INTERNATIONAL PACIFIC
HALIBUT COMMISSION

IPHC–2026–SRB028–00
Last Update: 19 May 2026

28th Session of the IPHC Scientific Review Board (SRB028) – *Compendium of meeting documents*

19-21 May 2026, Seattle, WA, USA

Commissioners

Canada	United States of America
Mark Waddell	Jon Kurland
Neil Davis	Robert Alverson
Peter DeGreef	Richard Yamada

Executive Director

David T. Wilson, Ph.D.

DISTRIBUTION: IPHC WEBSITE
LAST UPDATE: 19 May 2026

BIBLIOGRAPHIC ENTRY
IPHC 2026. 28th Session of the IPHC Scientific Review Board (SRB028) - Compendium of meeting documents. Int. Pac. Halibut Comm.

IPHC–2026–SRB028–00

The designations employed and the presentation of material in this publication and its lists do not imply the expression of any opinion whatsoever on the part of the International Pacific Halibut Commission (IPHC) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.
This work is protected by copyright. Fair use of this material for scholarship, research, news reporting, criticism or commentary is permitted. Selected passages, tables or diagrams may be reproduced for such purposes provided acknowledgment of the source is included. Major extracts or the entire document may not be reproduced by any process without the written permission of the Executive Director, IPHC.

The IPHC has exercised due care and skill in the preparation and compilation of the information and data set out in this publication. Notwithstanding, the IPHC, its employees and advisers, assert all rights and immunities, and disclaim all liability, including liability for negligence, for any loss, damage, injury, expense or cost incurred by any person as a result of accessing, using or relying upon any of the information or data set out in this publication, to the maximum extent permitted by law including the International Organizations Immunities Act.

Contact details:

International Pacific Halibut Commission
2320 W. Commodore Way, Suite 300
Seattle, WA, 98199-1287, U.S.A.
Phone: +1 206 634 1838
Fax: +1 206 632 2983
Email: secretariat@iphc.int
Website: http://iphc.int/

AGENDA & SCHEDULE FOR THE 28th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB028)

Date: 19-21 May 2026
Location: Hybrid - Seattle, WA, USA & Electronic
Venue: IPHC HQ (for SRB and Science advisors only) & Adobe Connect (observers)
Time: 09:00-17:00 (19-20th), 09:00-12:00 (21st) PDT
Chairperson: Dr. Olaf Jensen (USA)
Vice-Chairperson: Vacant

1. OPENING OF THE SESSION

1.1. Election of a Chairperson (Executive Director)

2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

3. IPHC PROCESS

3.1. SRB annual workflow (D. Wilson)
3.2. Update on the actions arising from the 27th Session of the SRB (SRB027) (D. Wilson)
3.3. Outcomes of the 102nd Session of the IPHC Annual Meeting (AM102) (D. Wilson)
3.4. Observer updates (e.g. Science Advisors)

4. INTERNATIONAL PACIFIC HALIBUT COMMISSION INTEGRATED RESEARCH AND MONITORING PLAN

4.1. RESEARCH

4.1.1. Biology and ecology
4.1.2. Pacific halibut stock assessment
4.1.3. Management strategy evaluation

4.2. MONITORING

4.2.1. Fishery-dependent data
4.2.2. Fishery-independent data
- IPHC Fishery-Independent Setline Survey (FISS)
  - 2027 FISS design evaluation (R. Webster)
  - Updates to space-time modelling (R. Webster)

4.2.3. Age composition data (both fishery-dependent and fishery-independent)

5. OTHER BUSINESS

6. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 28th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB028)

SCHEDULE FOR THE 28th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB028)

