advice for tactical and strategic decision-making.

6.1.1.2.2 Data weighting

The stock assessment currently relies on iterative “Francis” weighting of the age compositional data using a multinomial likelihood formulation (Francis 2011) based on the number of samples available in each year. Exploration of a stronger basis for input sample sizes through analysis of sampling design, estimation of sample weighting and alternative likelihoods may all provide for a more stable approach and a better description of the associated uncertainty.

6.1.1.2.3 Environmental covariates to recruitment

The two long time-series models included in the stock assessment ensemble allow for the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) to be a binary covariate indicating periods of higher or lower average recruitment. This relationship has been observed to be consistent since its development over 20 years ago (Clark et al 1999) and is re-estimated in each year’s stock assessment models. With additional years of data, evaluation of the strength of this relationship, as compared to other metrics of the PDO (e.g., annual deviations, running averages) or other indicators of NE Pacific Ocean productivity should be undertaken in order to provide the best estimates and projections of Pacific halibut recruitment and to provide for alternative hypotheses for use in the MSE. This assessment priority partially informs *6.1.3.2 Reproduction* as described below.

6.1.1.2.4 ‘Leading’ parameter estimation

Stock assessments are generally very sensitive to the estimates of leading parameters (stock-recruitment parameters, natural mortality, sex-specific dynamics, etc.). For Pacific halibut some of these are fully integrated into the estimation uncertainty (average unexploited recruitment), or partially integrated (e.g. estimation of natural mortality in two of the four models). As time-series of critically informative data sources like the FISS and the sex-ratio of the commercial landings grow longer it may be possible to integrate additional leading parameters directly in the assessment models and/or include them as nested models within the ensemble.

6.1.1.3 Stock Assessment biological inputs

6.1.1.3.1 Maturity, skip-spawning, and fecundity

Management of Pacific halibut is currently based on reference points that rely on relative female spawning biomass. Therefore, any changes to the understanding of reproductive output – either across age/size (maturity), over time (skip spawning) or as a function of body mass (fecundity) are crucially important. Each of these components directly affects the annual reproductive output estimated in the assessment. Ideally, the IPHC would have a program in place to monitor each of these three reproductive processes over time and use that information in the estimation of the stock-recruitment relationship, and the annual reproductive output relative to reference points. This would reduce the potential for biased time-series estimates created by non-stationarity in these traits (illustrated via sensitivity analyses in several of the recent assessments). However, at present we have only historical time-aggregated estimates of maturity and fecundity schedules. Therefore, the current research priority is to first update our estimates for each of these traits to reflect current environmental and biological conditions. After current stock-wide estimates have been achieved, a program for extending this information to a time-series via transition from research to monitoring can be developed. This assessment priority directly informs *6.1.3.2 Reproduction* as described below.

6.1.1.3.2 Stock structure of IPHC Regulatory Area 4B relative to the rest of the convention area

The current stock assessment and management of Pacific halibut assume that IPHC Regulatory Area 4B is functionally connected with the rest of the stock, i.e., that recruitment from other areas can support harvest in Area 4B and that biomass in Area 4B can produce recruits that may contribute to other Areas. Tagging (Webster et al. 2013) and genetic (Drinan et al. 2016) analyses have indicated the potential for Area 4B to be demographically isolated. An alternative to current assessment and management structure would be to treat Area 4B separately from the rest of the coast. This would not likely have a large effect on the coastwide stock assessment as Area 4B represents only approximately 5% of the surveyed stock (Stewart and Webster 2022). However, it would imply that the specific mortality limits for Area 4B could be very important to local dynamics and should be separated from stock-wide trends. Therefore, information on the stock structure for Area 4B has been identified as a top priority. This assessment priority directly informs *6.1.3.1 Migration and Population Dynamics* as described below.

6.1.1.3.3 Meta-population dynamics (connectivity) of larvae, juveniles, and adults

The stock assessment and current management procedure treat spawning output, juvenile Pacific halibut abundance, and fish contributing to the fishery yield as equivalent across all parts of the Convention Area. Information on the connectivity of these life-history stages could be used for a variety of improvements to the assessment and current management procedure, including: investigating recruitment covariates, structuring spatial assessment models, identifying minimum or target spawning biomass levels in each Biological Region, refining the stock-recruitment relationship to better reflect source-sink dynamics and many others. Spatial dynamics have been highlighted as a major source of uncertainty in the Pacific halibut assessment for decades and will continue to be of high priority until they are better understood. This assessment priority directly informs *6.1.3.1 Migration and Population Dynamics* as described below.

6.1.1.4 Stock Assessment fishery yield

6.1.1.4.1 Biological interactions with fishing gear

In 2020, 16% of the total fishing mortality of Pacific halibut was discarded (Stewart et al. 2021). Discard mortality rates can vary from less than 5% to 100% depending on the fishery, treatment of the catch and other factors (Leaman and Stewart 2017). A better understanding of the biological underpinnings for discard mortality could lead to increased precision in these estimates, avoiding potential bias in the stock assessment. Further, improved biological understanding of discard mortality mechanisms could allow for reductions in this source of fishing mortality, and thereby increased yield available to the fisheries. This assessment priority directly informs *6.1.3.4 Mortality and Survival Assessment* as described below.

6.1.1.4.2 Guidelines for reducing discard mortality

Much is already known about methods to reduce discard mortality, in non-directed fisheries as well as the directed commercial and recreational sectors. Promotion and adoption of best handling practices could reduce discard mortality, lead to greater retained yield, and reduce the potential uncertainty associated with large quantities of estimated mortality due to discarding. This assessment priority directly informs *6.1.3.4 Mortality and Survival Assessment* as described below.

Outside of the four general assessment categories, the IPHC has recently considered adding close-kin genetics (e.g., Bravington et al. 2016) to its ongoing research program (see section 6.1.3.1). Close-kin mark-recapture can potentially provide estimates of the absolute scale of the spawning output from the Pacific halibut population. This type of information can be fit directly into the stock assessment, and if estimated with a reasonable amount of precision, even a single data point could substantially reduce the uncertainty in the scale of total population estimates. Further, close-kin genetics may provide independent estimates of total mortality (and therefore natural mortality conditioned on catch-at-age), relative fecundity-at-age, and the spatial dynamics of spawning and recruitment. All of these quantities could substantially improve the structure of the current assessment and reduce uncertainty. Data collection of genetic samples from 100% of the sampled commercial landings has been in place since 2017 (as part of the sex-ratio monitoring) and from the FISS since 2021. The genetic analysis required to produce data allowing the estimation of reproductive output and other population parameters from close-kin mark-recapture modelling is both complex and expensive, and it could take several years for this project to get fully underway. This five-year plan should consider a pilot evaluation, such that a broader study could be undertaken in the future, providing the likely results would meet the Commission's objectives and prove possible given financial constraints. Research related to close-kin genetics would be pursued under *6.1.3.1 Migration and Population Dynamics* as described below.

6.1.2 Management Strategy Evaluation

MSE priorities have been subdivided into three categories: 1) biological parameterisation, 2) fishery parameterization, and 3) technical development. Research provides specifications for the MSE simulations, such as inputs to the Operating Model (OM), but another important outcome of the research is to define the range of plausibility to include in the MSE simulations as a measure of uncertainty. The following topics have been identified as top priorities.

6.1.2.1 MSE Biological and population parameterization

6.1.2.1.1 Distribution of life stages and stock connectivity

Research topics in this category will mainly inform parameterization of movement in the OM, but will also provide further understanding of Pacific halibut movement, connectivity, and the temporal variability. This knowledge may also be used to refine specific MSE objectives to reflect reality and plausible outcomes. Research under Section 6.1.3.1 will inform this MSE priority.

This research includes examining larval and juvenile distribution which is a main source of uncertainty in the OM that is currently not fully incorporated. Outcomes will assist with conditioning the OM, verify patterns simulated from the OM, and provide information to develop reasonable sensitivity scenarios to test the robustness of MPs.

Also included in this number one priority is stock structure research, especially regarding IPHC Regulatory Area 4B. The dynamics of this IPHC Regulatory Area are not fully understood and it is useful to continue research on the connectivity of IPHC Regulatory Area 4B with other IPHC Regulatory Areas.

Finally, genomic analysis of population size is also included in this ranked category because that would help inform development of the OM as well as the biological sustainability objective related to maintaining a minimum spawning biomass in each IPHC Regulatory Area. An understanding of the spatial distribution of population size will help to inform this objective as well as the OM conditioning process.

6.1.2.1.2 Spatial spawning patterns and connectivity between spawning populations

An important parameter that can influence simulation outcomes is the distribution of recruitment across Biological Regions. Continued research in this area will improve the OM and provide justification for parameterising temporal variability. Research includes assigning individuals to spawning areas and establishing temporal and spatial spawning patterns. Outcomes may also provide information on recruitment strength and the relationship with environmental factors. For example, recent work by Sadorus et al (2020) used a biophysical and spatio-temporal models to examine connectivity across the Bering Sea and Gulf of Alaska. Furthermore, close-kin mark-recapture (Bravington et al. 2016) may provide insights into spatial relationships between juveniles and adults as well as abundance in specific regions. Research under Sections 6.1.3.1 and 6.1.3.2 will inform this MSE priority.

6.1.2.1.3 Understanding growth variation

Changes in the average weight-at-age of Pacific halibut is one of the major drivers of changes in biomass over time. The OM currently simulates temporal changes in weight-at-age via a random autocorrelated process which is unrelated to population size or environmental factors. Ongoing research in drivers related to growth in Pacific halibut will help to improve the simulation of weight-at-age. Research under Section 6.1.3.3 will inform this MSE priority.

6.1.2.1.4 MSE fishery parameterization

The specifications of fisheries and their parameterizations involved consultation with Pacific halibut stakeholders but some aspects of those parameterizations benefit from targeted research. One specific example is knowledge of discarding and discard mortality rates in directed and non-directed fisheries. Discard mortality can be a significant source of fishing mortality in some IPHC Regulatory Areas and appropriately modelling that mortality will provide a more robust evaluation of MPs. Research under Sections 6.1.3.4 and 6.1.3.5 will inform this MSE priority.

6.1.2.2 MSE technical development

Technical improvements to the MSE framework will allow for rapid development of alternative operating models and efficient simulation of management strategies for future evaluation. Coordination with the technical development of the stock assessment (Section 6.1.1.2.1) is necessary to ensure consistent assumptions and hypotheses for tactical (i.e. stock assessment) and strategic (i.e. MSE) models. Investigations done in the stock assessment will inform the stock assessment, which will then be informed by investigations using the closed-loop simulation framework. Multi-year assessments may allow for additional opportunity to coordinate between stock assessment and MSE.

6.1.2.2.1 Alternative migration scenarios

Including alternative migration hypotheses in the MSE simulations will assist in identifying management procedures that are robust to this uncertainty. This exploration will draw on general research on the movement and migration of Pacific halibut, observations from FISS and fisheries data, and outcomes of the stock assessment. Identification of reasonable hypotheses for the movement of Pacific halibut is essential to the robust investigation of management procedures. Research under Section 6.1.3.1 will inform this MSE priority.

6.1.2.2.2 Realistic simulations of estimation error

Closed loop simulation uses feedback from the management procedure to update the population in the projections. The management procedure consists of data collection, an estimation model, and harvest rules; currently IPHC uses a stock assessment as the estimation model. Future development of an efficient simulation process to mimic the stock assessment will more realistically represent the current management process. This involves using multiple estimation models to represent the ensemble and appropriately adding data and updating those models in the simulated projections. Improvements to the current MSE framework include adding additional estimation models to better represent the ensemble stock assessment, ensuring that the simulated estimation accurately represent the stock assessment now and, in the future, and speeding up the simulation process.

6.1.2.2.3 Incorporate additional sources of implementation uncertainty

Implementation uncertainty consists of three subcategories: 1) decision-making uncertainty, 2) realized uncertainty, and 3) perceived uncertainty. Decision-making uncertainty is the difference between mortality limits determined from the management procedure and those adopted by the Commission. This uncertainty is currently not implemented in the MSE framework but has been requested by the SRB and the independent peer review of the MSE. Realized uncertainty is the difference between the mortality limit set by the Commission and the actual mortality realized by the various fisheries. This type of uncertainty is currently partially implemented in the MSE framework. Finally, perceived uncertainty is the difference between the realized mortality and the estimated mortality limits from the various fisheries, which would be used in the estimation model. This third type of implementation uncertainty has not been implemented in the MSE framework. Implementing decision-making uncertainty is a priority for the MSE and will assist in understanding the performance of management procedures when they may not be followed exactly.

6.1.2.3 MSE Program of Work for 2021–2023

Following the 11th Special Session of the IPHC, an MSE program of work for 2021–2023 was developed. Seven tasks were identified that pertained to further developments of the MSE framework, evaluation of alternative MPs, and improvements in evaluation and presentation of results. Table 1 lists these tasks and provides a brief description. Additional details can be found in the program of work available on the MSE webpage.

Table 1. Tasks recommended by the Commission at SS011 (IPHC-2021-SS011-R para 7) for inclusion in the IPHC Secretariat MSE Program of Work for 2021–23.

ID	Category	Task	Deliverable
F.1	Framework	Develop migration scenarios	Develop OMs with alternative migration scenarios
F.2	Framework	Implementation variability	Incorporate additional sources of implementation variability in the framework
F.3	Framework	Develop more realistic simulations of estimation error	Improve the estimation model to more adequately mimic the ensemble stock assessment
F.5	Framework	Develop alternative OMs	Code alternative OMs in addition to the one already under evaluation.
M.1	MPs	Size limits	Identification, evaluation of size limits
M.3	MPs	Multi-year assessments	Evaluation of multi-year assessments
E.3	Evaluation	Presentation of results	Develop methods and outputs that are useful for presenting outcomes to stakeholders and Commissioners

6.1.2.4 Potential Future MSE projects

Management Strategy Evaluation is an iterative process where new management procedures may be evaluated, current management procedures may be re-evaluated under different assumptions, and the understanding of the population, environment, and fisheries may be updated with new information stemming from the stock assessment and biological/ecological research. The current Program of Work (Table 1) focuses on two elements of Management Procedures, but in the future other elements may be of interest, such as distribution procedures. The research being done now will inform the development of the MSE in the future to ensure a robust evaluation of any management procedure.

6.1.3 Biology and Ecology

Capitalizing on the outcomes of the previous 5-year plan (IPHC–2019–BESRP-5YP) (Appendix I), the IPHC Secretariat has identified five research areas that will provide key inputs for stock assessment and the MSE process. In addition to linking genetics and genomics with migration and distribution studies in the newly coined area of Migration and Population Dynamics, the IPHC Secretariat has incorporated a novel research area on Fishing Technology. A series of key objectives for each the five research areas have been identified.

6.1.3.1 Migration and Population Dynamics

Genetic and genomic studies aimed at improving current knowledge of Pacific halibut migration and population dynamics throughout all life stages in order to achieve a complete understanding of stock structure and distribution across the entire distribution range of Pacific halibut in the North Pacific Ocean and the biotic and abiotic factors that influence it (specifically excluding satellite tagging). Specific objectives in this area include:

- Improve current knowledge of the genetic structure of the Pacific halibut population through the use of state-of-the-art low-coverage whole genome resequencing approaches. Establishment of genetic signatures of spawning sites.
- Improve our understanding of the mechanisms and magnitude of larval connectivity in the North Pacific

Ocean. Identification of environmental and biological predictors of larval abundance and recruitment.

- Improve our understanding of spawning site contributions to nursery/settlement areas in relation to year-class, recruit survival and strength, and environmental conditions in the North Pacific Ocean. Measure of genetic diversity of Pacific halibut juveniles from the eastern Bering Sea and the Gulf of Alaska.
- Improve our understanding of the relationship between nursery/settlement origin and adult distribution and abundance over temporal and spatial scales. Genomic assignment of individuals to source populations and assessment of distribution changes.
- Integrate analyses of Pacific halibut connectivity and distribution changes by incorporating genomic approaches.
- Improve estimates of population size, migration rates among geographical regions, and demographic parameters (e.g. fecundity-at-age, survival rate), through the application of close-kin mark-recapture-based approaches.
- Improve our understanding of the influences of oceanographic and environmental variation on connectivity, population structure and adaptation at a genomic level using seascape genomics approaches.
- Exploration and development of alternative methods for aging Pacific halibut based on genetic analyses of DNA methylation patterns in tissues (fin clips).
- Exploration of methods for individual identification based on computer-assisted tail image matching systems as an alternative for traditional mark and recapture tagging.

6.1.3.2 Reproduction

Studies aimed primarily at addressing two critical issues for stock assessment analysis based on estimates of female spawning biomass: 1) the sex ratio of the commercial catch and 2) maturity estimations. Specific objectives in this area include:

- Continued improvement of genetic methods for accurate sex identification of commercial landings from fin clips and otoliths in order to incorporate recent and historical sex-at-age information into the stock assessment process.
- Improve our understanding of the temporal progression of reproductive development and gamete production during an entire annual reproductive cycle in female and male Pacific halibut.
- Update current maturity-at-age estimates.
- Provide estimates of fecundity-at-age and fecundity-at-size.
- Investigate the possible presence of skip spawning in Pacific halibut females.
- Improve accuracy in current staging criteria of maturity status used in the field.
- Investigate possible environmental effects on the ontogenetic establishment of the phenotypic sex and their influence on sex ratios in the adult Pacific halibut population.
- Improve our understanding of potential temporal and spatial changes in maturity schedules and spawning patterns in female Pacific halibut and possible environmental influences.
- Improve our understanding of the genetic basis of variation in age and/or size-at-maturity, fecundity, and spawning timing, by conducting genome-wide association studies.

6.1.3.3 **Growth**

Studies aimed at describing the role of factors responsible for the observed changes in size-at-age and at evaluating growth and physiological condition in Pacific halibut. Specific objectives in this area include:

- Evaluate possible variation in somatic growth patterns in Pacific halibut as informed by physiological growth markers, physiological condition, energy content and dietary influences.
- Investigate the effects of environmental and ecological conditions that may influence somatic growth in Pacific halibut. Evaluate the relationship between somatic growth and temperature and trophic histories in Pacific halibut through the integrated use of physiological growth markers.
- Improve our understanding of the genetic basis of variation in somatic growth and size-at-age by conducting genome-wide association studies.

6.1.3.4 Mortality and Survival Assessment

Studies aimed at providing updated estimates of discard mortality rates (DMRs) for Pacific halibut in the guided recreational fisheries and at evaluating methods for reducing mortality of Pacific halibut. Specific objectives in this area include:

- Provide information on the types of fishing gear and fish handling practices used in the Pacific halibut recreational (charter) fishery as well as on the number and size composition of discarded Pacific halibut in this fishery.
- Establish best handling practices for reducing discard mortality of Pacific halibut in recreational fisheries.
- Investigate new methods for improved estimation of depredation mortality from marine mammals.

6.1.3.5 Fishing Technology

Studies aimed at developing methods that involve modifications of fishing gear with the purpose of reducing Pacific halibut depredation and bycatch. Specific objectives in this area include:

- Investigate new methods for whale avoidance and/or deterrence for the reduction of Pacific halibut depredation by whales (e.g. catch protection methods).
- Investigate physiological and behavioral responses of Pacific halibut to fishing gear in order to reduce bycatch.

6.2 Monitoring

The Commission's extensive monitoring programs include both direct data collection and coordination with domestic agencies to produce both fishery-dependent and fishery-independent information on the stock and fishery trends, and other information. These critical sources include estimates of fishing mortality from all fisheries encountering Pacific halibut, biological sampling from these fisheries as well as catch-rates and biological sampling from longline and trawl surveys. Monitoring data provide the basis for stock assessment and MSE analysis, many biological research studies, and some inputs directly to the decision-making process (Figure 4). While not the primary focus of this 5-year plan, a basic summary of the components led by the IPHC and those that are provided by domestic agencies is provided below.

6.2.1 Fishery-dependent data

Data collection and monitoring activities aimed at providing standardised time-series of mortality, fishery, and biological data from both direct target fisheries as well as fisheries that incidentally catch Pacific halibut. Directed commercial fisheries data are managed by IPHC. Non-directed commercial discard mortality data, subsistence fisheries data, and recreational fisheries data are managed by Contracting Party domestic agencies.

6.2.1.1 Directed commercial fisheries data

6.2.1.2 Annually review the spatial distribution of sampling effort among ports, data collection methods, sampling rates, and quality assurance/quality control (QAQC) processes, including in-season review of port sampling activities

Ensure current data collection efforts meet current and future needs of stock assessment, MSE and management. Collaborate and coordinate with other Secretariat functions to develop methods and procedures for incorporating promising research results into long-term monitoring program. The IPHC relies on domestic and Tribal agency programs to report annual mortality from incidental catches in non-directed commercial fisheries, catches from subsistence fisheries, and catches from recreational fisheries. Non-directed commercial discard mortality data

Annually collaborate with observer programs and other partners to ensure robust data collection and sampling, QAQC processes, and reporting of incidental catch and mortality, as well as biological sampling.

6.2.1.3 Subsistence fisheries data

Annually collaborate with Tribal, State and Federal agencies of each Contracting Party to ensure high quality data collection, sampling, and reporting in the subsistence fisheries in Canada and the United States of America.

6.2.1.4 Recreational fisheries data

Annually collaborate with National/State agencies of each Contracting Party to ensure and validate high quality data and reporting of recreational fishery mortality estimates and biological data.

6.2.2 Fishery-independent data

Data collection and monitoring activities aimed at providing a standardised time-series of biological and ecological data that is independent of the fishing fleet.

6.2.2.1 Fishery-independent setline survey (FISS)

An annual review process for the FISS station design has been developed (Fig. 9) and is expected to continue in coming years. This process involves scientific review of proposed FISS designs by the Scientific Review Board and includes input from stakeholders prior to review and approval of designs by the Commissioners.

Direct weighing of Pacific halibut has been integrated into the annual FISS sampling since 2019 and will continue into the future to ensure accurate estimation of WPUE and other weight-derived quantities. Sample rates for genetic monitoring will need to be determined for future sampling. Sampling rates of otoliths for aging, archive otoliths and tagged fish will continue to be reviewed annually to ensure the data needs of the IPHC stock assessment and research program are met. Annual FISS sampler training and data QAQC (including at point of data collection and during post-sampling review) will ensure high quality data from the FISS program. Procedures are reviewed annually.

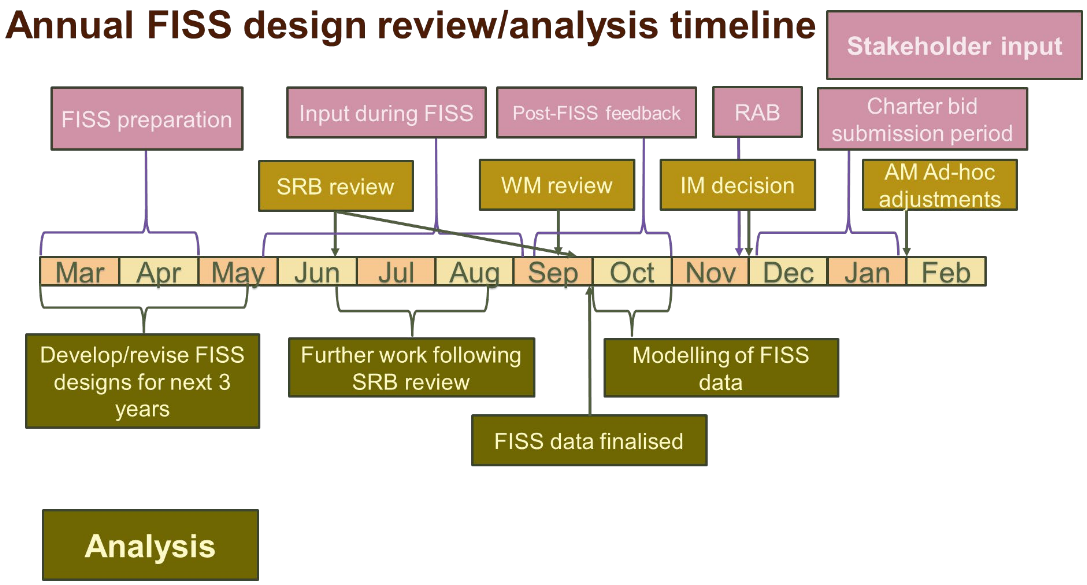

Figure 9. Timeline of annual FISS design review process.

6.2.2.2 Fishery-independent Trawl Survey (FITS)

The IPHC will continue to collaborate with NMFS on sampling procedures for Pacific halibut on the placement of an IPHC sampler onboard a survey vessel for the collection of biological data.

6.3 Potential of integrating human dynamics into management decision-making

Understanding the complexity of human dimension of the fisheries sectors is becoming increasingly important in the context of globalization. Local products compete on the market with a large variety of imported seafood. High exposure to international markets makes seafood accessibility fragile to perturbations, as shown by the COVID-19 pandemic (OECD 2020). Seafood production is also highly dependent on the production and price of imports. The IPHC's socioeconomic study showed that Pacific halibut contribution to households' income dropped by a quarter throughout the pandemic. While signs of strong recovery were present in 2021 (Fry 2021), the study called attention to Pacific halibut sectors' exposure to external factors beyond stock condition and the need for expanding the scope of management-supporting information the IPHC provides.

It is also unclear how small remote communities can capitalize on the high prices that the final customers are paying for premium seafood products. In 2021, fresh Alaskan Pacific halibut fillets routinely sold for USD 24-28 a pound, and often more, in downtown Seattle (e.g. USD 38 at Pike Place Market). Pacific halibut dishes at the restaurants typically sell for USD 37-43 for a dish including a 6oz fish portion. The IPHC's socioeconomic study detailed the geography of impacts of the Pacific halibut fisheries, providing a coherent picture of the exposure of fisheries-dependent households by location to changes in resource availability, but paying closer attention to quantifying leakage of economic benefits from communities strongly involved in fisheries, highlighted that the local earnings often do not align with how much fishing occurs within the community. This suggests the need for research focused on how to operationalize social equity in the context of the globalized market dynamics and the pursuit of stock sustainability.

In addition, fisheries are at the forefront of exposure to the accelerating impacts of climate change. For example, a rapid increase in water temperature off the coast of Alaska in 2014-16, termed *the blob*, affected fisheries (Cheung and Frölicher 2020) and may have a long-term impact on Pacific halibut distribution. The consequences may include shifts in the distribution of benefits, but possibly go further, affecting the stability of agreements over allocation of a shared resource. Research on decision quality under fast-progressing climate-induced changes to stock distribution may be warranted.

Conflicting objectives among stakeholders regarding the use of limited resource in the context of globalization, calls for social equity and climate change are a major challenge of decision-making in fisheries management. Integrating approaches aimed at understanding the human dynamics and external factors with stock assessment and MSE can assist fisheries in bridging the gap between the current and the optimal performance without compromising the stock biological sustainability. For example, socioeconomic performance metrics presented alongside already developed biological/ecological performance metrics would supplement IPHC's portfolio of tools for assessing policy-oriented issues (as requested by the Commission, IPHC-2021-AM097-R, AM097-Req.02) and support decision-making. Moreover, continuing investment in understanding the human dimension of Pacific halibut fishing can also inform on other drivers such as human behavior or human organization that affect the dynamics of fisheries, and thus contribute to improved accuracy of the stock assessment and the MSE (Lynch et al.2018). As such, it can contribute to research integration at the IPHC and provide a complementary resource for the development of harvest control rules.

Lastly, Pacific halibut value is also in its contribution to the diet through subsistence fisheries and importance to the traditional users of the resource. To native people, traditional fisheries constitute a vital aspect of local identity and a major factor in cohesion. One can also consider the Pacific halibut's existence value as an iconic fish of the Pacific Northwest. Recognizing and adopting such an all-encompassing definition of the Pacific halibut resource contribution, the IPHC echoes a broader call to include the human dimension into the research on the impact of management decisions, as well as changes in environmental or stock conditions.

7. Amendment

The intention is to ensure the plan is kept as a '*living plan*', that is reviewed and updated annually based on the resources available to undertake the work of the Commission (e.g. internal and external fiscal resources, collaborations, internal expertise). The IPHC Secretariat is committed to ensuring an exceptional level of transparency and commitment to the principles of open science.

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APPENDICES

Appendix I: Outcomes of the IPHC 5-Year Biological and Ecosystem Science Research Plan (2017-21)

Appendix II: Proposed schedule of outputs

Appendix III: Proposed schedule with funding and staffing indicators

APPENDIX I

Outcomes of the IPHC 5-Year Biological and Ecosystem Science Research Plan (2017-21) (IPHC–2019–BESRP-5YP)

A. Outcomes by Research Area:

1. Migration and Distribution.

1.1. Larval and juvenile connectivity and early life history studies. Planned research outcomes: improved understanding of larval and juvenile distribution.

Main results:

- Larval connectivity between the Gulf of Alaska and the Bering Sea occurs through large island passes across the Aleutian Island chain.
- The degree of larval connectivity between the Gulf of Alaska and the Bering Sea is influenced by spawning location.
- Spawning locations in the western Gulf of Alaska significantly contribute Pacific halibut larvae to the Bering Sea.
- Pacific halibut juveniles counter-migrate from inshore settlement areas in the eastern Bering Sea into the Gulf of Alaska through Unimak Pass.
- Elemental signatures of otoliths from juvenile Pacific halibut vary geographically at a scale equivalent to IPHC regulatory areas.

Publications:

Sadorus, L.; Goldstein, E.; Webster, R.; Stockhausen, W.; Planas, J.V.; Duffy-Anderson, J. Multiple life-stage connectivity of Pacific halibut (*Hippoglossus stenolepis*) across the Bering Sea and Gulf of Alaska. *Fisheries Oceanography*. 2021. 30:174-193. doi: https://doi.org/10.1111/fog.12512.

Loher, T., Bath, G. E., Wischniowsky, S. The potential utility of otolith microchemistry as an indicator of nursery origins in Pacific halibut (*Hippoglossus stenolepis*) in the eastern Pacific: the importance of scale and geographic trending. *Fisheries Research*. 2021. 243: 106072. https://doi.org/10.1016/j.fishres.2021.106072.

Links to 5-Year Research Plan (2022-2026):

- Evaluate the level of genetic diversity among juvenile Pacific halibut in the Gulf of Alaska and the Bering sea due to admixture.
- Assignment of individual juvenile Pacific halibut to source populations.

Integration with Stock Assessment and MSE: The relevance of research outcomes from activities in this research area for stock assessment is in the improvement of estimates of productivity. Research outcomes will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region and represent one of the top three biological inputs into stock assessment. The relevance of these research outcomes for MSE is in the improvement of the parametrization of the Operating Model and represent the top ranked biological input into the MSE.

2. **Reproduction**.

2.1 Sex ratio of commercial landings. Planned research outcomes: sex ratio information.

Main results:

- Establishment of TaqMan-based genetic assays for genotyping Pacific halibut in the IPHC Biological Laboratory.
- Sex ratio information for the 2017-2020 commercial landings.
- Transfer of genotyping efforts for sex identification to IPHC monitoring program.

Links to 5-Year Research Plan (2022-2026):

- Monitoring effort.

2.2 Histological maturity assessment. Planned research outcomes: updated maturity schedule.

Main results:

- Oocyte developmental stages have been characterized and fully described in female Pacific halibut for the first time.
- Oocyte developmental stages have been used for the classification of female developmental stages and to be able to characterize female Pacific halibut as group synchronous with determinate fecundity.
- Female developmental stages have been used for the classification of female reproductive phases and to be able to characterize female Pacific halibut as following an annual reproductive cycle with spawning in January and February.
- Female developmental stages and reproductive phases of females collected in the central Gulf of Alaska have been used to identify the month of August as the time of the transition between the Vtg2 and Vtg3 developmental stages marking the beginning of the spawning capable reproductive phase.
- Future gonad collections for revising maturity schedules and estimating fecundity can be conducted in August during the FISS.

Publications:

Fish, T., Wolf, N., Harris, B.P., Planas, J.V. A comprehensive description of oocyte developmental stages in Pacific halibut, *Hippoglossus stenolepis*. *Journal of Fish Biology* 2020. 97: 1880-1885. doi: 10.1111/jfb.14551.

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Links to 5-Year Research Plan (2022-2026):

- Revision of maturity schedule by gonad collection during the FISS, as informed by previous studies on reproductive development.

- Estimation of fecundity by age and size, as informed by previous studies demonstrating determinate fecundity.

Integration with Stock Assessment and MSE: Research activities in this Research Area aim at providing information on key biological processes related to reproduction in Pacific halibut (maturity and fecundity) and to provide sex ratio information of Pacific halibut commercial landings. The relevance of research outcomes from these activities for stock assessment is in the scaling of Pacific halibut biomass and in the estimation of reference points and fishing intensity. These research outputs will result in a revision of current maturity schedules and will be included as inputs into the stock assessment and represent the most important biological inputs for stock assessment. The relevance of these research outcomes for MSE is in the improvement of the simulation of spawning biomass in the Operating Model.

3. **Growth**.

3.1 Identification of physiological growth markers and their application for growth pattern evaluation. Planned research outcomes: informative physiological growth markers.

Main results:

- Transcriptomic profiling by RNAseq of white skeletal muscle from juvenile Pacific halibut subjected to growth suppression and to growth stimulation resulted in the identification of a number of genes that change their expression levels in response to growth manipulations.
- Proteomic profiling by LC-MS/MS of white skeletal muscle from juvenile Pacific halibut subjected to growth suppression and to growth stimulation resulted in the identification of a number of proteins that change their abundance in response to growth manipulations.
- Genes and proteins that changed their expression levels in accordance to changes in the growth rate in juvenile Pacific halibut were selected as putative growth markers for future studies on growth pattern evaluation.

Publications:

Planas et al. 2022. In Preparation.

Links to 5-Year Research Plan (2022-2026):

- Application of identified growth markers in studies aiming at investigating environmental influences on growth patterns and at investigating dietary influences on growth patterns and physiological condition.

3.2 Environmental influences on growth patterns. Planned research outcomes: information on growth responses to temperature variation.

Main results:

- Laboratory experiments under controlled temperature conditions have shown that temperature affects the growth rate of juvenile Pacific halibut through changes in the expression of genes that regulate growth processes.

Publications:

Planas et al. 2022. In Preparation.

Links to 5-Year Research Plan (2022-2026):

- Identification of temperature-specific responses in skeletal muscle through comparison between transcriptomic responses to temperature-induced growth changes and to density- and stress-induced growth changes.
- Application of growth markers for additional studies investigating the link between environmental variability and growth patterns and the effects of diet (prey quality and abundance) on growth and physiological condition.

Integration with Stock Assessment and MSE: Research activities conducted in this Research Area aim at providing information on somatic growth processes driving size-at-age in Pacific halibut. The relevance of research outcomes from these activities for stock assessment resides, first, in their ability to inform yield-per-recruit and other spatial evaluations for productivity that support mortality limit-setting, and second, in that they may provide covariates for projecting short-term size-at-age and may help delineate between fishery and environmental effects, thereby informing appropriate management responses. The relevance of these research outcomes for MSE is in the improvement of the simulation of variability and to allow for scenarios investigating climate change.

4. Mortality and Survival Assessment.

4.1 Discard mortality rate estimation in the longline Pacific halibut fishery. Planned research outcomes: experimentally-derived DMR.

Main results:

- Different hook release methods used in the longline fishery result in specific injury profiles and viability classification.
- Plasma lactate levels are high in Pacific halibut with the lowest viability classification.
- Mortality of discarded fish with the highest viability classification is estimated to be between 4.2 and 8.4%.

Publications:

Kroska, A.C., Wolf, N., Planas, J.V., Baker, M.R., Smeltz, T.S., Harris, B.P. Controlled experiments to explore the use of a multi-tissue approach to characterizing stress in wild-caught Pacific halibut (*Hippoglossus stenolepis*). *Conservation Physiology* 2021. 9(1):coab001; doi:10.1093/conphys/coab001.

Loher, T., Dykstra, C.L., Hicks, A., Stewart, I.J., Wolf, N., Harris, B.P., Planas, J.V. Estimation of postrelease longline mortality in Pacific halibut using acceleration-logging tags. *North American Journal of Fisheries Management*. 2022. 42: 37-49. DOI: https://doi.org/10.1002/nafm.10711.

Links to 5-Year Research Plan (2022-2026):

- Integration of information on capture and handling conditions, injury and viability assessment and physiological condition will lead to establishing a set of best handling practices in the longline fishery.

4.2 Discard mortality rate estimation in the guided recreational Pacific halibut fishery. Planned research outcomes: experimentally-derived DMR.

Main results:

- Field experiments testing two different types of gear types (i.e. 12/0 and 16/0 circle hooks) resulted in the capture, sampling and tagging of 243 Pacific halibut in IPHC Regulatory Area 2C (Sitka, AK) and 118 in IPHC Regulatory Area 3A (Seward, AK).
- The distributions of fish lengths by regulatory area and by hook size were similar.

Links to 5-Year Research Plan (2022-2026):

- Estimation of discard mortality rate in the guided recreational fishery.
- Integration of information on capture and handling conditions, injury and viability assessment and physiological condition linked to survival.
- Establishment of a set of best handling practices in the guided recreational fishery.

Integration with Stock Assessment and MSE: The relevance of research outcomes from these activities for stock assessment resides in their ability to improve trends in unobserved mortality in order to improve estimates of stock productivity and represent the most important inputs in fishery yield for stock assessment. The relevance of these research outcomes for MSE is in fishery parametrization

5. Genetics and genomics.

5.1 Generation of genomic resources for Pacific halibut. Planned research outcomes: sequenced genome and reference transcriptome.

Main results:

- A first draft of the chromosome-level assembly of the Pacific halibut genome has been generated.
- The Pacific halibut genome has a size of 602 Mb and contains 24 chromosome-size scaffolds covering 99.8% of the complete assembly with a N50 scaffold length of 27 Mb at a coverage of 91x.
- The Pacific halibut genome has been annotated by NCBI and is available as NCBI Hippoglossus stenolepis Annotation Release 101 (https://www.ncbi.nlm.nih.gov/assembly/GCA_022539355.2/).
- Transcriptome (i.e. RNA) sequencing has been conducted in twelve tissues in Pacific halibut and the raw sequence data have been deposited in NCBI's Sequence Read Archive (SRA) under the bioproject number PRJNA634339 (https://www.ncbi.nlm.nih.gov/bioproject/PRJNA634339) and with SRA accession numbers SAMN14989915 - SAMN14989926.

Publications:

Jasonowicz, A.C., Simeon, A., Zahm, M., Cabau, C., Klopp, C., Roques, C., Iampietro, C., Lluch, J., Donnadieu, C., Parrinello, H., Drinan, D.P., Hauser, L., Guiguen, Y., Planas, J.V. Generation of a chromosome-level genome assembly for Pacific halibut (*Hippoglossus stenolepis*) and characterization of its sex-determining genomic region. *Molecular Ecology Resources. 2022. In Press*. doi: https://doi.org/10.1111/1755-0998.13641.

Jasonowicz et al. 2022. In Preparation.

Links to 5-Year Research Plan (2022-2026):

- Genome-wide analysis of stock structure and composition.

5.2 Determine the genetic structure of the Pacific halibut population in the Convention Area. Planned research outcomes: genetic population structure.

Main results:

- The collection of winter genetic samples in the Aleutian Islands completed the winter sample collection needed to conduct studies on the genetic population structure of Pacific halibut in the Convention Area.
- Initial results of low coverage whole genome resequencing of winter samples indicate that an average of 26.5 million raw sequencing reads per obtained per sample that provided average individual genomic coverages for quality filtered alignments of 3.2x.

Links to 5-Year Research Plan (2022-2026):

- Fine-scale delineation of population structure, with particular emphasis on IPHC Regulatory 4B structure.

Integration with Stock Assessment and MSE: The relevance of research outcomes from these activities for stock assessment resides in the introduction of possible changes in the structure of future stock assessments, as separate assessments may be constructed if functionally isolated components of the population are found (e.g. IPHC Regulatory Area 4B), and in the improvement of productivity estimates, as this information may be used to define management targets for minimum spawning biomass by Biological Region. These research outcomes provide the second and third top ranked biological inputs into stock assessment. Furthermore, the relevance of these research outcomes for MSE is in biological parametization and validation of movement estimates and of recruitment distribution.

B. List of ranked biological uncertainties and parameters for stock assessment (SA) and their links to research areas and activities contemplated in the IPHC 5-Year Biological and Ecosystem Science Research Plan (2017-21)

SA Rank	Research outcomes	Relevance for stock assessment	Specific analysis input	Research Area	Research activities
1. Biological input	Updated maturity schedule	Scale biomass and reference point estimates	Will be included in the stock assessment, replacing the current schedule last updated in 2006	Reproduction	Histological maturity assessment
	Incidence of skip spawning		Will be used to adjust the asymptote of the maturity schedule, if/when a time-series is available this will be used as a direct input to the stock assessment		Examination of potential skip spawning
	Fecundity-at-age and -size information		Will be used to move from spawning biomass to egg-output as the metric of reproductive capability in the stock assessment and management reference points		Fecundity assessment
	Revised field maturity classification		Revised time-series of historical (and future) maturity for input to the stock assessment		Examination of accuracy of current field macroscopic maturity classification
2. Biological input	Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area	Altered structure of future stock assessments	If 4B is found to be functionally isolated, a separate assessment may be constructed for that IPHC Regulatory Area	Genetics and Genomics	Population structure
3. Biological input	Assignment of individuals to source populations and assessment of distribution changes	Improve estimates of productivity	Will be used to define management targets for minimum spawning biomass by Biological Region		Distribution
	Improved understanding of larval and juvenile distribution		Will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region	Migration	Larval and juvenile connectivity studies
1. Assessment data collection and processing	Sex ratio-at-age	Scale biomass and fishing intensity	Annual sex-ratio at age for the commercial fishery fit by the stock assessment	Reproduction	Sex ratio of current commercial landings
	Historical sex ratio-at-age		Annual sex-ratio at age for the commercial fishery fit by the stock assessment		Historical sex ratios based on archived otolith DNA analyses
2. Assessment data collection and processing	New tools for fishery avoidance/deterence; improved estimation of depredation mortality	Improve mortality accounting	May reduce depredation mortality, thereby increasing available yield for directed fisheries. May also be included as another explicit source of mortality in the stock assessment and mortality limit setting process depending on the estimated magnitude	Mortality and survival assessment	Whale depredation accounting and tools for avoidance
1. Fishery yield	Physiological and behavioral responses to fishing gear	Reduce incidental mortality	May increase yield available to directed fisheries	Mortality and survival assessment	Biological interactions with fishing gear
2. Fishery yield	Guidelines for reducing discard mortality	Improve estimates of unobserved mortality	May reduce discard mortality, thereby increasing available yield for directed fisheries	Mortality and survival assessment	Best handling practices: recreational fishery

C. List of ranked biological uncertainties and parameters for management strategy evaluation (MSE) and their links to research areas and activities contemplated in the IPHC 5-Year Biological and Ecosystem Science Research Plan (2017-21)

MSE Rank	Research outcomes	Relevance for MSE	Research Area	Research activities
1. Biological parameterization and validation of movement estimates	Improved understanding of larval and juvenile distribution	Improve parametization of the Operating Model	Migration	Larval and juvenile connectivity studies
	Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area		Genetics and Genomics	Population structure
2. Biological parameterization and validation of recruitment variability and distribution	Assignment of individuals to source populations and assessment of distribution changes	Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model		Distribution
	Establishment of temporal and spatial maturity and spawning patterns	Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model	Reproduction	Recruitment strength and variability
3. Biological parameterization and validation for growth projections	Identification and application of markers for growth pattern evaluation	Improve simulation of variability and allow for scenarios investigating climate change	Growth	Evaluation of somatic growth variation as a driver for changes in size-at-age
	Environmental influences on growth patterns			
	Dietary influences on growth patterns and physiological condition			
1. Fishery parameterization	Experimentally-derived DMRs	Improve estimates of stock productivity	Mortality and survival assessment	Discard mortality rate estimate: recreational fishery

D. External funding received during the IPHC 5-Year Biological and Ecosystem Science Research Plan (2017-21):

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**Saltonstall-Kennedy NOAA**	Improving discard mortality rate estimates in the Pacific halibut by integrating handling practices, physiological condition and post-release survival (NOAA Award No. NA17NMF4270240)	IPHC	Alaska Pacific University	$286,121	Bycatch estimates	September 2017 – August 2020
2	**North Pacific Research Board**	Somatic growth processes in the Pacific halibut (*Hippoglossus stenolepis*) and their response to temperature, density and stress manipulation effects (NPRB Award No. 1704)	IPHC	AFSC-NOAA-Newport, OR	$131,891	Changes in biomass/size-at-age	September 2017 – February 2020
3	**Bycatch Reduction Engineering Program - NOAA**	Adapting Towed Array Hydrophones to Support Information Sharing Networks to Reduce Interactions Between Sperm Whales and Longline Gear in Alaska	Alaska Longline Fishing Association	IPHC, University of Alaska Southeast, AFSC-NOAA	-	Whale Depredation	September 2018 – August 2019
4	**Bycatch Reduction Engineering Program - NOAA**	Use of LEDs to reduce Pacific halibut catches before trawl entrainment	Pacific States Marine Fisheries Commission	IPHC, NMFS	-	Bycatch reduction	September 2018 – August 2019
5	**National Fish & Wildlife Foundation**	Improving the characterization of discard mortality of Pacific halibut in the recreational fisheries (NFWF Award No. 61484)	IPHC	Alaska Pacific University, U of A Fairbanks, charter industry	$98,902	Bycatch estimates	April 2019 – November 2021
6	**North Pacific Research Board**	Pacific halibut discard mortality rates (NPRB Award No. 2009)	IPHC	Alaska Pacific University,	$210,502	Bycatch estimates	January 2021 –March 2022
7	**Bycatch Reduction Engineering Program - NOAA**	Gear-based approaches to catch protection as a means for minimizing whale depredation in longline fisheries (NA21NMF4720534)	IPHC	Deep Sea Fishermen's Union, Alaska Fisheries Science Center-NOAA, industry representatives	$99,700	Mortality estimations due to whale depredation	November 2021 – October 2022
8	**North Pacific Research Board**	Pacific halibut population genomics (NPRB Award No. 2110)	IPHC	Alaska Fisheries Science Center-NOAA	$193,685	Stock structure	December 2021-January 2024
				Total awarded ($)	**$1,020,801**		

E. Publications in the peer-reviewed literature resulting from the IPHC 5-Year Biological and Ecosystem Science Research Plan (2017-21):

2020:

Fish, T., Wolf, N., Harris, B.P., Planas, J.V. A comprehensive description of oocyte developmental stages in Pacific halibut, *Hippoglossus stenolepis*. *Journal of Fish Biology*. 2020. 97: 1880-1885. https://doi: 10.1111/jfb.14551.

2021:

Carpi, P., Loher, T., Sadorus, L., Forsberg, J., Webster, R., Planas, J.V., Jasonowicz, A., Stewart, I. J., Hicks, A. C. Ontogenetic and spawning migration of Pacific halibut: a review. *Rev Fish Biol Fisheries*. 2021. https://doi.org/10.1007/s11160-021-09672-w.

Kroska, A.C., Wolf, N., Planas, J.V., Baker, M.R., Smeltz, T.S., Harris, B.P. Controlled experiments to explore the use of a multi-tissue approach to characterizing stress in wild-caught Pacific halibut (*Hippoglossus stenolepis*). *Conservation Physiology* 2021. 9(1):coab001. https://doi:10.1093/conphys/coab001.

Loher, T., Bath, G. E., Wischniowsky, S. The potential utility of otolith microchemistry as an indicator of nursery origins in Pacific halibut (*Hippoglossus stenolepis*) in the eastern Pacific: the importance of scale and geographic trending. *Fisheries Research*. 2021. 243: 106072. https://doi.org/10.1016/j.fishres.2021.106072.

Lomeli, M.J.M., Wakefield, W.W., Herrmann, B., Dykstra, C.L., Simeon, A., Rudy, D.M., Planas, J.V. Use of Artificial Illumination to Reduce Pacific Halibut Bycatch in a U.S. West Coast Groundfish Bottom Trawl. *Fisheries Research*. 2021. 233: 105737. doi: 10.1016/j.fishres.2020.105737.

Sadorus, L., Goldstein, E., Webster, R., Stockhausen, W., Planas, J.V., Duffy-Anderson, J. Multiple life-stage connectivity of Pacific halibut (*Hippoglossus stenolepis*) across the Bering Sea and Gulf of Alaska. *Fisheries Oceanography*. 2021. 30:174-193. doi: https://doi.org/10.1111/fog.12512.

2022:

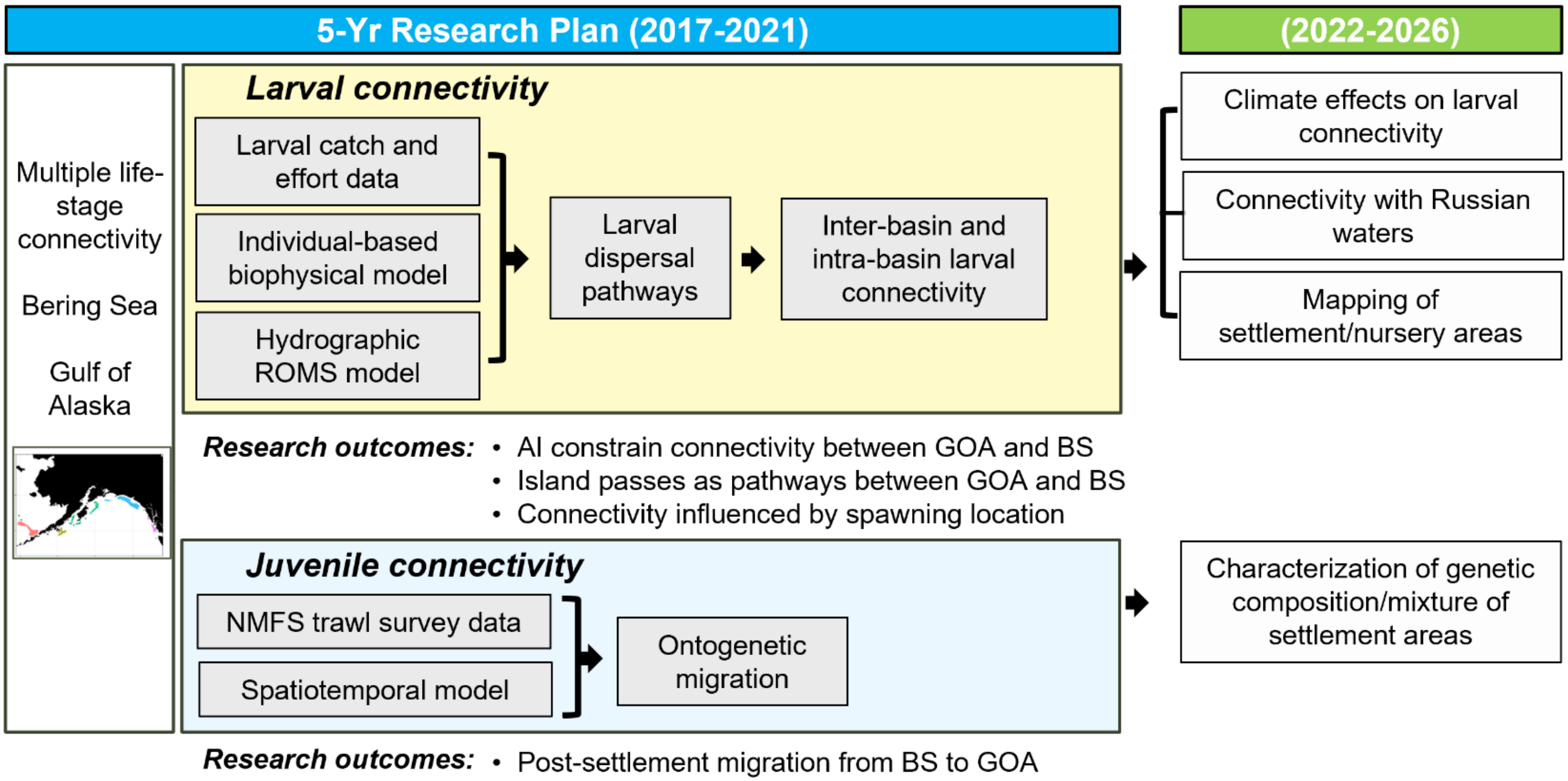
Fish, T., Wolf, N., Smeltz, T. S., Harris, B. P., and Planas, J. V. Reproductive Biology of Female Pacific Halibut (*Hippoglossus stenolepis*) in the Gulf of Alaska. *Frontiers in Marine Science* 2022. 9:801759. doi: 10.3389/fmars.2022.801759.

Jasonowicz, A.C., Simeon, A., Zahm, M., Cabau, C., Klopp, C., Roques, C., Iampietro, C., Lluch, J., Donnadieu, C., Parrinello, H., Drinan, D.P., Hauser, L., Guiguen, Y., Planas, J.V. Generation of a chromosome-level genome assembly for Pacific halibut (*Hippoglossus stenolepis*) and characterization of its sex-determining genomic region. *Molecular Ecology Resources.* 2022. In Press. doi: https://doi.org/10.1111/1755-0998.13641.

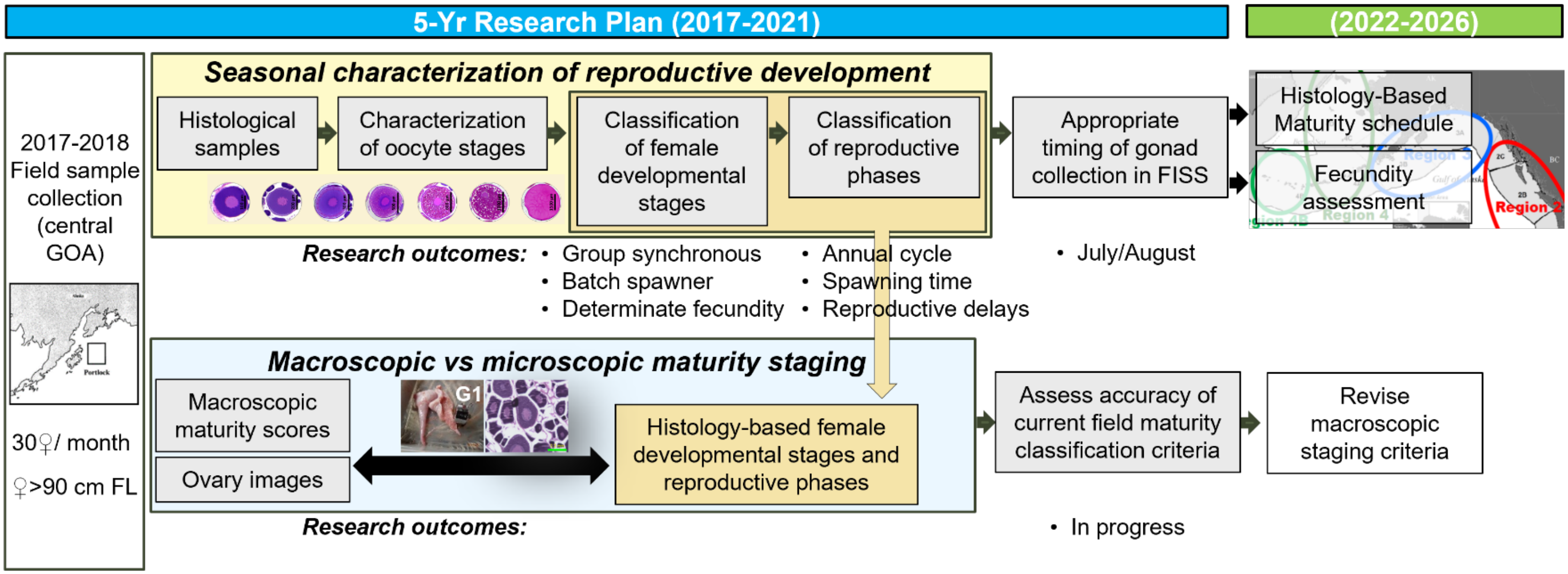
Loher, T., Dykstra, C.L., Hicks, A., Stewart, I.J., Wolf, N., Harris, B.P., Planas, J.V. Estimation of postrelease longline mortality in Pacific halibut using acceleration-logging tags. *North American Journal of Fisheries Management*. 2022. 42: 37-49. DOI: http://dx.doi.org/10.1002/nafm.10711.

F. Flow chart of progress resulting from the IPHC 5-Year Biological and Ecosystem Science Research Plan (2017-21) by research area leading to the IPHC 5-Year Program of Integrated Research and Monitoring (2022-2026)

1. Migration and Distribution



2. Reproduction

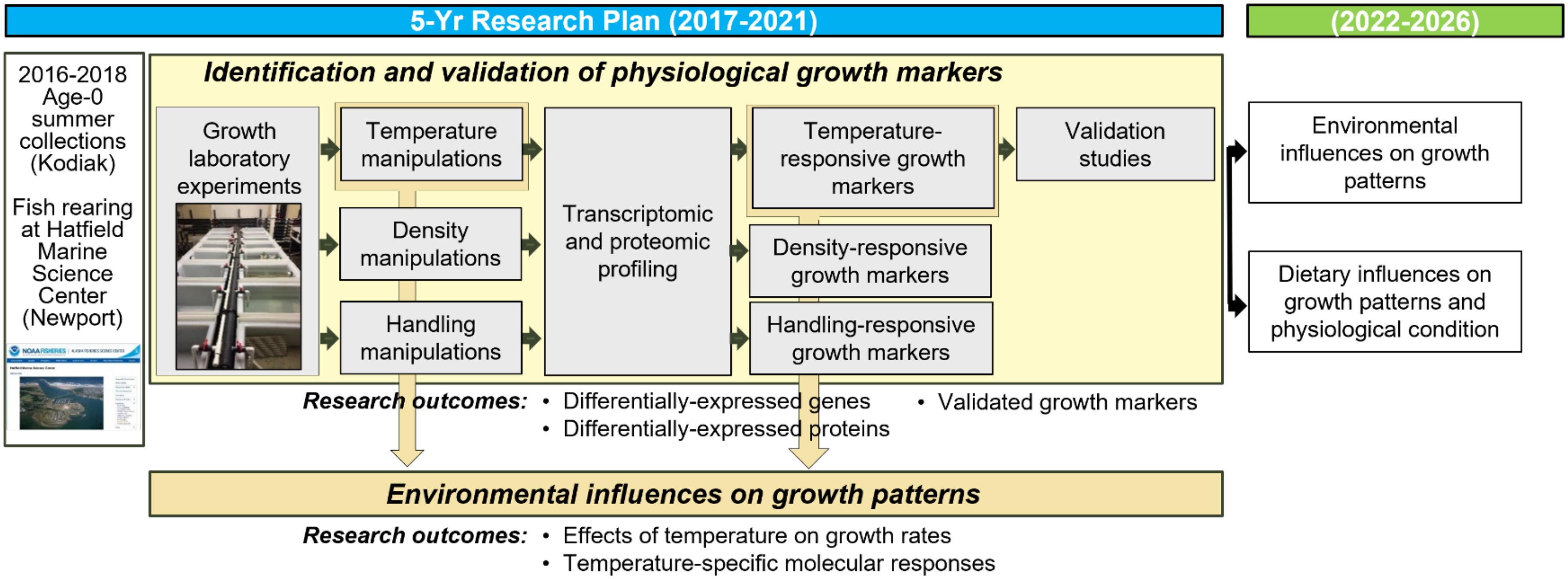


Staff involved: Teresa Fish, MSc APU (2018-2020), Crystal Simchick, Ian Stewart, Allan Hicks, Josep Planas

Funding: IPHC (2018-2020)

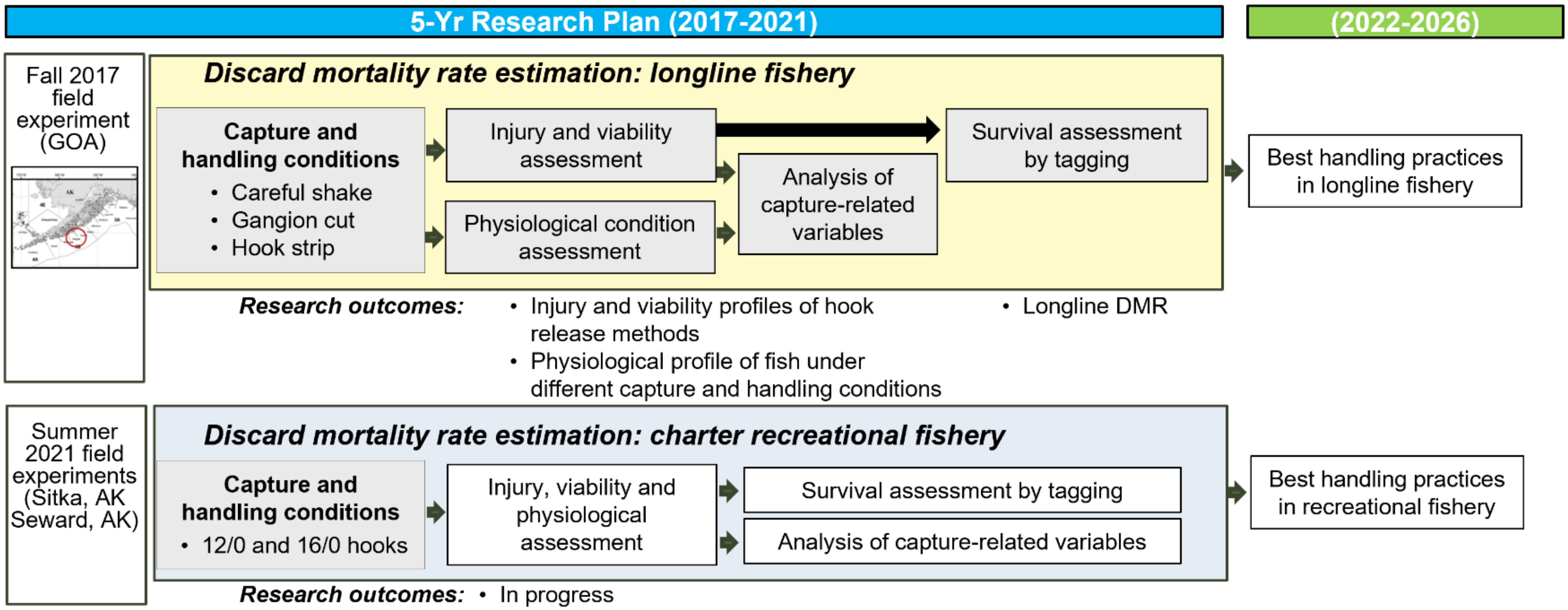
Publications (2): Fish et al. (2020) *J. Fish Biol*. **97**: 1880–1885 ; Fish et al. (2022) Front. Mar. Sci. 9:801759

3. Growth



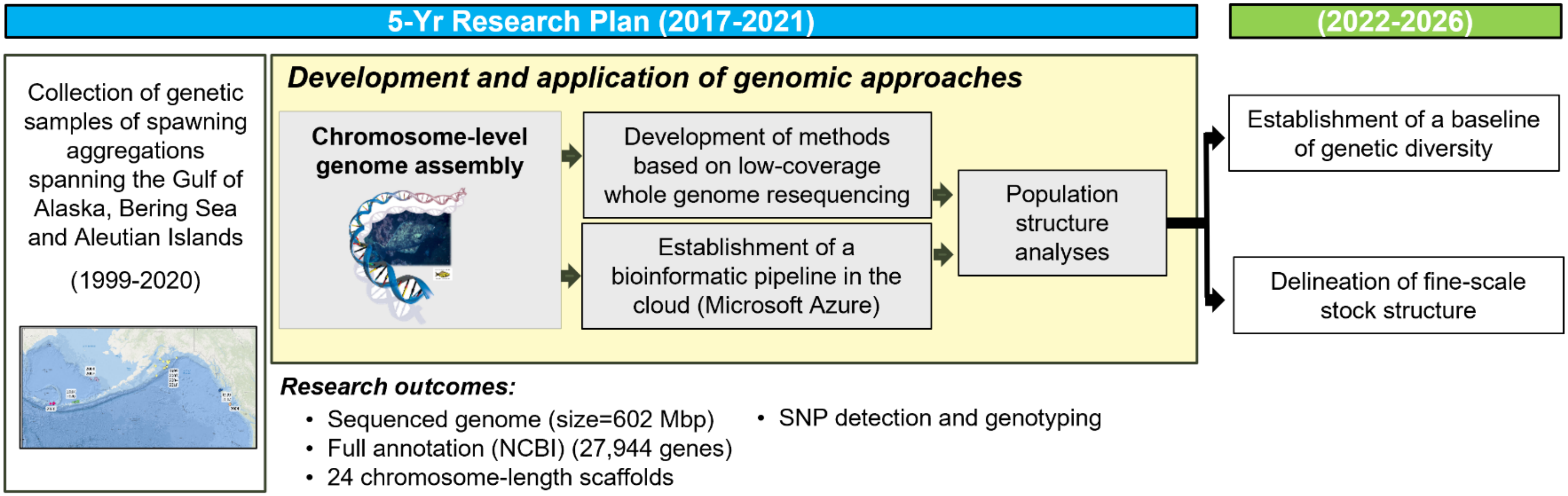
Staff involved: Andy Jasonowicz, Crystal Simchick, Josep Planas
Funding: NPRB Grant#1704 (Sept. 2017-Feb. 2020)
Publications: Planas et al. (in preparation)

4. Mortality and Survival Assessment



Staff involved: Claude Dykstra, Allan Hicks, Ian Stewart, Josep Planas
Funding (3): Saltonstall-Kennedy NOAA (Sept. 2017-Aug. 2020); NFWF (Apr. 2019-Nov. 2021); NPRB#2009 (Jan. 2021-Mar. 2022)
Publications (2): Kroska et al. (2021) *Conserv. Physiol*.; Loher et al. (2022) *North Amer. J. Fish. Manag. 42: 37-49*

5. Genetics and Genomics



Staff involved: Andy Jasonowicz, Josep Planas
Funding: IPHC, NPRB#2110
Publications: Jasonowicz et al. (2022) *Mol. Ecol. Resour. (In Review)*

APPENDIX II

Proposed schedule of outputs

	2022		**2023**		**2024**		**2025**		**2026**	
Biology and Ecology										
Migration and population dynamics										
Reproduction										
Growth										
Mortality and survival assessment										
Fishing technology										
Stock Assessment										
Management Strategy Evaluation										
Monitoring										

APPENDIX III

Proposed schedule of funding and staffing indicators: Biology and Ecology

Research areas	Research activities	Required FTEs/Year	IPHC FTEs/Year	2022	2023	2024	2025	2026	IPHC Funds	Grant Funds
Migration and Population Dynamics	Larval and juvenile connectivity and early life history studies	0.45	0.45		RB1	RB2			Yes	NPRB #2100
	Population structure	0.4	0.8		RB1				No	NPRB #2110
	Adult migration and distribution	0.4							No	NPRB #2110
	Close-kin mark-recapture studies	1	0						No	Planned
	Seascape genomics	1	0						No	Planned
	Genome-wide association analyses	1	0						No	Planned
	Genomic-based aging methods	1	1		RS 1				Yes	No
Reproduction	Maturity-at-age estimations	0.75	0						Yes	No
	Fecundity assessment	0.5	0.25			RB4	RS 2		Yes	No
	Examination of accuracy of current field macroscopic maturity classification	0.25							Yes	No
	Sex ratio of current commercial landings	0.5	0.75	LT					Yes	No
	Recruitment strength and variability	0.5	0				RS 2		Yes	Planned
Growth	Environmental influences on growth patterns	0.5	0.5			MSc student			No	Planned
	Dietary influences on growth patterns and physiological condition	0.5	0.2		RB3				No	Planned
Mortality and survival assessment	Discard mortality rate estimate: recreational fishery	0.5	1						No	NPRB #2009
	Best handling practices: recreational fishery	0.5		RB 3					No	NPRB #2009
	Whale depredation accounting and tools for avoidance	0.5							No	BREP
	Biological interactions with fishing gear	0.5							No	BREP

IPHC staff (Planned):

RS1: Research Scientist 1(PhD; Life History Modeler I). Full time temporary position (100% research;
RS2: Research Scientist 1(PhD; Life History Modeler II). Full time temporary position (100% research;
RB1: Research Biologist 1 (Geneticist; MSc). Full time temporary position (until April 2022; 1 FTE). 55% of salary covered by Grant NPRB#2110.
RB2: Research Biologist 2 (Early Life History; MSc). Full time permanent position (40% research; 0.4 FTE)
RB3: Research Biologist 3 (DMR; MSc). Full time permanent position (100% research; 1 FTE)
RB4: Research Biologist 4 (Maturity and Fecundity; MSc). Full time permanent position (100% research; 1 FTE)
LT: Laboratory Technician (MSc). Full time temporary position (100% research; 1 FTE)

2023-25 FISS design evaluation

PREPARED BY: IPHC SECRETARIAT (R. WEBSTER; 19 AUGUST 2022)

Part 1: 2023-25 FISS design evaluation

PURPOSE

To review the 2023-25 FISS designs presented at SRB020 and endorsed by the Scientific Review Board (SRB) at that meeting.

BACKGROUND

At SRB020, Secretariat staff presented proposed FISS designs for 2023-25 together with an evaluation of those designs (Webster 2022). Based on the evaluation, it is expected that the proposed designs would lead to estimated indices of density that would meet bias and precision criteria. In their report (IPHC-2022-SRB020-R, paragraph 12) the SRB stated:

> *The SRB* ***ENDORSED*** *the final 2023 FISS design as presented in Fig. 2, and provisionally* ***ENDORSED*** *the 2024-25 designs (Figs. 3 and 4), recognizing that these will be reviewed again at subsequent SRB meetings.*

PROPOSED DESIGNS FOR 2023-25

The designs proposed for 2023-25 (Figures 1,1 to 1.3) use efficient subarea sampling in IPHC Regulatory Areas 2A, 4A and 4B, and incorporate a randomized subsampling of FISS stations in IPHC Regulatory Areas 2B, 2C, 3A and 3B (except for the near-zero catch rate inside waters around Vancouver Island), with a sampling rate chosen to keep the sample size close to 1000 stations in an average year, a logistically feasible footprint for the annual FISS. In 2021, designs for 2023-24 were also approved subject to later revision (IPHC-2022-AM098-R). The designs developed in 2021 have largely been carried over into the current 2023-24 proposal, with exceptions noted below.

- IPHC Regulatory Area 2A: Sample the highest-density waters of IPHC Regulatory 2A in northern Washington and central/southern Oregon each year of the 2023-25 period, and in 2023 only, add the moderate density waters of southern Washington/northern Oregon and northern California **(revision from previous 2023 design proposal)**.
- IPHC Regulatory Area 4A: Sample the higher-density western subarea of IPHC Regulatory Area 4A in all three years, the medium-density northern shelf edge subarea in 2023 only, and the historically lower-density southeastern subarea in 2025 only.
- IPHC Regulatory Area 4B: Sample the high-density eastern subarea in all three years, and the western subarea in 2023 only **(revision from previous 2023 design proposal)**.

Stations in the moderate-density waters of IPHC Regulatory 2A proposed for 2023 sampling have not been sampled since 2017 (California) or 2019 (WA/OR). This is a revision from previous proposals, which did not include these stations prior to 2025 (Webster 2021). Evaluation of potential designs in IPHC Regulatory Area 2A showed that unless these waters were sampled in 2023, we project that precision targets would not be met, with an expected 2023 coefficient of variation for mean O32 WPUE of 20% (target range is <15%). We have also received anecdotal reports of increasing recreational catch rates in northern California, providing additional motivation for bringing forward sampling in those waters.

The design proposals again include full sampling of the standard FISS grid in IPHC Regulatory Area 4CDE. The Pacific halibut distribution in this area continues to be of particular interest, as it is a highly dynamic region with an apparently northward-shifting distribution of Pacific halibut, and increasing uncertainty regarding connectivity with populations adjacent to and within Russian waters.

RECOMMENDATION

That the Scientific Review Board:

1) **NOTE** paper IPHC-2022-SRB021-06, which reviewed the 2023-25 FISS designs presented at SRB020 and endorsed by the SRB at that meeting;
2) **RECOMMEND** that the Commission note the SRB endorsement of the proposed 2023 design (Figure 1.1) and provisional endorsement of the proposed 2024-25 designs (Figures 1.2 and 1.3).

References

IPHC 2022. Report of the 20th Session of the IPHC Scientific Review Board (SRB) IPHC-2022-SRB20-R. 19 p.

IPHC 2022. Report of the 98th Session of the IPHC Annual Meeting (AM098) IPHC-2022-AM098-R. 60 p.

Webster, R. A. 2021. 2022-24 FISS design evaluation. IPHC-2021-SRB020-05 Rev_1.

Webster, R. A. 2022. 2023-25 FISS design evaluation. IPHC-2022-SRB020-05.

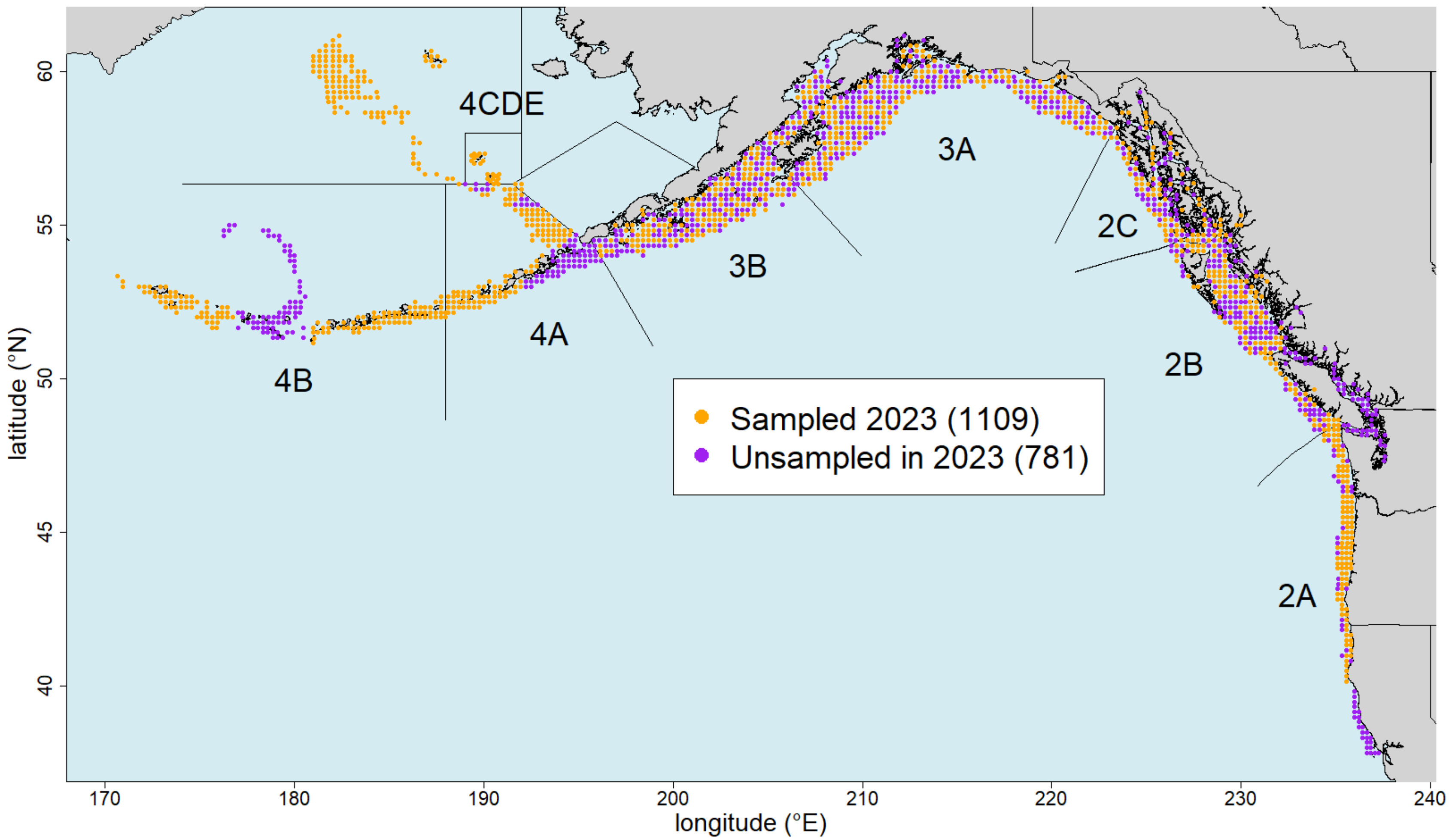


Figure 1.1. Proposed minimum FISS design in 2023 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

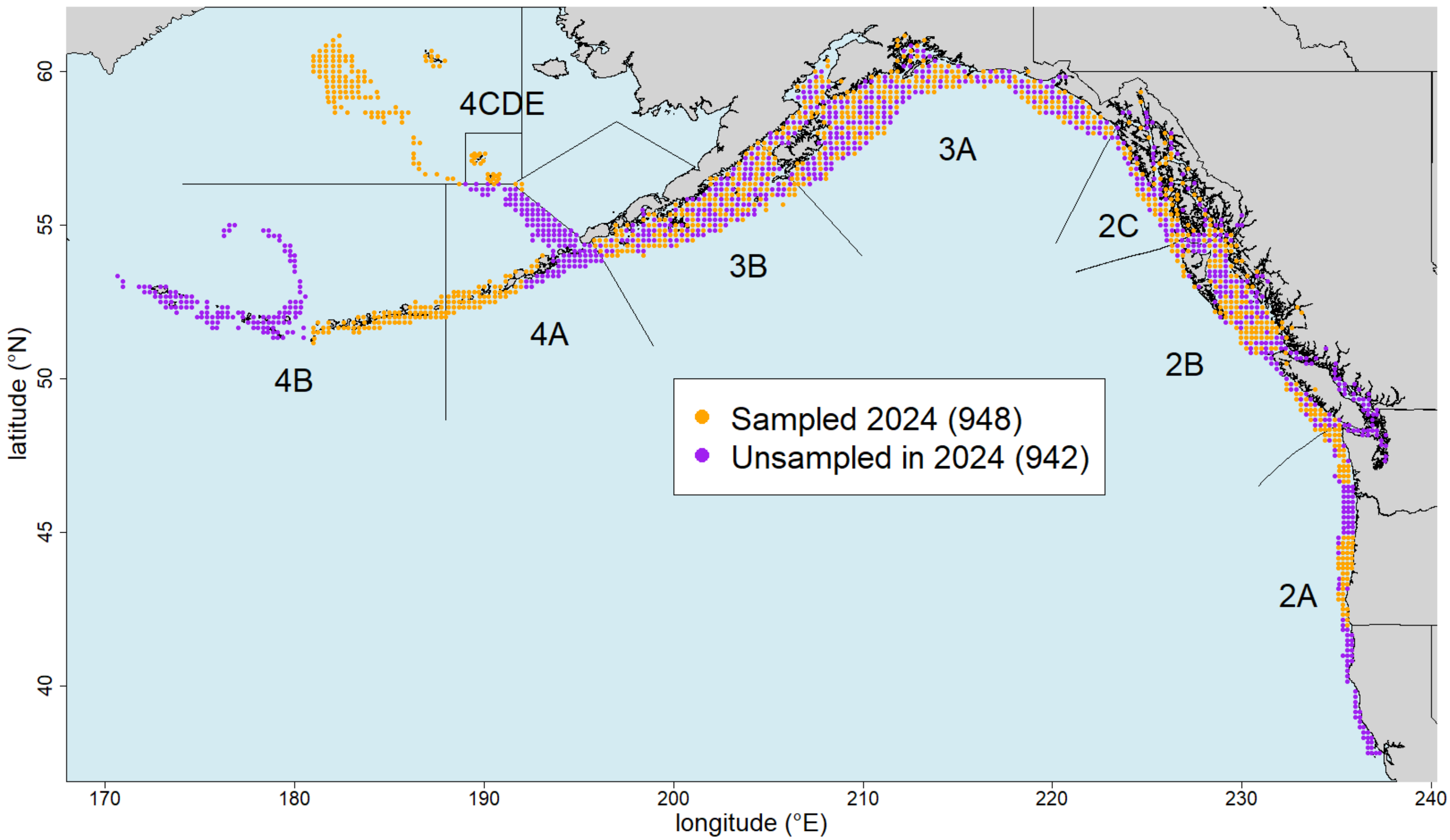


Figure 1.2. Proposed minimum FISS design in 2024 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

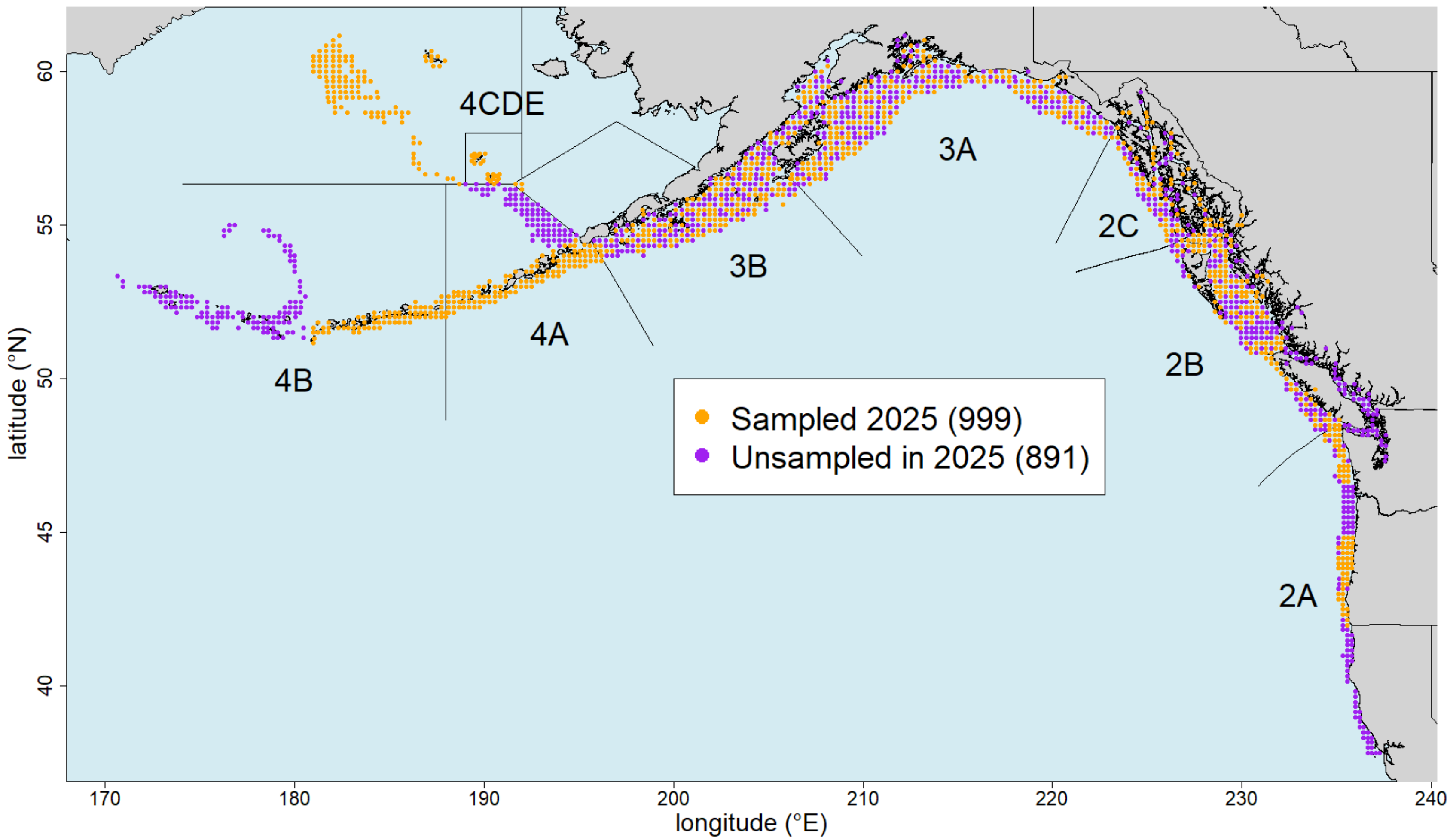


Figure 1.3. Proposed minimum FISS design in 2025 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

Part 2: Modelling updates

PURPOSE

To present an update to the space-time model for IPHC Regulatory 4CDE, and a proposal for revising the evaluation of bias potential in future FISS design proposals.

BACKGROUND/INTRODUCTION

The IPHC uses calibrated data from NMFS annual Bering Sea trawl survey along with our own Fishery Independent Setline Survey (FISS) data to provide comprehensive survey coverage of the Bering Sea. The trawl data are calibrated by length distribution and scaled to IPHC index units of lb/skate outside of the space-time models (Webster et al. 2021). While integrating the calibration into the space-time modelling is not possible within the R-INLA framework currently used, the scaling factors can be estimated within the models using a gear (trawl vs setline) coefficient. We propose using this approach going forward for space-time modelling of Bering Sea survey data for Pacific halibut.

As part of the annual evaluation process of proposed FISS designs, we consider the potential for bias in estimates of weight per unit effort (WPUE) caused by omitting part of an IPHC Regulatory Area from the design. Given that cost constraints mean that not all IPHC FISS stations can be fished each year, the potential for bias will always exist, but the intention is to limit the magnitude of the bias through our design choices.

For maintaining low potential for bias in estimates generated from FISS data, since 2020 we have looked at estimates of historical changes in the proportion of biomass in each subarea, and used that to guide the sampling frequency in future designs (Webster 2022). Thus, subareas that have historically had rapid changes in biomass proportion need to be sampled most frequently, and those that are relatively stable can be sampled less frequently. This approach has the disadvantage of giving all years in the time series equal weight – it does not consider how far into the past such rapid changes occurred.

Here we consider a new approach based on the posterior predictive distribution of trends in subarea WPUE. These distributions can give us the posterior probability that a subarea's biomass proportion has changed by more than a specified amount (we use 10% to ensure low bias) within a period of years. By focusing on values for more recent years rather than the entire time series, we can get a better sense of how likely unobserved changes of this magnitude are to occur under proposed FISS designs for the next three years.

BERING SEA MODEL UPDATE

The IPHC trawl to FISS length calibration is described in Webster et al. (2021). Once the trawl data are calibrated to have a length distribution that closely matches that of the FISS based on data from the years the two surveys overlapped (2006 and 2015), the resulting trawl density indices are scaled to have the same units (lb/skate) as the FISS WPUE index (or halibut/skate for numbers per unit effort, NPUE). A single scale factor is estimated from the combined 2006 and 2015 data, and this is applied to all calibrated trawl station-level catch rate data from the entire time series. As this is done outside of the space-time model, any variance associated with estimating this scalar is not propagated into the space-time model estimates.

The IPHC space-time model separates the WPUE process into zero and non-zero components (Webster et al. 2021), linked by a common spatially correlated error process. This means that we can include a gear covariate in each component of the model, thereby estimating separate coefficients for each model component. When implementing the models, we actually included three covariates in each component to ensure the gear coefficient estimates were only being made for data within the 2006 and 2015 gear calibration years. Table 2.1 describes the parameters added to zero (z) and non-zero (nz) model components.

Table 2.1. Parameters added to the space-time model for IPHC Regulatory Area 4CDE to account for gear and calibration experiment effects.

Variable	Description	Zero parameter	Non-zero parameter
Gear type	1=trawl, 0=FISS	g_z	g_{nz}
Calibration stations (overlapping trawl and FISS 2006, 2015 stations)	1=calibration, 0 otherwise	c_z	c_{nz}
Interaction (trawl stations within the calibration study)	1=trawl calibration, 0 otherwise	gc_z	gc_{nz}

Trawl stations within the calibration study have coefficients g_z+gc_z and $g_{nz}+gc_{nz}$, the sum of the overall gear difference and the calibration study-specific gear effect. The equivalent of the scale factors calculated previously are the exponential of these sums, given we are working on logit and log scales for the two model components, zeros and non-zeros respectively. While the second variable is not directly used in the estimation of gear differences, it was included to ensure the model accounted for variability due to differences between calibration stations in 2006 and 2015 and all other stations in the model.

Table 2.2 gives the parameter estimate for O32 WPUE. The estimate of the zero scale factor (8.1 =exp(−{−3.095+0.999})) is interpreted as the ratio of the odds of observing a setline non-zero value to the odds of a trawl non-zero, meaning that the odds that WPUE is not zero is about 8 times greater with setline than trawl gear. The estimated scalar of 16.8 = exp(−{−3.315+0.494}) for non-zero WPUE means that on average the setline index is about 17 times greater than the trawl index when fish are captured. Both measures imply that the calibrated trawl index needs to be scaled up to be equivalent to the setline O32 WPUE index, consistent with the original external estimate of about 37 (i.e., calibrated trawl index values were multiplied by 37 to yield O32 WPUE-equivalent values).

Table 2.2. Parameter estimates for gear difference coefficients from a space-time model for FISS and unscaled calibrated trawl data in IPHC Regulatory Area 4CDE.

Parameter	Posterior mean (SD)	Parameter	Posterior mean (SD)
g_z	−3.095 (0.130)	g_{nz}	−3.315 (0.050)
gc_z	0.999 (0.265)	gc_{nz}	0.494 (0.117)

This partition of the gear scaling into zero and non-zero model components has important implications for the overall index. Within the model, the scaling is applied by undertaking prediction at stations assuming FISS gear only. Figure 2.1 compares the 2021 output for IPHC Regulatory Area 4CDE with external scaling to the output from the above model with gear differences estimated internally. Except for 2006 and 2015 (calibration study years) and the years of highest density (1996-2001), the revised WPUE index is consistently greater than the original model estimate. The original external scalar is applied equally to all trawl stations, but the calibrated trawl stations have much higher proportions of zeros than setline stations. When scaled, these zeros remain zero. This is not the case with the revised model, as the scaling is essentially applied to the probability of being zero (or non-zero), and so the estimate for a station with zero observed trawl index can still increase when standardized for gear type. Thus, this revised approach not only scales non-zero indices, but also accounts for differences in the probability of zero catch between the two gear types. Failure to do this previously appears to have led to negative bias in the index unless there were direct FISS observations together with the trawl data (2006, 2015) or when densities were high and thus there were relatively few zero-observations on the trawl survey (1996-2001).

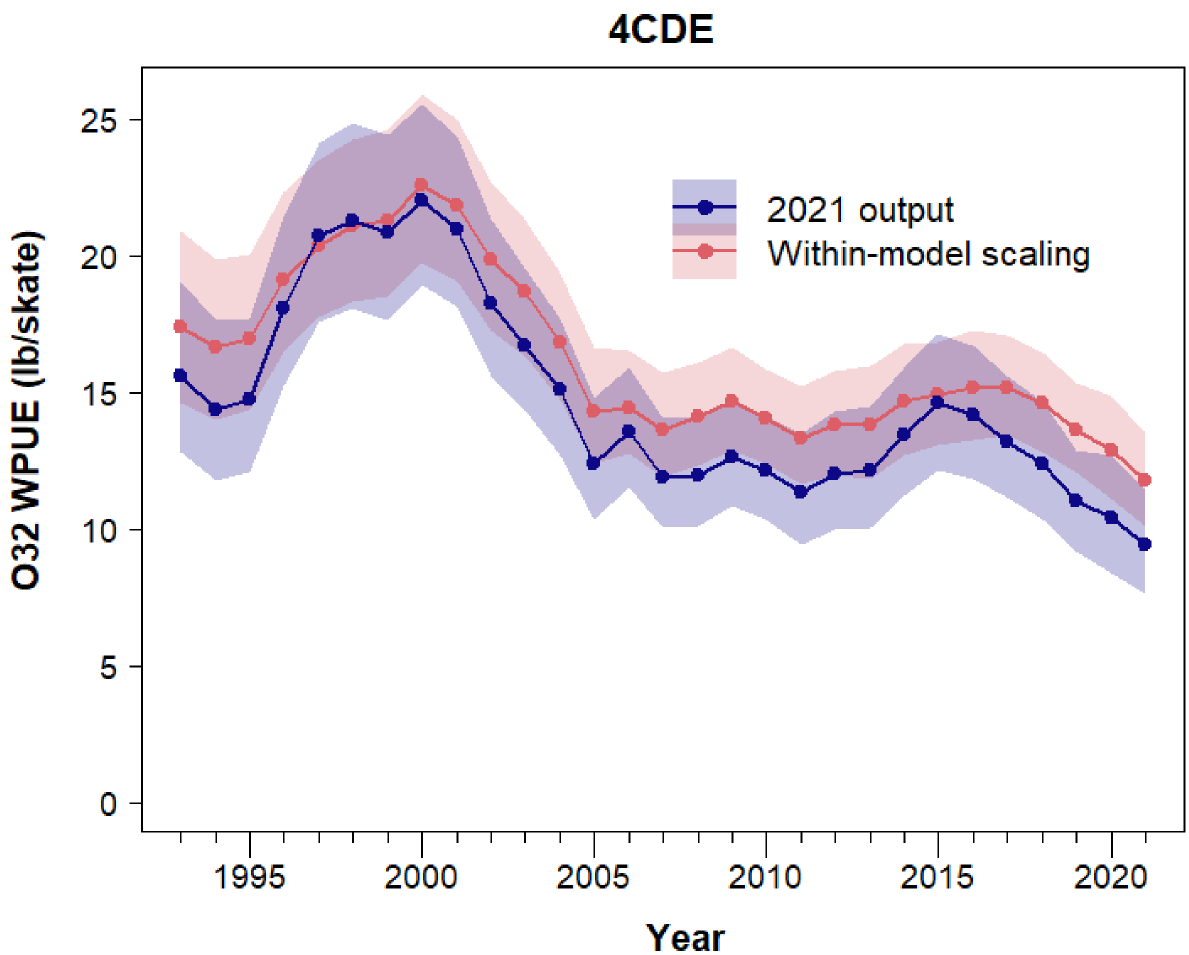


Figure 2.1 Estimated time series from space-time models fitted to IPHC Regulatory Area 4CDE data with gear scaling external to the model (2021 output) and within the model (Within-model scaling).

BIAS EVALUATION METHODOLOGY

At present, design proposals for IPHC Regulatory Areas with subarea sampling (2A, 4A and 4B) are evaluated for bias potential due to unsampled subareas by examining the estimated historical time series: proposals are made that ensure that over the number of unsampled years, the % change in a subarea's proportion of the Regulatory Area biomass did not exceed 10% over the same number of years in the historical time series. For example, if a subarea's time series shows less than 10% change over 3 years throughout the time series, but >10% for any 4-year historical period, we should sample it at least every three years.

This approach weights all part of the time series equally, and is therefore a conservative criterion when rapid relative change was more likely in the past. It also becomes more conservative as more years are added to the time series, with rare events weighted the same as frequently observed changes.

Here we consider an alternative approach making use of the posterior predictive distributions of station WPUE, something we save as a standard part of model output. For each station and each year of the time series, we have 2000 posterior samples. When averaged across stations, this can give us 2000 time series for each subarea of an IPHC Regulatory Area. Suppose we are interested in how likely a subarea's % of the biomass will change by more than 10% over two years. For each two-year period in the time series, we can estimate this as the proportion of samples for which the change was at least 10%:

$$\hat{P}\left(\left|p_{is}-p_{i-2,s}\right|>0.1\right)=\frac{\sum_{k=1}^{N} I\left(\left|p_{isk}-p_{i-2,sk}\right|>0.1\right)}{N}$$

where p_{isk} is the biomass proportion for subarea *s* in year *i* and the *k*th posterior sample, *N*=2000, and p_{is} is the true biomass proportion in subarea *s* in year *i*. *I*() here is the indicator function taking the value 1 is the argument is true and 0 otherwise. As our goal is to sample frequently enough so that we do not miss large changes (i.e., >10% biomass proportion) in a subarea, we should also include changes of >10% that occur in less than 2 years (in this example), i.e., in one year. More generally:

$$q_{ij^*}=\hat{P}\left(\left|p_{is}-p_{i-j,s}\right|>0.1,\forall j\le j^*\right)=\frac{\sum_{k=1}^{N} I\left(\left|p_{isk}-p_{i-j,sk}\right|>0.1,\forall j\le j^*\right)}{N}$$

where *j** is the number of years since the subarea was last sampled (2 in the example above) and j includes all periods less than or equal to this.