Tuesday, 19 May 2026

Time	Agenda item	Lead
09:00-09:05	1. OPENING OF THE SESSION 1.1 Election of Chairperson (D. Wilson)	D. Wilson
09:05-09:20	2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION • Introduction of new SRB member	Chairperson & M. Wilberg
09:20-09:50	3. IPHC PROCESS 3.1 SRB annual workflow (D. Wilson) 3.2 Update on the actions arising from the 26th Session of the SRB (SRB026) 3.3 Outcomes of the 101st Session of the IPHC Annual Meeting (AM101) 3.4 Observer updates (e.g. Science Advisors)	D. Wilson
09:50-10:00	4. INTERNATIONAL PACIFIC HALIBUT COMMISSION INTEGRATED RESEARCH AND MONITORING PLAN	D. Wilson
10:00-10:30	4.1 RESEARCH 4.1.1 Biology and ecology	J. Planas
10:30-11:00	Break	
11:00-11:30	4.1.1 Biology and ecology (cont.)	J. Planas
11:30-12:30	4.1.2 Pacific halibut stock assessment	I. Stewart
12:30-13:30	Lunch	

13:30-14:00	4.1.2 Pacific halibut stock assessment (cont.)	I. Stewart
14:00-14:30	4.1.3 Management Strategy Evaluation	A. Hicks
14:30-14:45	Break	
14:45-16:00	4.1.3 Management Strategy Evaluation (cont.)	A. Hicks
16:00-17:00	SRB drafting session	SRB members
18:30-21:00	SRB Function (Location TBA)	SRB
Wednesday, 20 May 2026		
Time	**Agenda item**	**Lead**
09:00-09:30	Review of Day 1 and discussion of SRB Recommendations from Day 1	Chairperson
09:30-10:30	4.2 MONITORING 4.2.1 Fishery-dependent data 4.2.2 Fishery-independent data • IPHC Fishery-Independent Setline Survey (FISS) ○ 2027 FISS design evaluation (R. Webster) ○ Updates to space-time modelling (R. Webster) 4.2.3 Age composition data (both fishery-dependent and fishery-independent)	R. Webster B. Hutniczak
10:30-11:00	Break	
11:00-12:30	*Offline collaborative session (SRB and subject matter teams)*	SRB
12:30-13:30	Lunch	
13:30-16:00	*Offline collaborative session (SRB and subject matter teams)*	SRB
16:00-17:00	SRB drafting session	SRB members
Thursday, 21 May 2026		
Time	**Agenda item**	**Lead**
09:00-09:30	5. OTHER BUSINESS	Chairperson

09:30-10:30	SRB drafting session	SRB members
10:30-11:30	Time for all participants to review the draft report	All
11:30-12:30	6. ADOPTION OF THE REPORT OF THE 28th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB028)	Chairperson
12:30-13:30	Lunch and departure	

Last updated: 19 May 2026

LIST OF DOCUMENTS FOR THE 28th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB028)

Document	Title	Availability
IPHC-2026-SRB028-01	Agenda & Schedule for the 28th Session of the Scientific Review Board (SRB028)	✓ 16 Dec 2025 ✓ 12 Mar 2026 ✓ 19 Apr 2026
IPHC-2026-SRB028-02	List of Documents for the 28th Session of the Scientific Review Board (SRB028)	✓ 16 Dec 2025 ✓ 16 Apr 2026 ✓ 19 May 2026
IPHC-2026-SRB028-03	Update on the actions arising from the 27th Session of the SRB (SRB027) (IPHC Secretariat)	✓ 16 Apr 2026
IPHC-2026-SRB028-04	Outcomes of the 102nd Session of the IPHC Annual Meeting (AM102) (D. Wilson)	✓ 15 Apr 2026
IPHC-2026-SRB028-05	International Pacific Halibut Commission Integrated Research and Monitoring Plan (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, & B. Hutniczak)	✓ 15 Apr 2026
IPHC-2026-SRB028-06	Report on current and future biological and ecosystem science research activities (J. Planas, C. Dykstra, A. Jasonowicz, & C. Jones)	✓ 15 Apr 2026
IPHC-2026-SRB028-07	Development of the 2026 Pacific halibut (*Hippoglossus stenolepis*) stock assessment (I. Stewart & A. Hicks)	✓ 15 Apr 2026
IPHC-2026-SRB028-08 Rev_1	An update of the IPHC Secretariat MSE Program of Work (A. Hicks & I. Stewart)	✓ 16 Apr 2026 ✓ 5 May 2026
IPHC-2026-SRB028-09	2027-31 FISS design evaluation (R. Webster, I. Stewart, K. Ualesi, T. Jack, & D. Wilson)	✓ 15 Apr 2026
Information papers		
IPHC-2026-SRB028-INF01	Using artificial intelligence (AI) for supplementing Pacific halibut age determination from collected otoliths - project update (B. Hutniczak)	✓ 8 May 2026