As an example, we will consider the sampling of subarea 1 in IPHC Regulatory Area 4B, which comprises the western portion of the area. This subarea last had sampling in 2019 and was proposed for sampling in 2022 but failed to receive any bids. Previously evaluation based solely on the full historical time series (Webster 2022) implied that we could exceed the 10% change threshold over the three years since 2019 as that is something we estimate to have happened at least once in the past.

Figure 2.2 presents the probabilities (as percentages) of at least a 10% change in biomass proportion over the previous *j**=3 years by subarea. For most of the time series, subarea 1 has had high probabilities of this magnitude of change over a 3-year time span. However, this has not been the case from 2016-2021. For those years, the chance of this type of change is estimated to be no more than 6%, reflecting the fact that this subarea has had low and stable biomass in recent years. This implies that we could leave the subarea unsampled for a longer period without risk of large bias in the overall estimates of WPUE.

Note that these probabilities incorporate uncertainty: if an area has not been sampled, the posterior distribution of WPUE values will have greater variability and the probabilities in Figure 2.2 will be greater. This appears to be what is driving the higher probabilities in subarea 2, the central portion of IPHC Regulatory Area 4B. Much of this subarea has been sampled just once, in 2017, with no new data from the subarea since 2019. With less historical data than subarea 1, and (like subarea 1) no recent data, the chance of a change of at least 10% in biomass proportion is approaching 30%. Fortunately, the 2022 FISS has successfully sampled this subarea, observing almost no change since 2017, and therefore we expect these probabilities to be revised downwards once the new data are incorporated into the model.

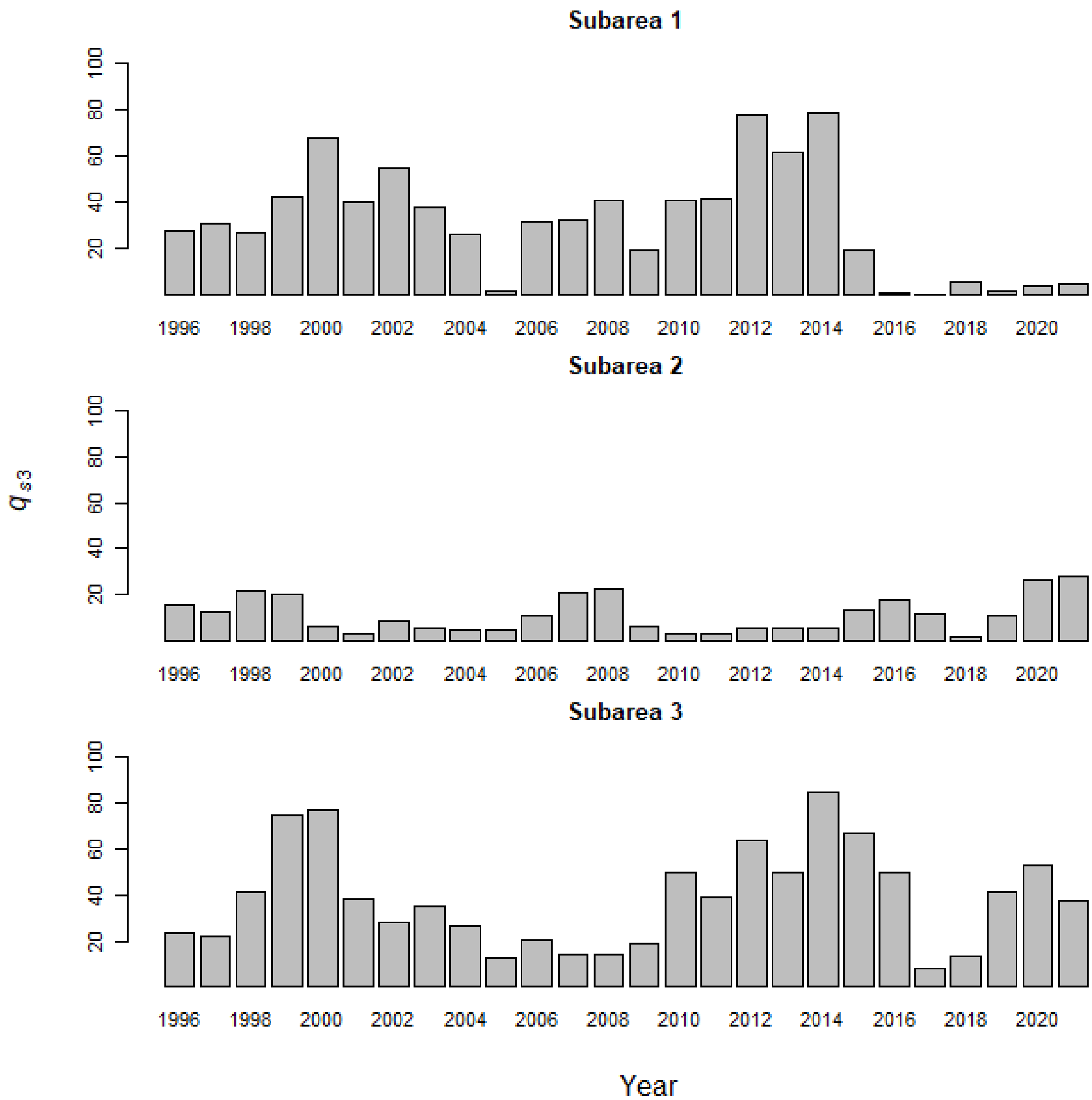


Figure 2.2 Values of q_{s3} (as %) for subareas, *s*, of IPHC Regulatory Area 4B and time interval of j*=3 year, for 1996 to 2021.

DISCUSSION

We consider both the space-time model update and the bias evaluation revision to provide improvements over approaches currently in use. Any input the Scientific Review can provide on these changes will be appreciated by the Secretariat.

RECOMMENDATION

That the Scientific Review Board:

1) **NOTE** paper IPHC-2022-SRB021-06 (part 2) that presents an update to the space-time model for IPHC Regulatory 4CDE, and a proposal for revising the evaluation of bias potential in future FISS design proposals.

References

Webster R. A., Soderlund E, Dykstra C. L., and Stewart I. J. (2020). Monitoring change in a dynamic environment: spatio-temporal modelling of calibrated data from different types of fisheries surveys of Pacific halibut. Can. J. Fish. Aquat. Sci. 77(8): 1421-1432.

Webster, R. A. 2022. 2023-25 FISS design evaluation. IPHC-2022-SRB020-05.

IPHC Secretariat MSE Program of Work (2022–2023) and an update on progress

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PURPOSE

To provide the Scientific Review Board (SRB) with an update of progress on the Management Strategy Evaluation (MSE) program of work for 2022–2023 and a look at preliminary results.

1 INTRODUCTION

The current interim management procedure (MP) at the International Pacific Halibut Commission (IPHC) is shown in Figure 1.

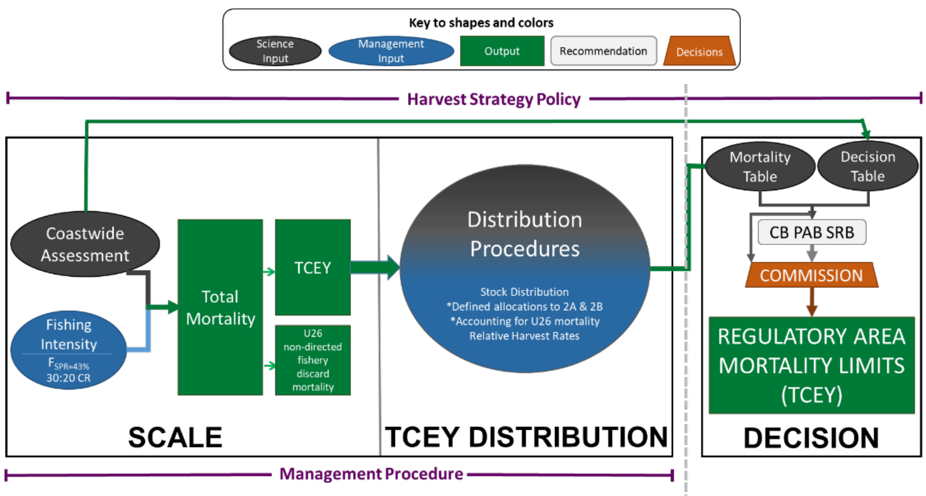

Figure 1. Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC-2020-CR-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are interim agreements in place through 2022. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

The Management Strategy Evaluation (MSE) at the IPHC completed an evaluation in 2021 of management procedures (MPs) relative to the coastwide scale and distribution of the Total Constant Exploitation Yield (TCEY) to IPHC Regulatory Areas for the Pacific halibut fishery using a recently developed closed-loop simulation framework. The development of this closed-loop simulation framework supports the evaluation of the trade-offs between fisheries management scenarios. Descriptions of the MPs evaluated and simulation results are presented in Hicks et al. (2021). Additional tasks were identified at the 11th Special Session of the IPHC (IPHC-2021-SS011-R) to supplement and extend this analysis for future evaluation (Table 1). Document IPHC-2021-MSE-02 contains details of the current MSE Program of Work.

Table 1. Tasks recommended by the Commission at SS011 (IPHC-2021-SS011-R para 7) for inclusion in the IPHC Secretariat MSE Program of Work for 2021–2023.

ID	Category	Task	Deliverable
F.1	Framework	Develop migration scenarios	Develop OMs with alternative migration scenarios
F.2	Framework	Implementation variability	Incorporate additional sources of implementation variability in the framework
F.3	Framework	Develop more realistic simulations of estimation error	Improve the estimation model to more adequately mimic the ensemble stock assessment
F.5	Framework	Develop alternative OMs	Code alternative OMs in addition to the one already under evaluation.
M.1	MPs	Size limits	Identification, evaluation of size limits
M.3	MPs	Multi-year assessments	Evaluation of multi-year assessments
E.3	Evaluation	Presentation of results	Develop methods and outputs that are useful for presenting outcomes to stakeholders and Commissioners

This document provides updates on the progress for the framework related tasks and the MP related tasks. Potential improvements to the evaluation and presentation of results are provided in this document and work will continue in 2022 with input from the SRB and MSAB.

2 Closed-Loop Simulation Framework

The closed-loop framework (Figure 2) with a multi-area operating model (OM) and three options for examining estimation error was initially described in Hicks et al. (2020b). Technical details are updated as needed in IPHC-2022-MSE-01 on the IPHC MSE webpage. Improvements to the framework have been made in accordance with this program of work and a new OM has been developed.

2.1 Development of a new Operating Model

The IPHC stock assessment (Stewart & Hicks 2022) consists of four stock synthesis models integrated into an ensemble to provide probabilistic management advice accounting for observation, process, and structural uncertainty. A similar approach was taken when developing the models for the closed-loop simulation framework along with some other specifications to improve the efficiency when conditioning models and running simulations.

2.1.1 General specifications of the OM

The emerging understanding of Pacific halibut diversity across the geographic range of its stock indicates that IPHC Regulatory Areas should be only considered as management units and do not represent relevant sub-populations (Seitz et al. 2017). Therefore, four Biological Regions (Figure 3) were defined with boundaries that matched some of the IPHC Regulatory Area boundaries (see Hicks et al 2020b for more description). The OM is a multi-regional model with population dynamics modelled within and between each Biological Region, and fisheries mostly operating at the IPHC Regulatory Area scale. Multiple fisheries within a Biological Region may have different selectivity and retention patterns to mimic differences similar to that of an areas-as-fleets approach. Thirty-three fisheries were defined for five general sectors consistent with the definitions in the recent IPHC stock assessment:

- **directed commercial** representing the O32 mortality from the directed commercial fisheries including O32 discard mortality (from lost gear or regulatory compliance);
- **directed commercial discard** representing the U32 discard mortality from the directed commercial fisheries, comprised of Pacific halibut discarded due to the minimum size limit;
- **non-directed commercial discard** representing the mortality from incidentally caught Pacific halibut in non-directed commercial fisheries;
- **recreational** representing recreational landings (including landings from commercial leasing) and recreational discard mortality; and
- **subsistence** representing non-commercial, customary, and traditional use of Pacific halibut for direct personal, family, or community consumption or sharing as food, or customary trade.

Additionally, there are four modelled surveys, one for each Biological Region.

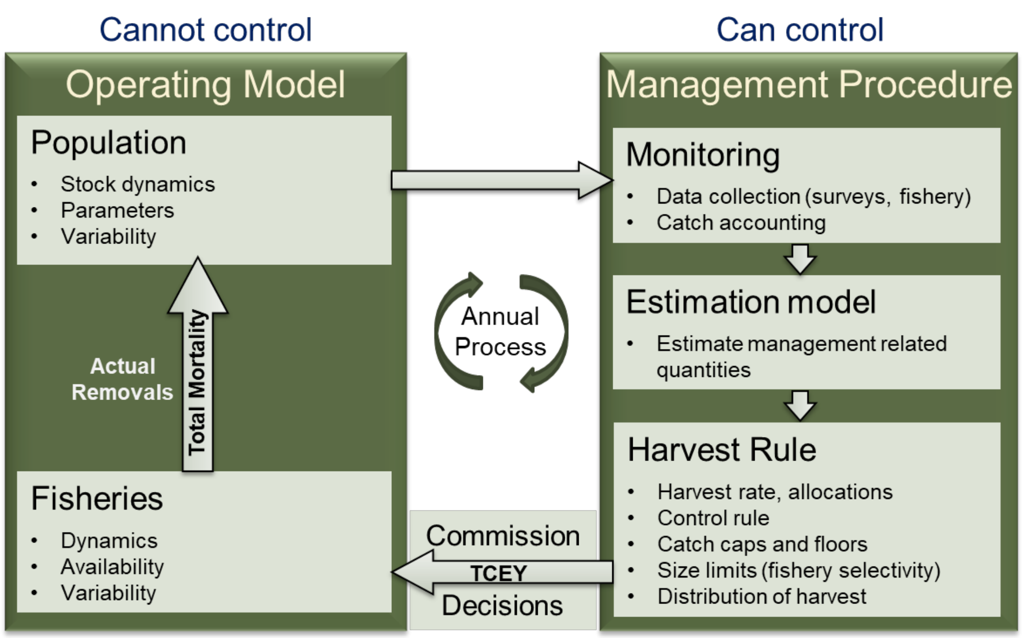

Figure 2. Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

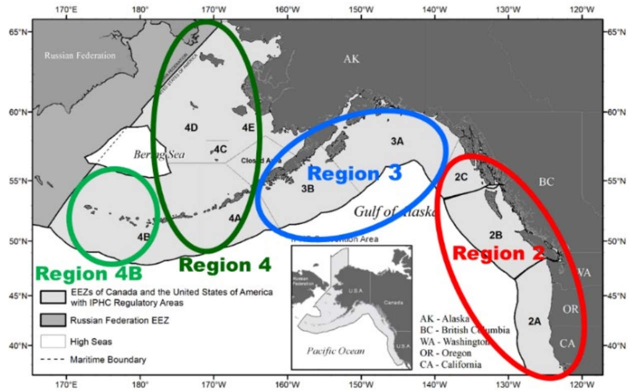

Figure 3. IPHC Regulatory Areas, Biological Regions, and the Pacific halibut geographical range within the territorial waters of Canada and the United States of America.

Two of the four models in the IPHC stock assessment (Stewart & Hicks 2022) consider a long time-series of observations beginning in 1888. One model specifies coastwide fisheries (called the coastwide (CW) long model) and the other model specifies four regions in an areas-as-fleets approach (called the areas-as-fleets (AAF) long model). The previous MSE OM also started in 1888 and simulated the entire time-series up to recent years before starting the forward simulations. However, the early portion of the time-series is challenging to model due to relatively little data, some significant catches in Biological Region 2, and the potential for unknown differences in population dynamics (e.g. movement between Biological Regions) compared to recent periods. To reduce the technical complexity and focus on information contained in the richer data set in the later period, the 2022 OM models were started in 1958. In order to allow for flexible starting conditions, 30 years of initial recruitment and an average fishing mortality were estimated for each fleet. This initialized the models after a bottleneck of potentially high fishing mortality in the 1930's that is confounded with the estimation of movement, while allowing for a sufficient period of time to burn-in the population such that projections began at an appropriate population size and age composition. The period from 1958 to the present includes major changes in fishery catches, weight-at-age in the population, and population size.

To account for structural uncertainty, as with the ensemble stock assessment, four individual models are integrated into a single OM. The first model was parameterised from and conditioned to results from the long AAF stock assessment model. The second model was parameterised from and conditioned using results from the long CW stock assessment model. Because these two OM models started in 1958, they are called the medium AAF (medAAF) and medium CW (medCW) models. The two remaining models also started in 1958 and were conditioned to the same observations, but parameterised with lower values of natural mortality, as in the 2021 'short' assessment models. These two models are noted as medAAF_lowM and medCW_lowM. All four models are regional models with movement between the four biological regions.

The "lowM" models were added after SRB020 because the medAAF and medCW models alone seemed to be overly optimistic relative to short-term projections of fishing mortality compared to the ensemble stock assessment (Figure 4). The inclusion of the "lowM" models produced short-term projections from the OM that were reasonably similar to the short-term projections from the ensemble stock assessment (Figure 5).

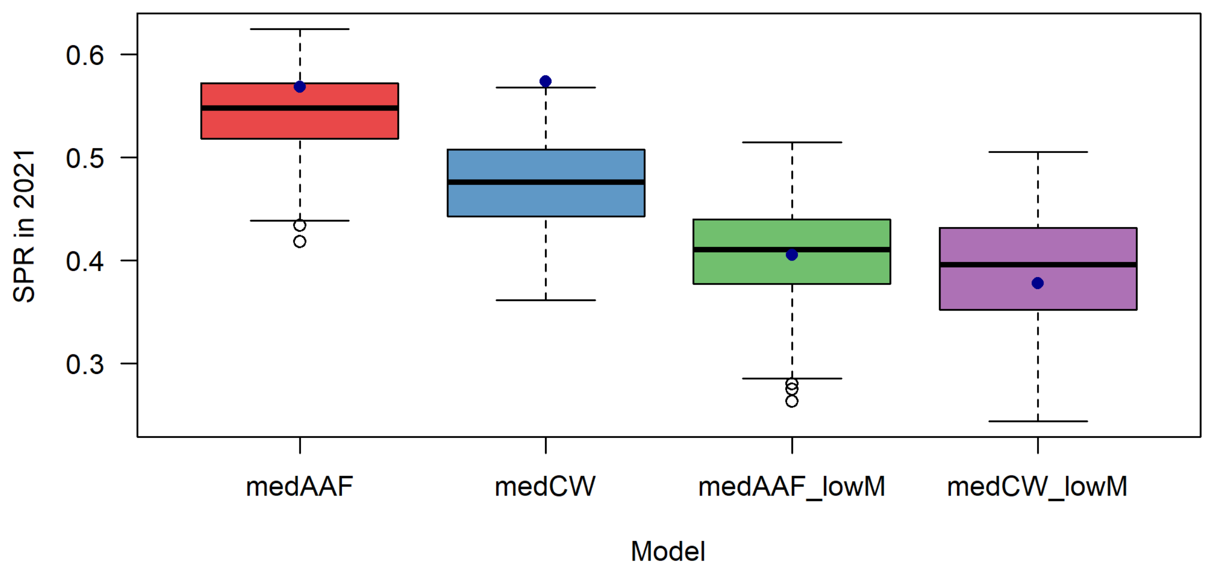

Figure 4. Estimated SPR in 2021 for each OM model (colored boxplot) compared to the estimated SPR in 2021 for each comparable individual 2021 stock assessment model (medAAF=long AAF, medCW=long CW, medAAF_lowM=short AAF, medCW_lowM=short CW).

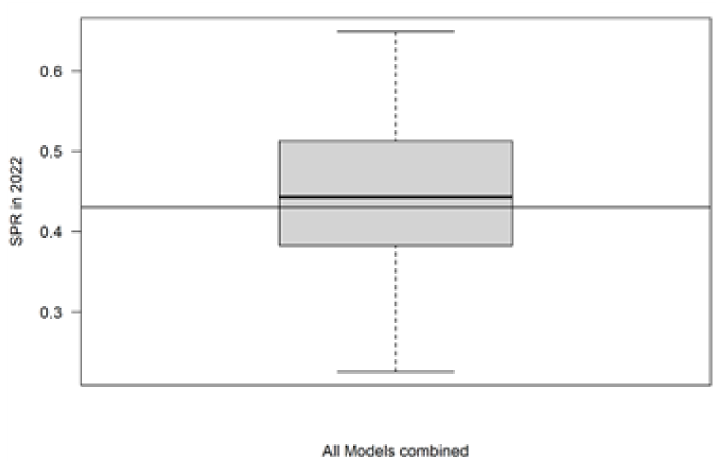

Figure 5. SPR in 2022 given fixed catches and distribution set by the Commission at the 98th IPHC Annual Meeting (IPHC-2022-AM098-R). The gray horizontal line is an SPR of 43%, corresponding to the coastwide mortality limit.

Many parameters used in the OM models were drawn from the corresponding stock assessment model. Natural mortality was fixed in each model, separately for males and females. Maturity, mean weight-at-age, recruitment deviations, the relationship between R_0 and the Pacific Decadal Oscillation (PDO), selectivity, and fishing mortality were fixed at the values from the stock assessment.

Parameters estimated during conditioning included

- R_0: initial average recruitment for the low PDO period;
- multinomial logit parameters for recruitment distribution among Biological Regions: there are 6 parameters, 3 defining the proportion among Biological Regions and 3 adjusting those parameters in high PDO years to change the distribution of age-0 recruits;
- a multiplier on initial fishing mortality: increased or decreased the initial fishing mortality input to initialize the population;
- movement from Biological Region 4 to Biological Region 3 (5 parameters) and movement from Biological Region 3 to Biological Region 2 (5 parameters), which were estimated for low PDO and high PDO periods (thus 20 total parameters).

There is considerable confounding between the recruitment distribution and movement parameters (which was evident during the conditioning process), thus some parameters for movement between Biological Regions were fixed at values estimated from previous analyses (see Figure 3 in Hicks et al 2020). The previous OM estimated considerably higher movement rates-at-age from region 2 back to region 3, which was unexpected. Fixing movement from Biological Region 2 to Biological Region 3 at values estimated directly from data resulted in more stable estimation with similar outputs.

The models were conditioned to five general sources of information:

- Historical spawning biomass estimated from the corresponding stock assessment. For example, the medAAF model was conditioned to the spawning biomass estimates from 1958 to 1992 from the 2021 long AAF stock assessment model.
- Recent ensemble spawning biomass from the corresponding spatial structure of the stock assessment. For example, the medCW model was conditioned to the spawning biomass estimates from 1993 to 2021 from the integration of the 2021 long CW and short CW stock assessment models.
- Fishery Independent Setline Survey (FISS) indices of abundance for each Biological Region.
- FISS estimates of proportions-at-age for each Biological Region. This component was downweighted compared to other components.
- Proportion of all-sizes weight-per-unit-effort (WPUE) in each Biological Region from the space-time model analysis of FISS observations. This is also called stock distribution and was given the highest weight as this is an important component for the OMs to mimic.

The conditioning was heavily weighted to the stock distribution and spawning biomass components. The goal was to have models adequately predicting stock distribution and spawning biomass in recent years, with some variability.

Even though many parameters were fixed when conditioning the models, variability was propagated from the estimated as well as some fixed parameters, accounting for correlations between parameters. Bounds were enforced on some parameters and randomly drawn parameter sets that resulted in unrealistically low population sizes or extremely poor fits to stock distribution or spawning biomass were rejected. Multiple trajectories from 1958 through 2021 were produced for each model.

2.1.2 OM results and outputs

The four individual OM models showed important structural differences in terms of movement rates-at-age, recruitment distribution, and historical spawning biomass trends. The long AAF and long CW stock assessment models, which are the basis for conditioning each OM model, estimate significantly different historical spawning biomass trajectories before the early 2000s and subtle differences in recent trajectories (Figure 6). These differences are attributable to the very different assumptions about how the stock was distributed and connected via movement in relation to historical fishing mortality, and it is important to capture these differences through movement in the OM.

The four OM models generally captured these trends in spawning biomass with the medCW models fitting the lower spawning biomass trend of the long CW assessment model and the medAAF model fitting the higher spawning biomass trend of the long AAF assessment model (Figure 7). The lowM models showed a higher probability that the spawning biomass is declining in recent years. The uncertainty in the OM also spanned the 2021 ensemble stock assessment uncertainty, except for the low spawning biomass in the 1970’s (Figure 8).

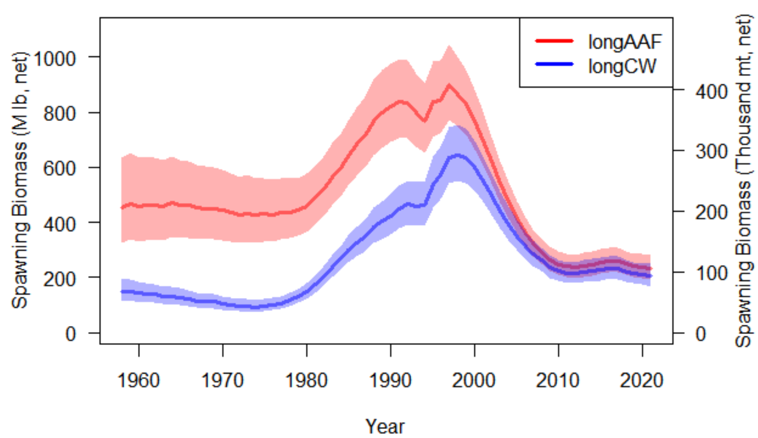

Figure 6. Estimated spawning biomass trajectories from 1958 to 2021 from the 2021 long AAF and long CW stock assessment models (Stewart & Hicks 2022).

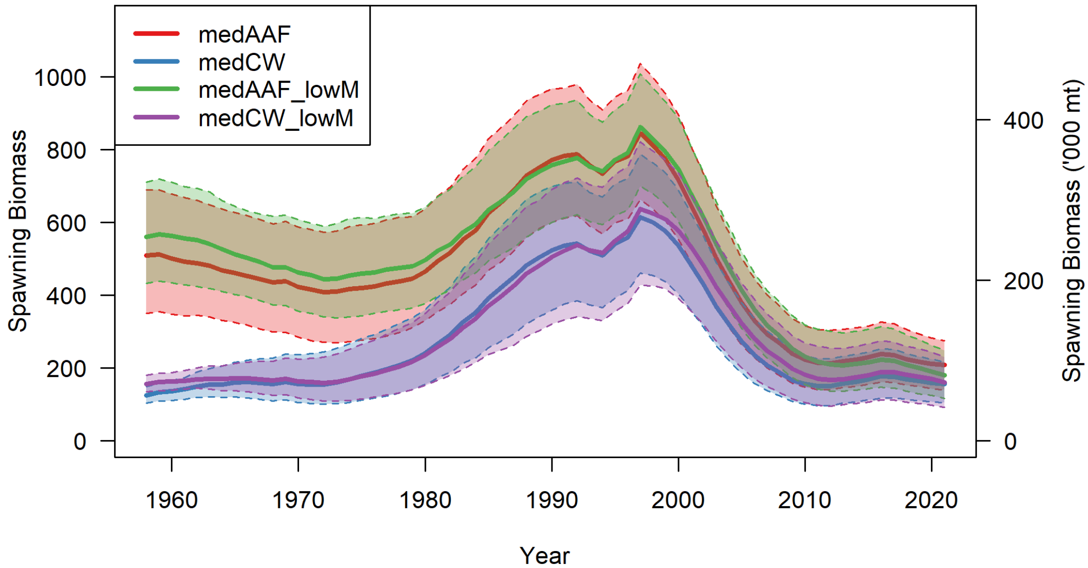

Figure 7. Median, 5th, and 95th quantiles for the four OM models.

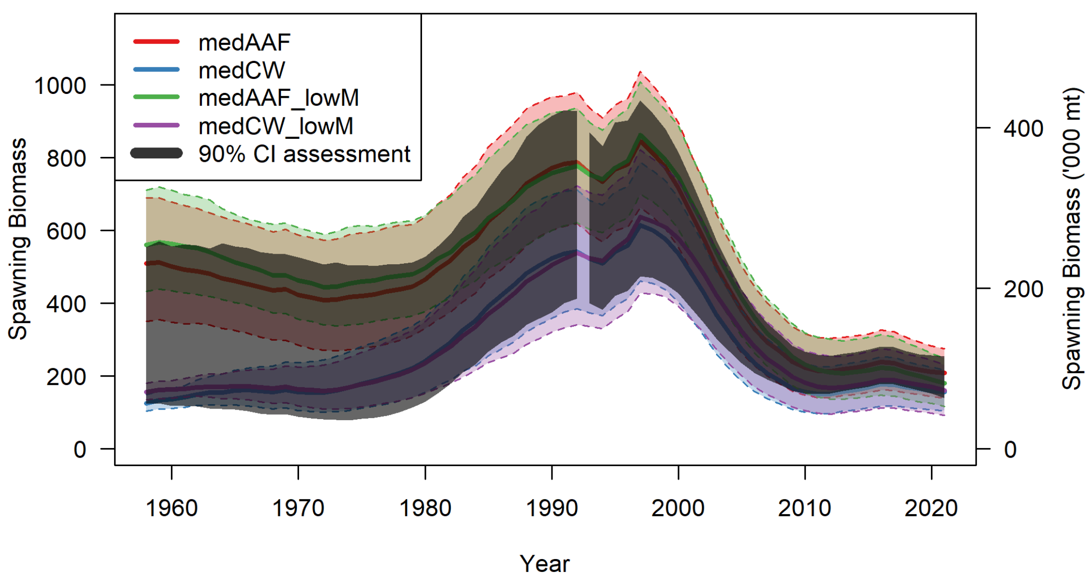

Figure 8. Median, 5th, and 95th quantiles for the four OM models with the ensemble stock assessment range between the 5th and 95th quantiles shown in grey.

Stock distribution was fit well by both OM models (Figure 9) and showed similar patterns of lack of fit across all models. Specifically, the earliest years in Biological Region 4 were overfit by the OM, and recent years overfit in Biological Region 3 corresponding with a slight underfitting in region 4. All OM models matched closely with the proportion of biomass observed in 2021.

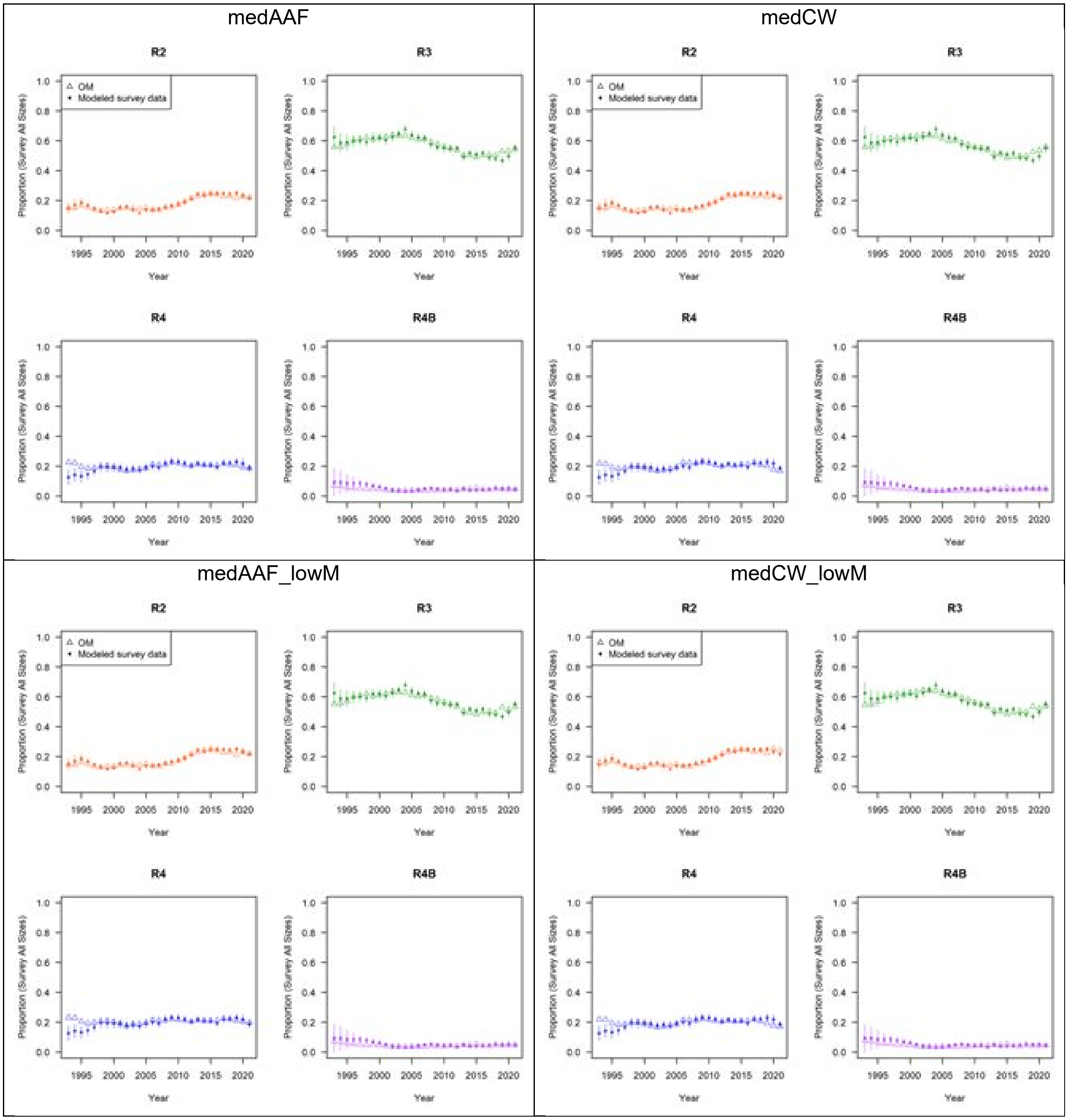

Figure 9. Fits to stock distribution across Biological Regions for each OM model.

The distribution of age-0 recruits showed a high proportion going to Biological Region 4 in both low and high PDO regimes. The medCW showed a higher proportion of recruits going to Biological Region 4 in high PDO years, but the medAAF model showed a slightly smaller proportion.

Movement rates between Biological Regions 3 and 2, and Biological Regions 4 and 3 were different between the four OM models (Figure 10). Both models generally showed high movement rates around ages 4 and 5 and slight differences between low and high PDO periods. Movement of fish younger than age 4 was very small from Biological Region 4 to 3 for both models and regimes, but there are few observations of fish younger than age 6 and a number of different movement rates of very young fish in combination with ages 4–6 could achieve similar results.

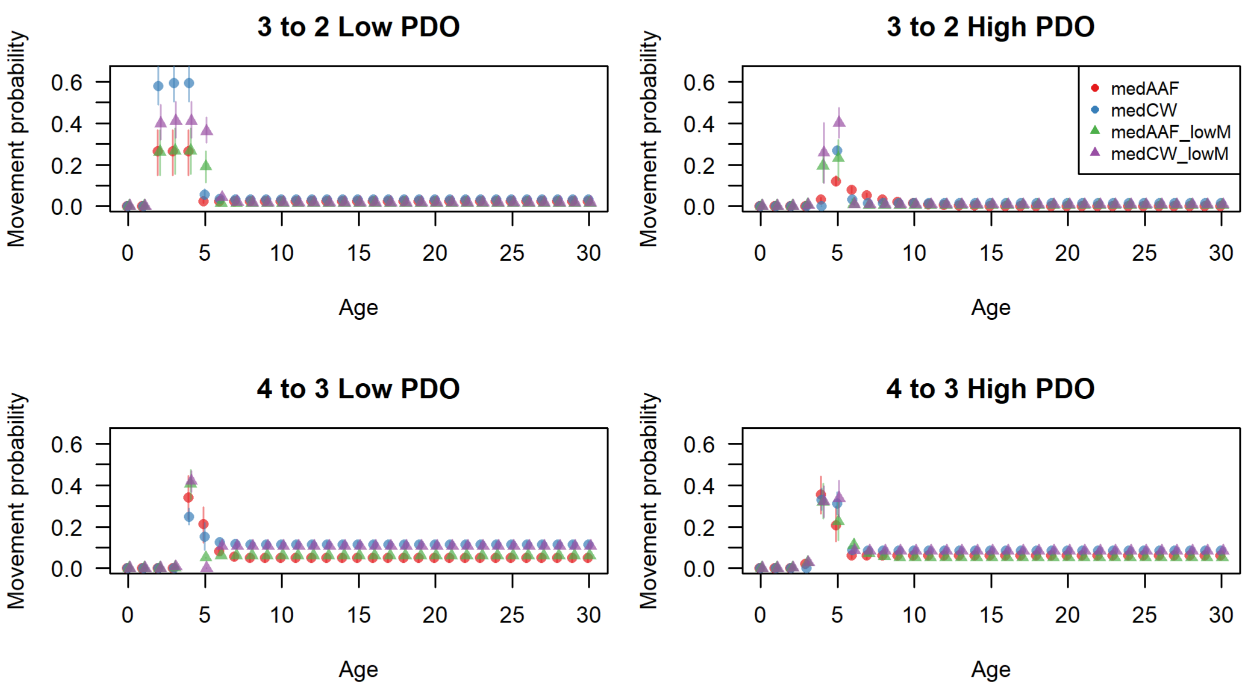

Figure 10. Probability of movement-at-age from Biological Region 3 to region 2 (top) and region 4 to region 3 (bottom) in low PDO (left) and high PDO (right) regimes for the four OM models.

2.2 Projections

The conditioned OM with multiple trajectories is the base of setting up the replicate projections of population and fishery processes. After which, they are left untouched as the closed-loop simulation projects forward in time using various management procedures (MPs) and assumptions. The simulated projection of weight-at-age, selectivity/retention deviations, and the environmental regime do not depend on the population dynamics and can be created ahead of time to save time in the simulations, although any of these processes could be dependent on the size of the population, or a certain demographic, and included in the simulation process.

Other processes, such as implementation variability, are simulated during the closed-loop simulations.

2.2.1 Implementation variability and uncertainty

Implementation variability is defined as the deviation of the fishing mortality from the mortality limit determined from an MP. It can be thought of as what actually (or is believed to have) happened compared to the limits that were set. Decision-making variability is the difference between the MP mortality limits and the adopted mortality limits set by the Commission.

Decision-making uncertainty can be applied to the mortality limit specified by the MP ($TCEY_t$) as a multiplier.

$$\widetilde{TCEY}_t = TCEY_t \varepsilon_I$$

where $\widetilde{TCEY}_t$ is the adopted mortality and ε_I is the multiplier. Using observations from 2014 to 2021 of the MP mortality limit determined from the interim management procedure and the adopted mortality limits set by the Commission for that year and IPHC Regulatory Area, the multipliers are shown in Figure 11. These years were chosen because they used a relatively consistent management procedure, although explicit use of SPR was added in 2017, additional agreements were added in 2019 and 2020, and the reference SPR changed from 46% to 43% in 2021. Decision-making uncertainty is likely different depending on the management procedure and the presence of any agreements. Additionally, in 2021 and 2022, the adopted coastwide TCEY was equal to the coastwide TCEY specified by the interim management procedure, thus distribution was the only decision-making variability.

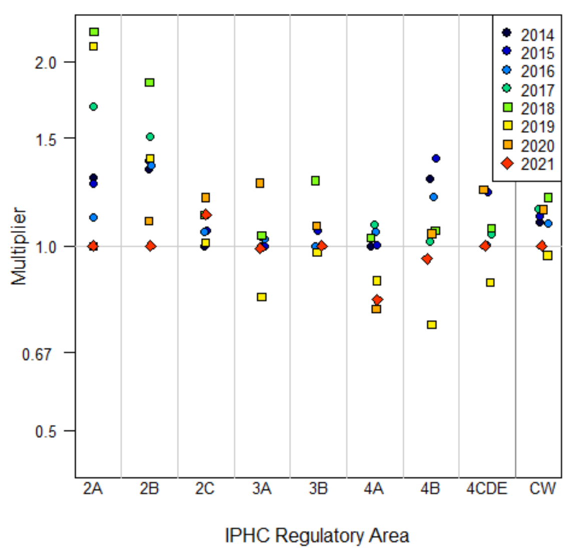

Figure 11. Multipliers for the difference between MP mortality limits and adopted mortality limits from 2014 to 2021. “CW” refers to coastwide.

2.2.1.1 Method to simulate decision-making uncertainty

The multiplier to simulate decision-making uncertainty is drawn from a lognormal distribution with correlation between multipliers for each IPHC Regulatory Area. The mean ($\boldsymbol{\mu_\varepsilon}$) and standard deviation ($\boldsymbol{\sigma_\varepsilon}$) of that distribution are modified as follows depending on the TCEY from the MP.

$$\boldsymbol{\mu_\varepsilon} \ or \ \boldsymbol{\sigma_\varepsilon} = \begin{cases} \bar{\boldsymbol{x}} \ or \ \boldsymbol{s} & TCEY < TCEY_{low} \\ \boldsymbol{a} + \boldsymbol{b} * TCEY & TCEY_{low} \leq TCEY \leq TCEY_{high} \\ \mathbf{1.0} \ or \ \boldsymbol{s}/\mathbf{2} & TCEY > TCEY_{high} \end{cases}$$

Using IPHC Regulatory Area 2A as an example (without a TCEY agreement in place), with a coastwide $TCEY_{low}$ of 30 Mlbs and a coastwide $TCEY_{high}$ equal to 60 Mlbs, the distribution of simulated multipliers gets closer to 1 as the TCEY increases (Figure 12).

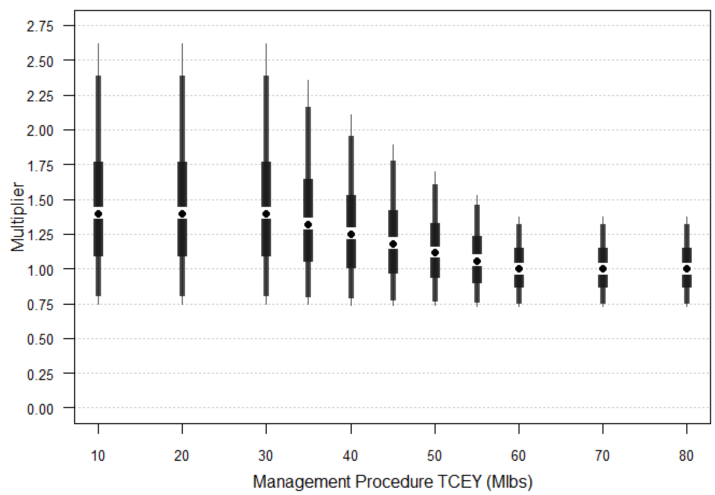

Figure 12. Simulated multipliers for IPHC Regulatory 2A at different values of the coastwide TCEY (without the recent agreement on the 2A TCEY). The thickest portion of the vertical bar represents the 25th and 75th percentiles, followed by the 5th and 95th percentiles, and then the 2.5th and 97.5th percentiles.

Each IPHC Regulatory Area will have a specific parameterisation to simulate decision-making variability, which will be dependent on the specific management procedure. For example, an agreement of a specific TCEY for an IPHC Regulatory Area will not have decision-making variability for that area, but other IPHC Regulatory Areas may have increased decision-making variability as a result. Furthermore, two general concepts will be used for decision-making variability:

1. The coastwide TCEY is equal to the coastwide TCEY from the MP, but distribution contains decision-making variability.
2. The coastwide TCEY may deviate from the MP, along with distribution, due to decision-making variability.

Actual decision-making variability is likely more complex than these simple methods. In fact, some IPHC Regulatory Areas show a consistent adopted TCEY over a range of MP TCEYs (e.g., 4B in Figure 13). However, the goal of including decision-making uncertainty in the MSE simulations isn't to exactly simulate what the pattern is, but to identify the effect of decision-making uncertainty and identify MPs that are robust to a plausible amount of uncertainty. Therefore, simulations will be done with and without decision-making uncertainty to identify MPs that are robust to this uncertainty and/or illustrate the benefits of reducing decision-making uncertainty. Various modifications may be made to decision-making uncertainty to explore sensitivity to various hypotheses. For example, different offsets depending on the trend in the population or TCEY, as suggested by the SRB (SRB019–Rec.06, para. 35).

2.2.1.2 Methods to simulate realized and perceived implementation uncertainty

Realized uncertainty is currently implemented in the OM by simulating a range of actual non-directed discard mortality, recreational mortality, and subsistence mortality. These are likely the largest sources of realized variability in the Pacific halibut fisheries, which is relatively small compared to many fisheries.

Perceived uncertainty is currently not simulated in the OM but will be considered as work progresses. Perceived uncertainty may include uncertainty related to sampling of catch or prohibited discarding (e.g. high-grading) that is not observed. Inclusion of perceived uncertainty in the MSE framework will likely not occur before the 99th Annual Meeting.

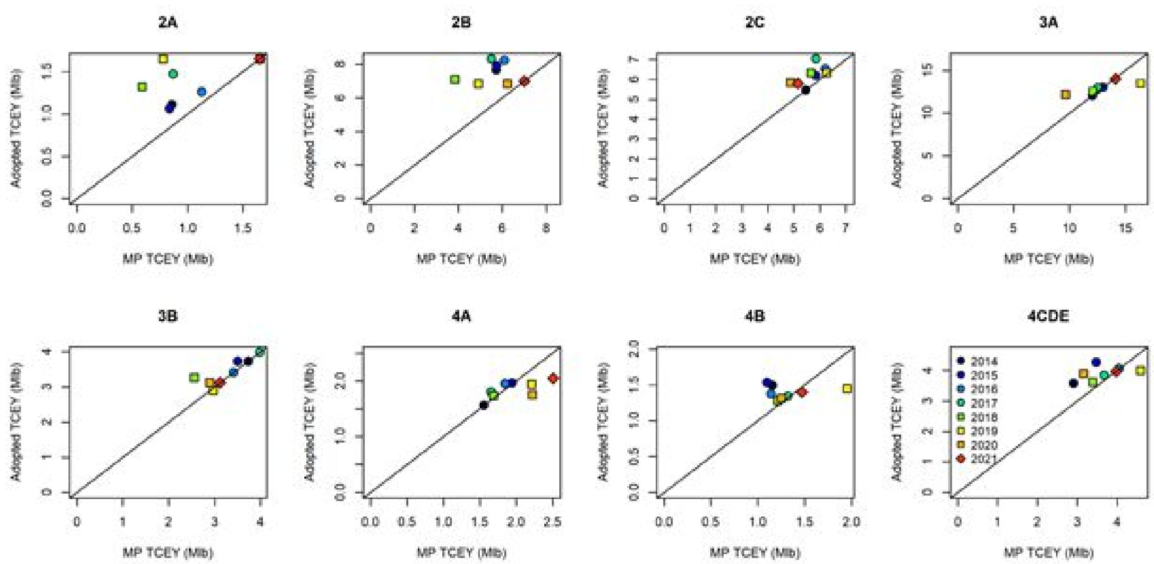

Figure 13. Adopted TCEYs plotted against MP TCEYs for each IPHC Regulatory Area and years 2014 to 2021.

2.2.2 Estimation error

Estimation error is the uncertainty in parameters that are estimated for use in a management procedure. For example, relative spawning biomass is used in the 30:20 control rule and is an estimate from the stock assessment. The total mortality given a fixed SPR is also subject to estimation error.

There are three options for examining the effect of estimation error. The first is No Estimation Error, which is useful to understand the intrinsic qualities of a management procedure. The second is Simulated Estimation Error, which simulates the correlated uncertainty in estimated relative spawning biomass and estimated total mortality. This mimics the variability that may arise from a stock assessment, but not may not capture some of the nuances of the estimates from a stock assessment, such as bias. The third is to run a stock assessment as part of the closed-loop simulation process (Simulated Stock Assessment). This can be time-consuming, especially with a complex ensemble assessment, thus simplifications are often made. Currently, a single simplified model from the Pacific halibut ensemble assessment is implemented in the MSE framework, and is useful for comparison to the simulated estimation error, but is not complete for decision-making purposes. Improvements to the simulated stock assessment method will be made in 2022 if time allows.

2.3 Runs and Scenarios

The primary closed-loop simulations consist of integrating the four OM models with equal weight by simulating an equal number of trajectories/projections from each model. Results from the full set of projections are used to calculate the performance metrics. Additional scenarios may be evaluated that include different types of implementation error or alternative scenarios of fishery selectivity (e.g. targeting or avoiding small Pacific halibut).

3 MANAGEMENT PROCEDURES

Two categories of MPs were prioritised in the MSE Program of Work for 2021–2023. One was the investigation of size limits (M.1) and the other was to investigate multi-year stock assessments (i.e. not conducting the stock assessment annually; M.3). Due to improvements in the MSE framework and changes in the OM, select MP elements investigated previously, such as SPR, may need to be re-evaluated.

3.1 Size limits

Since 1973, IPHC has restricted the directed commercial fishery for Pacific halibut with a 32 inch (81.3 cm) minimum size limit, although other forms of size limits have been in place since 1940 (Myhre 1973). Many investigations of size limits have been completed since then including IPHC (1960), Clark & Parma (1995), Parma (1999), Valero & Hare (2012), Martell et al. (2015a), Martell et al. (2015b), Stewart & Hicks (2018), and Stewart et al (2021). Most of these analyses have focused on short-term effects or effects on reference points. The novelty of this analysis using the MSE framework will be to examine long-term effects of different size limits in relation to defined conservation and fishery objectives. Additionally, long-term changes to the stock and fishery distribution as well as changes in productivity will be examined.

The Commission requested that three size limits be investigated: 32 inches, 26 inches, and no size limit.

> **IPHC-2022-AM098-R, para. 61**: *The Commission RECALLED SS011-Rec.01 and REQUESTED that the current size limit (32 inches), a 26 inch size limit, and no size limit be investigated. to understand the long-term effects of a change in the size limit.*

It is uncertain how selectivity of the directed commercial fisheries may change with the implementation of a different size limit than the current 32 inches. Fisheries may choose to target smaller fish to increase efficiency, they may maintain current practices, or they may target larger fish if that provides improved economic gains. Some sensitivities to changes in selectivity (e.g. alternative scenarios) may be investigated.

An important concept to bring into the evaluation of size limits is market considerations. Stewart et al. (2021) used the ratio between the U32 price and O32 price for Pacific halibut to determine what ratio is necessary for the fishery to break even economically. It is unknown what prices will be for U32 Pacific halibut if a size limit was removed, but the FISS has recently begun selling U32 fish, which may be an indicator for future market conditions of small fish. Regardless, a performance metric related to economics will be important to consider in this evaluation.

3.2 Multi-year assessments

Management procedures with multi-year assessments incorporate a process where the stock assessment occurs at intervals longer than annually. The mortality limits in a year with the stock assessment can be determined as in previously defined MPs, but in years without a stock assessment, the mortality limits would need an alternative approach. This may be as simple as maintaining the same mortality limits for each IPHC Regulatory Area in years with no stock assessment, or as complicated as invoking an alternative MP that does not require a stock assessment (such as an empirical-based MP relying only on data/observations).

The Commission requested that the Secretariat investigate biennial assessments and potentially longer intervals as time allows.

> **IPHC-2022-AM098-R, para 64**: *The Commission REQUESTED that multi-year management procedures include the following concepts:*
>
> *a) The stock assessment occurs biennially (and possibly triennial if time in 2022 allows) and no changes would occur to the FISS (i.e. remains annual);*
>
> *b) The TCEY within IPHC Regulatory Areas for non-assessment years:*
>
> *i. remains the same as defined in the previous assessment year, or*
>
> *ii. changes within IPHC Regulatory Areas using simple empirical rules, to be developed by the IPHC Secretariat, that incorporate FISS data.*

There are many different empirical rules that could be applied to determine the TCEY in non-assessment years. We identified three empirical rules for determining IPHC Regulatory Area specific TCEYs in non-assessment years, which either use no observations or FISS observations .

a. The same TCEY from the previous year for each IPHC Regulatory Area.
b. Updating the coastwide TCEY proportionally to the change in the coastwide FISS O32 WPUE and updating the distribution of the TCEY using FISS results and the applied distribution procedure.
c. Maintaining the same coastwide TCEY as the previous year but updating the distribution of the TCEY using FISS results and the applied distribution procedure.

Empirical rule (a) does not update the TCEY in Regulatory Areas, which may deviate from distributions agreements related to a percentage of the coastwide TCEY, if present, due to changes in the distribution of biomass. Empirical rules (b) and (c) both adjust the distribution of the coastwide TCEY and would maintain any agreements related to distribution.

The coastwide TCEY set in the assessment year also can be calculated using different methods. The coastwide TCEY may simply be determined from the one-year projection of the stock assessment without any consideration of the projections beyond one year. This is the method assumed in the above empirical rules. An alternative method would be to take an average of the coastwide TCEYs, given a defined fishing intensity, projected for all years before the next assessment. This would account for potential changes in the population and may maintain the stock closer to target biomass levels and the fishing intensity closer to reference SPR levels. Alternative methods of averaging projected TCEYs were not considered.

An alternative approach that would not require a stock assessment for setting mortality limits in any year would be to adopt an empirical-based MP as the method for setting annual mortality limits. The stock assessment would be used at a defined interval to verify that management is effective and to potentially tune the MSE OM and existing MP (Cox and Kronlund 2008).

The Commission has realized that there are some benefits to multi-year assessments, including stability and transparency in mortality limits for multiple rather than single years, additional time during the Interim/Annual meeting process to focus on topics other than setting mortality limits, time for development/improvement of the stock assessment, and the potential for increased collaborative research across branches within the IPHC Secretariat. However, there may be some costs associated with multi-year assessments. For example, performance in meeting conservation and fishery objectives may be reduced depending on the interval for multi-year assessments and the specifics of the selected management procedure.

The Commission has asked the SRB to assist the Secretariat in identifying potential costs and benefits of not conducting an annual stock assessment.

> **IPHC-2022-AM098-R, para 63:** *The Commission REQUESTED that the IPHC Secretariat work with the SRB and others as necessary to identify potential costs and benefits of not conducting an annual stock assessment. This will include a prioritized list of work items that could be accomplished in its place.*

The SRB provided some insight at SRB020 and the Secretariat will continue to work with the SRB in identifying costs and benefits.

> IPHC-2022-SRB020-R, para 27. *The SRB NOTED that assessment research activities (e.g. paras. 23-26) are examples of work that could be done more extensively in non-assessment years within a multi-year assessment schedule. Other work could include investigating optimal sub-sampling designs for ages, sex-ratio, annual assessment methods to use within the MPs, and well as any of the several topics listed under Stock Assessment Research. The quantifiable costs of multi-year assessments could be estimated within the MSE, for example, of potentially lower average yield for longer assessment cycles to achieve the same levels of risk associated with annual assessments.*

It may be premature to begin identifying detailed costs and benefits of multi-year assessments until an evaluation has been done to determine whether multi-year assessments may meet the Commission objectives already defined. An evaluation of multi-year assessments using Commission conservation and fishery objectives will be presented at the 99th IPHC Annual Meeting, after which a discussion of detailed costs and benefits would be informative.

3.3 Modelling distribution

The fisheries in the OM are specified by IPHC Regulatory Area because many of the Commission objectives used to evaluate MPs are specific to IPHC Regulatory Areas and the OM is spatially structured by Biological Region. This makes it necessary to distribute the TCEY across the fisheries to appropriately remove biomass from each Biological Region and allow for the calculation of necessary performance metrics. Distribution procedures have been evaluated (Hicks et al. 2021), but a specific MP has not been implemented. Even though distribution procedures are not currently being evaluated and there is no specific agreement on a single distribution procedure, they are part of the MP and need to be included in the simulations. Therefore, the Commission has recommended five different distribution procedures representing a practicable range to provide a robust analysis of size limits and multi-year assessments.

> **IPHC-2022-SS012-R, para 11**: *The Commission RECOMMENDED the following five distribution procedures to be used in the management strategy evaluation of size limits and multi-year assessments, noting that these distribution procedures are for analytical purposes only and are not endorsed by both parties, thus would be reviewed in the future if the Commission wishes to evaluate them for implementation.*
>
> > *a) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3A, relative harvest rates of 0.75 for IPHC Regulatory Areas 3B-4, and no application of the current interim agreements for 2A and 2B;*
> >
> > *b) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3A, relative harvest rates of 0.75 for IPHC Regulatory Areas 3B-4, and current interim agreements for 2A and 2B;*

c) Baseline based on recent year O32 FISS results with 1.65 Mlbs to 2A and 20% of the coastwide TCEY to 2B;

d) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3, 4A, and 4CDE, a relative harvest rate of 0.75 for IPHC Regulatory Area 4B, and no agreements for 2A and 2B;

e) Baseline based on recent year O32 FISS results, relative harvest rates of 1.0 for IPHC Regulatory Areas 2-3, 4A, and 4CDE, a relative harvest rate of 0.75 for IPHC Regulatory Area 4B, and current interim agreements for IPHC Regulatory Areas 2A and 2B

Three of the five distribution procedures contain agreements for IPHC Regulatory Areas 2A and 2B (b, c, and e). Implementation variability for these two areas is set to zero when agreements are in place.

3.4 MP combinations

It is easy in any MSE to specify a large set of runs due to the combination of many MP elements. Given that the simulation time for a single MP may be days, it is useful to identify a small set of runs that will provide insight into the performance of each element of the MP of interest. The components of size limits and multi-year assessments presented above have multiple elements that are combined as shown in Table 2. For each MP, an SPR of 43% was used, with some specific combinations using SPR values of 40% and 46%.

Table 2. Primary MPs to be evaluated. The multi-year assessment specifies the frequency of the stock assessment and the procedure for years without a stock assessment (see Section 3.2).

MP ID	Multi-year assessment	Size Limit (inches)
MP-A32	Annual	32
MP-Ba32	Biennial, constant TCEY	32
MP-Bb32	Biennial, empirical rule	32
MP-Bc32	Biennial, update distribution	32
MP-A26	Annual	26
MP-A0	Annual	0

A secondary set of MPs will be developed based on the performance of the primary set. This may include crossing size limits with biennial assessments, tuning SPR values to best meet objectives, examining different levels of estimation error, and incorporating various forms of implementation variability. This secondary set will not be a full factorial, but instead a specific investigation of relevant factors, and to refine the best performing MPs relative to stock and fishery objectives.

Furthermore, a set of sensitivities will be done using alternative scenarios as described above. These will be performed on a small set of the best performing MPs.

4 Results and Evaluation

The MPs were integrated across the distribution procedures, resulting in the six MPs in Table 2 as distribution is considered an uncertainty in this evaluation. However, any interesting differences between distribution procedures may be reported.

Improvement of the methods to evaluate simulation results and present those for decision-making are ongoing. Current tasks specifically include updates to the MSE Explorer tool, improving the ranking procedure to identify best performing management procedures, determining new methods to identify best performing management procedures, and providing new types of plots and tables that effectively communicate the results. This task will benefit from interactions with stakeholders and management agencies, which may include MSAB meetings.

4.1 Projections

The improvements to the MSE framework, including the updated OM, resulted in some different outcomes, although general conclusions were consistent with previous analyses. The additional years at the end of the historical time-series in the OM resulted in immediate optimistic trends in the spawning biomass (Figure 14) due to a possibly large 2012 year class, a positive PDO regime, and increasing trends in weight-at-age.

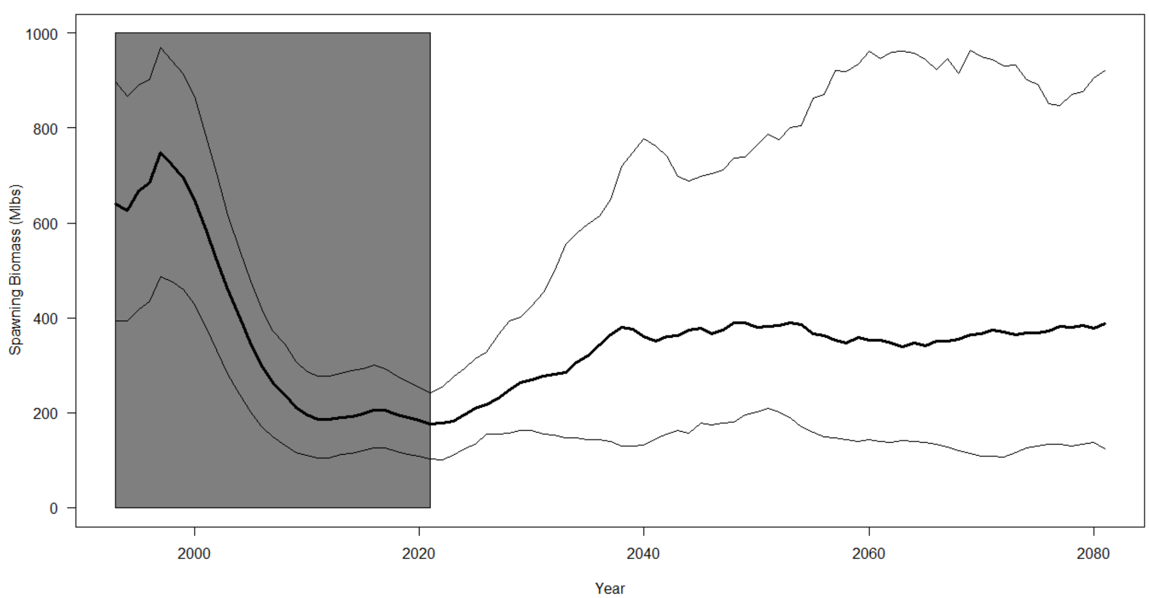

Figure 14. Projected spawning biomass with MP-A32, an SPR of 43%, and no estimation error. The shaded area is the historical region with fixed data and fishing mortality. The thick line is the median and the thin lines are the 5th and 95th percentiles.

4.2 Size limits

Applying the three size limits resulted in little change to the biological sustainability performance metrics with or without simulated estimation error (Table 3). Simulated estimation error resulted in a lower average fishing intensity (i.e. higher SPR) but a slightly lower average relative spawning biomass. The lower portion of the distribution of average relative spawning biomass was more compact than without estimation error as shown by the lower probability of being less than 36%. The upper portion of the distribution of average RSB was wider with estimation error (Figure 15).

Table 3. Performance metrics related to primary objectives for size limit MPs with no decision-making variability. The same MPs are simulated with no estimation error or simulated estimation error. Biological sustainability metrics are long-term and fishery sustainability are short-term (4–13 years).

MP name	**MP-A0**	**MP-A26**	**MP-A32**	**MP-A0**	**MP-A26**	**MP-A32**
Decision-making variability	**None**	**None**	**None**	**None**	**None**	**None**
Estimation Error	**None**	**None**	**None**	**Sim**	**Sim**	**Sim**
Assessment Frequency	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Size Limit	**0**	**26**	**32**	**0**	**26**	**32**
SPR	**0.43**	**0.43**	**0.43**	**0.43**	**0.43**	**0.43**
Median average SPR	43.00%	43.00%	43.00%	43.90%	43.90%	44.00%
Biological Sustainability						
Median average RSB	39.3%	39.3%	39.3%	39.0%	39.0%	39.0%
P(any RSB_y<20%)	0	0	0	0	0	0
P(all RSB<36%)	0.17	0.17	0.18	0.14	0.14	0.14
Fishery Sustainability						
Median average TCEY	62.26	62.08	58.92	60.18	59.69	58.09
P(any3 change TCEY > 15%)	0.058	0.058	0.072	0.934	0.946	0.966
Median AAV TCEY	5.2%	5.3%	5.7%	18.2%	18.3%	18.7%

Short-term fishery sustainability performance metrics showed some improvements when lowering the size limit (Table 3). The TCEY, on average, was 5.4% higher with a 26-inch size limit and 5.7% higher with no size limit. With simulated estimation error the average TCEY was less, and increases to the TCEY with a 26-inch size limit and no size limit were 2.8% and 3.6%, respectively. The percentage gain in the TCEY is variable across years and is higher in the short-term given starting conditions of the projections (Figure 16), and there is a very small probability that the TCEY is less without a size limit. The high percent gain in recent projected years is due to starting conditions, which declines as recruitment, weight-at-age, and environmental regimes become more integrated across the range of possible values. Annual variability in the TCEY was slightly reduced with lower size limits but above 15% with estimation error (Table 3).

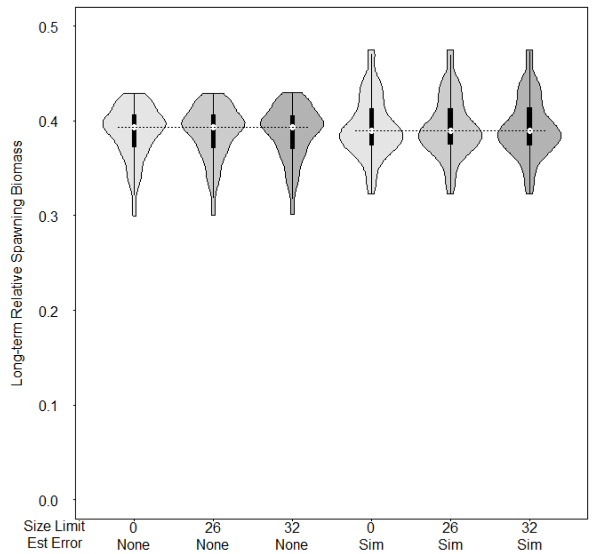

Figure 15. Violin plots of long-term relative spawning biomass for the three size limits (different shades of grey) and no estimation error (left) or simulated estimation error (right). A dashed line is drawn at the median for the 32 inch size limit of each estimation error type.

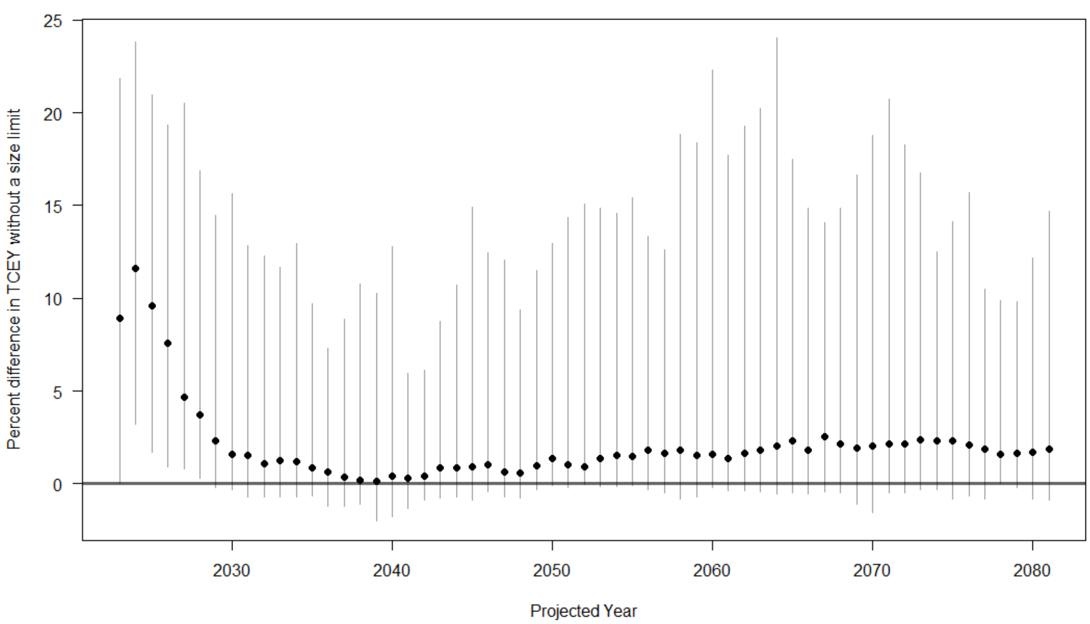

Figure 16. Percent difference in the TCEY without a size limit compared to a 32-inch size limit for each projected year when simulating estimation error. The points are the median and the vertical lines connect the 5th and 95th percentiles.

The coastwide TCEY differed between the short-term and the long-term (Figure 17). The median coastwide TCEY was higher and differences between size limits were less pronounced in the long-term (as also shown in Figure 16). Estimation error also had a greater effect on the range of TCEY in the long-term.

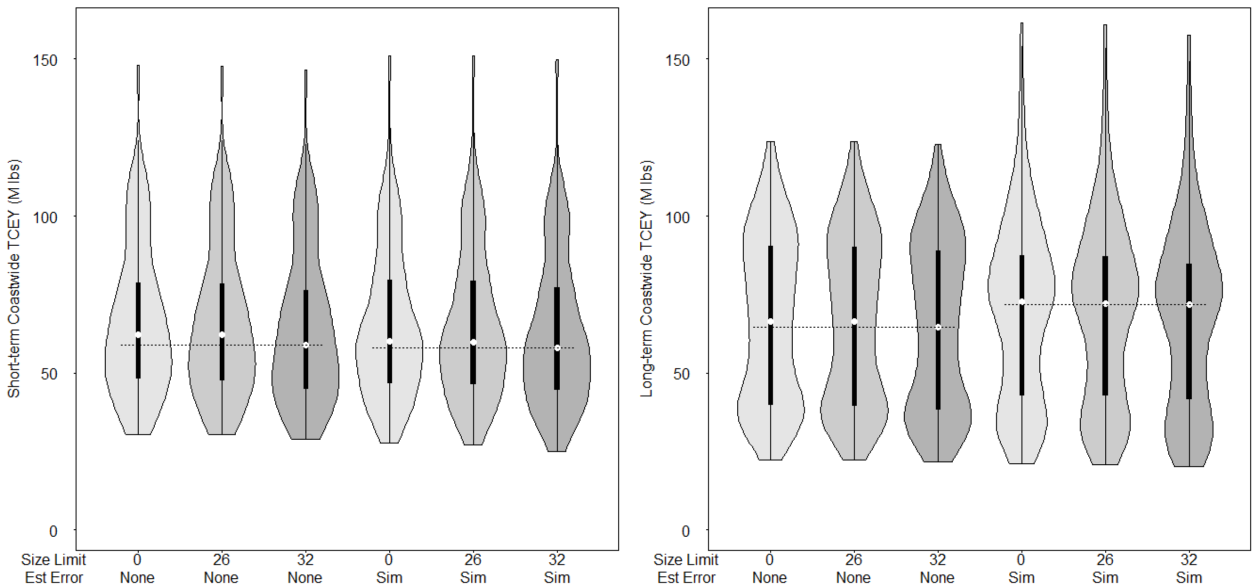

Figure 17. Short-term coastwide TCEY (left) and long-term coastwide TCEY (right) for the three size limits and no or simulated estimation error.

The patterns were similar for performance metrics calculated for each IPHC Regulatory Area (Table 4). The median average TCEY (with simulated estimation error) in the IPHC Regulatory Areas increased between 4.5% and 5.7% except for IPHC Regulatory Area 2A (no change since three of the five distribution procedures had a fixed 1.65 Mlbs) and IPHC Regulatory Area 4B (6.9%). Even though the TCEY in IPHC Regulatory Area 3A showed a modest percent increase without a size limit, the absolute increase in the TCEY was over 1 million pounds. Annual variability in the TCEY for each IPHC Regulatory Area decreased when lowering the size limit, but remained above 14.5% when simulating estimation error.

The majority of the gain in median average TCEY and the reduction in annual variability of the TCEY was achieved when lowering the size limit from 32 inches to 26 inches. This is because the directed commercial gear has a low selectivity for Pacific halibut less than 26 inches.

Table 4. Performance metrics related to area-specific primary objectives for size limit MPs with no decision-making variability. Fishery sustainability metrics are short-term (4–13 years).

MP name	**MP-A0**	**MP-A26**	**MP-A32**	**MP-A0**	**MP-A26**	**MP-A32**
Decision-making variability	**None**	**None**	**None**	**None**	**None**	**None**
Estimation Error	**None**	**None**	**None**	**Sim**	**Sim**	**Sim**
Assessment Frequency	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Size Limit	**0**	**26**	**32**	**0**	**26**	**32**
SPR	**0.43**	**0.43**	**0.43**	**0.43**	**0.43**	**0.43**
Median average TCEY-2A	1.65	1.65	1.65	1.61	1.61	1.61
Median average TCEY-2B	9.14	9.09	8.72	8.97	8.9	8.58
Median average TCEY-2C	6.82	6.77	6.55	6.7	6.67	6.41
Median average TCEY-3A	24.7	24.59	23.6	24.57	24.36	23.36
Median average TCEY-3B	7.75	7.70	7.46	7.47	7.42	7.09
Median average TCEY-4A	3.72	3.69	3.56	3.74	3.70	3.54
Median average TCEY-4CDE	5.11	5.06	4.89	4.18	4.12	3.99
Median average TCEY-4B	2.47	2.42	2.33	2.93	2.87	2.74
P(any3 change TCEY 2A > 15%)	0.012	0.012	0.012	0.302	0.310	0.336
P(any3 change TCEY 2B > 15%)	0.030	0.030	0.032	0.728	0.738	0.786
P(any3 change TCEY 2C > 15%)	0.040	0.044	0.042	0.762	0.766	0.810
P(any3 change TCEY 3A > 15%)	0.030	0.030	0.036	0.734	0.748	0.790
P(any3 change TCEY 3B > 15%)	0.022	0.020	0.022	0.734	0.746	0.790
P(any3 change TCEY 4A > 15%)	0.034	0.036	0.042	0.818	0.828	0.852
P(any3 change TCEY 4CDE > 15%)	0.006	0.006	0.016	0.580	0.574	0.568
P(any3 change TCEY 4B > 15%)	0.036	0.032	0.03	0.826	0.82	0.848
Median AAV TCEY 2A	0.0%	0.0%	0.0%	3.1%	3.1%	3.4%
Median AAV TCEY 2B	5.7%	5.8%	6.3%	18.3%	18.7%	19.1%
Median AAV TCEY 2C	6.5%	6.6%	7.0%	19.3%	19.5%	20.2%
Median AAV TCEY 3A	5.9%	6.0%	6.4%	19.1%	19.4%	19.6%
Median AAV TCEY 3B	5.9%	6.0%	6.4%	19.0%	19.3%	19.5%
Median AAV TCEY 4A	6.2%	6.2%	6.5%	19.3%	19.7%	20.4%
Median AAV TCEY 4CDE	6.1%	6.2%	6.3%	14.5%	14.6%	14.9%
Median AAV TCEY 4B	6.0%	6.0%	6.4%	19.9%	20.1%	20.6%

4.3 Multi-year assessments

Simulations without estimation error of a biennial assessment frequency using option c (constant coastwide TCEY in non-assessment years but updated distribution) showed very small differences in long-term biological sustainability metrics when compared to an annual assessment frequency (Table 5). Short-term fishery sustainability metrics showed a slightly smaller median TCEY with a biennial assessment frequency. The annual variability of the TCEY was much greater with biennial assessments, even though the coastwide TCEY changed in only 5 of the 10 years used to calculate the metric. This suggests that the TCEY had to make large changes to account for the constant TCEY over two-years. There are no current objectives that would indicate whether a stable 2-year period with a larger biennial change is preferable to annual changes in the TCEY.

Table 5. Performance metrics related to primary objectives for annual and biennial MPs with a size limit of 32 inches and no estimation error or decision-making variability. The biennial MP uses option c. Biological sustainability metrics are long-term and fishery sustainability are short-term (4–13 years).

MP name	**MP-A32**	**MP-Bc32**
Decision-making variability	**None**	**None**
Estimation Error	**None**	**None**
Assessment Frequency	**Annual**	**Biennial**
Size Limit	**32**	**32**
SPR	**0.43**	**0.43**
Median average SPR	43.0%	43.3%
Biological Sustainability		
Median average RSB	39.3%	38.9%
P(any RSB_y<20%)	0.00	0.00
P(all RSB<36%)	0.18	0.17
Fishery Sustainability		
Median average TCEY	58.92	57.53
P(any3 change TCEY > 15%)	0.072	0.784
Median AAV TCEY	5.7%	14.7%

4.4 Additional results anticipated for the 99th IPHC Annual Meeting

Many more results and comparisons will be provided at the 99th IPHC Annual Meeting. Implementation variability and estimation error will be simulated and contrasted to runs without these sources of variability. Additional performance metrics will also be examined, including the age/size composition of landings, the amount of fish discarded and discard mortality in the directed commercial fisheries, and other sector-specific metrics.

RECOMMENDATION/S

That the SRB

a) **NOTE** paper IPHC-2022-SRB021-07 describing improvements to the closed-loop simulation framework, two types of management procedures to simulate and evaluate in 2022, and preliminary results from different size limits.

b) **IDENTIFY** costs and benefits associated with multi-year assessments, including whether multi-year assessments meet the Commission's primary objectives.

c) **RECOMMEND** any changes, additional MPs, or evaluation to be presented at IM098.

d) **RECOMMEND** additional improvements or additional MSE tasks to be done in 2023.

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APPENDICES

Appendix A: Supplementary material

APPENDICES

Appendix A: Supplementary material

In addition to this document, an MSE technical document is available electronically. This is document IPHC-2022-MSE-01 and is available on the IPHC MSE page (https://www.iphc.int/management/science-and-research/management-strategy-evaluation).

The MSE Explorer will also be updated with additional results.

(http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/MSE-Explorer/).

Update on the development of the 2022 stock assessment

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 17 AUGUST 2022)

PURPOSE

To provide the IPHC's Scientific Review Board (SRB) a response to requests from SRB020 (IPHC-2022-SRB020-R) and to provide the Commission with an update on the development of the 2022 assessment.

INTRODUCTION

This document provides an update on stock assessment development progress since SRB020. The 2022 stock assessment represents a full analysis, following updates in 2020 and 2021 of the 2019 full assessment. The preliminary analysis presented for SRB020 (IPHC-2022-SRB020-7) included extensive detail on improvements to data sources, software, structural modelling choices, bridging analyses from the 2021 assessment, as well as the introduction of a new method for weighting models within the ensemble. This document includes a response to recommendations from SRB020, a description of three minor updates to the modelling and/or data, as well as a brief summary of data that will be included in the final assessment for 2022.

SRB RECOMMENDATIONS, REQUESTS AND RESULTS

The SRB made the following assessment recommendations and requests during SRB020:

1) SRB020-Rec.02 (para. 23):

   "The SRB NOTED that most models within the ensemble produced reasonable and well-constrained estimates of natural mortality (M) and RECOMMENDED that estimation of M should be adopted in the short AAF assessment model with consideration in other models as part of the stock assessment research program."

2) SRB020-Rec.03 (para. 24):

   "The SRB NOTED that the bootstrapping approach to determining maximum samples sizes for age-composition data improved assessment model performance and stability and, therefore, RECOMMENDED that the bootstrapping approach be adopted for data-weighting in future assessments."

3) SRB020-Rec.04 (para. 25):

   "The SRB NOTED apparent discrepancies in marine mammal prevalence among anecdotal reports, FISS observations, and preliminary evaluation of logbook data, and therefore RECOMMENDED further investigation of methods to better estimate marine mammal prevalence and impacts on the fishery."

4) SRB020-Req.06 (para. 26):

   "The SRB NOTED the proposed new ensemble model weighting scheme using the MASE criterion and REQUESTED investigation of predictive skill on additional quantities such as fishery CPUE and mean age in FISS samples."

A response to each of these requests is provided below.

1. Estimation of natural mortality

As in the preliminary assessment, the final 2022 stock assessment is planned to include a short Areas-As-Fleets (AAF) model that includes estimation of natural mortality (*M*) constrained by a relatively diffuse prior based on maximum observed age. Future modelling exploration for the coastwide (CW) short model will focus on parameters and processes that may be correlated and/or confounded with *M* and a search for a set of model structural assumptions that would allow estimation of *M* in this model as well.

2. Bootstrapped sample sizes

Also consistent with the preliminary assessment presented at SRB020, the final 2022 stock assessment will begin internal data weighting from bootstrapped sample sizes following the methods described in Stewart and Hamel (2014) and Stewart and Hicks (2022). The addition of sex-ratio at age data from 2021 (described below) provided a test of the technical feasibility of adding an additional processing step to the normal work-flow of data input to the models included in the ensemble. Because the bootstrapping code has been integrated into the R code for age composition generation, this additional processing step does not appreciably affect the efficiency of model updating.

3. Marine mammal depredation

Following SRB020 the secretariat has continued to explore avenues for better understanding the prevalence of marine mammal depredation in the directed commercial Pacific halibut fishery. Following the end of the 2022 fishing season, the logbook fields being recorded, the way in which IPHC field specialists collect the information if the harvester has not filled out the fields and an improved outreach program will be evaluated. An update of the existing analysis of depredation is underway for the sablefish (*Anoplopoma fimbria*) fishery (Goethel et al. 2021). The IPHC secretariat will coordinate with this effort, as the logbooks are collected by IPHC field specialists and the harvesters overlap substantially between the two fisheries. Finally, the IPHC has an ongoing research project to test catch protection methods to reduce depredation in the directed commercial fishery using either a 'shuttle' to collect the fish from the hooks underwater or a 'shroud' to cover fish captured on branchline-rigged demersal longlines. These devices are being adapted from technology developed in the southern ocean and applied to toothfish fisheries. An update on all of these efforts will be provided at SRB022 in June 2023.

4. Model weighting

Based on the initial investigation of model weighting presented at SRB020, the secretariat has continued evaluation of Mean Absolute Standardized Error (MASE; Hyndman and Koehler 2006) as a tool for measuring the skill of each model in predicting one year ahead observations. The MASE statistic is calculated as

$$MASE = \frac{\frac{1}{n}\sum_{t=1}^{n} \left| \frac{O_t - E_t}{\sigma_t} \right|}{\frac{1}{n}\sum_{t=1}^{n} \left| \frac{O_t - O_{t-1}}{\sigma_t} \right|}$$

Where *O* indicates the observation at time *t*, *E* the prediction (or expected value) and σ_t is the standard deviation of the observation. The calculation can be averaged over any number of years or lags relevant to the predictive problem. As defined, MASE estimates must be positive, and the range of values is interpreted as:

>1: model predictive skill is worse than the naïve prediction (last year's index) – model not worth pursuing further

1: model predictive skill is exactly equal to the naïve prediction

<1: model predictive skill exceeds that of the naïve prediction

0: model predictions perfectly match subsequent observations

In order to turn the MASE statistic into a model weight we need to specify the scale of the weighting and the behavior at the end-points. In this case, for model (*m*) within the set of models (*M*; limited to those models with MASE values <1):

$$MASE\ weight_m = \frac{1 - MASE_m}{\sum_{m=1}^{M} 1 - MASE_m}$$

This approach ensures that a model that does not outperform the naïve prediction (MASE >= 1) will get zero weight, and that a set of models all perfectly predicting the next observation will receive equal weights.

Initial application of this approach to the Fishery Independent Setline Survey (FISS) index of abundance presented at SRB020 resulted in all models performing better than the naïve predictor when averaging over the most recent 1, 2 3, or 4 years (Table 1, Figure 1). Therefore, MASE weights averaging over the same time-periods were relatively stable (Table 2). The secretariat therefore preliminarily recommended that MASE weights be calculated based on the most recent year's performance only, in order to tie the weights to the most relevant performance observed in the time series.

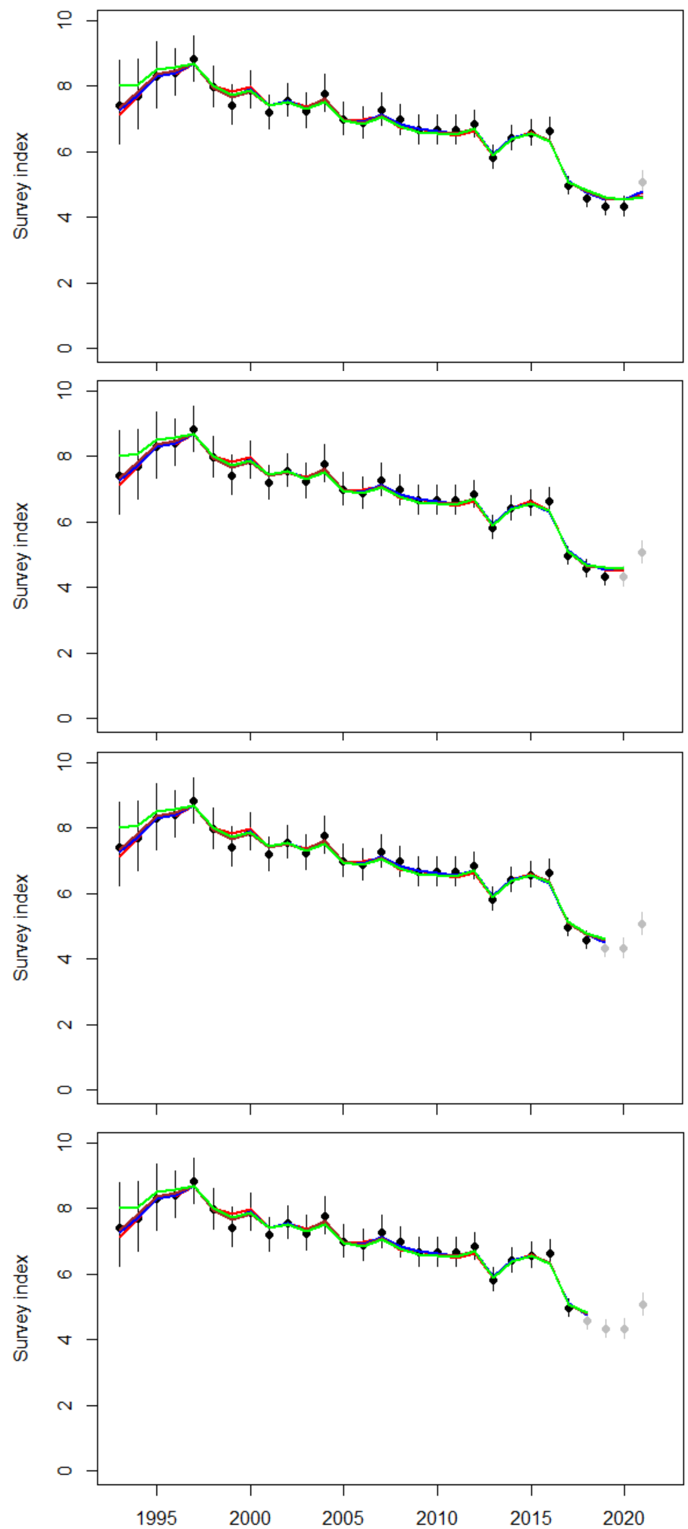


Figure 1. Predictions from each of the four models (colored lines) for the 2021 to 2018 (top to bottom panels) FISS observations (grey dots and CIs) using data through 2020 to 2017 (black dots and CI).

Table 1. One-year ahead standardized MASE estimates for each of the four stock assessment models averaged over the most recent 1, 2, 3, and 4 years.

	Model			
Years included	CW short	CW long	AAF short	AAF long
4	0.70	0.65	0.82	0.72
3	0.83	0.75	0.94	0.83
2	0.86	0.76	0.88	0.78
1	0.59	0.46	0.52	0.44

Table 2. One-year ahead standardized MASE weights for each of the four stock assessment models averaged over the most recent 1, 2, 3, and 4 years.

	Model			
Years included	CW short	CW long	AAF short	AAF long
4	27.5%	31.3%	15.8%	25.4%
3	26.0%	38.0%	9.3%	26.8%
2	19.1%	33.9%	16.4%	30.6%
1	20.5%	27.2%	24.0%	28.3%
Status quo weights	25.0%	25.0%	25.0%	25.0%

At the request of SRB020, this calculation was extended to include coastwide commercial fishery Weight-Per-Unit-Effort (WPUE). In contrast to the FISS index, the fishery WPUE index has been nearly flat over the most recent four years (Figure 2). With very little contrast, the naïve predictor (the previous index value) equaled or exceeded model predictions, and led to weighting that varied from 0.0 to 100% and never included more than 2 models in any of the averaged periods (Table 3), except in 2021 when all four models performed more poorly than the naïve predictor and were assigned equal weights. This difference from the FISS-based weights is probably also enhanced by the use of time-vary catchability for the fishery WPUE, which provides for relatively good fits to the data, but relatively poor forward predictions.

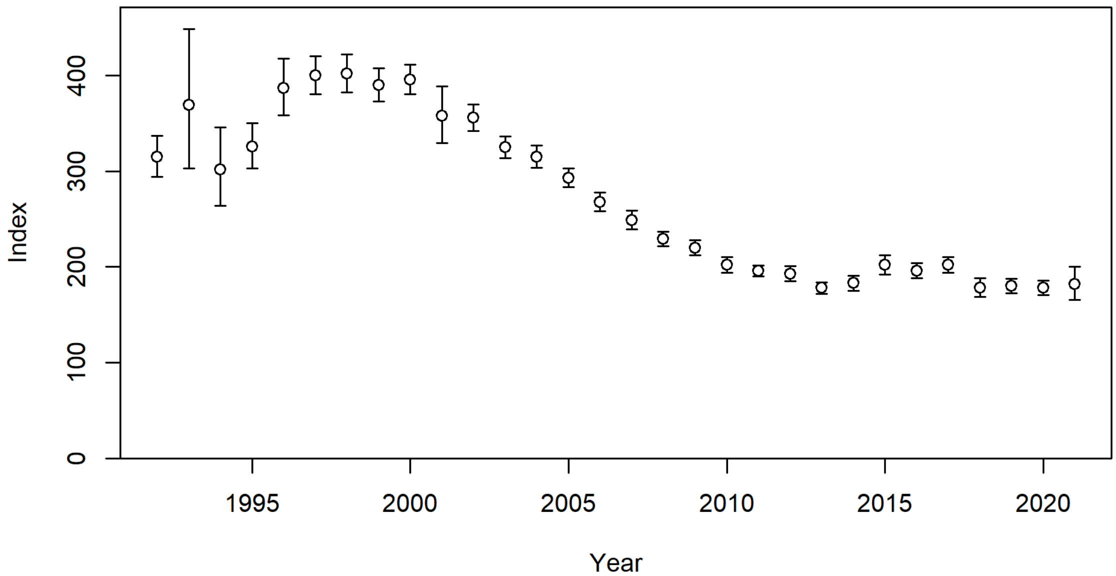


Figure 2. Time series of directed commercial fishery WPUE observations (grey dots and approximate 95% CIs), 1992-2021.

Table 3. One-year ahead standardized MASE weights based on commercial fishery WPUE for each of the four stock assessment models averaged over the most recent 1, 2, 3, and 4 years. Note that in 2021, all four models had MASE values >1.

	Model			
Years included	CW short	CW long	AAF short	AAF long
4	0.0%	53.1%	0.0%	46.9%
3	0.0%	27.8%	0.0%	72.2%
2	0.0%	0.0%	0.0%	100.0%
1	25.0%	25.0%	25.0%	25.0%
Status quo weights	25.0%	25.0%	25.0%	25.0%

Based on the variability observed for the commercial fishery WPUE, the MASE weights based on FISS predictions were further evaluated to better understand the role of contrast in the underlying data to the calculated weights. In the case of the FISS, the 2021 observation represented a sharp increase from earlier observations (Figure 1, top panel), which was predicted well by all four models. This meant that as 2-, 3- and 4-year averages were calculated, the 2021 prediction maintained the stability in the weighting. When single-year MASE weights were calculated for each of the four years alone, they were more variable ranging from 0.0 to 45.5% (Figure 3). In 2020, all four models performed more poorly than the naïve predictor, and so were assigned equal weights.

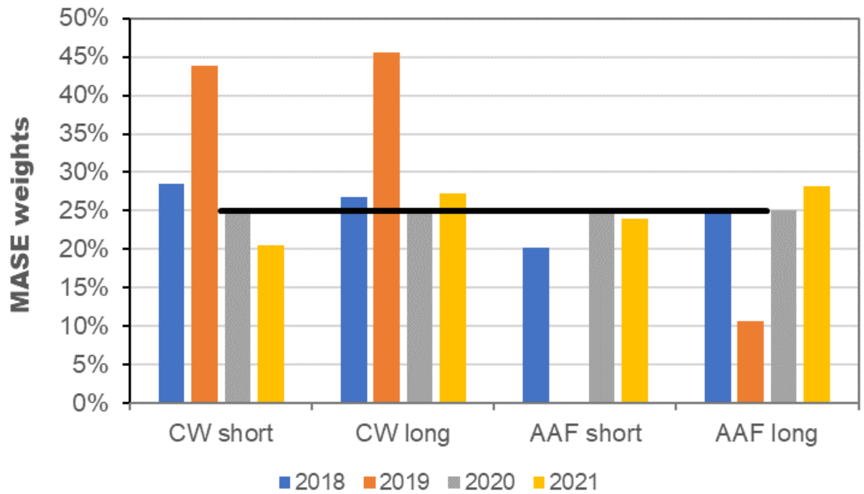


Figure 3. Comparison of one-year MASE weights for each of the four models calculated in each of the most recent four years. Horizontal line indicates the *status quo* equal weighting (25%).

With only four years of data to work with (2018-2021) the 2- 3- and 4-year averages calculated in each of the terminal years have fewer replicates to compare (Figure 4). These comparisons show that the ability of the MASE statistic to rank and weight models depends heavily on the contrast in the underlying observations. It seems desirable to have at least one year included in the calculation that has the 'power' to detect model skill. This is also consistent with the concept that management quantities will be most affected by rapid changes in the index (either up or down) and therefore the model predictive skill when the stock is changing is most relevant.

Based on this extended evaluation, the secretariat recommends moving forward with 4-year average MASE weights based on FISS predictions for the 2022 assessment (Table 2, top row; Figure 4, bottom panel). Looking forward, a 4-year moving average will continue to include the 2021 prediction through the next full stock assessment planned for 2025, and therefore have a reduced risk of large and/or abrupt changes in model weighting during the updated assessments conducted in 2023 and 2024. However, it will still provide for an updating of model weights as individual model performance evolves. In 2025, with several additional years of data and weighting available a more informed evaluation of the stability and performance of MASE weights can be undertaken.

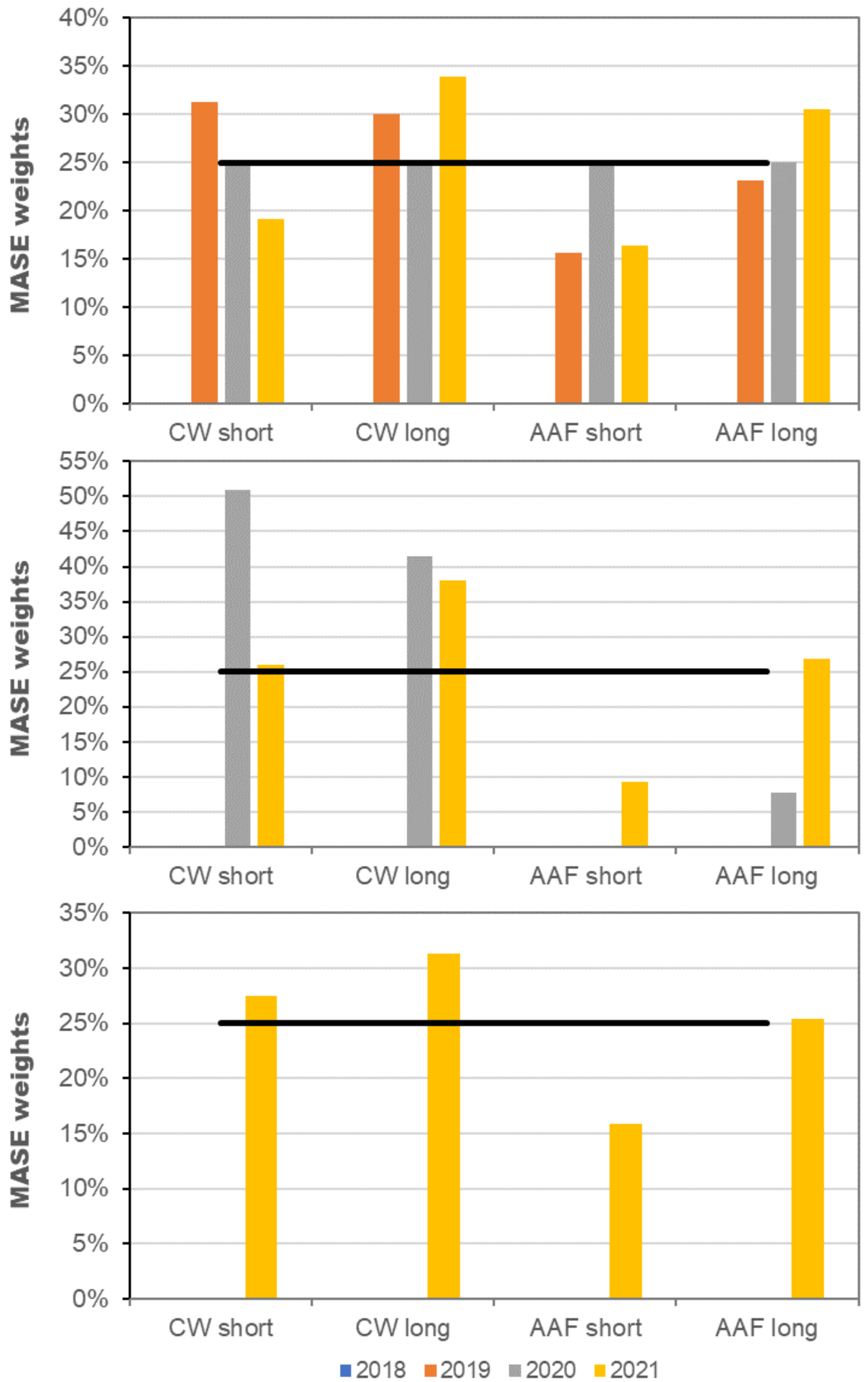


Figure 4. Comparison of 2-year (top panel), 3-year (middle panel) and 4 year (lower panel) MASE weights for each of the four models by terminal year. Horizontal lines indicate the *status quo* equal weighting (25%). Note that the scale of the y-axis differs among panels.