IPHC-2026-SRB028-03

UPDATE ON THE ACTIONS ARISING FROM THE 27TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB027)

PREPARED BY: IPHC SECRETARIAT (16 APRIL 2026)

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 SRB027.

BACKGROUND

At the SRB027, the members recommended/requested a series of actions to be taken by the IPHC Secretariat, as detailed in the SRB026 meeting report (IPHC-2025-SRB027-R) available from the IPHC website, and as provided in Appendix A.

DISCUSSION

During the 28th Session of the SRB (SRB028), 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 Secretariat 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).

RECOMMENDATIONS

That the SRB:

1) **NOTE** paper IPHC-2026-SRB028-03, that 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 (SRB027).
2) **AGREE** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB028.

APPENDICES

Appendix A: Update on actions arising from the 27th Session of the IPHC Scientific Review Board (SRB027).

APPENDIX A

Update on actions arising from the 27th Session of the IPHC Scientific Review Board (SRB027)

RECOMMENDATIONS

Action No.	Description	Update
SRB027–Rec.01 (para. 14)	***Research - Biology and ecology*** The SRB **RECOMMENDED** that evaluation of epigenetic aging be expanded from random selection of cross-validation samples to include testing out-of-sample interannual predictive performance. That is, how well can an epigenetic aging method trained on data from one set of years predict age of individuals sampled in other years?	***In Progress*** **Update**: The IPHC Secretariat has selected a set of genetic samples separate from those used for the epigenetic clock development to test out-of-sample interannual predictive performance, as detailed in document IPHC-2026-SRB028-06.
SRB027–Rec.02 (para. 16)	***Pacific halibut stock assessment*** The SRB **RECOMMENDED** that the analysis of projection performance be expanded to include plotting receiver operating characteristic (ROC) curves and evaluating the area under the curve (AUC) to understand the predictive performance of probabilistic advice from the stock assessment projections. This approach is commonly used as a threshold-independent metric of performance in applications such as species distribution modelling.	***Completed*** **Update**: Analysis provided in document IPHC-2026-SRB028-07.
SRB027–Rec.03 (para. 18)	***Management strategy evaluation*** The SRB **RECOMMENDED** that the definition of "overfishing" be tied to the Fmsy proxy rather than a probability of becoming overfished or depleted. This is a standard definition of overfishing and distinguishes it from the state of being overfished/depleted.	***Completed*** **Update**: The IPHC Harvest Strategy Policy (IPHC-2025-HSP) was updated and adopted by the Commission with language suggested by the SRB.
SRB027–Rec.04 (para. 19)	The SRB **NOTED** the definition of "overfishing" in the draft Harvest Strategy Policy and **RECOMMENDED** adopting the revised definition developed at SRB027 to align with the recommendation in paragraph 18.	***Completed*** **Update**: The IPHC Harvest Strategy Policy (IPHC-2025-HSP) was updated and adopted by the Commission with language suggested by the SRB.