ADDITIONAL STOCK ASSESSMENT DEVELOPMENT IN 2022

In addition to the request and recommendations made during SRB020, the secretariat has also continued with minor updates and improvements to each of the models and data sets. These included: 1) an investigation of the use of small constants in the population size-at-age calculations within in the Stock Synthesis modelling software, and 2) the effect of sparse weight-at-age data observed in 2021 for the oldest ages observed in IPHC Regulatory Area 3A.

During ongoing development of the Stock Synthesis software a potential convergence issue was identified relating to the small constant added to the internal age-length key used to convert numbers of fish to size and biomass. Previously, a small constant (0.0001) was recommended to be added to the calculations (page 21, Methot Jr et al. 2021). In cases where the growth curve was internally estimated, this small constant was found to occasionally cause convergence issues. Because the Pacific halibut model uses empirical weight-at-age it was largely unaffected by this issue; model runs removing this constant did not differ after routine rounding for any management quantities.

During development of the Operating Models for the 2022 Management Strategy Evaluation it was discovered that very sparse data for the oldest ages in Biological Region 3 had led to negative estimated raw weight-at-age for female Pacific halibut. This was caused by the extrapolation of trend from the last two ages with data, which showed a negative trend. The issue only arose for the raw observations used in fitting the FISS index, as all population matrices are smoothed to reduce the effects of observation error (Stewart and Webster 2022). Because there were only trivial numbers of fish in these ages, when the weight-at-age was forced to remain constant across missing ages there was no change in model fit or estimated quantities.

The sex-ratio-at-age based on genetic analyses for the biological samples collected during the 2021 fishery were made available by the Biological and Ecosystem Sciences Branch in time for inclusion in a set of preliminary model runs. The sex-ratio-at-age information from 2021 was largely consistent with model estimates and resulted in only minor changes (<2%) to the spawning biomass of any of the four models. However, these data continue to improve our understanding of recent population dynamics. This information has been critically important to accurately estimating the spawning biomass and the effect of fishing on the lifetime reproductive output of the stock beginning with the 2019 stock assessment. As the time-series grows longer, it is now possible to evaluate better how the sex ratios are changing over time, and to better delineate trends from interannual variability. Generally, the observed sex-ratio is closely correlated to the average age in the landings: younger fish are a higher proportion female than older fish (Figure 5). Thus, as the 2005 year-class has aged the proportion female has generally decreased, and the pattern was mixed among Biological Regions in 2021, reflecting the uneven contribution of the younger 2012 year-class to those landings (Table 4). The contributions of the 2011 and 2012 year-classes can be clearly seen in the female age information from 2021, while male landings continue to be largely comprised of the 2005 and older year-classes (Figure 6). Some of the observed variability in the sex-ratio information is likely due to sampling variability; in particular Biological Region 4B has included only 10-17 fishery deliveries sampled over this period, and Region 4 only 47 and 43 deliveries in 2020 and 2021, down from over 100 in earlier years. With five years of sex-ratio information now available it may be timely to consider whether annual processing of the genetic samples is optimal, given the cost and trade-off with other potential research.

Figure 5. Relationship between percent female and average age in the directed commercial Pacific halibut fishery by Biological Region. Each point represents one year (2017-2021).

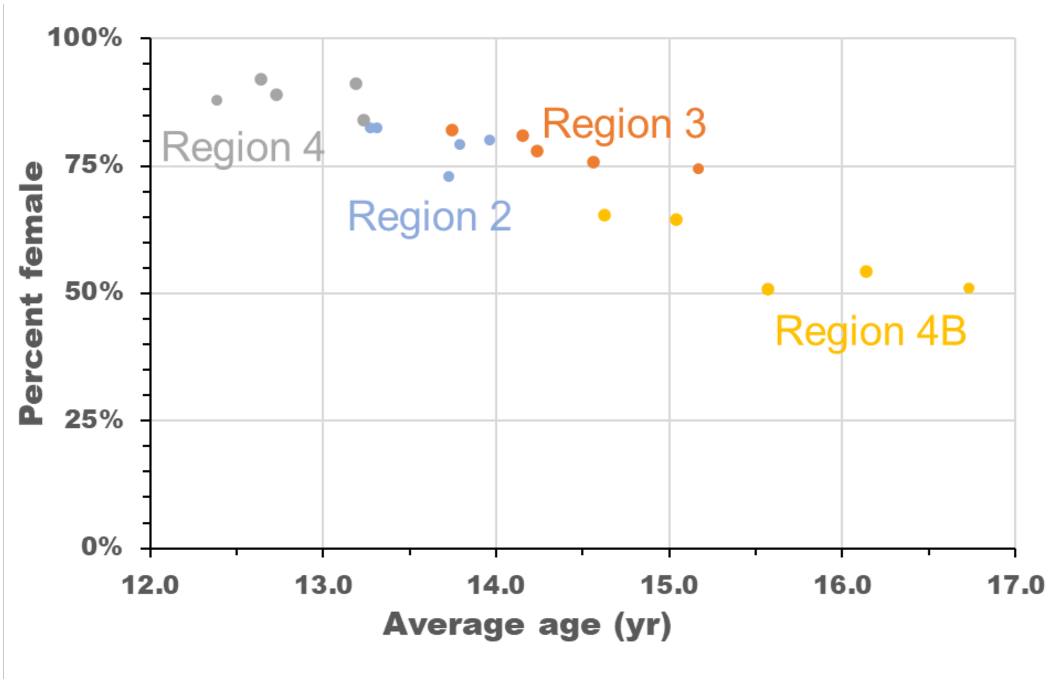
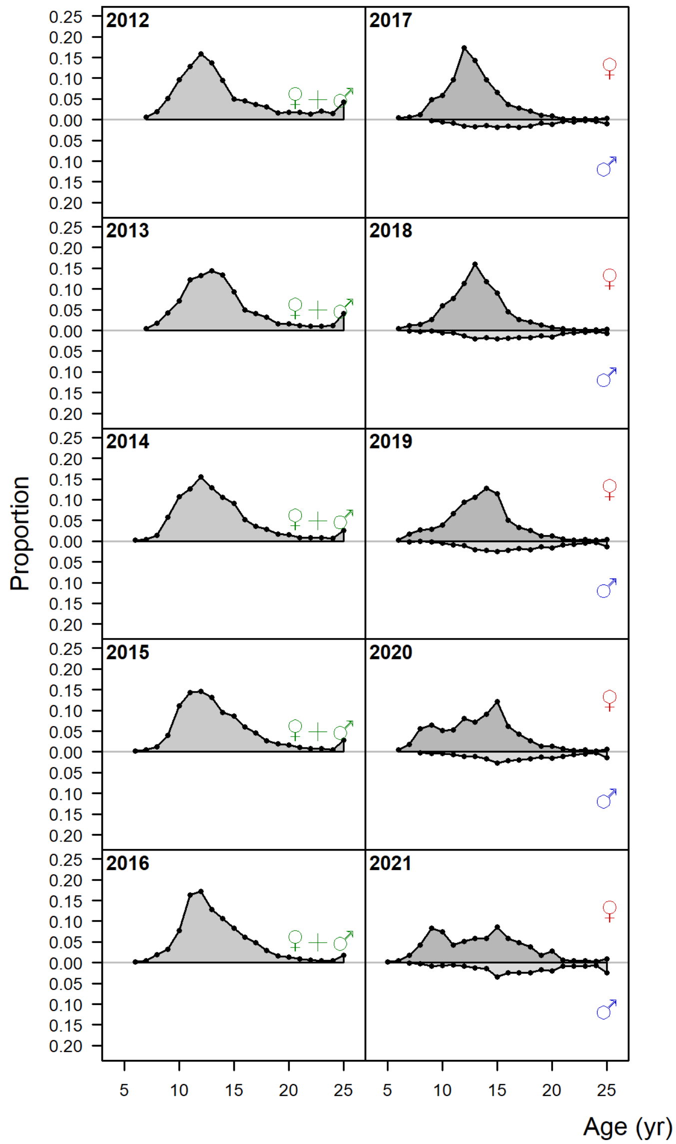


Table 4. Percent of the directed commercial fishery landings comprised of female Pacific halibut.

Year	Coastwide	Biological Region 2	Biological Region 3	Biological Region 4	Biological Region 4B
2017	82%	82%	82%	92%	65%
2018	80%	82%	78%	91%	65%
2019	78%	80%	76%	89%	51%
2020	80%	79%	81%	84%	54%
2021	74%	73%	74%	88%	51%

Figure 6. Recent age compositions from the directed commercial landings.



PRELIMINARY DATA UPDATES

No preliminary data was available from 2022 in time for this document. Standard data sources that will be included in the final 2022 stock assessment include:

1) New modelled trend information from the 2022 FISS for all IPHC Regulatory Areas.
2) Age, length, individual weight, and average weight-at-age estimates from the 2022 FISS.
3) Directed commercial fishery logbook trend information from 2022 (and any earlier logs that were not available for the 2021 assessment) for all IPHC Regulatory Areas.
4) Directed commercial fishery biological sampling from 2022 (age, length, individual weight, and average weight-at-age) from all IPHC Regulatory Areas.

5) Biological information (lengths and/or ages) from non-directed discards (all IPHC Regulatory Areas) and the recreational fishery (IPHC Regulatory Area 3A only) from 2021. The availability of these data routinely lags one year.
6) Updated mortality estimates from all sources for 2021 (where preliminary values were used) and estimates for all sources in 2022.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2022-SRB021-08 which provides a response to requests from SRB020, and an update on model development for 2022.
b) **RECOMMEND** any changes to be included in the final 2022 stock assessment to be completed for presentation at IM098.
c) **REQUEST** any further analyses to be provided at SRB022, June 2023.

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Report on Current and Future Biological and Ecosystem Science Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, 18 AUGUST 2022)

PURPOSE

To provide the Scientific Review Board with a description of progress towards research activities described in the IPHC's five-year Program of Integrated Research and Monitoring (2022-2026).

BACKGROUND

The primary biological and ecological research activities at IPHC that follow Commission objectives are identified and described in the Program of Integrated Research and Monitoring (2022-2026). These activities are integrated with stock assessment and the management strategy evaluation processes (Appendix I) and are summarized in five main areas, as follows:

1) Migration and Distribution. Studies are aimed at further understanding reproductive migration and identification of spawning times and locations as well as larval and juvenile dispersal.
2) Reproduction. Studies are aimed at providing information on the sex ratio of the commercial catch and to improve current estimates of maturity.
3) Growth and Physiological Condition. Studies are aimed at describing the role of some of the factors responsible for the observed changes in size-at-age and to provide tools for measuring growth and physiological condition in Pacific halibut.
4) Discard Mortality Rates (DMRs) and Survival. Studies are aimed at providing updated estimates of DMRs in both the longline and the trawl fisheries.
5) Genetics and Genomics. Studies are aimed at describing the genetic structure of the Pacific halibut population and at providing the means to investigate rapid adaptive changes in response to fishery-dependent and fishery-independent influences.

A ranked list of biological uncertainties and parameters for stock assessment (Appendix II) and the management strategy evaluation process (Appendix III) and their links to research activities and outcomes derived from the five-year research plan are provided.

SRB REQUESTS

The SRB issued the following requests in their report of SRB020 (IPHC-2022-SRB020-R):

*SRB020–Req.07 (para. 29) The SRB **NOTED** continued progress toward integration of biological and ecosystem sciences activities with the needs of Stock Assessment (SA) and MSE programs, and **REQUESTED** that future presentations/documents identify (a) the planned statistical analysis of biological data and (b) parameters or structural decisions within SA and MSE to be informed by the results.*

*SRB020–Req.08 (para. 30) The SRB **NOTED** progress on further developing genomic resources through low-coverage whole genome sequencing and, therefore, **REQUESTED** that the Secretariat provide a detailed plan for bioinformatic interrogation and how data will be used to address IPHC questions related to stock assessment.*

UPDATE ON PROGRESS ON THE MAIN RESEARCH ACTIVITIES

1. Migration and Distribution.

   Research activities in this Research Area aim at improving existing knowledge on Pacific halibut larval and juvenile distribution. The relevance of research outcomes from these activities for stock assessment (SA) is in the improvement of estimates of productivity. These research outcomes will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region and represent one of the top three biological inputs into SA (Appendix II). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in the improvement of the parametrization of the Operating Model and represent the top ranked biological input into the MSE (Appendix III).

   1.1. Estimation of Pacific halibut juvenile habitat. The IPHC Secretariat recently conducted a study to investigate the connectivity between spawning grounds and possible settlement areas based on a biophysical larval transport model (please see paper in the journal Fisheries Oceanography: https://doi.org/10.1111/fog.12512). Although it is known that Pacific halibut initiate their demersal stage as roughly 6-month-old juveniles following the pelagic larval phase and settle in shallow nursery (settlement) areas, near or outside the mouths of bays (please see paper in *Reviews in Fish Biology and Fisheries*: https://doi.org/10.1007/s11160-021-09672-w), very little information is available on the geographic location and physical characteristics of these areas. In order to fill this knowledge gap, the IPHC Secretariat has initiated studies to identify potential settlement areas for juvenile Pacific halibut throughout IPHC Convention Waters. A first objective of this study is to create a map of suitable settlement habitat by combining available bathymetry information (e.g. benthic sediment composition and shoreline morphological data) and information on recorded presence of age-0, age-1 and age-2 Pacific halibut juveniles as well as absence of young Pacific halibut noted by various nursery habitat projects focused on other flatfish species. Data sources are currently being collected.

   1.2. Wire tagging of U32 Pacific halibut. The patterns of movement of Pacific halibut among IPHC Regulatory Areas have important implications for management of the Pacific halibut fishery. The IPHC Secretariat has undertaken a long-term study of the migratory behavior of Pacific halibut through the use of externally visible tags (wire tags) on captured and released fish that must be retrieved and returned by workers in the fishing industry. In 2015, with the goal of gaining additional insight into movement and growth of young Pacific halibut (less than 32 inches [82 cm]; U32), the IPHC began wire-tagging small Pacific halibut encountered on the National Marine Fisheries Service (NMFS) groundfish trawl survey and, beginning in 2016, on the IPHC fishery-independent setline survey (FISS). As of 28 July 2022, 1,330 Pacific halibut have been tagged and released on the 2022 IPHC FISS but no tagging was conducted in the NMFS groundfish trawl surveys in 2022. Therefore, a total of 7,441 U32 Pacific halibut have been wire tagged and released on the IPHC FISS and 135 of those have been recovered to date. In the NMFS groundfish trawl surveys through 2019, a total of 6,421 tags have been released and, to date, 78 tags have been recovered.

2. Reproduction.

Research activities in this Research Area aim at providing information on key biological processes related to reproduction in Pacific halibut (maturity and fecundity) and to provide sex ratio information of Pacific halibut commercial landings. The relevance of research outcomes from these activities for stock assessment (SA) is in the scaling of Pacific halibut biomass and in the estimation of reference points and fishing intensity. These research outputs will result in a revision of current maturity schedules and will be included as inputs into the SA (Appendix II), and represent the most important biological inputs for stock assessment (please see document IPHC-2021-SRB018-06). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in the improvement of the simulation of spawning biomass in the Operating Model (Appendix III).

2.1. Sex ratio of the commercial landings.

The IPHC Secretariat finalized the processing of genetic samples from the 2021 aged commercial landings, completing five consecutive years of sex ratio information (2017-2020).

2.2. Maturity assessment.

Recent sensitivity analyses have shown the importance of changes in spawning output due to skip spawning and/or changes in maturity schedules for stock assessment (Stewart and Hicks, 2018). Information of these key reproductive parameters provides direct input to stock assessment. For example, information on fecundity-at-age and –at-size could be used to replace spawning biomass with egg output as the metric of reproductive capability in the stock assessment and management reference points. This information highlights the need for a better understanding of factors influencing reproductive biology and success of Pacific halibut. In order to fill existing knowledge gaps related to the reproductive biology of female Pacific halibut, research efforts are devoted to characterize female maturity in this species. Specific objectives of current studies include: 1) update of maturity schedules based on histological-based data; and, 2) fecundity determinations.

2.2.1. Update of maturity schedules based on histological-based data. The IPHC Secretariat is undertaking studies to revise maturity schedules in all four biological regions through histological (i.e. microscopic) characterization of maturity, as reported previously. The maturity schedule that is currently used in stock assessment was based on visual (i.e. macroscopic) maturity classification in the field (FISS). In order to be able to accomplish this objective, the IPHC Secretariat is currently collecting ovarian samples for histology in the 2022 FISS. The sample targets are to collect 400 ovarian samples from Biological Region 3, 300 from each Biological Regions 2 and 4, and 250 samples from Biological Region 4B. Ovarian samples will be processed for histology in the Fall of 2022 and, subsequently, histological maturity classifications will be conducted by IPHC

Secretariat staff. Females classified as developing, regressing and spawning capable, according to the classification of reproductive phases defined histologically in our recent publication in *Frontiers in Marine Science*: https://doi.org/10.3389/fmars.2022.801759, will be considered mature. Following this maturity classification criteria, all sampled Pacific halibut females will be assigned to either the mature or immature categories.

The proportion of Pacific halibut females that are mature at a given length or age will be evaluated through the generation of maturity ogives. Maturity ogives will be represented using a logistic curve to which the maturity data (each female will be assigned as mature or immature according to histological classification) will be fit applying a generalized linear model with a binomial data distribution and a logit link function, as described by Dominguez-Petit et al. (2017) and with publicly available R code. The length and age at 50% maturity will be calculated from fitted models using the dose.p function and the proportion of mature individuals (p) set to 0.5.

2.2.2. Fecundity estimations. Methods for fecundity determinations were investigated and, based on the current literature and recommendations from experts in the field, the auto-diametric method was selected as the method of choice (Witthames et al., 2009). The IPHC Secretariat is currently designing plans for ovarian sample collection for fecundity estimations as part of the 2023 FISS. No further updates to report.

3. Growth.

Research activities conducted in this Research Area aim at providing information on somatic growth processes driving size-at-age in Pacific halibut. The relevance of research outcomes from these activities for stock assessment (SA) resides, first, in their ability to inform yield-per-recruit and other spatial evaluations for productivity that support mortality limit-setting, and, second, in that they may provide covariates for projecting short-term size-at-age and may help delineate between fishery and environmental effects, thereby informing appropriate management responses (Appendix II). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in the improvement of the simulation of variability and to allow for scenarios investigating climate change (Appendix III).

The IPHC Secretariat has conducted studies aimed at elucidating the drivers of somatic growth leading to the decline in SAA by investigating the physiological mechanisms that contribute to growth changes in the Pacific halibut. The two main objectives of these studies have been: 1) the identification and validation of physiological markers for somatic growth; and 2) the application of molecular growth markers for evaluating growth patterns in the Pacific halibut population.

No updates to report.

4. Discard Mortality Rates (DMRs) and Survival Assessment.

Information on all Pacific halibut removals is integrated by the IPHC Secretariat, providing annual estimates of total mortality from all sources for its stock assessment. Bycatch and wastage of Pacific halibut, as defined by the incidental catch of fish in non-target fisheries and by the mortality that occurs in the directed fishery (i.e. fish discarded for sublegal size or regulatory reasons), respectively, represent important sources of mortality that can result in significant reductions in exploitable yield in the directed fishery. Given that the incidental mortality from the commercial Pacific halibut fisheries and bycatch fisheries is included as part of the total removals that are accounted for in stock assessment, changes in the estimates of incidental mortality will influence the output of the stock assessment and, consequently, the catch levels of the directed fishery. Research activities conducted in this Research Area aim at providing information on discard mortality rates and producing guidelines for reducing discard mortality in Pacific halibut in the longline and recreational fisheries. The relevance of research outcomes from these activities for stock assessment (SA) resides in their ability to improve trends in unobserved mortality in order to improve estimates of stock productivity and represent the most important inputs in fishery yield for stock assessment (Appendix II). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in fishery parametrization (Appendix III).

For this reason, the IPHC Secretariat is conducting two research projects to investigate the effects of capture and release on survival and to improve estimates of DMRs in the directed longline and guided recreational Pacific halibut fisheries:

4.1. Evaluation of the effects of hook release techniques on injury levels and association with the physiological condition of captured Pacific halibut and estimation of discard mortality using remote-sensing techniques in the directed longline fishery.

The results of the study reporting discard mortality rate estimations in the directed longline fishery have been published in the journal *North American Journal of Fisheries Management:* https://doi.org/10.1002/nafm.10711. The results of the second component of this study, namely the description of relationships among hook release techniques, injury levels, stress levels and physiological condition of released fish, are presently being analyzed using random forest analyses (Breiman 2001) in which viability category is used as the response variable, and hook release method, physiological characteristics, and physical and environmental conditions are used as predictor variables (classification, 500 trees, 2 variables per split). Multinomial logistic regression (Tabachnick and Fidell 2001) modeling is performed on the five most common injuries seen by release method in relation to fish weight, a variable from the random forest analyses shown to have some predictive value on injury type. The multinomial regression is being conducted in the following manner: (InjuryType ~ RoundWeight) wherein the levels of InjuryType were c(torn cheek, torn jaw, cheek and jaw, eye, torn face). Owing to non-normal distributions, relationships among injury types, physiological characteristics, and environmental conditions are examined using Kruskal-Wallis rank sum tests followed by Dunn’s pairwise comparison tests. Specific relationships between all variables are examined using Pearson's correlation coefficients. All statistical analyses and graphic outputs are performed in R version 3.6.2 (R Core Team 2019).

4.2. Estimation of discard mortality rates in the charter recreational sector.

To date, of the 281 fish that were tagged with opercular wire tags (243 fish in IPHC Regulatory Area 2C and 38 in IPHC Regulatory Area 3A) 28 tags have been recovered (19 from IPHC Regulatory Area 2C and 9 from IPHC Regulatory Area 3A).

Seventy-six (76) of the 80 electronic accelerometer-based survivorship pop-up archival transmitting (sPAT tags) provided useable data reports. Survival analysis (R package = "survival") produces a mortality rate estimate of 2.04% with a 95% CI of 0.0-5.92%. These are the first field-corroborated estimates of recreational discard mortality and affirm the use of current methodologies embedded in recreational mortality estimates that feed into the SA and MSE process. Further analyses are being conducted on diurnal activity patterns overall, as well as in the periods shortly after capture and release, versus the periods shortly before tag detachment in order to determine if there are any typical patterns in activity rates as fish recover from the capture event.

Furthermore, the plasma levels of physiological stress indicators (i.e. cortisol, glucose and lactate) in captured and discarded Pacific halibut are currently being analyzed in order to relate stress levels with capture and handling conditions.

5. Genetics and genomics. The IPHC Secretariat is conducting studies that incorporate genomics approaches in order to produce useful information on population structure and distribution and connectivity of Pacific halibut. The relevance of research outcomes from these activities for stock assessment (SA) resides (1) in the introduction of possible changes in the structure of future stock assessments, as separate assessments may be constructed if functionally isolated components of the population are found (e.g. IPHC Regulatory Area 4B), and (2) in the improvement of productivity estimates, as this information may be used to define management targets for minimum spawning biomass by Biological Region. These research outcomes provide the second and third top ranked biological inputs into SA (Appendix II). Furthermore, the relevance of these research outcomes for the management and strategy evaluation (MSE) process is in biological parametrization and validation of movement estimates, on one hand, and of recruitment distribution, on the other hand (Appendix III).

5.1. Population genomics.

The primary objective of the studies that the IPHC Secretariat is currently conducting is to investigate the genetic structure of the Pacific halibut population and to conduct genetic analyses to inform on Pacific halibut movement and distribution within the Convention Area.

5.1.1. Pacific halibut genome and characterization of the sex determining region in Pacific halibut. The IPHC Secretariat has updated the Pacific halibut genome assembly. The updated Pacific halibut genome has an estimated size of 602 Mb, 24 chromosome-length scaffolds that contain 99.8% of the assembly and a N_{50} scaffold length of 27.3 Mb. The Pacific halibut whole genome sequencing data are openly available in NCBI at https://www.ncbi.nlm.nih.gov/bioproject/622249, under BioProject PRJNA622249, and the updated assembly is openly available in NCBI at https://www.ncbi.nlm.nih.gov/assembly/GCA_022539355.2/ with GenBank assembly accession number GCA_022539355.2. The master record for the whole genome shotgun sequencing project has been deposited at DDBJ/ENA/GenBank under the accession JAKRZP000000000 and is openly available in NCBI at https://www.ncbi.nlm.nih.gov/nuccore/JAKRZP000000000. Sample metadata is openly available in NCBI at https://www.ncbi.nlm.nih.gov/biosample?Db=biosample&DbFrom=bioproject&Cmd=Link&LinkName=bioproject_biosample&LinkReadableName=BioSample&ordinalpos=1&IdsFromResult=622249, under BioSamples SAMN14503176, SAMN25516224, SAMN25600010 and SAMN25600011. A detailed description of the genome of Pacific halibut and its sex-determining region has been published in the journal Molecular Ecology Resources: https://doi.org/10.1111/1755-0998.13641. No further updates to report.

Genomic sequencing	Sequencing Run # 1	Sequencing Run # 2	Sequencing Run # 3
Number of samples	249	249	102
Sequencing Platform	Illumina NovaSeq S4	Illumina NovaSeq S4	Illumina NovaSeq S4
Raw Reads Per Sample (Millions)	24.7 (10.7-47.2)	24.9 (13.0-51.6)	25.8 (10.9-85.8)
Reads Retained (%)	62 (22-69)	61 (46-70)	In progress
Coverage Per Sample (x)	3.0 (0.9-5.0)	3.0 (1.3-5.9)	In progress

Table 1. Summary of raw sequence data and genome alignments for three Pacific halibut lcWGR sequencing runs. *numbers in parenthesis indicate number of samples with > 1,000,000 raw sequence reads. **expressed as mean (min – max).

5.1.2. Studies to resolve the genetic structure of the Pacific halibut population in the Convention Area. This project has recently received funding from the North Pacific Research Board (NPRB Project No. 2110; Appendix IV; project narrative provided in the supplementary documentation). Details on sample collection, bioinformatic processing and proposed analyses utilizing low-coverage whole genome sequencing (lcWGR) to investigate Pacific halibut population structure were provided in document IPHC-2021-SRB018-08. Further details on bioinformatic processing are provided below, including a summary flow chart in Appendix V. All libraries have now been constructed, quantified, pooled, and sequenced on an Illumina NovaSeq 6000 platform using an S4 flow cell (2x150 bp paired end reads) on three separate lanes. Preliminary results show that the sequencing yield per sample was 25.1 million reads in average (range = 10.7 – 85.8 million reads), with 61% retained reads (in average) and an average coverage per sample of 3x (Table 1).

5.1.2.1. Initial QC. FastQC (Andrews, Krueger, Seconds-Pichon, Biggins, & Wingett, 2015) will be used to perform an initial quality check of raw sequence reads (Figure 1A). This is to ensure consistent quality across sequencing runs and identify samples that may not be suitable for further analysis. Specifically, the raw base quality scores for each sample will be used to identify samples that were poorly sequenced and should be omitted from downstream analyses. Additionally, the presence of other sequencing artifacts may be detected at this step as well. Per base sequence content will be used to identify the presence of poly-G tails that are common when using the NovaSeq platform (Lou & Therkildsen, 2021).

5.1.2.2. Bioinformatic Processing and Read Alignment. The raw sequence reads will then be processed to remove Illumina adapter sequences and poly-G tails using Trimmomatic (Bolger, Lohse, & Usadel, 2014) and fastp (Chen, Zhou, Chen, & Gu, 2018) (Figure 1A). Adapter sequences will be removed using the following parameters; maximum of 2 mismatches allowed, palindrome clip threshold of 30, simple clip threshold of 10, minimum adapter length of 1, retaining both reads after palindromic trimming is done. In addition to poly-G trimming implemented in fastp, sliding window trimming will also be used to trim the ends of sequence reads read if the average base quality score drops below 15 in a window of 4 bases. Lou and Therkildsen (2021) have demonstrated this to be an effective means of poly-G tail removal.

Trimmed sequence reads will be aligned to the Pacific halibut reference genome (RefSeq assembly accession: GCF_022539355.2) using the short read preset option in minimap2 (Li, 2018) (Figure 1A). The resulting sequence alignment map (SAM) files will be coordinate sorted and converted to the binary alignment map format (BAM) using samtools (Li et al., 2009). The MarkDuplicates module in Picard (http://broadinstitute.github.io/picard/) will be used to remove PCR and optical duplicate reads (Figure 1A). Overlapping read pairs will be clipped to reduce redundancy using the clipOverlap tool in BamUtil (Jun, Wing, Abecasis, & Kang, 2015) (Figure 1A). Finally, local realignment around insertion/deletions (indels) will then be performed using GTAK (v3.8) (Van der Auwera & O'Connor, 2020) to produce analysis ready alignments (Figure 1A). Metrics (Figure 1B) for the final sequence alignments will be obtained using samtools to summarize the bit values set in the FLAG field of each BAM file for each sample and mosdepth

(Pedersen & Quinlan, 2018) to calculate the average sequencing depth per sample.

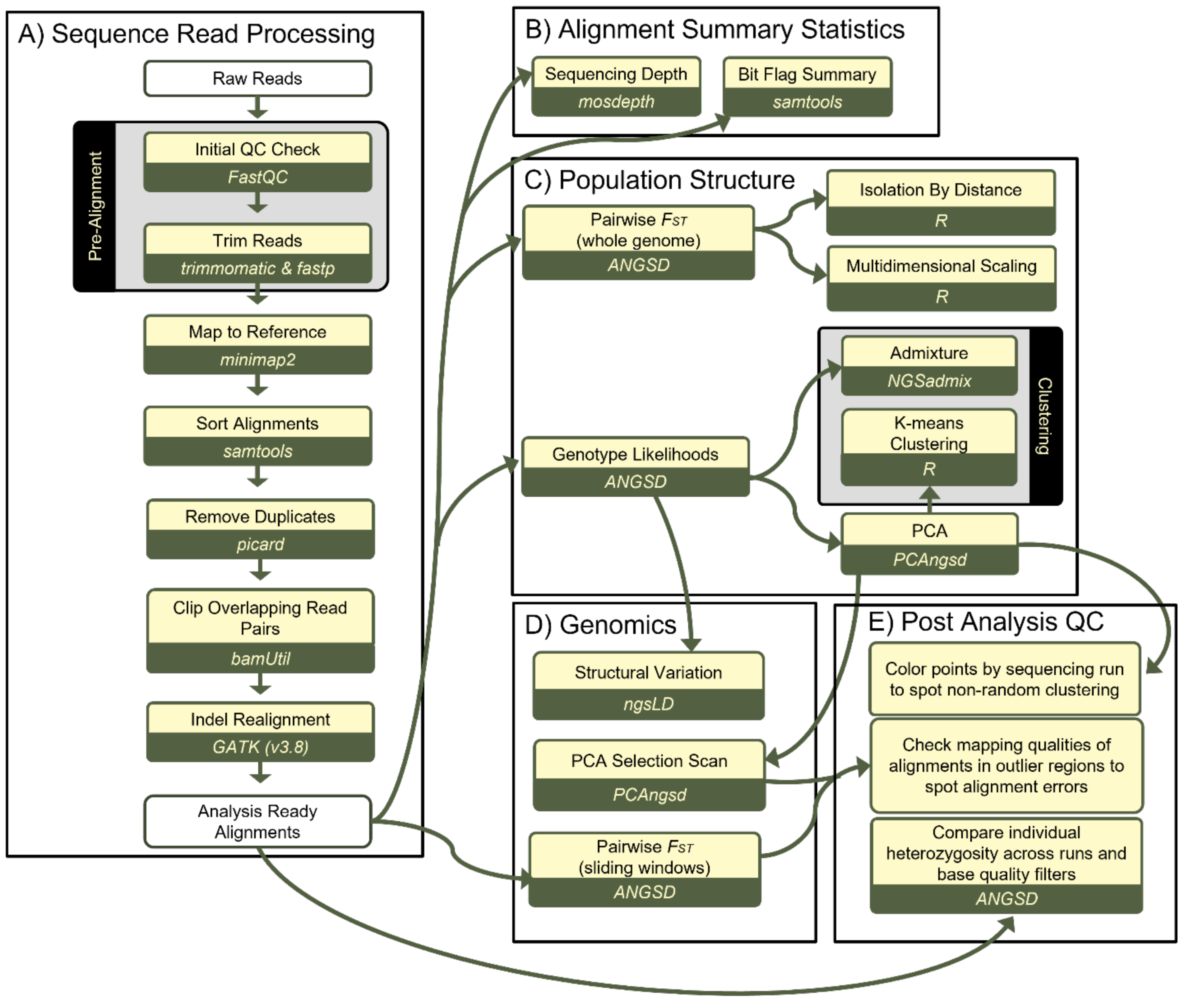

Figure 1. Proposed bioinformatic workflow for the interrogation of low-coverage whole genome sequence data. This diagram tracks the flow of data through the main stages of this project, (A) raw sequence read processing, (B) alignment summaries, (C) analysis of population structure, (D) genomic analyses, and (E) quality control steps to be taken.

5.1.2.3. <u>Analysis</u>. Genotype likelihoods will be estimated from the low-coverage data (Figure 1C) using GATK model implemented in ANGSD (Korneliussen, Albrechtsen, & Nielsen, 2014). This model assumes that sequencing errors are independent at a given site and the base quality scores accurately reflect the probability of sequencing error. This is in contrast to the other models implemented in ANGSD which may fail to correctly identify low frequency mutations and classify them as sequencing errors instead (Lou &

Therkildsen, 2021). Sites will be retained that have a minimum minor allele frequency of 0.01, have a high confidence of being variable ($p \geq 1e-6$), covered by at least one read in 75% (≥ 450) of individuals. A maximum depth threshold of 3,600 will also be applied to reduce calling SNPs from reads that may have mapped to poorly assembled repetitive regions in the genome. Following Clucas, Lou, Therkildsen, and Kovach (2019), this threshold was chosen as twice the average sequencing depth of 3x multiplied by the number of samples.

5.1.2.4. Population Genetics & Structure. To quantify the level of differentiation among these sample collections, pairwise F_{ST} will be estimated using two-dimensional site frequency spectra (SFS) for population pairs (Figure 1C). The site frequency spectra will be calculated for all sites in ANGSD using the GATK model for genotype likelihood estimation and supplying the Pacific halibut reference genome as ancestral. The realSFS tool included with ANGSD will then be used to perform the calculation of F_{ST}. We propose to compare estimates among all sample areas (all collection years combined), areas within sampling years, and examine genetic change over time within specific areas by examining comparisons across collection years. Multidimensional scaling will be used to visualize these comparisons (Figure 1C). To examine patterns of isolation by distance (Figure 1C), a Mantel test will be used to test for a correlation between genetic and geographic distance.

Individual based methods that do not rely on *a priori* population groupings will also be used to investigate population structure. PCAngsd (Meisner & Albrechtsen, 2018) will be used to conduct principal component analysis (PCA), sites with a minor allele frequency ≥ 0.05 will be removed prior to conducting PCA (Figure 1C). The resulting principal component scores will be used as input for unsupervised clustering methods (e.g. k-means clustering) to identify groupings in the data (Figure 1C). Additionally, NGSadmix (Skotte, Korneliussen, & Albrechtsen, 2013) will be used to estimate individual ancestry coefficients and identify genetically homogeneous groups within the data (Figure 1C).

5.1.2.5. Genomics. Genome scans will also be conducted to identify regions of the genome that may be under selection. Pairwise F_{ST} will be calculated in a sliding window fashion across the genome from the two-dimensional SFS previously. We propose to use the realSFS utility to report F_{ST} values in overlapping 15 Kb windows with a 7.5 Kb step (Figure 1D). PCAngsd also implements a PCA based selection scan (Meisner, Albrechtsen, & Hanghj, 2021) and we propose to use the FastPCA model to complement the F_{ST} based selection scans (Figure 1D). Additionally, we will estimate intrachromosomal pairwise linkage disequilibrium (LD) for each sample collection using ngsLD (Fox, Wright, Fumagalli, & Vieira, 2019) (Figure 1D). This may point to stock specific structural variation (e.g. inversions) present in the genome that may be useful in stock delineation.

5.1.2.6. Post Analysis QC. We also intend to conduct additionally quality checks recommended by Lou and Therkildsen (2021) to ensure integrity of the data following the alignment of the raw reads to the genome and the proposed analyses (Figure 1E). To ensure that base quality scores are calibrated correctly among the sequencing runs, estimates of individual genome wide heterozygosity will be compared using relaxed (Q20) and stringent (Q33) base quality filtering thresholds. The outcome of this analysis will also help determine an appropriate base quality threshold to use for genotype likelihood estimation. This will be performed on a subset of samples within each run (e.g. 50) to save on computational resources. To determine whether differences in data quality among the sequencing runs represent a major source of variation in the data, individual points in the PCA plot will be colored by sequencing run and a visual inspection will be made. To ensure that any outlier regions identified are not an artifact of alignment errors, we will check the mapping qualities of reads in these regions. If a large number of low quality reads are mapping to these regions, alignment artifacts may be likely. Lou and Therkildsen (2021) offer a comprehensive set of suggestions for the mitigation of various sources of technical bias in low-coverage whole genome resequencing datasets and other suggestions will be implemented as needed.

5.1.2.7. Application to SA & MSE. Results from previous genetic studies have suggested that fish in the western Aleutian Islands may be genetically distinct from the rest of the stock (Drinan, et al, 2016). A distinct genetic stock in this region would have implications for the stock assessment and management of Pacific halibut in this area. An accurate understanding of stock structure is necessary for effective fisheries management and stock assessment, therefore, the analysis of population structure outlined here is intended to provide a tool that will advance our current understanding of Pacific halibut population structure using modern, high resolution genomic technology. Additionally, the IPHC Secretariat plans to leverage this genomic resource to explore the development of tools to address specific questions regarding stock specific harvest and movement rates among fisheries and regulatory areas, both of which are relevant to stock assessment and MSE efforts. In addition to the management implications of this work highlighted in the heading of section 5, spatial dynamics represent a major source of uncertainty in the Pacific halibut assessment and are, therefore, a research area of high priority.

6. Whale depredation avoidance strategies. The IPHC Secretariat has determined that research to provide the Pacific halibut fishery with tools to reduce whale depredation is considered a high priority. This research is now contemplated as one of the research areas of high priority within the 5-year Program of Integrated Research and Monitoring (2022-2026). Towards this goal, the IPHC secretariat has recently obtained funding from NOAA's Bycatch Research and Engineering Program (BREP) to investigate gear-based approaches to catch protection as a means for minimizing whale depredation in the Pacific halibut and other longline fisheries (NOAA Award NA21NMF4720534; Appendix IV). The objectives of this study are to: 1) work with fishermen and gear manufacturers, via direct communication and through an

international workshop, to identify effective methods for protecting hook-captured flatfish from depredation; and 2) develop and pilot test 2-3 simple, low-cost catch-protection designs that can be deployed effectively using current longline fishing techniques and on vessels currently operating in the Northeast Pacific Ocean.

The results and outcome of the first phase of this project were reported in the documentation to the previous SRB meeting: IPHC-2022-SRB020-08.

During the second phase of the project, the IPHC Secretariat has worked with catch protection device manufacturers for the design of two different types of devices for field testing: one based on a modification of Sago's catch protection device (i.e. shuttle) and one based on a modification of a slinky pot. These two devices are currently being manufactured and will be tested on a chartered fishing vessel off a port in Alaska (to be determined) in the Spring of 2023.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2022-SRB021-09 which provides a response to requests from SRB020, and a report on current research activities contemplated within the IPHC's five-year Program of Integrated Research and Monitoring (2022-2026).

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APPENDIX I

Integration of biological research, stock assessment and harvest strategy policy (2017-21)

Biological research		Stock assessment	Stock assessment MSE
Research areas	**Research outcomes**	**Relevance for stock assessment**	**Inputs to stock assessment and MSE development**
Reproduction	Sex ratio Spawning output Age at maturity	Spawning biomass scale and trend Stock productivity Recruitment variability	Sex ratio Maturity schedule Fecundity
Growth	Identification of growth patterns Environmental effects on growth Growth influence in size-at-age variation	Temporal and spatial variation in growth Yield calculations Effects of ecosystem conditions Effects of fishing	Predicted weight-at-age Mechanisms for changes in weight-at-age
Discard Survival	Bycatch survival estimates Discard mortality rate estimates	Scale and trend in mortality Scale and trend in productivity	Bycatch and discard mortality estimates Variability in bycatch and uncertainty in discard mortality estimates
Migration	Larval distribution Juvenile and adult migratory behavior and distribution	Geographical selectivity Stock distribution	Information for structural choices Recruitment indices Migration pathways and rates Timing of migration
Genetics and Genomics	Genetic structure of the population Sequencing of the Pacific halibut genome	Spatial dynamics Management units	Information for structural choices

APPENDIX II

List of ranked biological uncertainties and parameters for stock assessment (SA) and their links to potential research areas and research activities (2017-21)

SA Rank	Research outcomes	Relevance for stock assessment	Specific analysis input	Research Area	Research activities
1. Biological input	Updated maturity schedule	Scale biomass and reference point estimates	Will be included in the stock assessment, replacing the current schedule last updated in 2006	Reproduction	Histological maturity assessment
	Incidence of skip spawning		Will be used to adjust the asymptote of the maturity schedule, if/when a time-series is available this will be used as a direct input to the stock assessment		Examination of potential skip spawning
	Fecundity-at-age and -size information		Will be used to move from spawning biomass to egg-output as the metric of reproductive capability in the stock assessment and management reference points		Fecundity assessment
	Revised field maturity classification		Revised time-series of historical (and future) maturity for input to the stock assessment		Examination of accuracy of current field macroscopic maturity classification
2. Biological input	Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area	Altered structure of future stock assessments	If 4B is found to be functionally isolated, a separate assessment may be constructed for that IPHC Regulatory Area	Genetics and Genomics	Population structure
3. Biological input	Assignment of individuals to source populations and assessment of distribution changes	Improve estimates of productivity	Will be used to define management targets for minimum spawning biomass by Biological Region		Distribution
	Improved understanding of larval and juvenile distribution		Will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region	Migration	Larval and juvenile connectivity studies
1. Assessment data collection and processing	Sex ratio-at-age	Scale biomass and fishing intensity	Annual sex-ratio at age for the commercial fishery fit by the stock assessment	Reproduction	Sex ratio of current commercial landings
	Historical sex ratio-at-age		Annual sex-ratio at age for the commercial fishery fit by the stock assessment		Historical sex ratios based on archived otolith DNA analyses
2. Assessment data collection and processing	New tools for fishery avoidance/deterence; improved estimation of depredation mortality	Improve mortality accounting	May reduce depredation mortality, thereby increasing available yield for directed fisheries. May also be included as another explicit source of mortality in the stock assessment and mortality limit setting process depending on the estimated magnitude	Mortality and survival assessment	Whale depredation accounting and tools for avoidance
1. Fishery yield	Physiological and behavioral responses to fishing gear	Reduce incidental mortality	May increase yield available to directed fisheries	Mortality and survival assessment	Biological interactions with fishing gear
2. Fishery yield	Guidelines for reducing discard mortality	Improve estimates of unobserved mortality	May reduce discard mortality, thereby increasing available yield for directed fisheries	Mortality and survival assessment	Best handling practices: recreational fishery

APPENDIX III

List of ranked biological uncertainties and parameters for management strategy evaluation (MSE) and their potential links to research areas and research activities (2017-21)

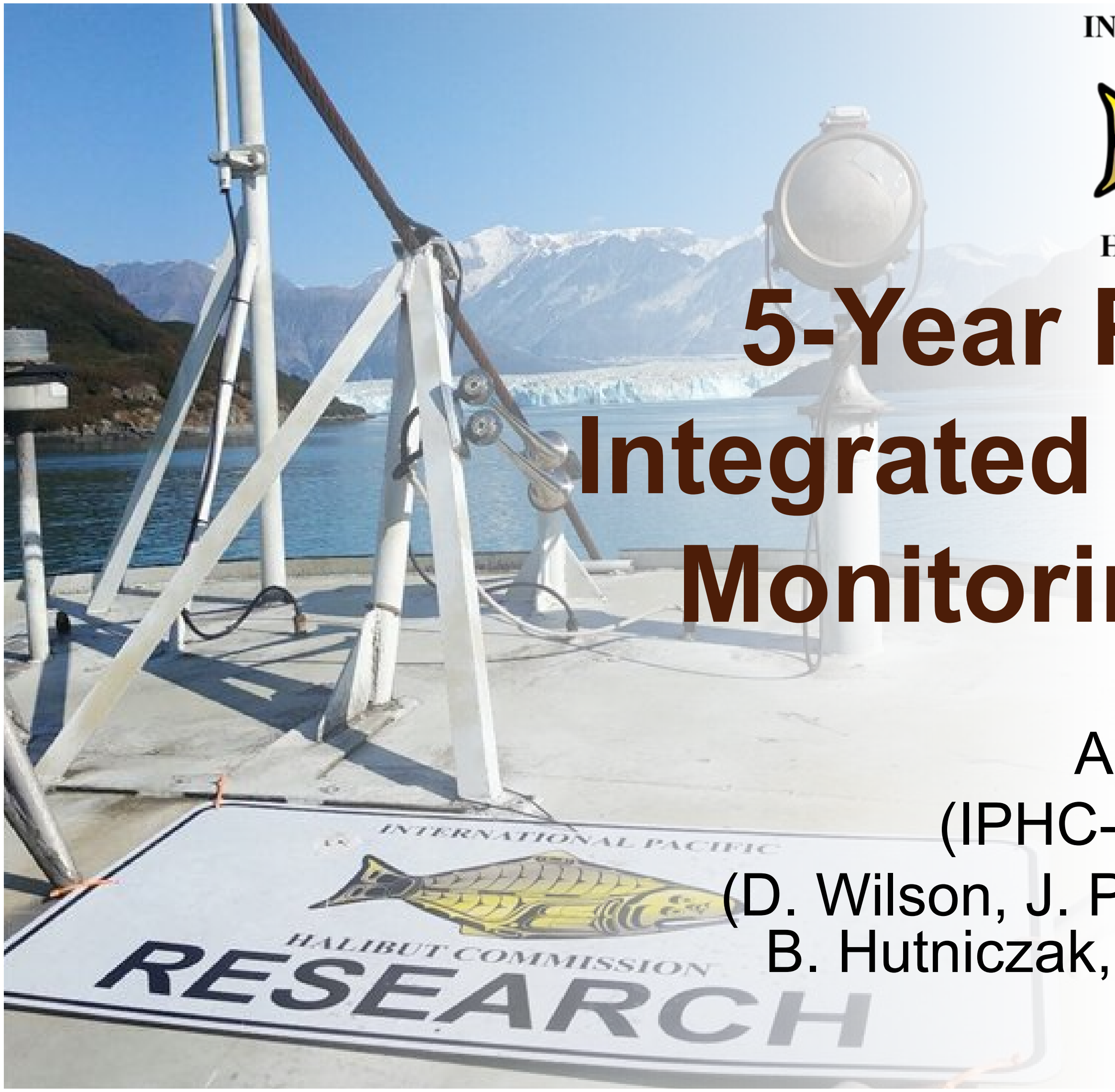
MSE Rank	Research outcomes	Relevance for MSE	Research Area	Research activities
1. Biological parameterization and validation of movement estimates	Improved understanding of larval and juvenile distribution	Improve parametization of the Operating Model	Migration	Larval and juvenile connectivity studies
	Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area		Genetics and Genomics	Population structure
2. Biological parameterization and validation of recruitment variability and distribution	Assignment of individuals to source populations and assessment of distribution changes	Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model		Distribution
	Establishment of temporal and spatial maturity and spawning patterns	Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model	Reproduction	Recruitment strength and variability
3. Biological parameterization and validation for growth projections	Identification and application of markers for growth pattern evaluation	Improve simulation of variability and allow for scenarios investigating climate change	Growth	Evaluation of somatic growth variation as a driver for changes in size-at-age
	Environmental influences on growth patterns			
	Dietary influences on growth patterns and physiological condition			
1. Fishery parameterization	Experimentally-derived DMRs	Improve estimates of stock productivity	Mortality and survival assessment	Discard mortality rate estimate: recreational fishery

APPENDIX IV
Summary of active research grants

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**Bycatch Reduction Engineering Program - NOAA**	Gear-based approaches to catch protection as a means for minimizing whale depredation in longline fisheries (NA21NMF4720534)	IPHC	Deep Sea Fishermen's Union, Alaska Fisheries Science Center-NOAA, industry representatives	$99,700	Mortality estimations due to whale depredation	November 2021 – October 2022
2	**North Pacific Research Board**	Pacific halibut population genomics (NPRB No. 2110)	IPHC	Alaska Fisheries Science Center-NOAA	$193,685	Stock structure	December 2021- January 2024
Total awarded ($)					**$293,385**		

INTERNATIONAL PACIFIC
HALIBUT COMMISSION

5-Year Program of Integrated Research and Monitoring (2022-26)

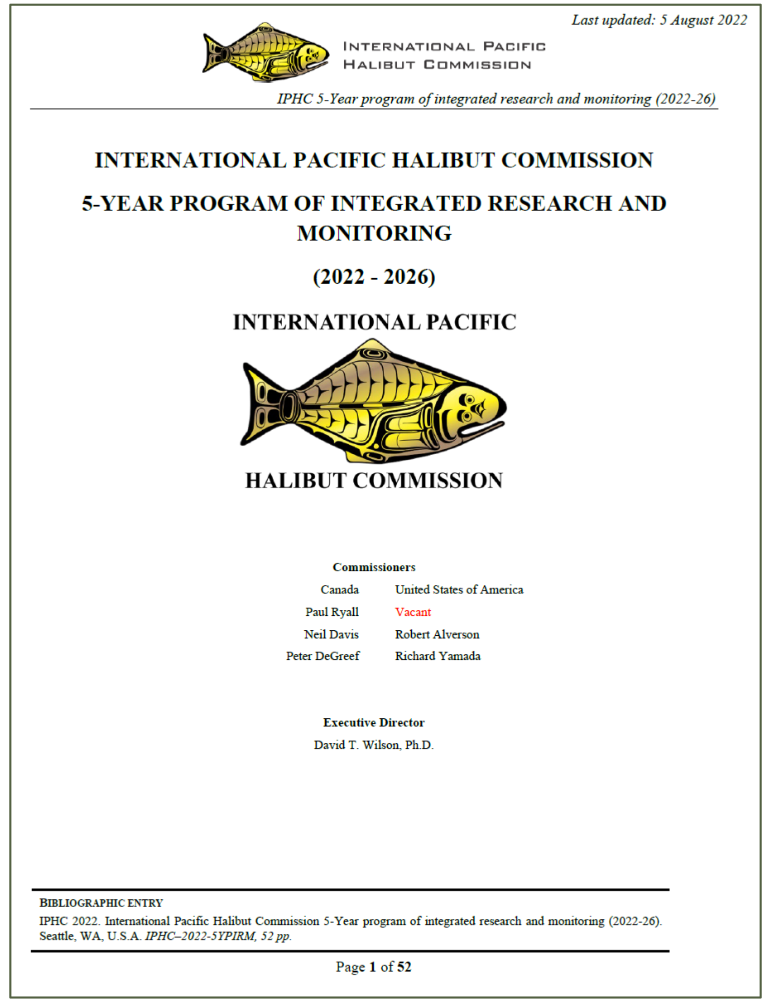


Agenda Item 4
(IPHC-2022-SRB021-05)

(D. Wilson, J. Planas, I. Stewart, A. Hicks, B. Hutniczak, R. Webster, & J. Jannot)

Purpose

- To provide the SRB with the IPHC 5-year Program of Integrated Research and Monitoring (2022-26)


Last updated: 5 August 2022

INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC 5-Year program of integrated research and monitoring (2022-26)

INTERNATIONAL PACIFIC HALIBUT COMMISSION

5-YEAR PROGRAM OF INTEGRATED RESEARCH AND MONITORING

(2022 - 2026)

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

Commissioners

Canada	United States of America
Paul Ryall	Vacant
Neil Davis	Robert Alverson
Peter DeGreef	Richard Yamada

Executive Director

David T. Wilson, Ph.D.