	a) **Overfishing**: When the annual fishing intensity is higher than the level required to sustain maximum sustainable yield (MSY). The MSY fishing intensity is currently FSPR=35% based on current understanding of Pacific halibut population dynamics and fishery characteristics. The MSY fishing intensity may be revised as new information becomes available.	
SRB027–Rec.05 (para. 20)	The SRB **NOTED** the paragraphs describing “overfished” and “depleted” in the draft Harvest Strategy Policy and **RECOMMENDED** adopting the revised paragraphs developed at SRB027 which clarify these descriptions while retaining the intended meaning. a) Overfished is a relative limit reference point defining an unacceptably low ratio of spawning biomass to dynamic unfished spawning biomass that results from fishing alone rather than the combined effects of fishing and the environment. The dynamic unfished spawning biomass is that which would have occurred without any fishing given natural variability (e.g. recruitment deviations, changes in size-at-age, etc). Therefore, an overfished state may be fully mitigated by management actions. b) Depleted is an absolute limit reference point defined by a spawning biomass below which the potential for recovery is uncertain. Natural variability affects stock size resulting in fluctuations of the spawning biomass, which along with fishing may result in a ‘depleted’ stock where reductions in fishing mortality may not lead to recovery without a change in the environmental conditions affecting the stock. Therefore, a depleted state may be only partially mitigated by management actions. c) Because overfished and depleted represent 'limit' reference points, the Commission may choose additional	***Completed*** **Update**: The IPHC Harvest Strategy Policy (IPHC-2025-HSP) was updated and adopted by the Commission with language suggested by the SRB.

	precautionary actions whenever needed, including when at, or approaching, either of these states.	
SRB027–Rec.06 (para. 21)	The SRB **RECOMMENDED** defining an "exceptional circumstance" if the stock is determined to be "depleted" as this state is unlikely to occur under the circumstances in which the HSP is implemented and may be indicative of a need for model revision.	***In Progress*** **Update**: This will be discussed with the MSAB and SRB following more work on defining a Depleted reference point.
SRB027–Rec.07 (para. 22)	The SRB **RECOMMENDED** considering some fishery performance indicators that represent metrics directly observable by stakeholders, e.g. fishery CPUE.	***In Progress*** **Update**: This will be discussed at MSAB022.
SRB027–Rec.08 (para. 23)	The SRB **RECOMMENDED** increasing simulation sample sizes to achieve a smooth curve so that a "depleted" threshold can be identified as the lowest spawning stock biomass that results in near 100% probability of recovery.	***In Progress*** **Update**: This will be completed following the conditioning of the OM.
SRB027–Rec.09 (para. 24)	The SRB **RECOMMENDED** considering the development of an assessment model within the MSE framework. This would have multiple benefits including: a) facilitating analysis of the economic consequences of reduced FISS sampling and the associated increased potential for bias in assessment-relevant metrics such as WPUE, the maturity schedule, size-at-age, and age composition. b) Understanding the impacts of uncertainty in natural mortality on management performance.	***In Progress*** **Update**: An estimating model is currently being developed and tested.
SRB027–Rec.10 (para. 31)	***Updates to space-time modelling*** The SRB **RECOMMENDED** continuing the development of the spatial models of maturity and expanding this very promising modelling approach in the following ways: a) Adding a temporal component to the model; b) Extending this approach to coast-wide modelling of WPUE and NPUE.	***In Progress*** **Update**: A verbal update will be provided at SRB028, as the development of the spatial models of maturity is still a work in progress.

REQUESTS

Action No.	Description	Update
SRB027–Req.01 (para. 12)	***International Pacific Halibut Commission Integrated Research and Monitoring Plan*** The SRB **REQUESTED** that, in a future iteration of the Plan, the following elements be considered: a) **Tactical workplan**: Develop a 3-5 year tactical workplan with defined milestones. b) **Prioritizing research**: according to needs for stock assessment, MSE, and other potential applications. This may require a new process for determining priority such as sensitivity analyses on the stock assessment or MSE. c) **Range-wide research**: including collaboration with western Pacific Ocean countries fishing for Pacific halibut (Ref. PRIPHC02-Rec.03). d) **Cost-benefit analysis**: innovation and emerging scientific methods could use a procedure for determining the cost-benefit of proposed or ongoing projects. For example, AI-assisted ageing and epigenetic ageing presumably have different operational costs as supplemental ageing methods (although non-lethal epigenetic ageing has other potential applications) e) **Addition of decision-points**: to determine whether internally funded projects continue or stop. Many of the items in the IRMP are potentially open-ended but should not be continued indefinitely if the question is answered sufficiently to remove it from the high priority list. For example, questions about stock structure could certainly be continued, but they have been sufficiently addressed that the possibility of stock structure is no longer a high priority risk f) **Observer coverage**: Evaluation of observer coverage and/or other methods of catch and	***Completed & Ongoing*** **Update**: See paper IPHC-2026-SRB028-05

	discard reporting across the entire fishery (Ref. PRIPHC02-Rec.09) g) **Dashboards**: The IRMP emphasizes outreach via websites, meetings, publications, and plain language summaries. Outputs could be made more actionable for decision-makers and other stakeholders through graphical dashboard summaries of key stock and harvest indicators, perhaps by IPHC Regulatory Area. h) **Communication**: supplemental documentation is needed of completed projects, progress against independent review recommendations, etc., and how these may or may not affect organization and prioritization of ongoing projects. For example, the IRMP Supplement could include a brief summary of the stock structure conclusions and what that means for ongoing stock structure related projects. i) **Measures of Success**: although the plan lists broad performance categories, there is a need for project-level indicators. Some performance measures, such as relevance and impact, may require surveys of science information users to elicit performance data. j) **Capacity building**: Is there a formal capacity building plan to ensure the long-term viability of the IRMP?	

OUTCOMES OF THE 102ND SESSION OF THE IPHC ANNUAL MEETING (AM102)

PREPARED BY: IPHC SECRETARIAT (D. WILSON; 15 APRIL 2026)

PURPOSE

To provide the SRB with the outcomes of the 102nd Session of the IPHC Annual Meeting (AM102), relevant to the mandate of the SRB.

BACKGROUND

Nil

DISCUSSION

During the course of the 102nd Session of the IPHC Annual Meeting (AM102) the Commission made a number of specific recommendations and requests for action regarding the stock assessment, MSE process, and the Integrated Research and Monitoring Plan. Relevant sections from the report of the meeting are provided in Appendix A for the SRB's consideration.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2026-SRB028-04 which details the outcomes of the 102nd Session of the IPHC Annual Meeting (AM102), relevant to the mandate of the SRB.

APPENDICES

Appendix A: Excerpts from the 102nd Session of the IPHC Annual Meeting (AM102) Report (IPHC-2026-AM102-R).

APPENDIX A

Excerpts from the 102nd Session of the IPHC Annual Meeting (AM102) Report

(IPHC-2026-AM102-R)

3.4 Report of the IPHC Scientific Review Board (SRB)

(para. 11) The Commission **NOTED** the Reports of the 26th and 27th Sessions of the IPHC Scientific Review Board (IPHC-2025-SRB026-R; IPHC-2025-SRB027-R) that were presented by Dr Olaf Jenson (University of Wisconsin-Madison), as the Chairperson, Dr Sean Cox had stepped down from the SRB at the close of the SRB027 meeting.

(para. 12) The Commission **THANKED** Dr Cox for his chairmanship since the SRB was formed. Dr Cox has contributed greatly to the IPHC scientific peer review process and has led the SRB to where it is today. The IPHC Secretariat is actively seeking to fill the vacancy on the SRB prior to SRB028.

(para. 13) The Commission **CONSIDERED** the recommendations made by the SRB in 2025 and **AGREED** to take them into consideration when deliberating on relevant agenda items throughout the AM102.

6. MANAGEMENT STRATEGY EVALUATION

6.1 IPHC Management Strategy Evaluation & Harvest Strategy Policy

(para. 54) The Commission **NOTED** paper IPHC-2026-AM102-11 that provided the Commission with MSE results completed in 2025, a Harvest Strategy Policy (HSP) table, and an MSE/HSP Program of Work for 2026.

(para. 55) The Commission **RECALLED** that a Harvest Strategy Policy (HSP) was adopted by the Commission in late 2025. The HSP can be found at https://www.iphc.int/research-monitoring/harvest-strategy-policy.

(para. 56) The Commission **NOTED** that the 2026 MSE and HSP Program of Work will include the following high-priority topics:

a) Update and recondition the MSE Operating Model in accordance with the schedule defined in the Harvest Strategy Policy;

b) Evaluate a range of SPR values to determine if the optimal reference coastwide fishing intensity is different than the current reference fishing intensity (F43%) defined in the HSP;

c) Investigate productivity regimes to determine how the Pacific halibut population and fisheries respond to different productivity regimes, if the optimal reference fishing intensity differs across productivity regimes, and how productivity regimes may be incorporated into a Management Procedure;

d) Further develop the Depleted concept and identify a limit reference point below which recovery of the Pacific halibut population would be uncertain.