BIBLIOGRAPHIC ENTRY

IPHC 2022. International Pacific Halibut Commission 5-Year program of integrated research and monitoring (2022-26). Seattle, WA, U.S.A. *IPHC–2022-5YPIRM, 52 pp.*

Page **1** of **52**

Background

Recalling that:

a) the IPHC Secretariat conducts activities to address key issues identified by the Commission, its subsidiary bodies, the broader stakeholder community, and the IPHC Secretariat;

b) the process of identifying, developing, and implementing the IPHC's science-based activities involves several steps that are circular and iterative in nature, but result in clear project activities and associated deliverables;

c) the process includes developing and proposing projects based on direct input from the Commission, the experience of the IPHC Secretariat given its broad understanding of the resource and its associated fisheries, and concurrent consideration by relevant IPHC subsidiary bodies, and where deemed necessary, including by the Commission, additional external peer review;

d) the IPHC Secretariat commenced implementation of the new Plan in 2022 and will keep the Plan under review on an ongoing basis.

Background

The SRB should RECALL that:

a) the intention is to ensure that the new integrated plan is kept as a ‘*living plan*’, and is reviewed and updated at least annually based on the resources available to undertake the work of the Commission (e.g. internal and external fiscal resources, collaborations, internal expertise);

b) the plan focuses on core responsibilities of the Commission, and any redirection provided by the Commission;

c) each year the SRB may choose to recommend modifications to the current Plan, and that any modifications subsequently made would be documented both in the Plan itself, and through reporting back to the SRB and then the Commission.

The Plan

- An overarching goal of the IPHC 5-year Program of Integrated Research and Monitoring (2022-26) is to:
  - promote integration and synergies among the various research and monitoring activities of the IPHC Secretariat in order to improve knowledge of key inputs into:
    - the Pacific halibut stock assessment; and
    - Management Strategy Evaluation (MSE) processes;
    - thereby providing the best possible advice for management decision making processes.

The Plan

Along with the implementation of the short- and medium-term activities contemplated in the *IPHC 5-Year Program of Integrated Research and Monitoring (2022-26)*, and in pursuit of our overarching objective, the IPHC Secretariat will also aim to:

1) undertake cutting-edge research programs in fisheries research in support of Pacific halibut fisheries management;
2) undertake groundbreaking methodological research;
3) undertake applied research;
4) establish new collaborative agreements and interactions with research agencies and academic institutions;
5) promote the international involvement of the IPHC by continued and new participation in international scientific organizations and by leading international science and research collaborations;
6) effectively communicate IPHC research outcomes;
7) incorporate talented students and early researchers in research activities contemplated.

The Plan

The research and monitoring activities conducted by the IPHC Secretariat are directed towards fulfilling objectives within the following areas:

- data collection,
- biological and ecological research,
- stock assessment, and
- Management Strategy Evaluation (MSE).

In addition, the IPHC responds to Commission requests for additional inputs to management and policy development which are classified under management support.

The Plan

The overall aim is to provide a program of integrated research and monitoring:

Research

Stock assessment: apply the resulting knowledge to improve the accuracy and reliability of the current stock assessment and the characterization of uncertainty in the resultant stock management advice provided to the Commission;

Management Strategy Evaluation (MSE): to develop an accurate, reliable, and informative MSE process to appropriately characterize uncertainty and provide for the robust evaluation of the consequences of alternative management options, known as harvest strategies, using defined conservation and fishery objectives;

Biology and Ecology: identify and assess critical knowledge gaps in the biology and ecology of Pacific halibut within its known range, including the influence of environmental conditions on population and fishery dynamics;

Monitoring

Monitoring: collect representative fishery dependent and fishery-independent data on the distribution, abundance, biology, and demographics of Pacific halibut through ongoing monitoring activities;

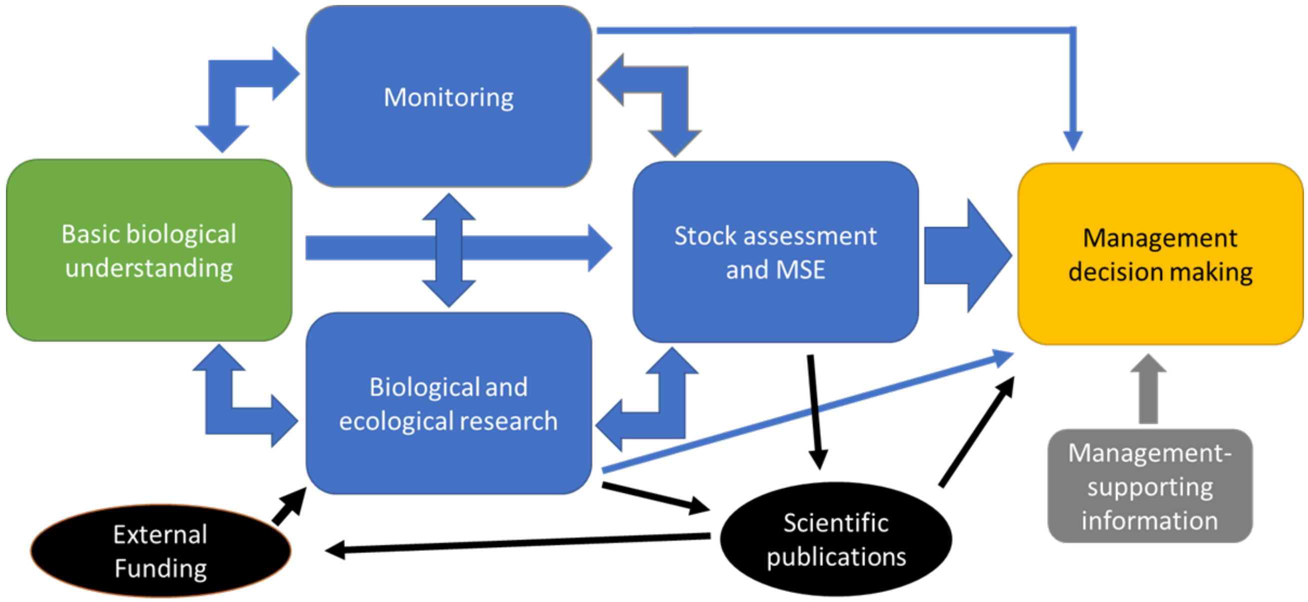
Integrated management support

Additional inputs: respond to Commission requests for any additional information supporting management and policy development.

The Plan

The Secretariat's success in implementing the IPHC 5-Year Program of Integrated Research and Monitoring (2022-26) will be measured according to the following criteria relevant to the stock assessment, the MSE and for all inputs to IPHC management:

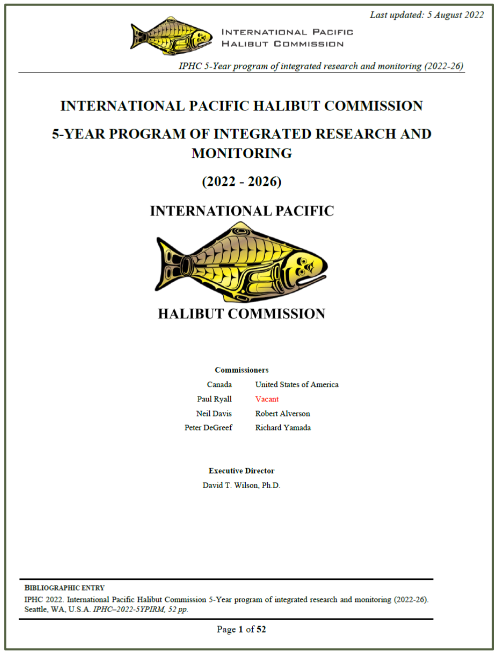
1) Timeliness – was the research conducted, analyzed, published, and provided to the Commission at the appropriate points to be included in annual management decisions?
2) Accessibility – was the research published and presented in such a way that it was available to other scientists, stakeholders, and decision-makers?
3) Relevance – did the research improve the perceived accuracy of the stock assessment, MSE, or decisions made by the Commission?
4) Impact – did the research allow for more precision or a better estimate of the uncertainty associated with information for use in management?
5) Reliability – has research resulted in more consistent information provided to the Commission for decision-making.



Flow of information from basic biological understanding of the Pacific halibut resource, through IPHC research components (monitoring, biological and ecological research, stock assessment, and MSE) to management decision-making. Management-supporting information (grey) constitute a range of additional decision-making drivers within and beyond IPHC's current research and monitoring programs. Arrows indicate the strength (size of the arrow) and direction of information exchange. Also identified (in black) are the external links from funding and scientific publications which supplement the IPHC's internal process.

Recommendation

That the SRB **NOTE** paper IPHC-2022-SRB021-05 which provides the IPHC 5-year program of Integrated Research and Monitoring (2022-26).


Last updated: 5 August 2022

INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC 5-Year program of integrated research and monitoring (2022-26)

INTERNATIONAL PACIFIC HALIBUT COMMISSION

5-YEAR PROGRAM OF INTEGRATED RESEARCH AND MONITORING

(2022 - 2026)

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

Commissioners

Canada	United States of America
Paul Ryall	Vacant
Neil Davis	Robert Alverson
Peter DeGreef	Richard Yamada

Executive Director

David T. Wilson, Ph.D.

BIBLIOGRAPHIC ENTRY

IPHC 2022. International Pacific Halibut Commission 5-Year program of integrated research and monitoring (2022-26). Seattle, WA, U.S.A. *IPHC–2022-5YPIRM, 52 pp.*

Page **1** of **52**

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2023-25 FISS design evaluation

Agenda item 5
IPHC-2022-SRB021-06
(R. Webster)

Topics

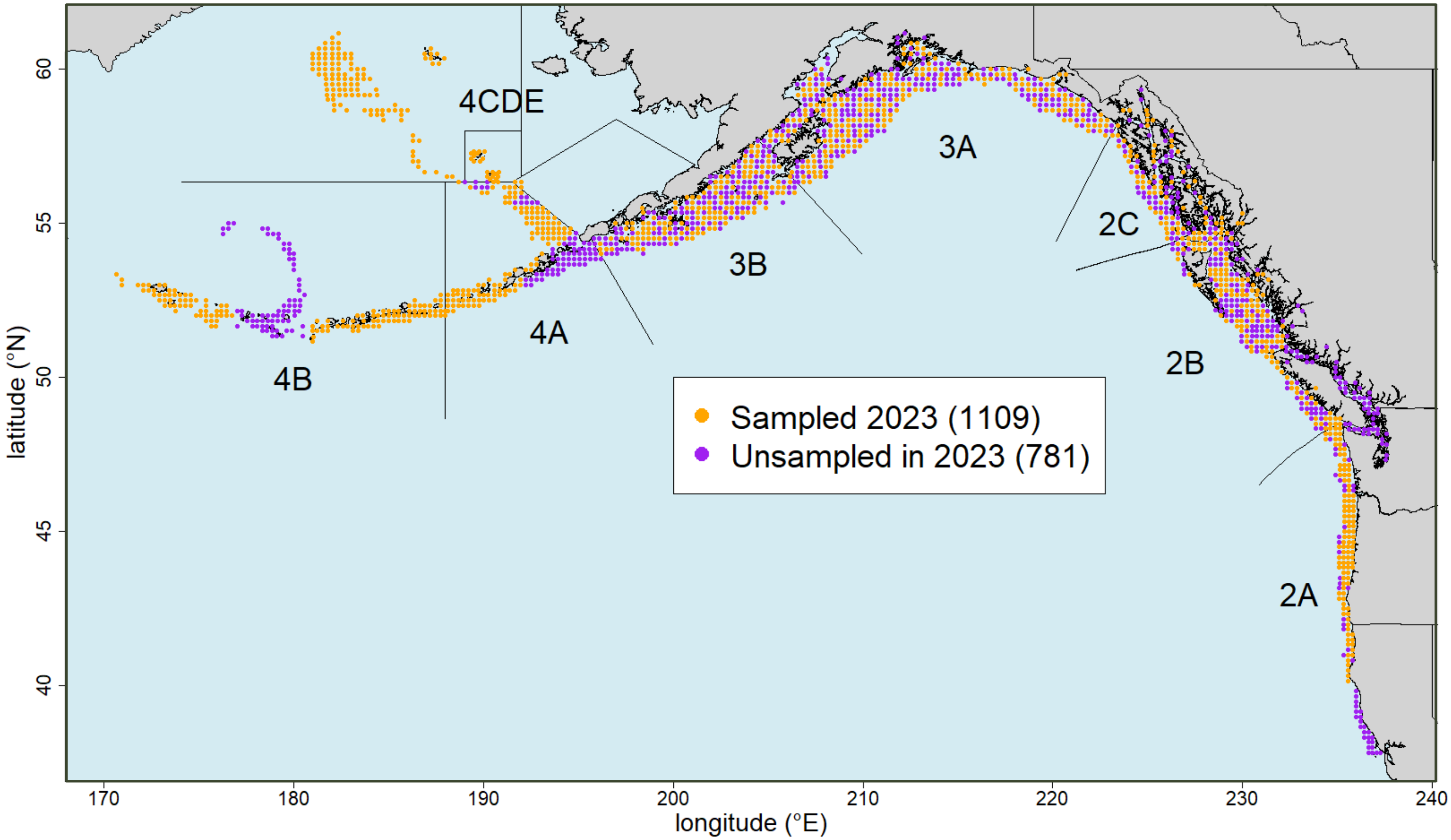
1. 2023-25 FISS design evaluation
2. Bering Sea model update
3. Bias evaluation methodology

1. 2023-25 FISS design evaluation

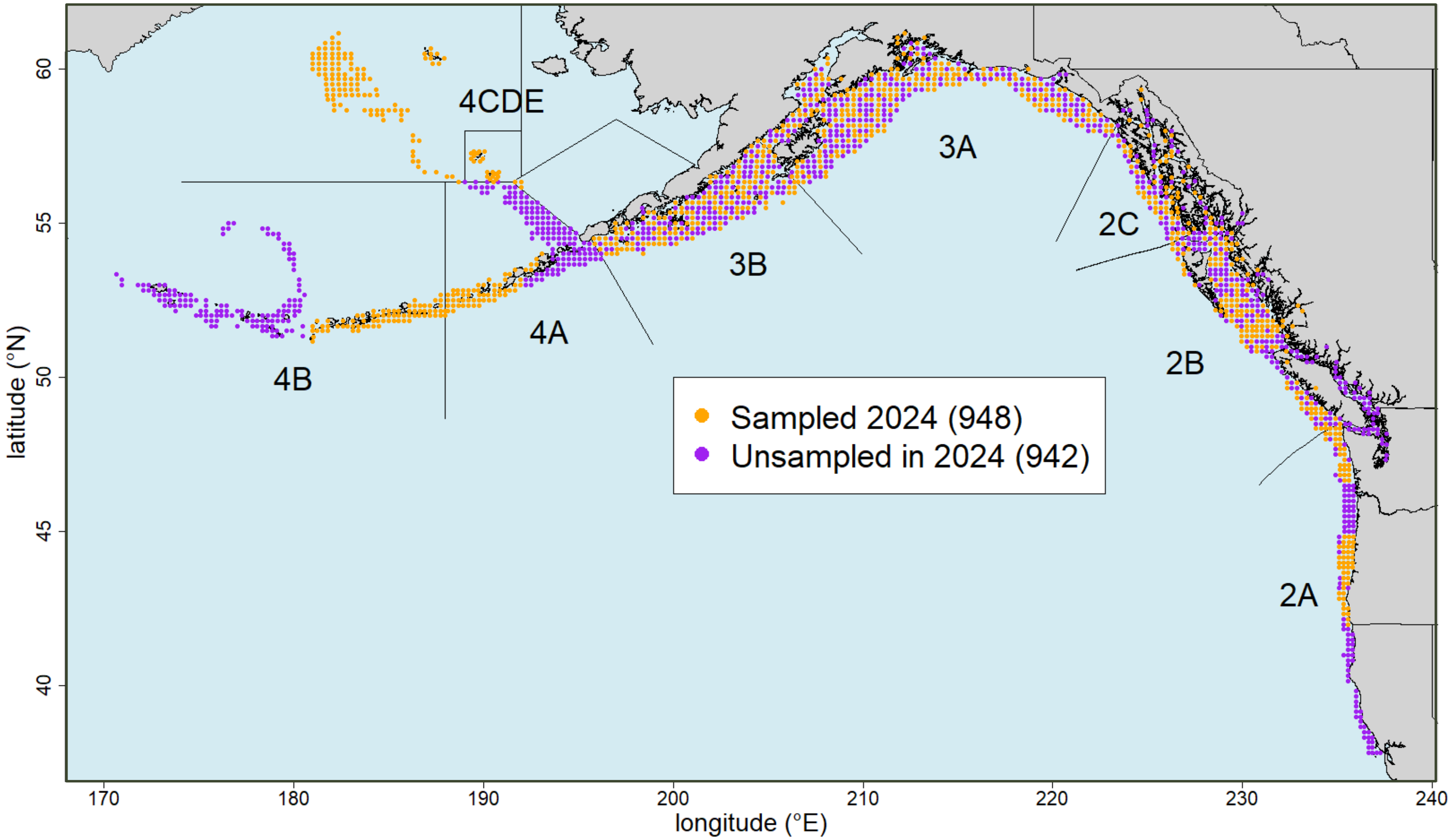
- At SRB020, the Secretariat presented proposed FISS designs for 2023-25 together with an evaluation of those designs.
- Based on the evaluation, it is expected that the proposed designs would lead to estimated indices of density that would meet bias and precision criteria.
- In their report (IPHC-2022-SRB020-R, paragraph 12) the SRB stated:

> *The SRB* ***ENDORSED*** *the final 2023 FISS design as presented in Fig. 2, and provisionally* ***ENDORSED*** *the 2024-25 designs (Figs. 3 and 4), recognizing that these will be reviewed again at subsequent SRB meetings.*

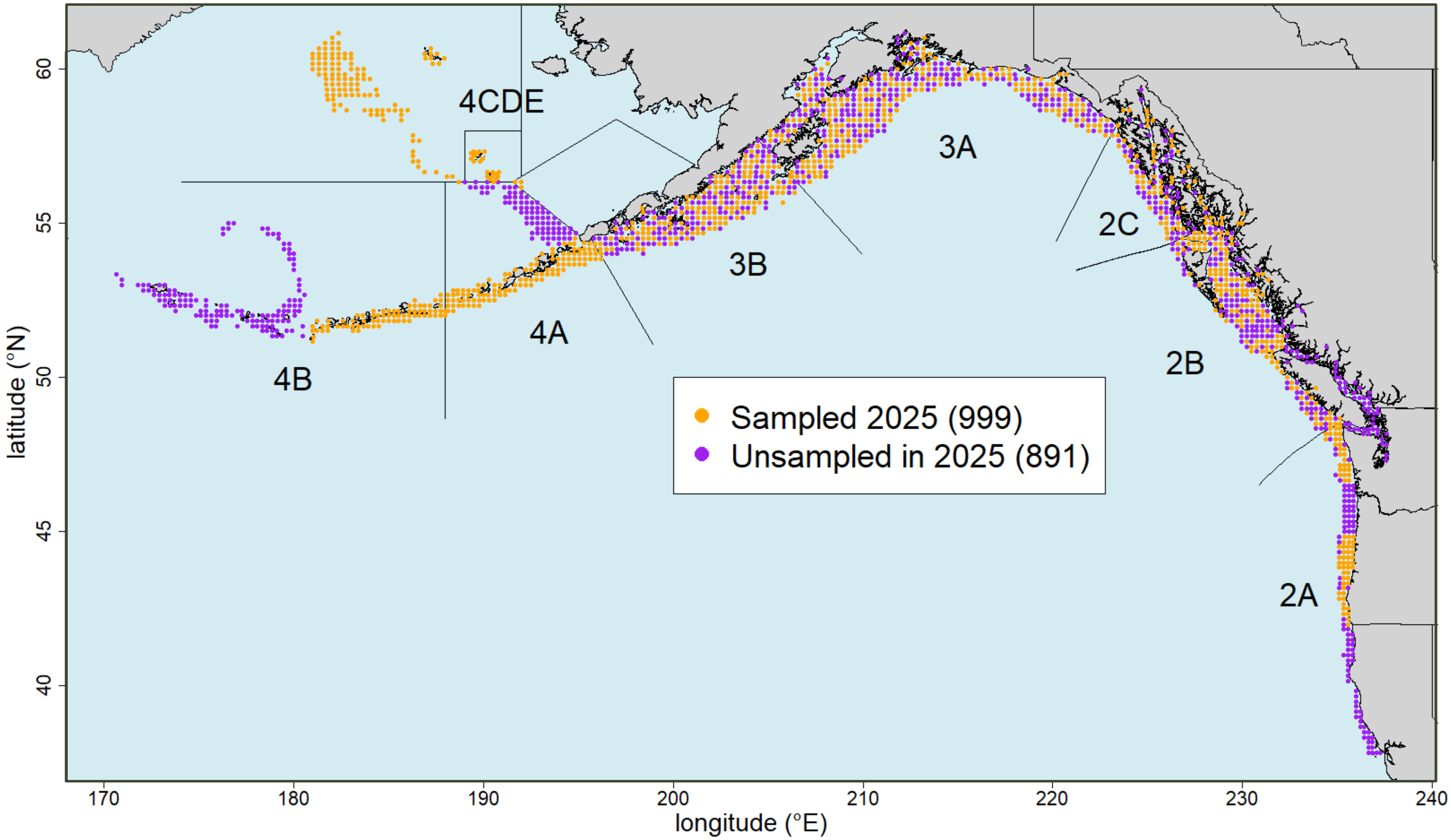
Proposed 2023 FISS design



Proposed 2024 FISS design



Proposed 2025 FISS design



Recommendation

That the Scientific Review Board:

1) **RECOMMEND** that the Commission note the SRB endorsement of the proposed 2022 design (Figure 1.1 of IPHC-2022-SRB021-06) and provisional endorsement of the proposed 2024-25 designs (Figures 1.2 and 1.3).

2. Bering Sea model update

- NMFS trawl to FISS calibration study conducted in 2006 and 2015 when surveys overlapped in eastern Bering Sea.
- Once a length calibration has been undertaken, the calibrated trawl index is scaled to have the same lb/skate units as FISS.
- Scale factors have been estimated external to the space-time modelling of combined FISS and trawl data.
- A single scale factor is estimated for each variable: O32 WPUE, all sizes WPUE and all sizes NPUE.
- Scalars are assumed known: no variance is propagated into the space-time model estimates.

Estimating gear scaling within the model

- The space-time model separates the WPUE or NPUE process into zero and non-zero components.
- Gear (calibrated trawl, setline) coefficients can be added to each model component to account for differences in index values due to gear effects.

Variable	Description	Zero parameter	Non-zero parameter
Gear type	1=trawl, 0=FISS	g_z	g_{nz}
Calibration stations (overlapping trawl and FISS 2006, 2015 stations)	1=calibration, 0 otherwise	c_z	c_{nz}
Interaction (trawl stations within the calibration study)	1=trawl calibration, 0 otherwise	gc_z	gc_{nz}

Parameter estimates

- Estimates for trawl effect parameters:

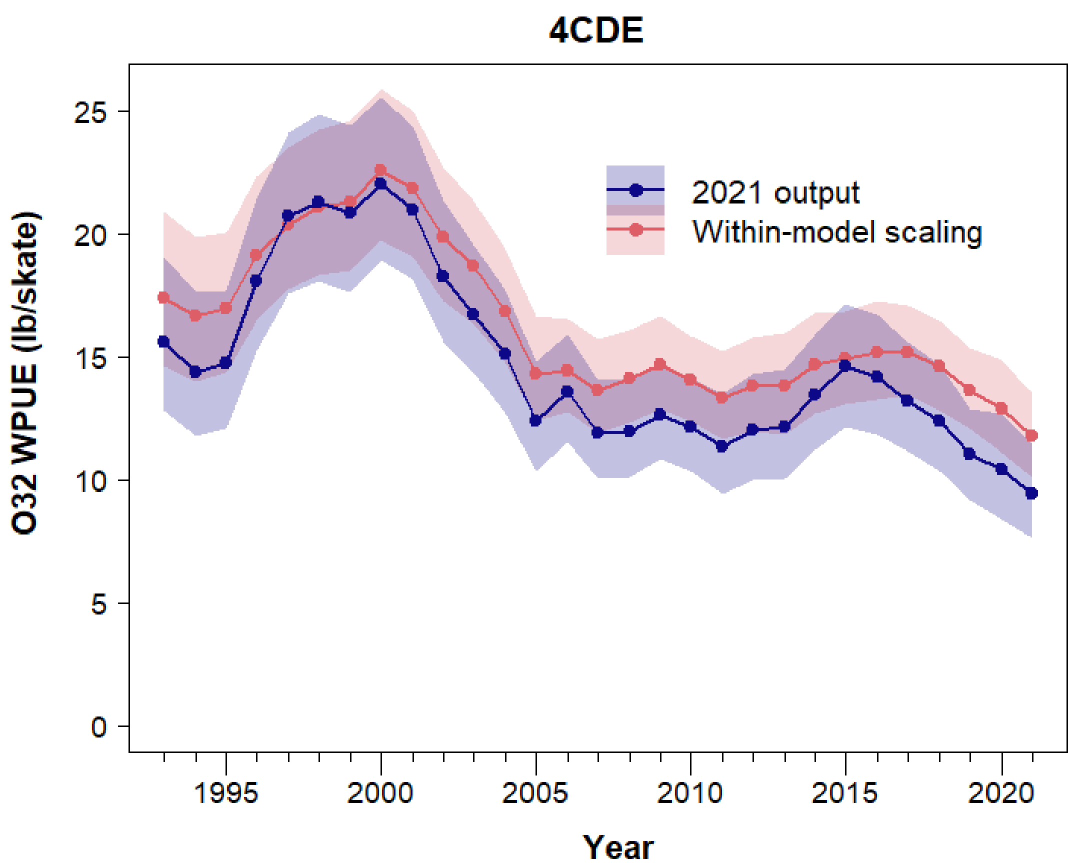
Parameter	Posterior mean (SD)	Parameter	Posterior mean (SD)
g_z	−3.095 (0.130)	g_{nz}	−3.315 (0.050)
gc_z	0.999 (0.265)	gc_{nz}	0.494 (0.117)

- This leads to these estimated scale effects:
  - 8.1 for zeros, meaning odds of non-zeros is ~8 times greater on FISS than trawl
  - 16.8 for non-zeros, meaning when fish are caught, the index value is ~17 times greater on the FISS than the trawl survey

Parameter estimates

- These values are generally consistent with the scale factor of 37 applied to all calibrated trawl values (zeros and non-zeros) outside of the model for O32 WPUE
  - The calibrated trawl index needs to be scaled up to match the units of the FISS index
- However, treating the zero-model component separately affects how zeros are handled:
  - The trawl survey has a higher proportion of zero values than the FISS
  - This is ignored when scaling all data by the same factor outside the model: 37 times 0 is still zero, and the model treats data from both gears as coming from the same process
  - By including the gear difference within the model, we allow the probability of a zero to be vary with gear type, and thus this probability gets adjusted when undertaking prediction (when values are predicted assuming FISS gear only)
  - This has an impact on the time series, especially when there are no FISS sets among the trawl sets (i.e., outside of 2006 and 2015) and when zeros are more common on the trawl (i.e., in years with lower Pacific halibut density)

Revised O32 time series for 4CDE



Comments

- Estimating gear differences within the model adds flexibility that better allows for differences in the data generating processes for each gear type.
- Our intention is to use this revised model for estimating the Regulatory Area 4CDE time series
- Some calibrated trawl data are also used in Regulatory Area 4A, but very few values come from the 2006 and 2015 experiment
  - Will continue to use external estimates of scaling factors for this area
- Some technical issues (with revised models crashing) still need to be resolved

3. Bias evaluation methodology

- At present we evaluate bias potential of a possible FISS design as follows:
  - Use space-time model output to estimate time series for each subarea (just for Regulatory Areas 2A, 4A and 4B at present).
  - For each year in each subarea, calculate number of years for a change of at least 10% in proportion of Reg Area’s biomass to have occurred.
  - If *at any point in the time series* the number of years is less than the proposed period since a subarea was last sampled, the possible design is rejected.
- This approach weights all years equally, regardless of how far in the past they are.
- As the time series grows, the chance of a 10% or greater change over a given interval for *at least one year in the time series* increases, i.e., possible designs are more likely to be rejected over time.

Proposed new approach

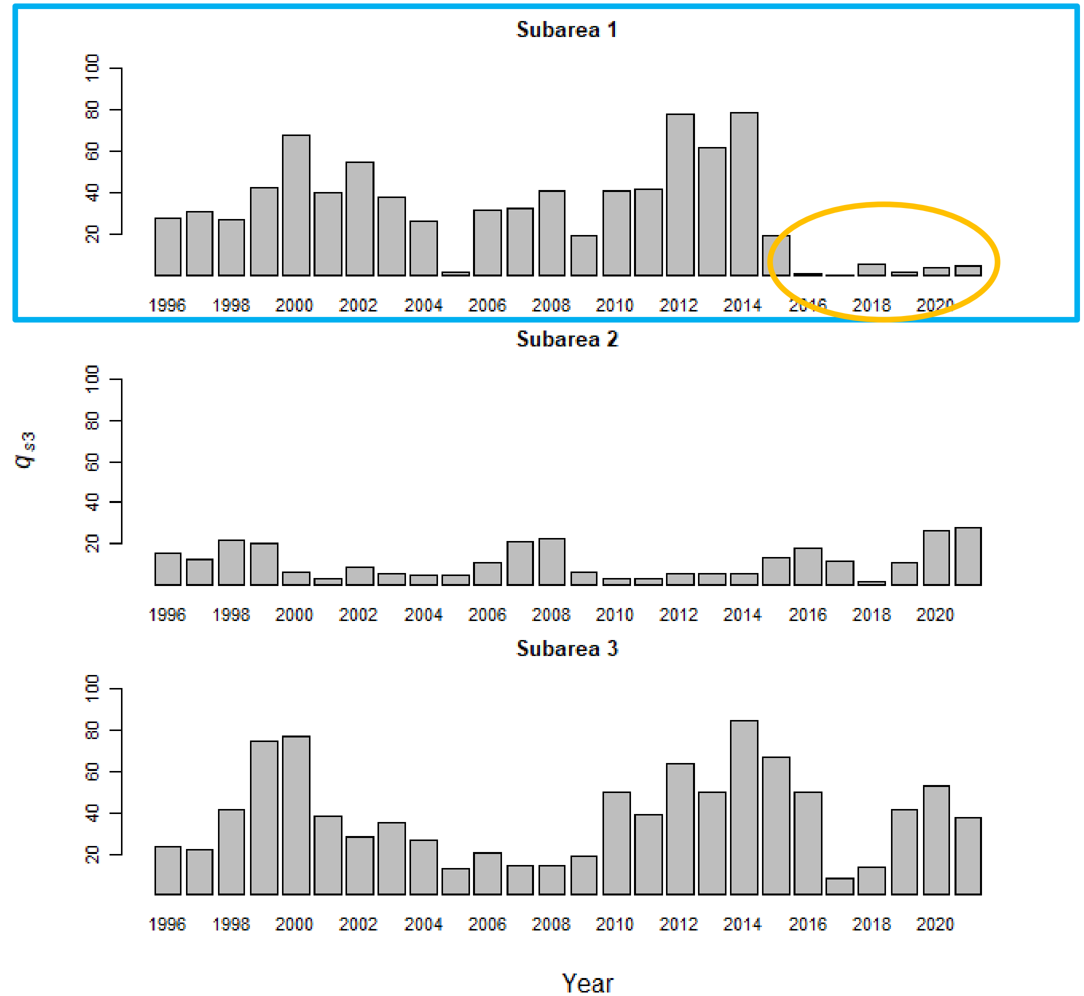
- Use the space-time model output to estimate the probability of at least a 10% change in biomass proportion over a specified time period
  - Do this for each year in each subarea
- Use these probabilities to assess the likelihood of this size of change over a proposed unsampled interval
  - Give greater weight to probabilities from recent years in this evaluation

Example: Subarea 1 in 4B

- This subarea encompasses the western Aleutian Islands.
- Last sampled in 2019, with some stations not sampled since 2017.
- Proposed for sampling in 2022 based on historical time series showing >10% change in biomass proportion over three years at least once in the past.
- No viable bids in 2022; proposed for sampling in 2023, four years since previous survey
- Current bias evaluation assumes high risk of bias based on entire historical time series

Estimated probabilities of at least 10% change in biomass proportion over previous three years.

Low probabilities of large change in recent years



Comments

- Time since high probability of large (>10% biomass) change is easily factored into the evaluation
  – Can focus on probabilities in the most recent years
- Probabilities incorporate uncertainty in the time series
  – For example, lack of sampling increases the variance of WPUE, and this variability propagates into the probabilities of large change

Recommendations

That the Scientific Review Board:

1) **NOTE** paper IPHC-2022-SRB021-06 (part 2) that presents an update to the space-time model for IPHC Regulatory 4CDE, and a proposal for revising the evaluation of bias potential in future FISS design proposals.

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MSE: Update

Agenda Item 6

IPHC-2022-SRB021-07

A. Hicks & I. Stewart

MSE Program of Work 2021-2023

IPHC-2021-MSE-02

ID	Category	Task	Deliverable
F.1	Framework	Develop migration scenarios	Develop OMs with alternative migration scenarios
F.2	Framework	Implementation variability	Incorporate additional sources of implementation variability in the framework
F.3	Framework	Develop more realistic simulations of estimation error	Improve the estimation model to more adequately mimic the ensemble stock assessment
F.5	Framework	Develop alternative OMs	Code alternative OMs in addition to the one already under evaluation.
M.1	MPs	Size limits	Identification, evaluation of size limits
M.3	MPs	Multi-year assessments	Evaluation of multi-year assessments
E.3	Evaluation	Presentation of results	Develop methods and outputs that are useful for presenting outcomes to stakeholders and Commissioners

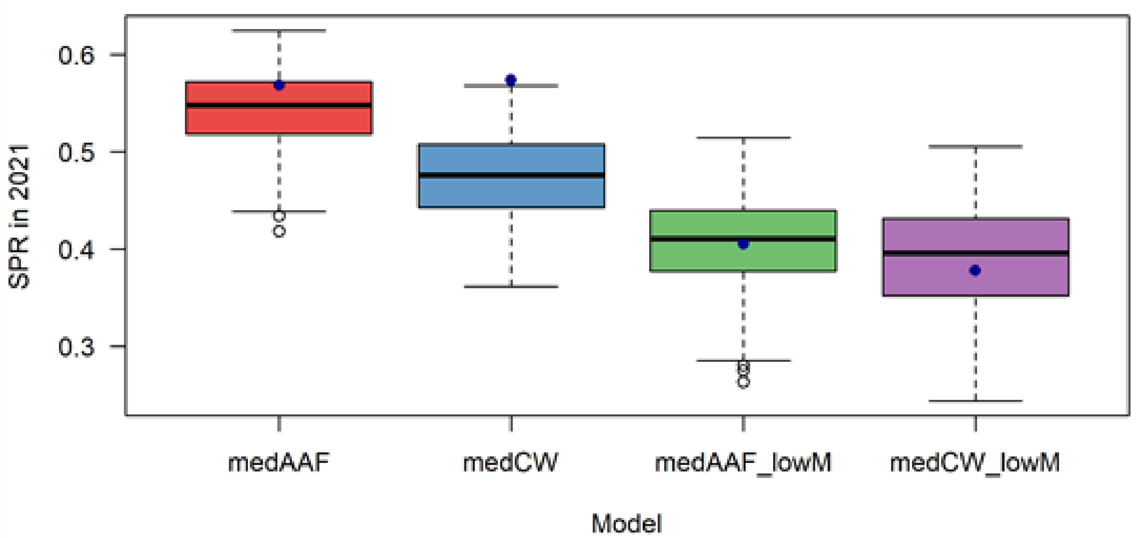
Framework

ID	Category	Task	Deliverable
F.1	Framework	Develop migration scenarios	Develop OMs with alternative migration scenarios
F.5	Framework	Develop alternative OMs	Code alternative OMs in addition to the one already under evaluation.