(para. 57) The Commission **NOTED** that the 2026 MSE and HSP Program of Work will include the following low-priority topics, which may not be completed before AM103:

a) Improve the estimation model used in the MSE framework to better characterize the stock assessment in the simulations;

b) Evaluate potential management actions to invoke when approaching a depleted limit reference point;

c) Evaluate additional elements of Management Procedures which may include a triennial assessment frequency, constraints and smoothers on the interannual change in the TCEY, and empirical rules to determine the reference TCEY in years without a stock assessment;

d) Determine reference points using the updated MSE Operating Model (e.g. F_{MSY} and MSY);

e) Develop guidance documents for the Harvest Strategy Policy (e.g. specifications of a rebuilding plan).

(para. 58) The Commission **NOTED** that the 2026 MSE and HSP Program of Work should not include topics related to the distribution of the TCEY, as this is part of the decision-making process and not part of the management procedure, as described in the Harvest Strategy Policy.

(para. 59) The Commission **NOTED** that outcomes of the 2026 MSE workplan (e.g. an optimal fishing intensity) may be used to update the Harvest Strategy Policy in the future.

8. FISS DESIGN EVALUATIONS 2026-2028

8.1 2026-28 FISS design evaluation

(para. 75) The Commission **ADOPTED** a revised 2026 FISS design (Fig. 6) on the understanding that vessel availability, bids received, additional bait needs, and field staff recruitment may impact operational feasibility (options refer to those in IPHC-2026-AM102-13, Appendix A, Table A.1) (total FISS stations 717 for 2026):

a) Option 2: Supplemented Reduced Loss design (692 stations previously agreed to at IM101; para. 66);

b) Option 4: IPHC Regulatory Area 3A: Replace Prince William Sound (67 stations) with Gore Point (48 stations);

c) Option 5: IPHC Regulatory Area 3A: Replace Yakutat (64 stations) with Fairweather (51 stations);

d) Option 6: IPHC Regulatory Area 2B: Add Goose Island (57 stations).

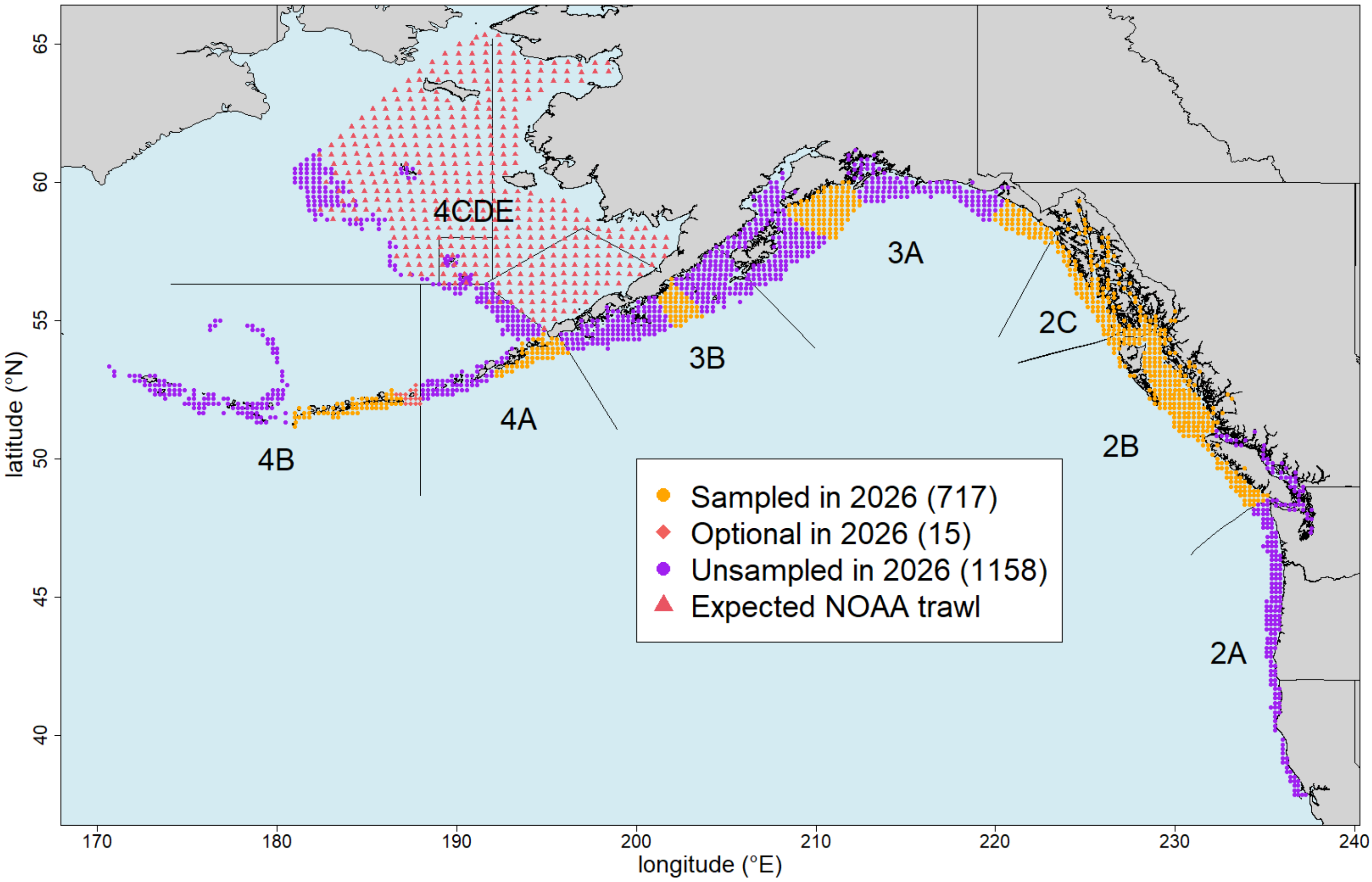


Figure 6. The AM102 approved 2026 FISS design (orange circles).

INTERNATIONAL PACIFIC HALIBUT COMMISSION INTEGRATED RESEARCH AND MONITORING PLAN

PREPARED BY: IPHC SECRETARIAT (D. WILSON, J. PLANAS, I. STEWART, A. HICKS, B. HUTNICZAK, AND R. WEBSTER; 15 APRIL 2026)

PURPOSE

The purpose of this paper is to provide the SRB with the International Pacific Halibut Commission Integrated Research and Monitoring Plan (IRMP) (IPHC–2026-IRMP) published on 17 March 2026, and iterative review and revision process moving forward.

BACKGROUND

The International Pacific Halibut Commission (IPHC) Secretariat conducts activities designed to address key issues identified by the Commission, its subsidiary bodies, the broader stakeholder community, and the Secretariat itself. The process of identifying, developing, and implementing the IPHC's science-based activities is circular and iterative, ultimately resulting in clear project activities and associated deliverables. This process includes proposing projects based on direct input from the Commission and the Secretariat's extensive understanding of the resource and its associated fisheries. These proposals undergo concurrent consideration by relevant IPHC subsidiary bodies and, where deemed necessary by the Commission, additional external peer review.

An overarching goal of the IPHC's Integrated Research and Monitoring Plan is to promote integration and synergies among the Secretariat's various research and monitoring activities. This integration improves the knowledge of key inputs for the Pacific halibut stock assessment and Management Strategy Evaluation (MSE) processes, thereby providing the best possible advice for management decision-making.

The first iteration of the Plan was formally presented to the Commission at IM097 in November 2021 (IPHC-2021-IM097-12) to raise general awareness of the document's ongoing development. Subsequently, at the 98th Session of the IPHC Annual Meeting (AM098) in January 2022, the Commission requested several amendments, which were promptly incorporated. Throughout 2023, 2024, and 2025, the Plan underwent annual review and refinement with the SRB, ensuring that suggested amendments were continuously integrated to improve the document.