- Improved OM
  - Four individual models
    - Different natural mortality (high and low)
    - Different resulting migration assumptions
  - Variability in migration rates
  - Incorporates representative uncertainty about the Pacific halibut population

Four models

- Predicted SPR was biased high (lower fishing intensity) compared to assessment

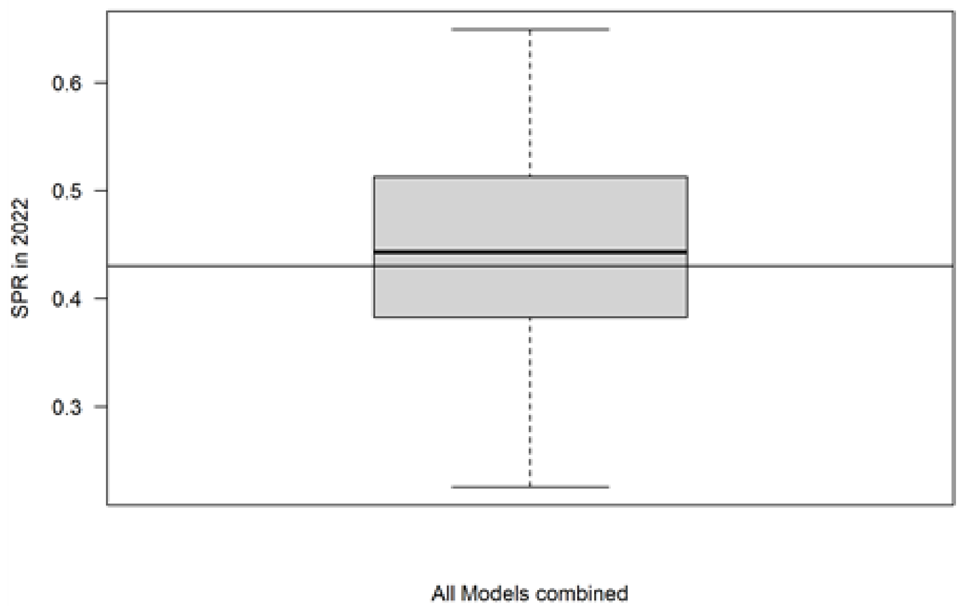


Boxplots are estimated SPR from each OM model

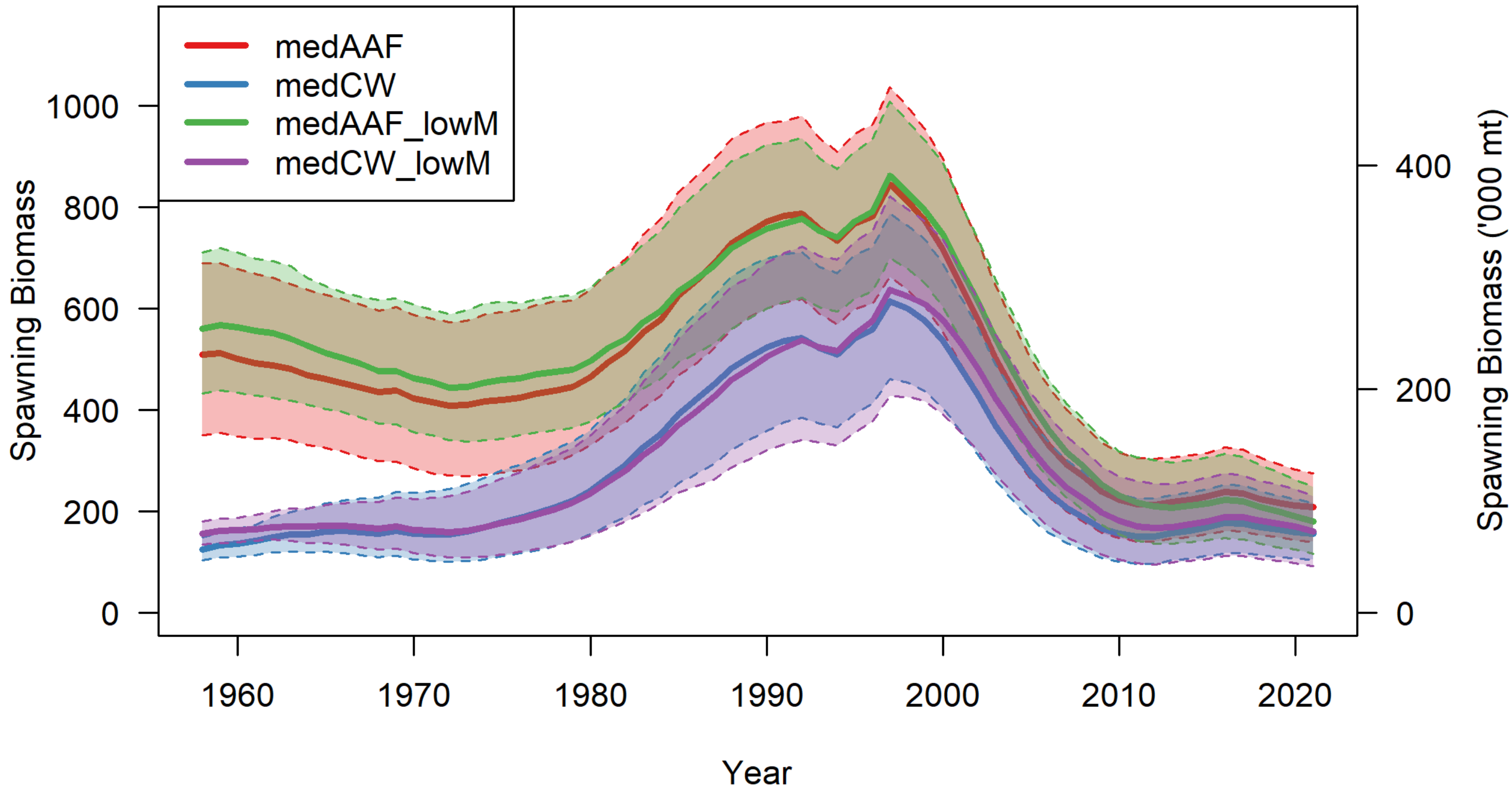
Points are SPR estimates from 2021 stock assessment

SPR in 2022

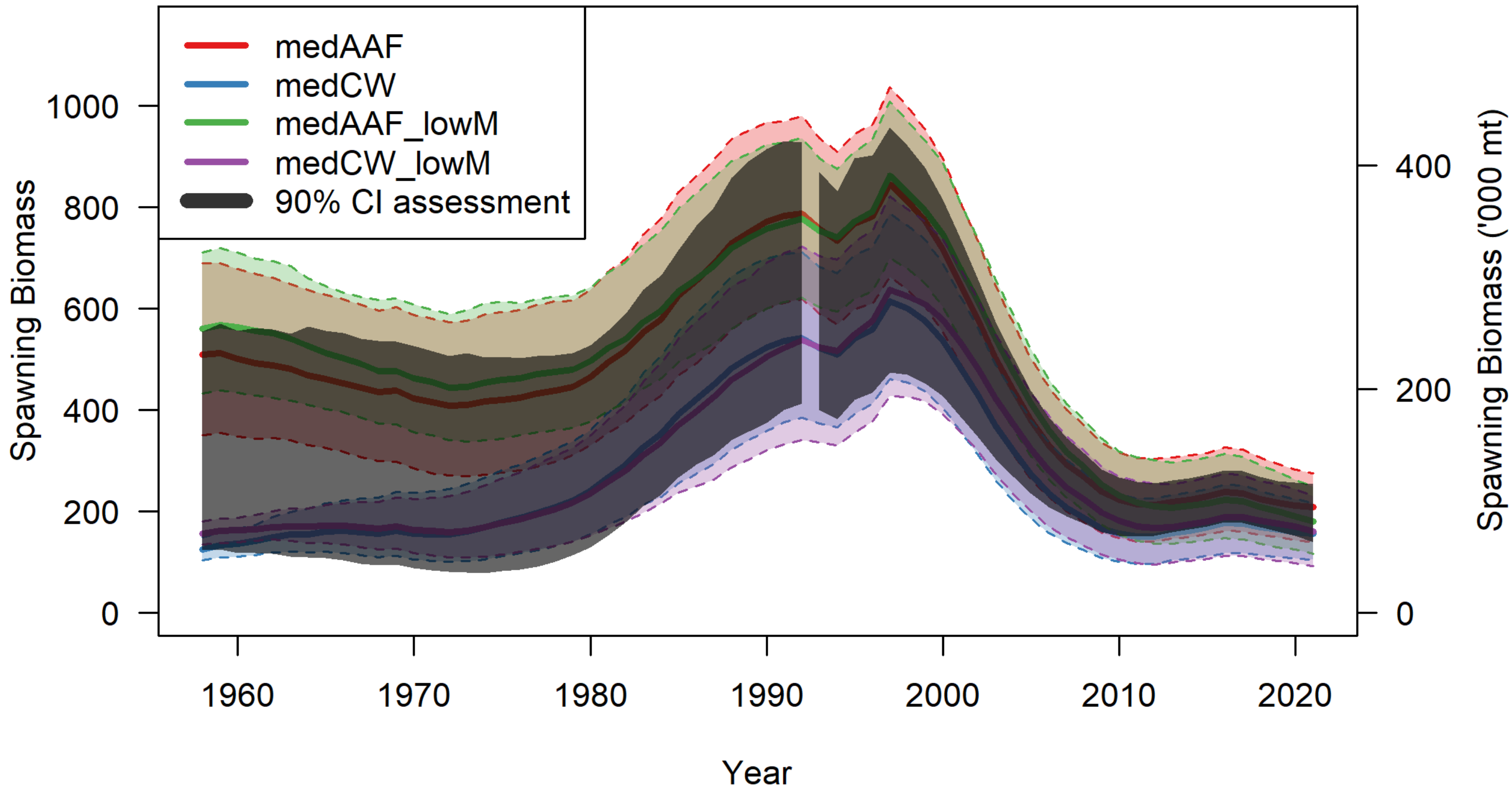
- OM is close to the adopted 43%



Operating Model

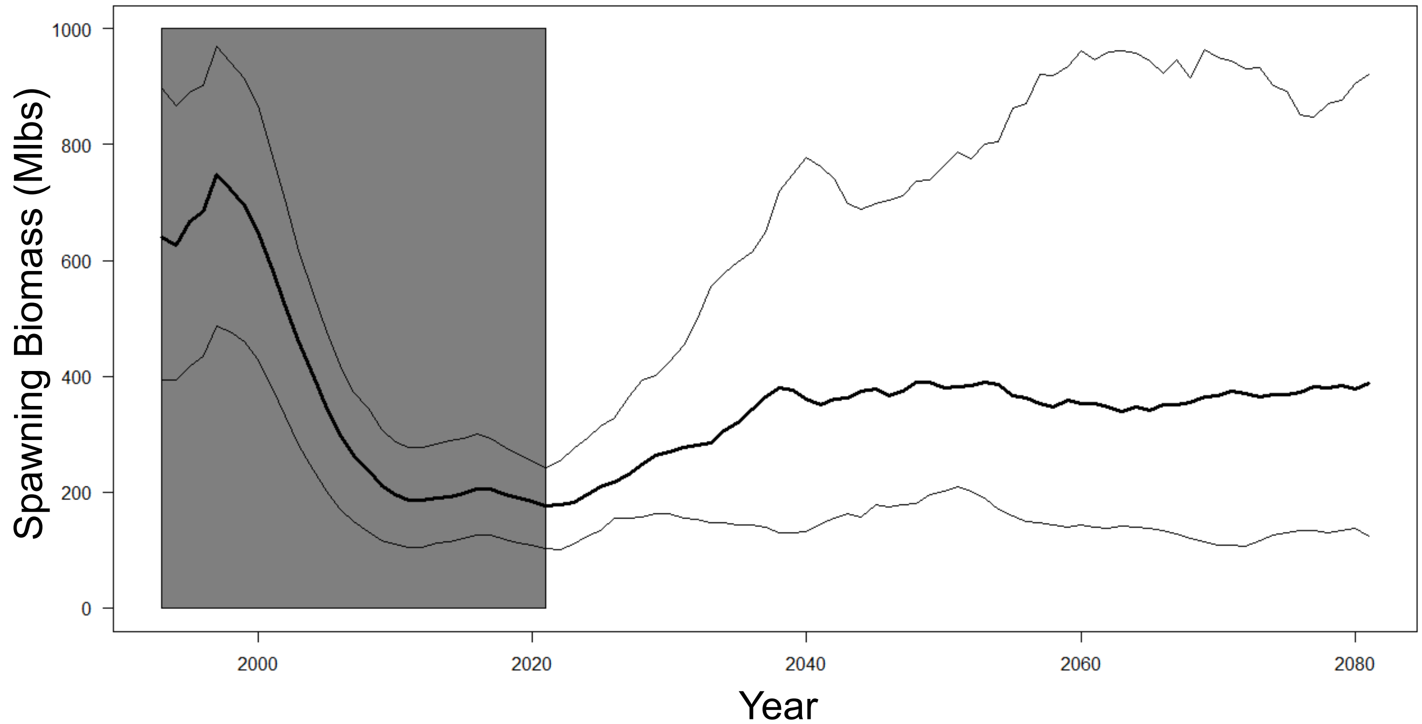


Operating Model



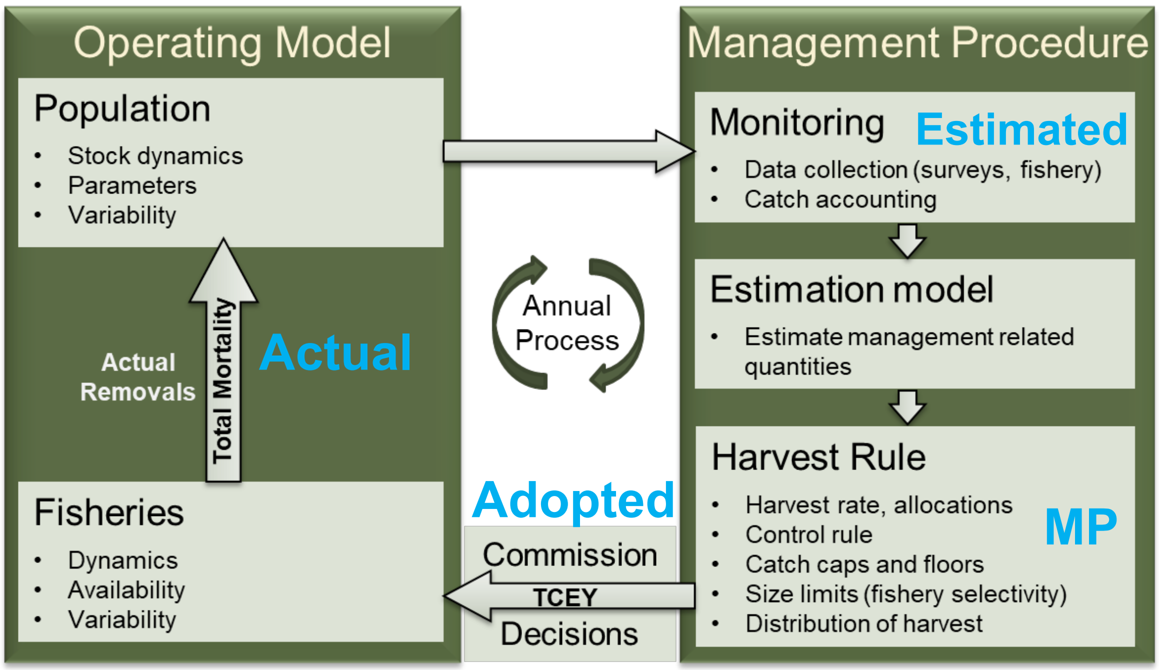
Projected spawning biomass

- SPR=43%
- 5th and 95th percentiles



F.2: Implementation variability & uncertainty

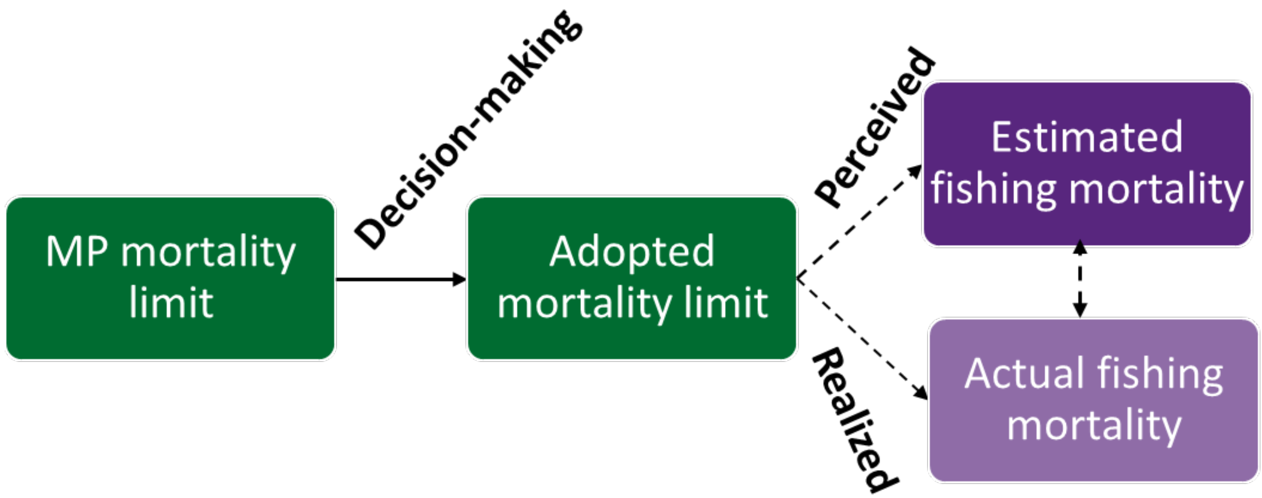
ID	Category	Task	Deliverable
F.2	Framework	Implementation variability	Incorporate additional sources of implementation variability in the framework



Mortality types in blue

Types of implementation variability

1. **Decision-making variability**: difference between MP mortality limits and the adopted mortality limits set by the Commission.
2. **Realized variability**: difference between the adopted mortality limits set by the Commission and the actual mortality resulting from fishing.
3. **Perceived variability**: difference between the actual & estimated fishing mortality



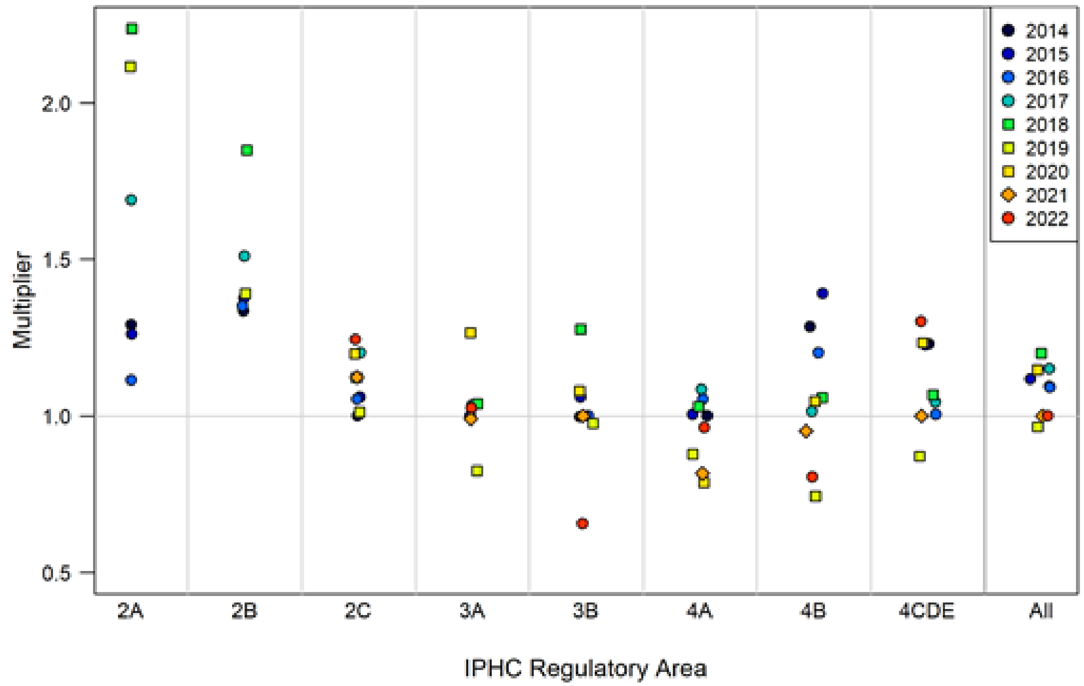
Decision-making variability

- Historically, the adopted TCEY has differed from the MP TCEY
- Can model this as a multiplier to the MP mortality limit

$$\widetilde{TCEY}_t = TCEY_t \times \varepsilon_I$$

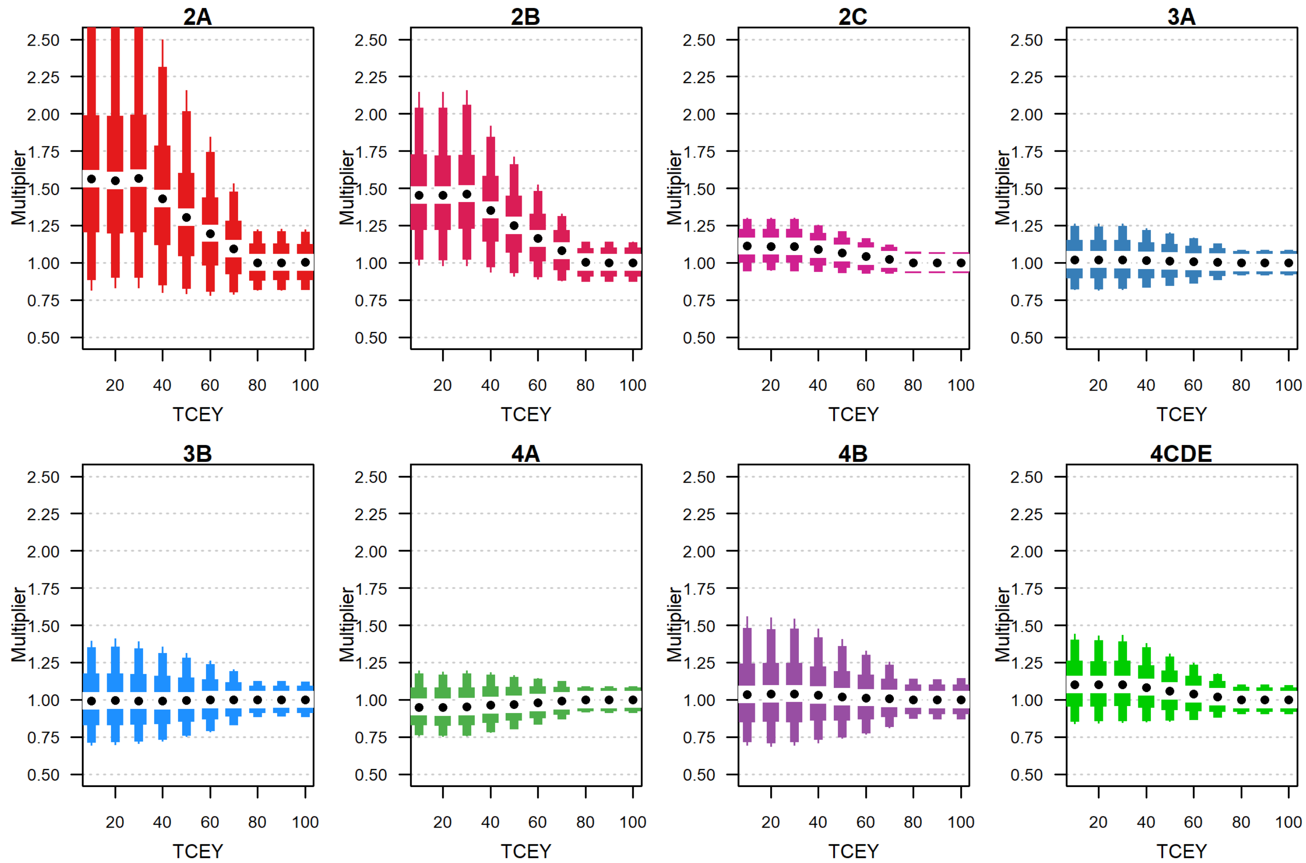
Adopted MP Multiplier

Multipliers for years/areas without agreement



Decision-making variability:No agreements

- 2 out of 5 distribution procedures
- Use 2014-2019 observations in 2A and 2B, and 2014-2022 for other areas to parameterize
- Higher adopted TCEYs result in multiplier at 1 and reduced variability



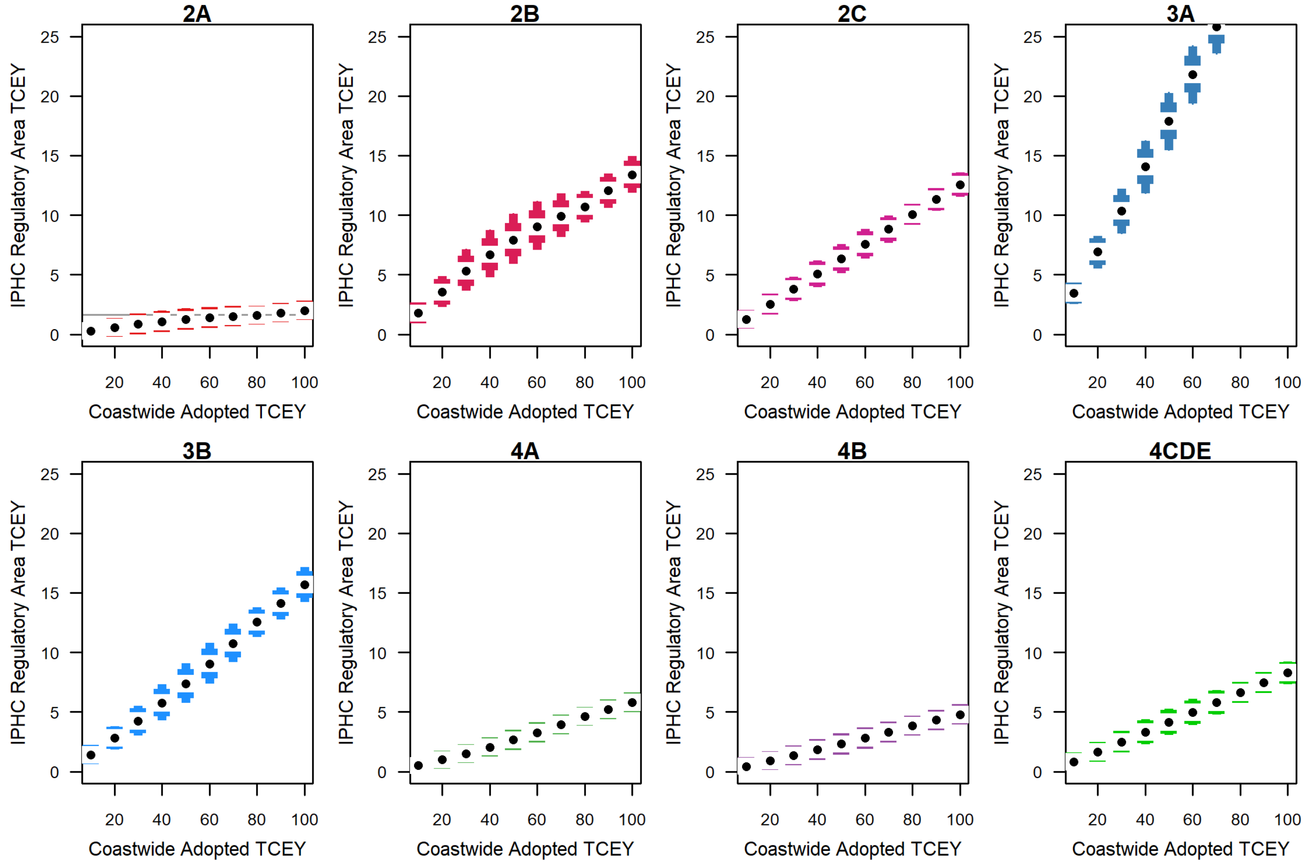
Decision-making variability: With agreements

- 2A and 2B
- 3 out of 5 distribution procedures
- 2C-4B as before
- 2A and 2B have multiplier at 1 and no variability

Decision-making variability: TCEYs

Using 2022 baseline stock distribution

Without agreements



Runs with Decision-making variability

IPHC-2022-SRB020-R, para 19. *The SRB REQUESTED that the ramped implementation bias scenario (Fig. 17 in paper IPHC-2022- SRB020-06 Rev_1) be run under the most aggressive fishing intensity targets to determine the scale of performance sensitivity to that source of implementation variability*.

Three options

0. No decision-making variability
1. Coastwide TCEY is set at MP, distribution of TCEY subject to variability
2. Coastwide TCEY and distribution of TCEY subject to variability

- Runs with SPR=40%, 43%, and 46%
  - SPR 40% and 43% for all three options
- With and without estimation error

F.3: Estimation Error

ID	Category	Task	Deliverable
F.3	Framework	Develop more realistic simulations of estimation error	Improve the estimation model to more adequately mimic the ensemble stock assessment

SRB017-R, para. 57. *The SRB … RECOMMENDED continuing work to incorporate actual estimation models, as in the third option, because that method would best mimic the current assessment process.*

SRB020-R, para. 20. *The SRB REQUESTED that the MSE not attempt to implement a Stock Synthesis estimation procedure as part of the management procedure and, instead, to integrate a simpler assessment modelling approach into the management procedure via tuning.*

F.3: Estimation Error

- Three methods implemented
  1. No estimation error
  2. Simulated estimation error
     - TM and stock status (correlated and autocorrelated)
  3. Use stock assessment model(s)
     - Stock synthesis (one model)

Size limits

ID	Category	Task	Deliverable
M.1	MPs	Size limits	Identification, evaluation of size limits

IPHC-2022-AM098-R, para 61: *The Commission RECALLED SS011-Rec.01 and REQUESTED that the current size limit (32 inches), a 26 inch size limit, and no size limit be investigated. to understand the long-term effects of a change in the size limit*

- Investigate various size limits
  - **32 inch (current) size limit (81.3 cm)**
  - **26 inch size limit (66.0 cm)**
  - **No size limit**
  - MSE framework updated to accommodate any size limit

MPs: Size limits

- Annual stock assessment

MP name	MP-A0	MP-A26	MP-A32
Decision-making variability	None, option 1, option 2		
Estimation Error	None, Simulated, *SS*		
Assessment Frequency	Annual	Annual	Annual
Size Limit	0	26	32
SPR	0.40, 0.43, 0.46		

Size Limits: No Estimation Error

	MP name	MP-A0	MP-A26	MP-A32
	Decision-making variability	**None**	**None**	**None**
	Estimation Error	**None**	**None**	**None**
	Assessment Frequency	**Annual**	**Annual**	**Annual**
	Size Limit	**0**	**26**	**32**
	SPR	**0.43**	**0.43**	**0.43**
	Median average SPR	43.0%	43.0%	43.0%
	Biological Sustainability			
Long-term	Median average RSB	39.3%	39.3%	39.3%
Long-term	P(any RSB_y<20%)	0	0	0
Long-term	P(all RSB<36%)	0.17	0.17	0.18
	Fishery Sustainability			
Short-term	Median average TCEY	62.3	62.1	58.9
Short-term	P(any3 change TCEY > 15%)	0.06	0.06	0.07
Short-term	Median AAV TCEY	5.2%	5.3%	5.7%

- Insignificant difference in long-term sustainability
- A 5.8% short-term increase in TCEY with no size limit
- A slight reduction in TCEY variability

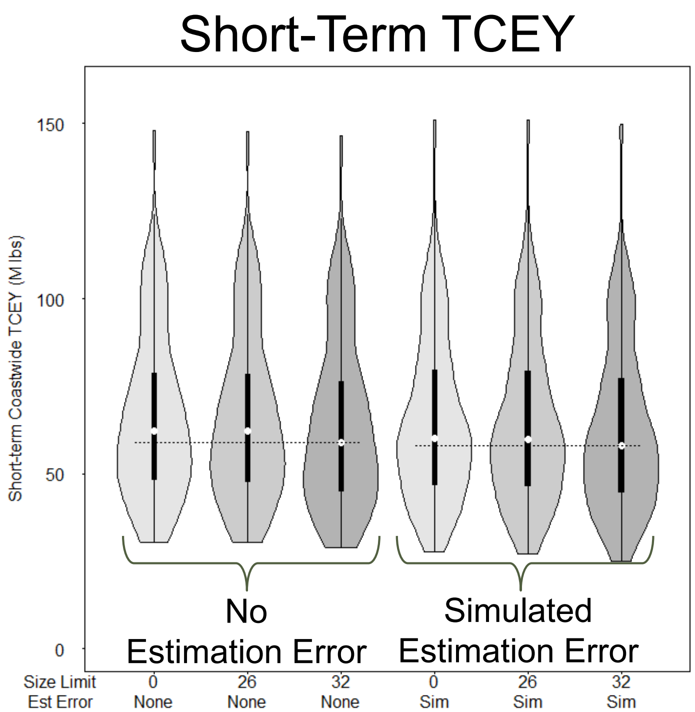
Size Limits: Simulated Estimation Error

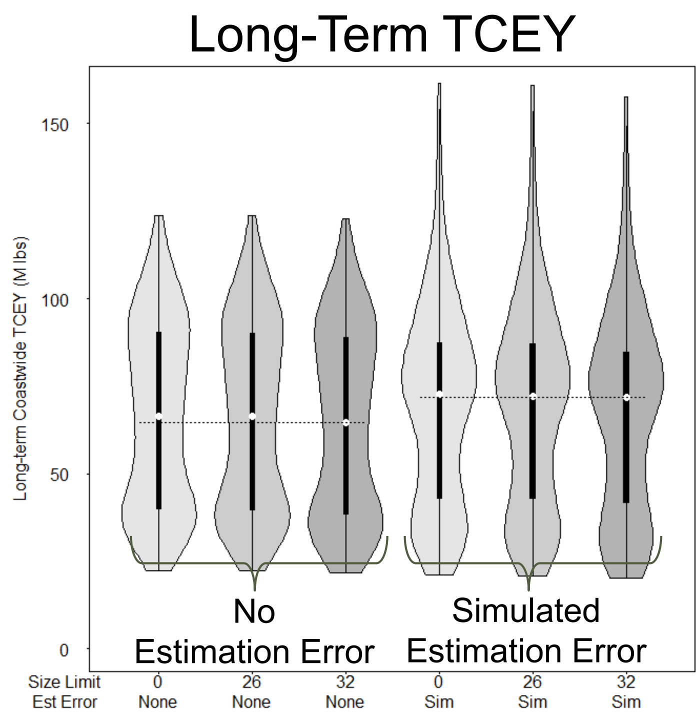
	MP name	MP-A0	MP-A26	MP-A32
	Decision-making variability	**None**	**None**	**None**
	Estimation Error	**Sim**	**Sim**	**Sim**
	Assessment Frequency	**Annual**	**Annual**	**Annual**
	Size Limit	**0**	**26**	**32**
	SPR	**0.43**	**0.43**	**0.43**
	Median average SPR	43.9%	43.9%	44.0%
	Biological Sustainability			
Long-term	Median average RSB	39.0%	39.0%	39.0%
Long-term	P(any RSB_y<20%)	0	0	0
Long-term	P(all RSB<36%)	0.14	0.14	0.14
	Fishery Sustainability			
Short-term	Median average TCEY	60.2	59.7	58.1
Short-term	P(any3 change TCEY > 15%)	0.93	0.95	0.97
Short-term	Median AAV TCEY	18.2%	18.3%	18.7%

- Insignificant difference in long-term sustainability
- A 3.6% short-term increase in TCEY with no size limit
- A slight reduction in TCEY variability
- Much more annual variability compared to no estimation error

Size limits: long-term effects

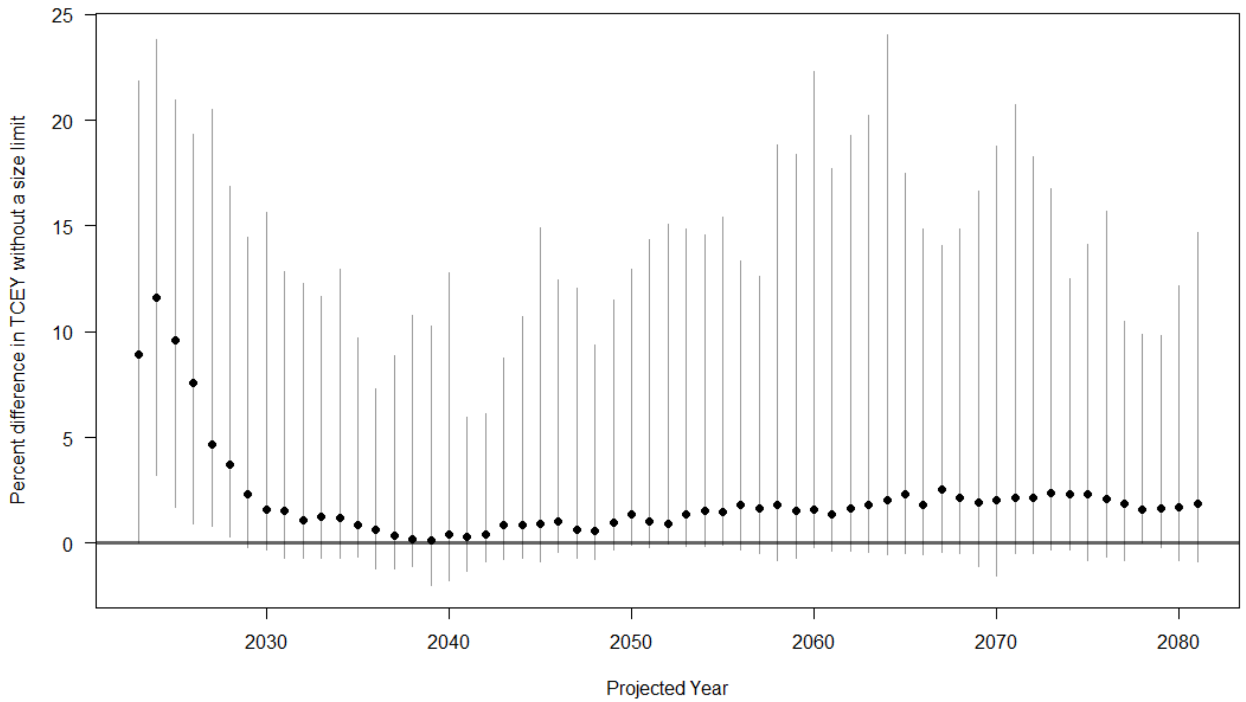
- Increase in long-term yield was 1.0% without a size limit





Percent difference in TCEY without a size limit

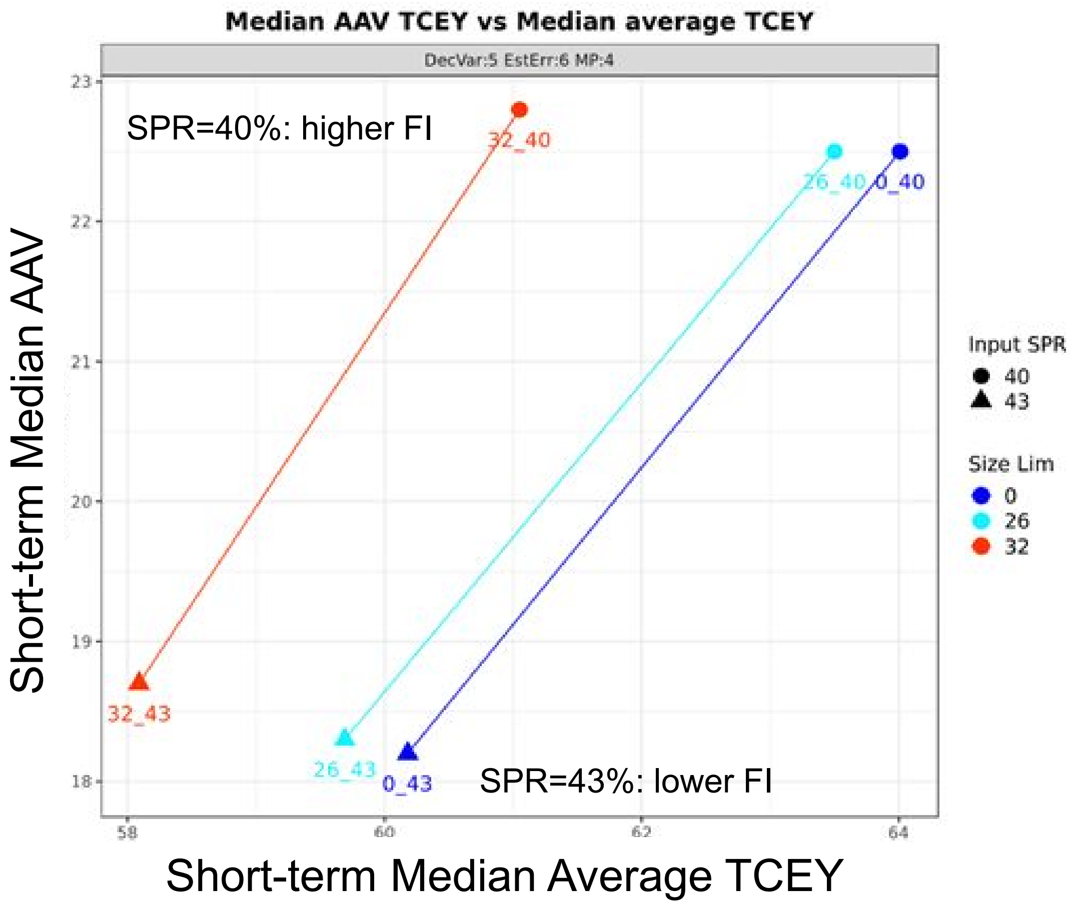
- Benefit of a size limit is dependent on stock conditions
  - Weight-at-age, environmental regime
  - Less often did ‘No size limit’ have a negative effect on yield



Size Limits: Higher fishing intensity

SPR=40%

- Higher TCEY and variability
- 4.8% increase in TCEY with no size limit (short-term)
- 1.0% increase in TCEY with no size limit (long-term)
- P(RSB<36%) = 56%



Evaluation of size limits

- Primary biological sustainability and yield metrics
- Other metrics and tradeoffs
  - Size distribution of landings
    - Proportion of U32
  - Amount of discards
  - Economic metrics
    - For example, value of fishery given differential price of U32
      - See IPHC-2021-AM097-09

Multi-year stock assessment

ID	Category	Task	Deliverable
M.3	MPs	Multi-year assessments	Evaluation of multi-year assessments

IPHC-2022-AM098-R, para 64: *The Commission REQUESTED that multi-year management procedures include the following concepts:*

a) The stock assessment occurs biennially (and possibly triennial if time in 2022 allows) and no changes would occur to the FISS (i.e. remains annual);

b) The TCEY within IPHC Regulatory Areas for non-assessment years:

i. remains the same as defined in the previous assessment year, or

ii. changes within IPHC Regulatory Areas using simple empirical rules, to be developed by the IPHC Secretariat, that incorporate FISS data

- MPs
  a) Biennial stock assessment with constant TCEY for IPHC Regulatory Areas
  b) Biennial stock assessment with coastwide TCEY updated proportionally to coastwide FISS index and distribution of TCEY updated via distribution procedure
  c) Biennial stock assessment with coastwide TCEY constant and distribution of TCEY updated via distribution procedure

FISS remains an annual survey

MPs: Multi-year stock assessment

MP name	MP-A32	MP-Ba32	MP-Bb32	MP-Bc32
Decision-making variability	None, option 1, option 2			
Estimation Error	None, Simulated, *SS*			
Assessment Frequency	Annual	Biennial	Biennial	Biennial
Size Limit	32 inches			
SPR	0.40, 0.43, 0.46			

a) Biennial stock assessment with constant TCEY for IPHC Regulatory Areas

b) Biennial stock assessment with coastwide TCEY updated proportionally to coastwide FISS index and distribution of TCEY updated via distribution procedure

c) Biennial stock assessment with coastwide TCEY constant and distribution of TCEY updated via distribution procedure

Multi-year: all-areas constant TCEY

MP name	MP-A32	MP-Ba32	MP-A32	MP-Ba32
Decision-making variability	**None**	**None**	**None**	**None**
Estimation Error	**None**	**None**	**Sim**	**Sim**
Assessment Frequency	**Annual**	**Biennial**	**Annual**	**Biennial**
Size Limit	**32**	**32**	**32**	**32**
SPR	**0.43**	**0.43**	**0.43**	**0.43**
Median average SPR	43.0%	42.9%	44.0%	43.3%
Biological Sustainability				
Median average RSB	39.3%	39.0%	39.0%	38.9%
P(any RSB_y<20%)	0	0	0	0
P(all RSB<36%)	0.18	0.20	0.14	0.17
Fishery Sustainability				
Median average TCEY	58.9	60.1	58.1	57.5
P(any3 change TCEY > 15%)	0.07	0.19	0.97	0.78
Median AAV TCEY	5.7%	5.8%	18.7%	14.7%

- Slightly higher chance of being below 36% RSB
- Effects on TCEY
  - Estimation error resulted in opposite effects
  - Reduced variability with lower yield with estimation error
  - Long-term TCEY about 2% higher in biennial

If we knew the management quantities without error, we would likely want to use them every year
With estimation error, biennial assessment with a constant TCEY provides some stability

Evaluation of multi-year assessments

- Primary biological sustainability and yield metrics
- Other metrics and tradeoffs
  - Measures of TCEY variability
    - Change in assessment years only
  - Economic metrics
    - Example from Hutniczak et al 2019 (summer flounder)
      - Transformed biomass-based metrics to net economic benefits for commercial and recreational fisheries
      - An economic analysis can be complex to create, but once "economic models have been parameterized, the capacity to examine a wide range of scenarios is greatly enhanced"

Multi-year: a look at TCEY variability

MP name	MP-A32	MP-Ba32	MP-Bb32	MP-Bc32
Decision-making variability	**None**	**None**	**None**	**None**
Estimation Error	**Sim**	**Sim**	**Sim**	**Sim**
Assessment Frequency	**Annual**	**Biennial**	**Biennial**	**Biennial**
Size Limit	**32**	**32**	**32**	**32**
SPR	**0.43**	**0.43**	**0.43**	**0.43**
Median average SPR	44.0%	43.3%	43.9%	43.3%
Biological Sustainability				
Median average RSB	39.0%	38.9%	38.6%	38.9%
P(any RSB_y<20%)	0	0	0	0
P(all RSB<36%)	0.14	0.17	0.17	0.17
Fishery Sustainability				
Median average TCEY	58.1	57.5	58.6	57.5
P(any1 change TCEY > 15%)	1.00	0.99	1.00	0.99
P(any2 change TCEY > 15%)	1.00	0.97	0.98	0.97
P(any3 change TCEY > 15%)	0.97	0.78	0.92	0.78
P(any4 change TCEY > 15%)	0.76	0.52	0.71	0.52
P(any5 change TCEY > 15%)	0.59	0.16	0.41	0.17
Median AAV TCEY	18.7%	14.7%	19.5%	14.7%

- MP-Bb ≈ MP-A
  - Slightly lower risk
  - Higher AAV: changes in non-assessment year larger
- Effects on TCEY (MP-Ba, MP-Bc)
  - Slightly lower TCEY
  - Less variability because of the 5/10 stable years
  - Similar risk with increased fishing intensity would increase TCEY
    - Would increase variability metrics
- Long-term TCEY higher for all biennial MPs

Costs and benefits of multi-year assessments

SRB020-R, para. 27: *The SRB NOTED that assessment research activities (e.g. paras. 23-26) are examples of work that could be done more extensively in non-assessment years within a multi-year assessment schedule. Other work could include investigating optimal sub-sampling designs for ages, sex-ratio, annual assessment methods to use within the MPs, and well as any of the several topics listed under Stock Assessment Research. The quantifiable costs of multi-year assessments could be estimated within the MSE, for example, of potentially lower average yield for longer assessment cycles to achieve the same levels of risk associated with annual assessments.*

Costs	Benefits
Possibly more variability in non-assessment years	Biennial stability, short-term predictability, transparent process
Detailed harvest advice no available every year No following stock trends (Ba, partially Bc)	FISS is a reasonable proxy to coastwide and area changes in abundance (Bb, partially Bc)
	More focused assessment research
	Assist with other research

Evaluation

- MSE-Explorer
- Specific look at trade-offs
- Keep size limits and multi-year assessments as independent evaluations
- Distribution integrated

Evaluation

SRB020-R, para. 21. The SRB REQUESTED evaluating whether the relative ranking of MPs – defined only by multi-year assessment cycle and size limits - remains similar across the set of proposed distribution scenarios using objectives identified as priorities by the Commission.

- Will have a closer look before MSAB
  - 100 simulations per distribution procedure

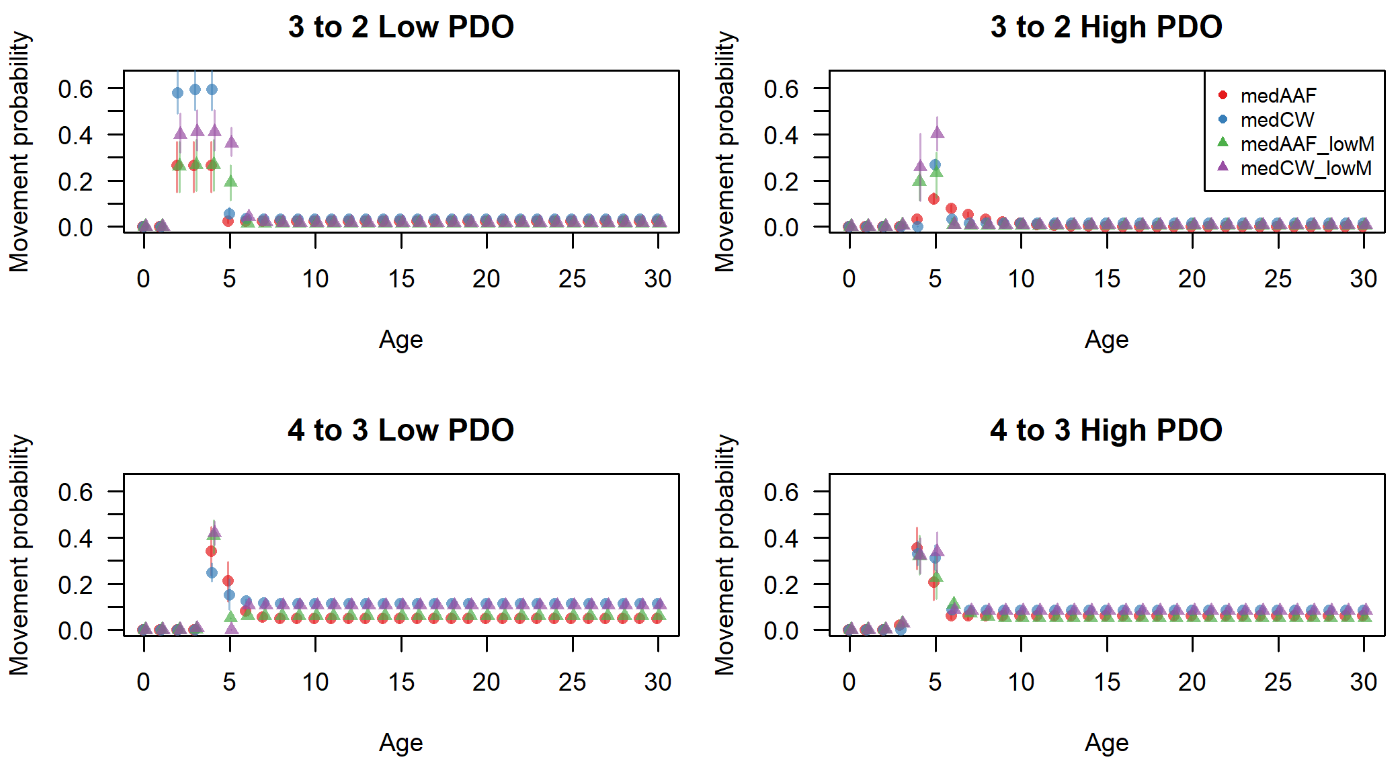
Potential OM Scenarios

- Targeting small Pacific halibut
- Avoiding small Pacific halibut
- Low or high weight-at-age
- Low or high recruitment

> **IPHC-2022-SRB020-R, para 18.** *The SRB NOTED the Secretariat's plan to further explore migration scenarios in the MSE and therefore REQUESTED that the set of migrations scenarios remain within bounds of plausible values identified via the OM development/fitting and previous tagging studies.*

- No migration-specific scenarios

Migration Variability



More to come…

- More results being produced
  - Decision-making variability
  - SPRs of 40%, 43%, and 46%
    - Tuning to SPR
  - Scenarios
  - Closer look at MP elements (e.g. averaging FISS distribution)

Recommendations

- **NOTE** paper IPHC-2022-SRB021-07 and additional results in the presentation
- **RECOMMEND** use of the updated OM with four individual models for MSE simulations
- **RECOMMEND** incorporating the decision-making variability framework described in the presentation
- **RECOMMEND** additional runs to assist with the evaluation of size limits and multi-year assessments
- **RECOMMEND** additional performance metrics to assist with the evaluation of size limits and multi-year assessments
- **NOTE** costs and benefits from implementing a multi-year assessment management procedure
- **RECOMMEND** additional MSE development to be completed in 2023 and beyond
- **NOTE** that future agreements of the Commission related to harvest policy can be tested using the MSE framework and used to focus further evaluations

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Development of the 2022 stock assessment

Agenda item 7

IPHC-2022-SRB021-08

(I. Stewart)

Outline

- Response to SRB recommendations and Requests
  - *M* estimation
  - Bootstrapping sample sizes
  - Marine mammal depredation
  - Model weighting
- Additional development
  - Modelling
  - Data
- Final 2022 assessment
  - Remaining data
  - Timeline

SRB recommendation

1) SRB020-Rec.02 (para. 23):

"The SRB NOTED that most models within the ensemble produced reasonable and well-constrained estimates of natural mortality (M) and RECOMMENDED that estimation of M should be adopted in the short AAF assessment model with consideration in other models as part of the stock assessment research program."

Estimation of M will be retained in the final short AAF model for 2022,
And explored further in the short coastwide model in 2023.

SRB recommendation

2) SRB020-Rec.03 (para. 24):

“The SRB NOTED that the bootstrapping approach to determining maximum samples sizes for age-composition data improved assessment model performance and stability and, therefore, RECOMMENDED that the bootstrapping approach be adopted for data-weighting in future assessments.”

Bootstrapping is now part of standard the data processing steps and will be applied to all new data for the final 2022 assessment. Bootstrapping of the 2021 sex-specific fishery data was easily accommodated.

SRB recommendation

3) SRB020-Rec.04 (para. 25):

"The SRB NOTED apparent discrepancies in marine mammal prevalence among anecdotal reports, FISS observations, and preliminary evaluation of logbook data, and therefore RECOMMENDED further investigation of methods to better estimate marine mammal prevalence and impacts on the fishery."

Next steps:

- Post-season review of logbook fields and collection methods (coordinating with sablefish analysts)
- Explore observer data
- Field research on catch-protection devices (April-May 2023)

Update at SRB022, June 2023.

SRB request

4) SRB020-Req.06 (para. 26):

“The SRB NOTED the proposed new ensemble model weighting scheme using the MASE criterion and REQUESTED investigation of predictive skill on additional quantities such as fishery CPUE and mean age in FISS samples.”

More on model weighting

MASE statistic: $$MASE = \frac{\frac{1}{n}\sum_{t=1}^{n} \left| \frac{O_t - E_t}{\sigma_t} \right|}{\frac{1}{n}\sum_{t=1}^{n} \left| \frac{O_t - O_{t-1}}{\sigma_t} \right|}$$

O_t = Observation at time t
E_t = Prediction at time t
σ_t = standard deviation of O_t

>1: Model skill is worse than the naïve prediction (last year's observation)
1: Equal to the naïve prediction
<1: Better than naïve prediction
0: Perfect prediction

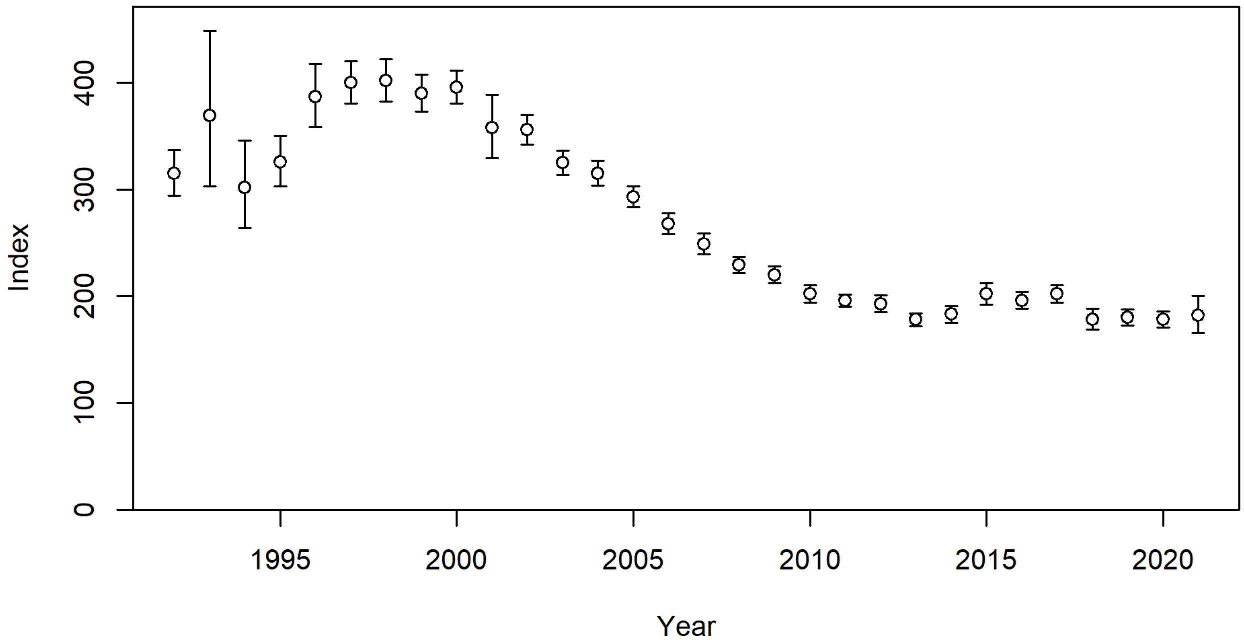
MASE weights

- For models with a MASE of <1:

$$MASE\ weight_m = \frac{1 - MASE_m}{\sum_{m=1}^{M} 1 - MASE_m}$$

- A model with MASE of 1 gets zero weight (unless all models >=1)
- A model with MASE of 0 gets maximum weight

Fishery WPUE



Very little contrast over last 4 years.

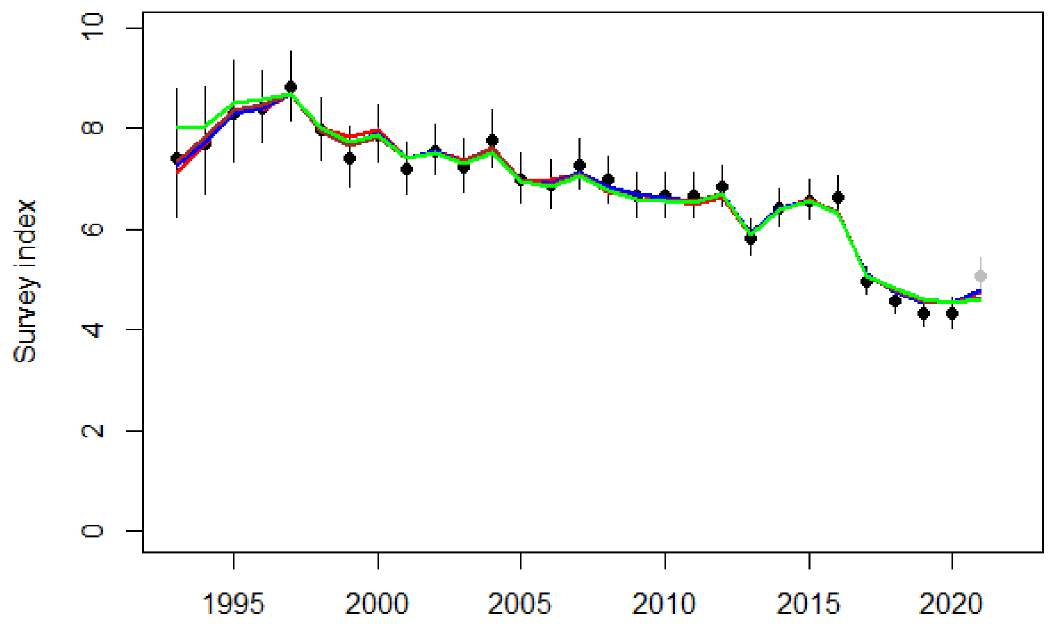
Fishery WPUE

	Model			
Years included	CW short	CW long	AAF short	AAF long
4	0.0%	53.1%	0.0%	46.9%
3	0.0%	27.8%	0.0%	72.2%
2	0.0%	0.0%	0.0%	100.0%
1	25.0%	25.0%	25.0%	25.0%
Status quo weights	25.0%	25.0%	25.0%	25.0%

(All models > 1)

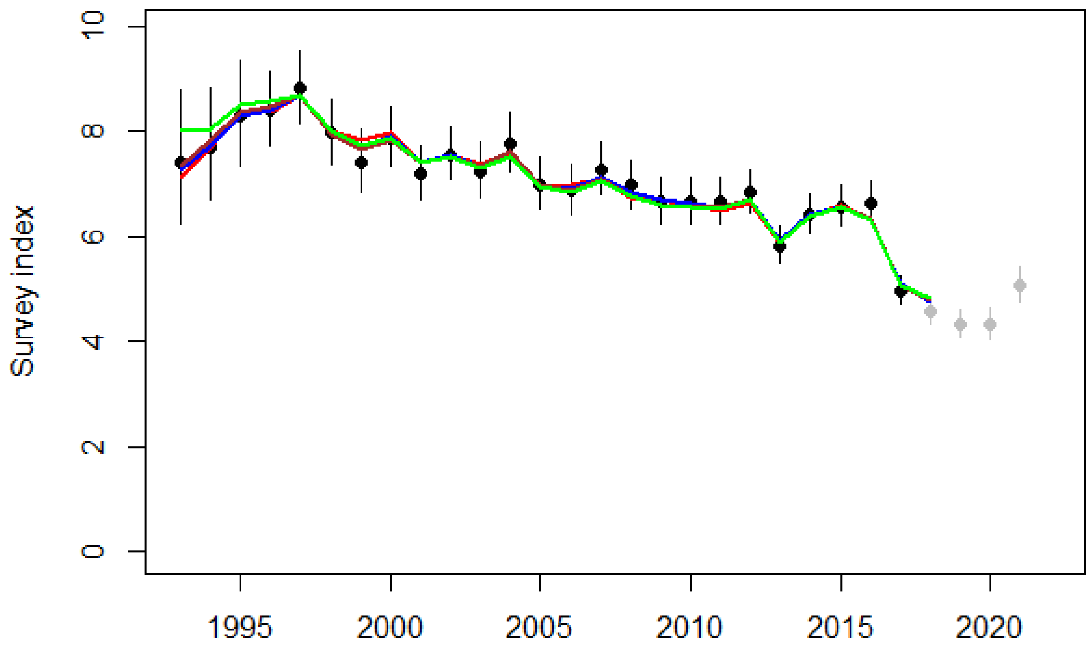
Highly variable MASE weights

Previous MASE results



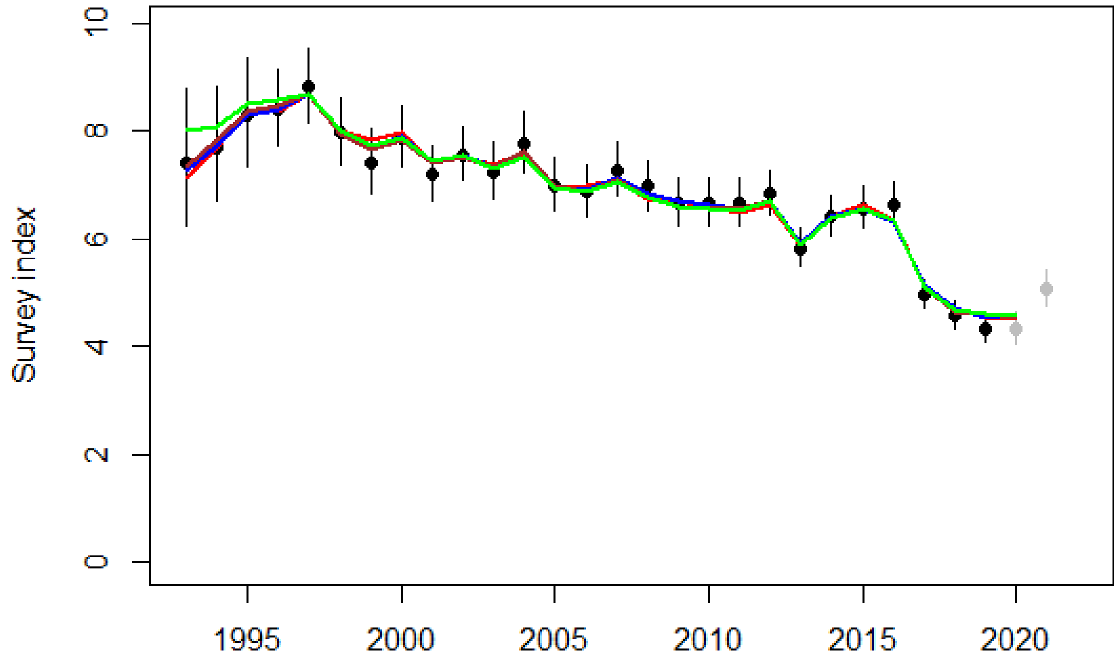
All models preformed better at predicting 2021 than for the 2020 observation. This had a strong effect on all the calculated averages.

Previous MASE results



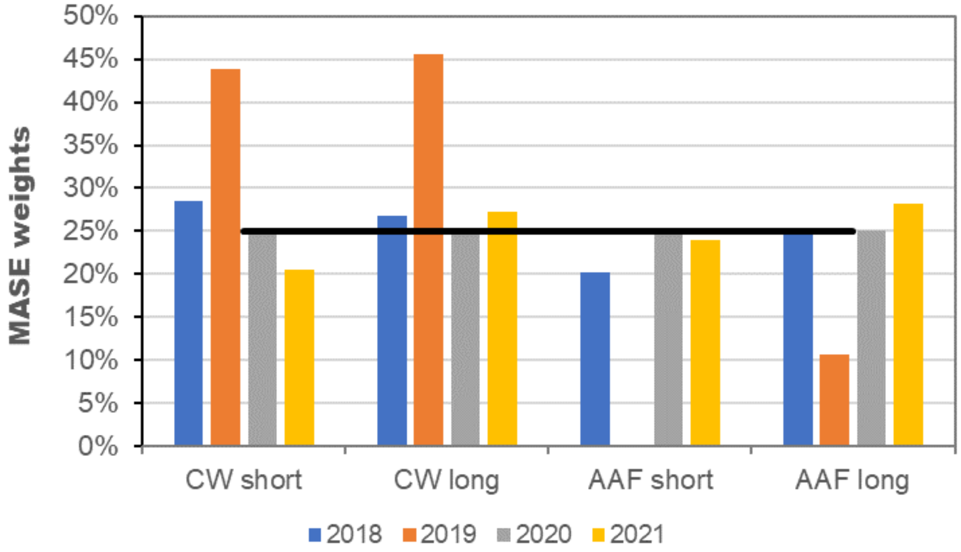
This was similar for 2018.

Previous MASE results



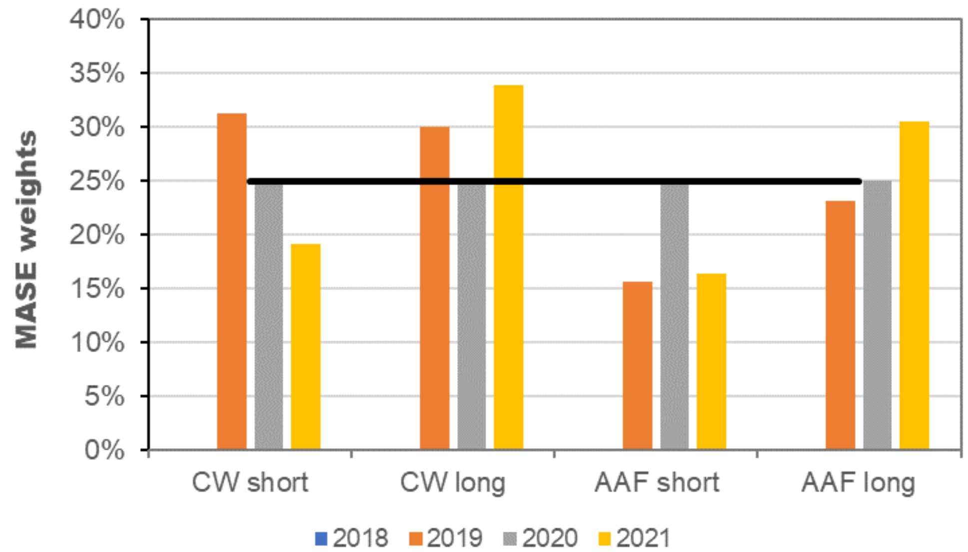
But definitely not 2020.

FISS predictive performance



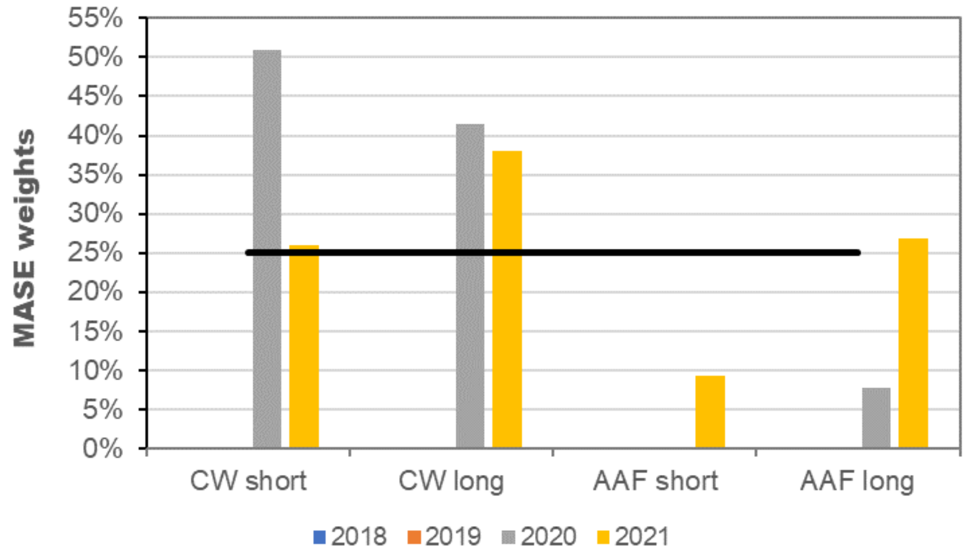
One-year MASE weights, calculated in each sequential year

FISS predictive performance



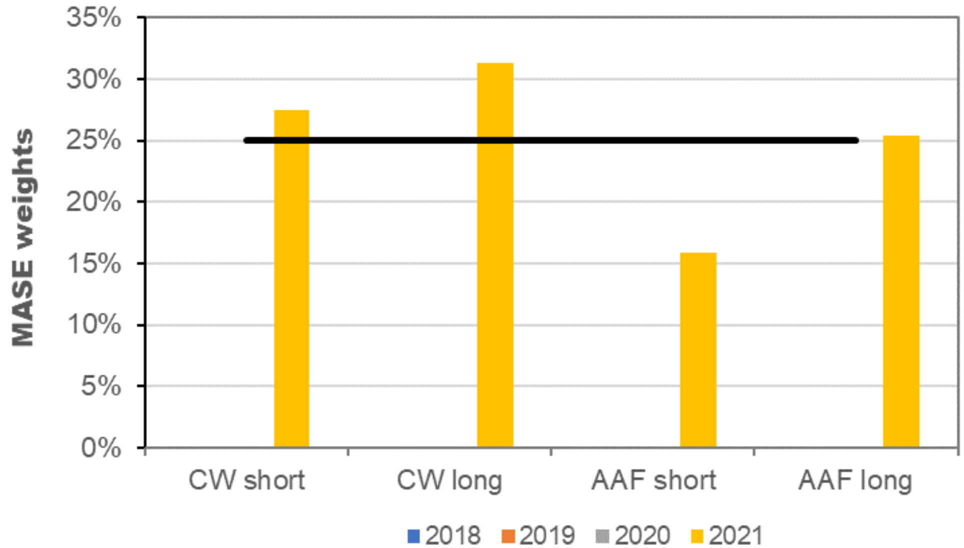
Two-year MASE weights, calculated in each sequential year

FISS predictive performance



Three-year MASE weights, calculated in each sequential year

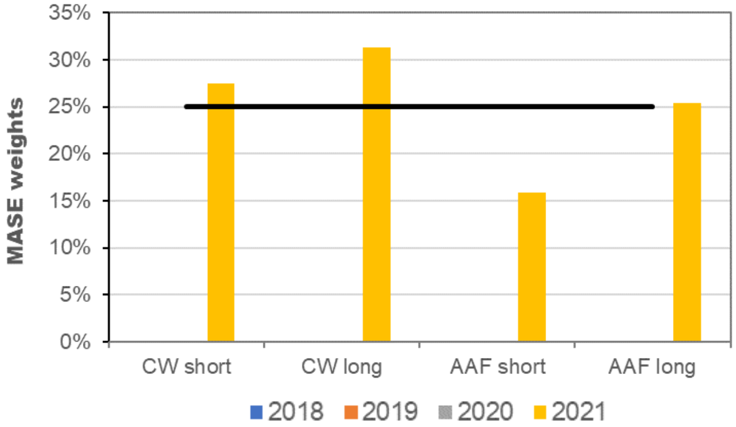
FISS predictive performance

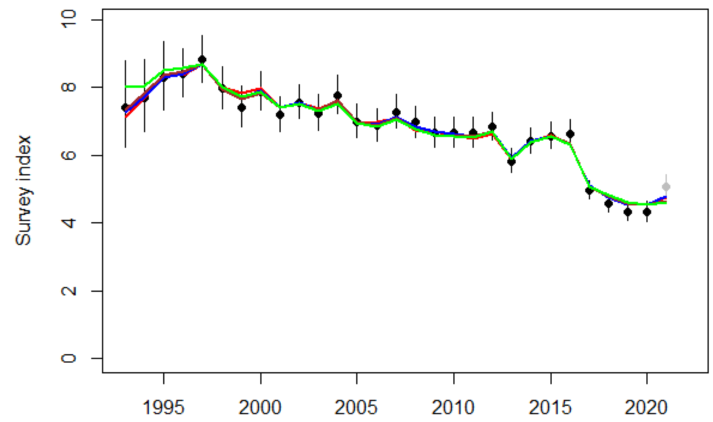


Four-year MASE weights – only one calculation available

FISS predictive performance

- Four-year average for 2022 would include 2019, 2020, 2021 and 2022
- Ensures that the good predictive performance observed in 2021 remains in the average through the next full assessment (2025)
- Allows the method to update weights, but gives us time to generate a slightly longer time-series to better evaluate performance vs. variability over time
- Change from previous recommendation of a one-year MASE statistic





Additional modelling exploration

- Internal age-length key constants in Stock Synthesis
  - Potential convergence issue
  - Mainly relevant where a growth curve is being internally estimated

Only trivial effects on halibut models

Additional data development

- Raw (unsmoothed) weight-at-age for Biological Region 3 female Pacific halibut
  - Sparse observations in 2019 & 2020
  - Rather than extrapolate trends at oldest ages, constant weight-at-age from the last observation was used

No change to model results

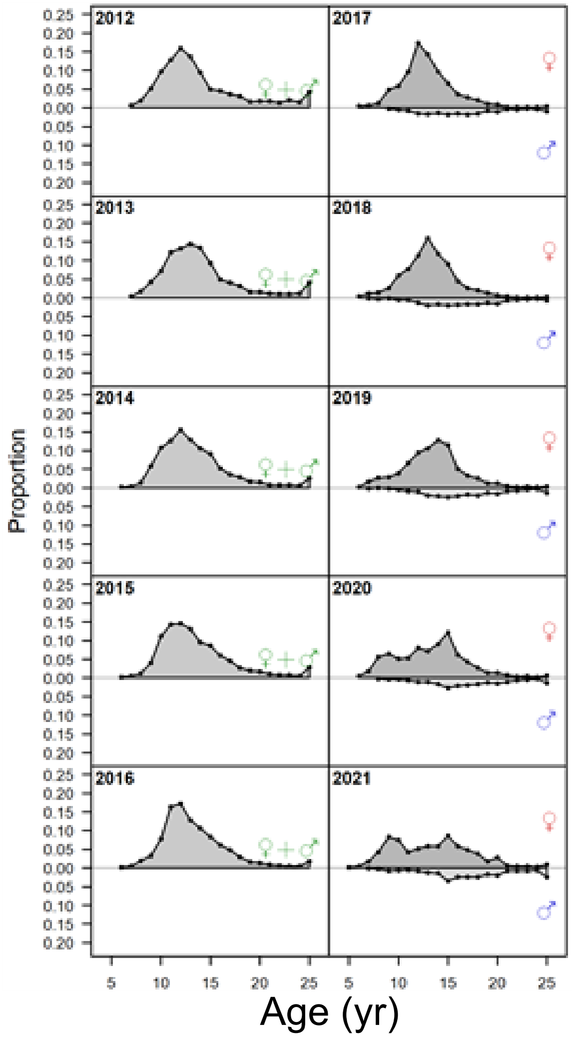
Additional data development

- 2021 Commercial fishery sex-ratios

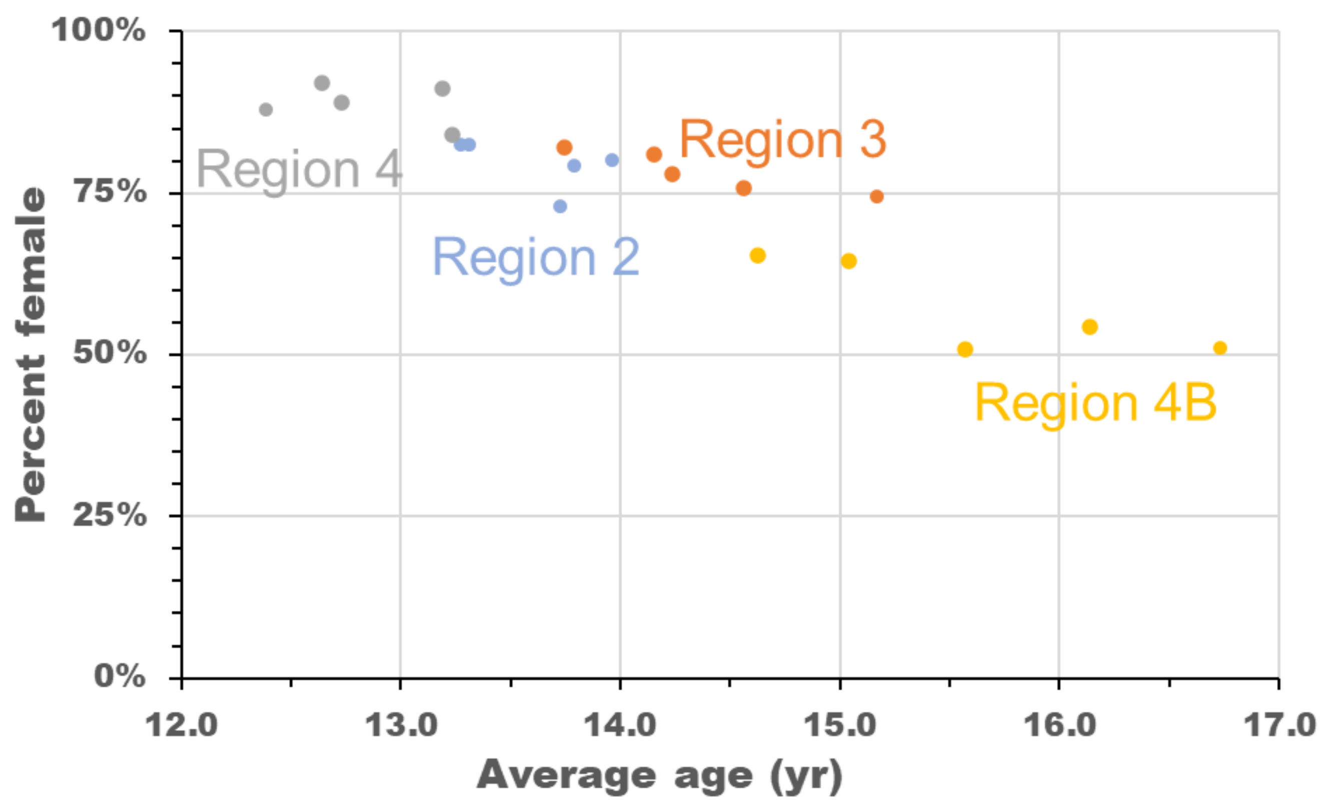
  (5th consecutive year of genetic data!)

	Coastwide % female	Region 2	Region 3	Region 4	Region 4B
2017	82%	82%	82%	92%	65%
2018	80%	82%	78%	91%	65%
2019	78%	80%	76%	89%	51%
2020	80%	79%	81%	84%	54%
2021	74%	73%	74%	88%	51%

Commercial sex-ratios



Commercial sex-ratios



Standard data for the 2022 assessment

1) New modelled trend information from the 2022 FISS for all IPHC Regulatory Areas.
2) Age, length, individual weight, and average weight-at-age estimates from the 2022 FISS.
3) Directed commercial fishery logbook trend information from 2022 (and any earlier logs that were not available for the 2021 assessment) for all IPHC Regulatory Areas.
4) Directed commercial fishery biological sampling from 2022 (age, length, individual weight, and average weight-at-age) from all IPHC Regulatory Areas.
5) Biological information (lengths and/or ages) from non-directed discards (all IPHC Regulatory Areas) and the recreational fishery (IPHC Regulatory Area 3A only) from 2021. The availability of these data routinely lags one year.
6) Updated mortality estimates from all sources for 2021 (where preliminary values were used) and estimates for all sources in 2022.

2022 Assessment timeline

- Post-September SRB
  - No further model changes
- November 1: data sets close
  - Final data + bootstrapping
  - Extend process error vectors
  - Retune data weighting
  - Recalculate model weighting
- November 30: Interim Meeting
  - First public release of results (Executive summary ~2 weeks prior)
- December 2022: Full documents posted
- January 2023: Annual Meeting (Decision making)

Recommendations

a) **NOTE** paper IPHC-2022-SRB021-08 which provides a response to requests from SRB020, and an update on model development for 2022.

b) **RECOMMEND** any changes to be included in the final 2022 stock assessment to be completed for presentation at IM098.

c) **REQUEST** any further analyses to be provided at SRB022, June 2023.

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Report on current and future biological and ecosystem science research activities

Agenda Item 8

IPHC-2022-SRB021-09

(J. Planas)

Outline

Progress and future activities in key research areas:

1. Migration and Distribution
2. Reproduction
3. Mortality and Survival Assessment
4. Population genomics

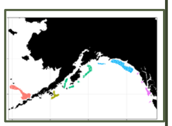
1. Migration and Distribution

5-Yr Research Plan (2017-2021)

Multiple life-stage connectivity

Bering Sea

Gulf of Alaska



Larval connectivity

- Larval catch and effort data
- Individual-based biophysical model
- Hydrographic ROMS model

→ Larval dispersal pathways → Inter-basin and intra-basin larval connectivity

Research outcomes:
- AI constrain connectivity between GOA and BS
- Island passes as pathways between GOA and BS
- Connectivity influenced by spawning location

Juvenile connectivity

- NMFS trawl survey data
- Spatiotemporal model

→ Ontogenetic migration

Research outcomes:
- Post-settlement migration from BS to GOA

PIRM 2022-2026

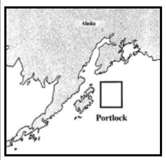
- Climate effects on larval connectivity
- Connectivity with Russian waters
- Mapping of settlement/nursery areas
- Characterization of genetic composition/mixture of settlement areas

GT-seq panel

External collaborators: EcoFOCI Program at AFSC-NOAA (Seattle, WA).
Publications: Sadorus et al. (2021) *Fisheries Oceanography*. ***30****: 174-193*

5-Yr Research Plan (2017-2021) | **PIRM 2022-2026**

2017-2018 Field sample collection (central GOA)

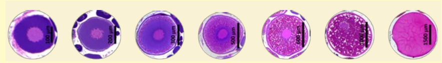


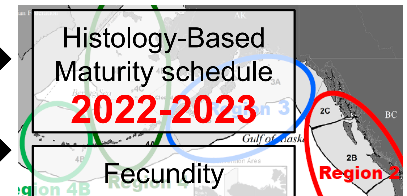
30♀/ month

♀>90 cm FL

Seasonal characterization of reproductive development

Histological samples → Characterization of oocyte stages → Classification of female developmental stages → Classification of reproductive phases → Appropriate timing of gonad collection in FISS → Histology-Based Maturity schedule **2022-2023**; Fecundity assessment **2023-2024**





Research outcomes:

- Group synchronous
- Batch spawner
- Determinate fecundity
- Annual cycle
- Spawning time
- Reproductive delays
- July/August

Macroscopic vs microscopic maturity staging

Macroscopic maturity scores

Ovary images

↔ Histology-based female developmental stages and reproductive phases → Assess accuracy of current field maturity classification criteria → Revise macroscopic staging criteria **2023-2024**

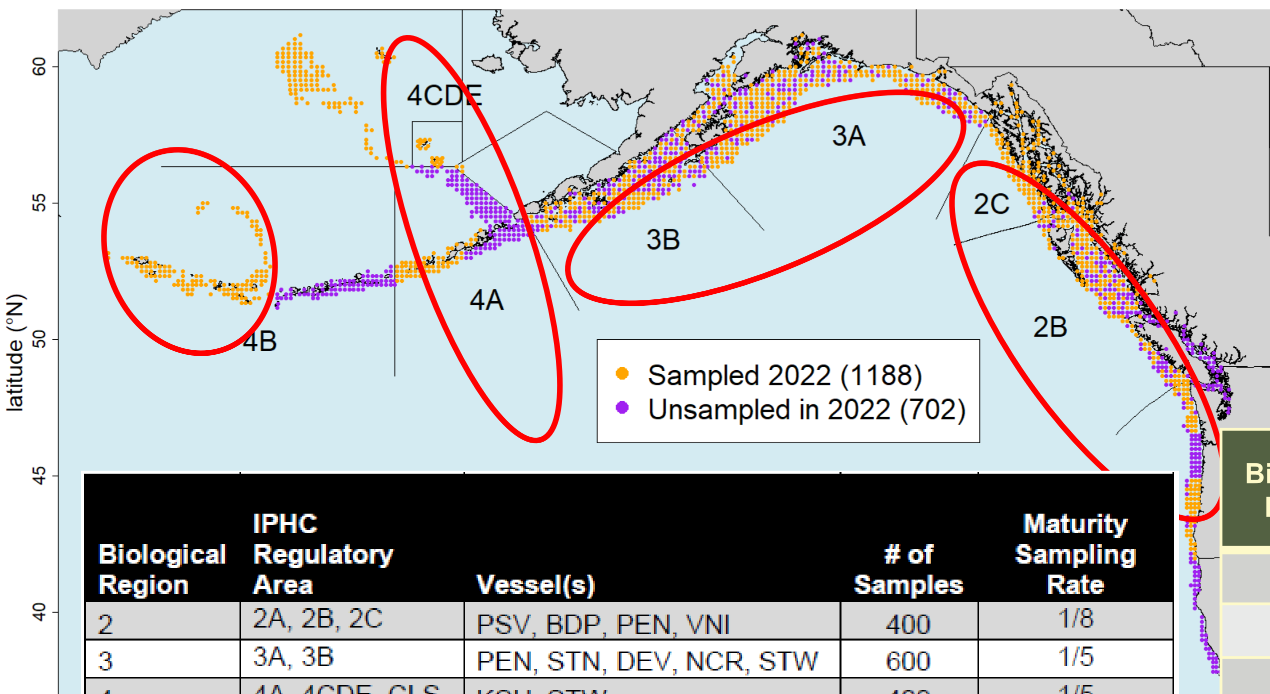
Research outcomes:

- In progress

Publications: Fish et al. (2020) *Journal of Fish Biology* **97**: 1880–1885
Fish et al. (2022) *Frontiers in Marine Science* **9**: 801759

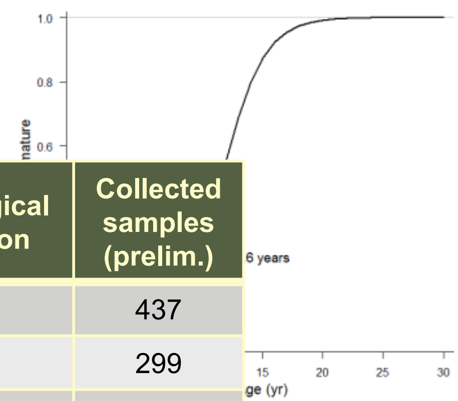
2. Reproduction

FISS 2022: ovarian sample collection for histology-based maturity



Biological Region	IPHC Regulatory Area	Vessel(s)	# of Samples	Maturity Sampling Rate
2	2A, 2B, 2C	PSV, BDP, PEN, VNI	400	1/8
3	3A, 3B	PEN, STN, DEV, NCR, STW	600	1/5
4	4A, 4CDE, CLS	KSU, STW	400	1/5
4B	4B	KSU	258	1

- **Revise maturity estimates per biological region by histological staging**



Biological Region	Collected samples (prelim.)
2	437
3	299
4	178
4B	51

3. Mortality and Survival Assessment

5-Yr Research Plan (2017-2021) | **PIRM 2022-2026**

Fall 2017 field experiment (GOA)

Discard mortality rate estimation: longline fishery

Capture and handling conditions
- Careful shake
- Gangion cut
- Hook strip

→ Injury and viability assessment → Survival assessment by tagging

→ Physiological condition assessment

→ Analysis of capture-related variables

→ Best handling practices in longline fishery

Research outcomes:
- Injury and viability profiles of hook release methods
- Physiological profile of fish under different capture and handling conditions
- Longline DMR

Summer 2021 field experiments (Sitka, AK Seward, AK)

Discard mortality rate estimation: charter recreational fishery

Capture and handling conditions
- 12/0 and 16/0 hooks

→ Injury, viability and physiological assessment → Survival assessment by tagging

→ Analysis of capture-related variables

→ Best handling practices in recreational fishery

Research outcomes:
- In progress

Whale depredation-related mortality

External funding: Saltonstall-Kennedy NOAA (2017-2020); NFWF (2019-2021); NPRB#2009 (2021-2022)

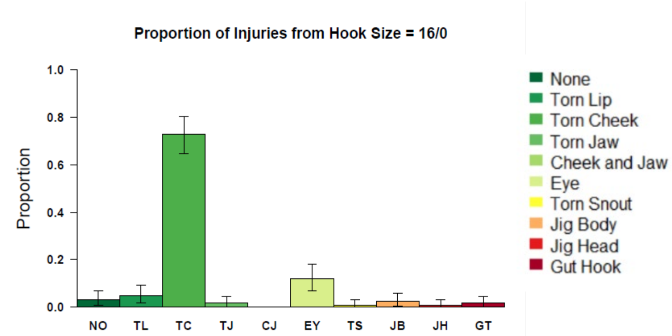
Publications: Kroska et al. (2021) *Conservation Physiology* **9**: coab001

Loher et al. (2022) *North American Journal of Fisheries Management* ***42****: 37-49*

3. Mortality and Survival Assessment

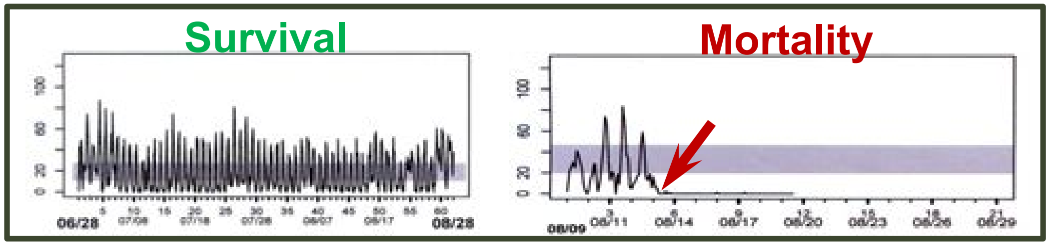
Direct discard mortality rate estimation in the guided recreational fishery by tagging

- Wire = 281 (243 in Sitka, 38 in Seward) – 28 recovered to date
- sPAT = 80 (Seward) – 76 provided functional data
  - 48 full duration (96 days)
  - 7 fishery recoveries
  - 21 premature release,
  - **Mortality rate estimate: 2.04% (0.00-5.92 CI)**



A) Wire Tag

B) sPAT Tag



C) Typical acceleration patterns for fish that survive and fish that die

3. Mortality and Survival Assessment

Reducing mortality from whale depredation by protecting longline catches

1. International Workshop on Protecting Fishery Catches from Whale Depredation:

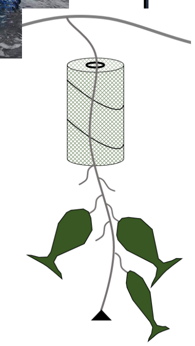
- Virtual workshop - 74 participants from 6 countries
- 3 presentations on different strategies for protecting the catch from longlines:
  - Shuttles – Sago Solutions (Norway),
  - Shrouds – INFREMER, IRD, MARBEC, (France)
  - Slinky Pots – Fish Tech Inc. (US)

NOAA FISHERIES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Bycatch Reduction Engineering Program (BREP) NA21NMF4720534

2. Field testing of catch protection devices

- Production of prototypes of two different devices:
  - Reduced size Sago Extreme shuttles (2) with modified entry (A)
  - Open end slinky pots over easy slip snap gear on branchlines (B)
- Field testing (**Spring 2023** in Gulf of Alaska):
  - Deployment / Retrieval logistics
  - Optimal configurations (weighting, attachments)
  - Basic performance (species/sizes)

A) Sago shuttle



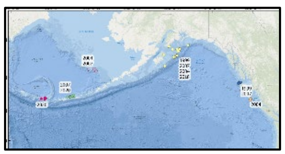
B) Slinky shroud

4. Population genomics

5-Yr Research Plan (2017-2021) | **PIRM 2022-2026**

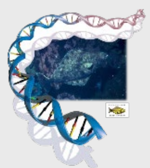
Collection of genetic samples of spawning aggregations spanning the Gulf of Alaska, Bering Sea and Aleutian Islands

(1999-2020)



Development and application of genomic approaches

Chromosome-level genome assembly



→ Development of methods based on low-coverage whole genome resequencing

→ Establishment of a bioinformatic pipeline in the cloud (Microsoft Azure)

→ Population structure analyses

→ Establishment of a baseline of genetic diversity

→ Delineation of fine-scale stock structure

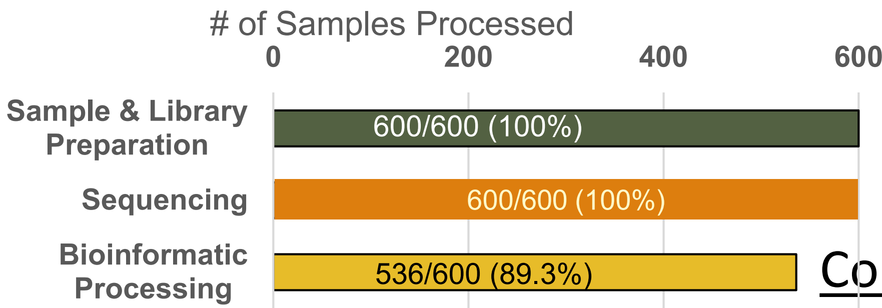
Research outcomes:

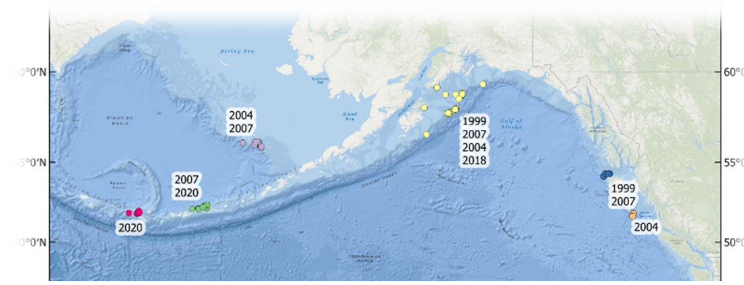
- Sequenced genome (size=602 Mbp)
- Full annotation (NCBI) (27,944 genes)
- 24 chromosome-length scaffolds
- SNP detection and genotyping

External Funding: NPRB#2110 (2021-2024)

Publications: Jasonowicz et al. (2022) *Molecular Ecology Resources* 22, 1– 16.

4. Population genomics





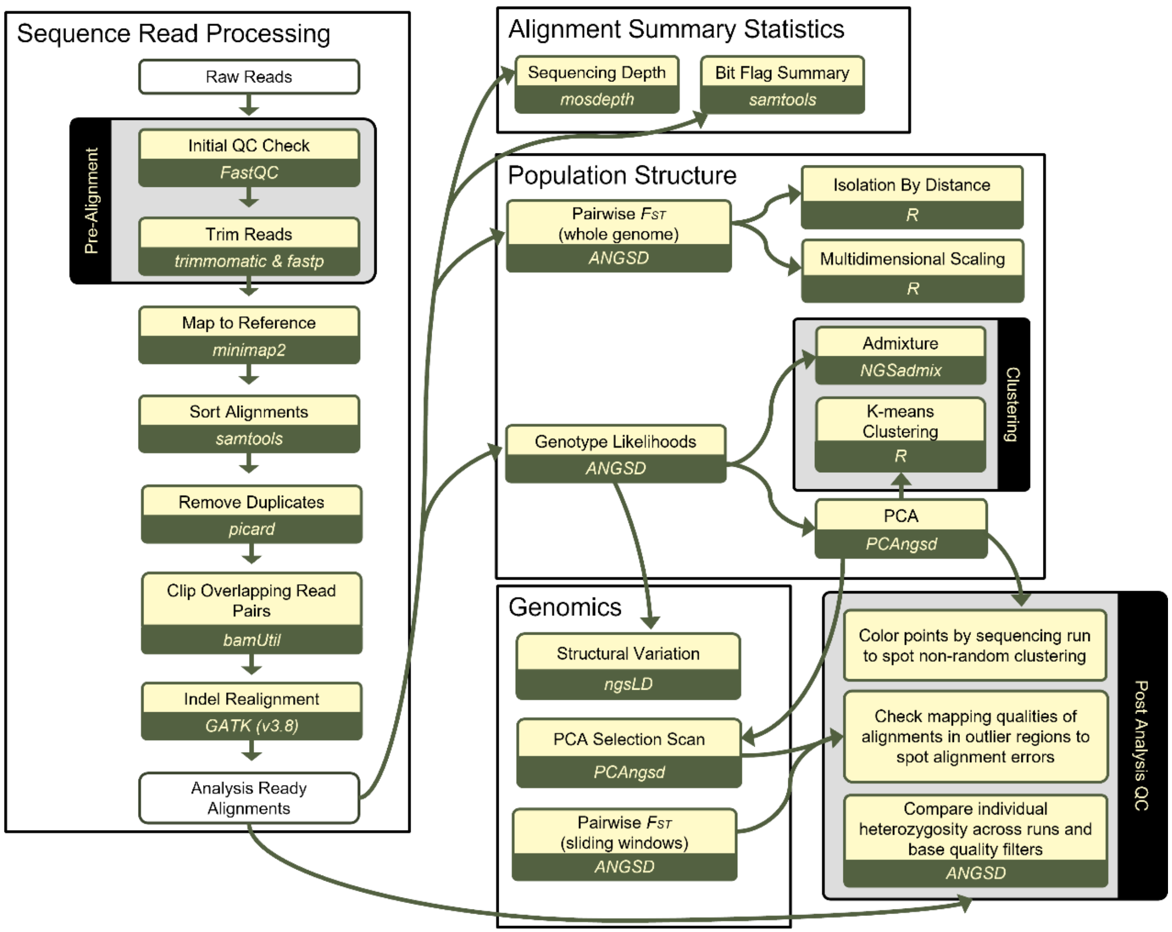
Completed sequencing runs to date:

Library	IPHC_001	IPHC_002	IPHC_003
Number of samples*	249	249	102
Sequencing Platform	Illumina NovaSeq S4	Illumina NovaSeq S4	Illumina NovaSeq S4
Raw Reads Per Sample (Millions)**	24.7 (10.7-47.2)	24.9 (13.0-51.6)	25.8 (10.9-85.8)
Reads Retained (%)**	62 (22-69)	61 (46-70)	In Progress
Coverage Per Sample (x)**	3.0 (0.9-5.0)	3.0 (1.3-5.9)	In Progress

*numbers in parenthesis indicate number of samples with > 1,000,000 raw sequence reads.

4. Population genomics

Bioinformatic Workflow



Current externally-funded collaborative research

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	Bycatch Reduction Engineering Program-NOAA	Gear-based approaches to catch protection as a means for minimizing whale depredation in longline fisheries (NOAA Award Number NA21NMF4720534)	IPHC	Deep Sea Fishermen's Union, Alaska Fisheries Science Center-NOAA, industry representatives	$99,700	Whale depredation	1 November 2021 – 31 October 2023
2	North Pacific Research Board	Pacific halibut population genomics (NPRB Award No. 2110)	IPHC	Alaska Fisheries Science Center-NOAA	$193,685	Stock structure	1 December 2021 – 31 January 2024
Total awarded ($)					**$293,385**		

Recommendation

That the SRB:

- **NOTE** paper IPHC-2022-SRB021-09 which outlines progress on the on biological and ecosystem science research activities, contained within the IPHC's 5-year Program of Integrated Research and Monitoring (2022-26).

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