DISCUSSION

The SRB should note that:

a) the intention is to ensure that the next 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 **NOTE** paper IPHC-2026-SRB028-05 that provides the IPHC's Integrated Research and Monitoring Plan, as well as the process for annual review.

APPENDICES

Appendix A: IPHC Integrated Research and Monitoring Plan (IRMP)

APPENDIX A

INTERNATIONAL PACIFIC HALIBUT COMMISSION INTEGRATED RESEARCH AND MONITORING PLAN

(IRMP)

INTERNATIONAL PACIFIC
HALIBUT COMMISSION

Commissioners

Canada	United States of America
Mark Waddell	Jon Kurland
Neil Davis	Robert Alverson
Peter DeGreef	Richard Yamada

Executive Director

David T. Wilson, Ph.D.

BIBLIOGRAPHIC ENTRY

IPHC 2026. International Pacific Halibut Commission Integrated Research and Monitoring Plan. Seattle, WA, U.S.A. *IPHC–2026-IRMP, 51 pp.*

INTERNATIONAL PACIFIC
HALIBUT COMMISSION

The designations employed and the presentation of material in this publication and its lists do not imply the expression of any opinion whatsoever on the part of the International Pacific Halibut Commission (IPHC) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

This work is protected by copyright. Fair use of this material for scholarship, research, news reporting, criticism or commentary is permitted. Selected passages, tables or diagrams may be reproduced for such purposes provided acknowledgment of the source is included. Major extracts or the entire document may not be reproduced by any process without the written permission of the Executive Director, IPHC.

The IPHC has exercised due care and skill in the preparation and compilation of the information and data set out in this publication. Notwithstanding, the IPHC, its employees and advisers, assert all rights and immunities, and disclaim all liability, including liability for negligence, for any loss, damage, injury, expense or cost incurred by any person as a result of accessing, using or relying upon any of the information or data set out in this publication, to the maximum extent permitted by law including the International Organizations Immunities Act.

Contact details:

International Pacific Halibut Commission

2320 W. Commodore Way, Suite 300

Seattle, WA, 98199-1287, U.S.A.

Phone: +1 206 634 1838

Fax: +1 206 632 2983

Email: secretariat@iphc.int

Website: http://www.iphc.int/

ACRONYMS

AI	Artificial Intelligence
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
IRMP	Integrated Research and Monitoring Plan
MP	Management Procedure
MSAB	Management Strategy Advisory Board
MSE	Management Strategy Evaluation
OM	Operating Model
PAB	Processor Advisory Board
PDO	Pacific Decadal Oscillation
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://www.iphc.int/glossary-of-terms-and-abbreviations/

TABLE OF CONTENTS

EXECUTIVE SUMMARY

An **overarching goal** of this current IPHC Integrated Research and Monitoring Plan (IRMP) is to continue to integrate all research activities of the IPHC Secretariat in order to improve the Pacific halibut stock assessment and MSE process and thereby provide the best possible advice for management decision-making processes. In doing so, the Plan also responds to emerging challenges and opportunities, including those presented by advances in artificial intelligence (AI), to enhance analytical capacity, improve efficiency, and support innovation across scientific and operational domains. The intention is no longer to designate the Plan for a defined period, but rather, to annually review and update the Plan as needed, based on resources available to the IPHC, as well as new Commission directives.

Along with the implementation of the short- and medium-term activities contemplated in this IRMP and in pursuit of the overarching goal, 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 organisations and by leading international science and research collaborations.
6) effectively communicate IPHC research outcomes; and
7) incorporate talented students and early researchers in research activities.

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 (2023-27)):

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, monitoring, 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, are operationalised through a multi-year tactical activity matrix at the organisational and management unit (Branch) level (Fig. 3). The tactical activity matrix is described 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.

The Secretariat's success in implementing the IRMP 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, analysed, 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 - was the information used to inform decisions made by the Commission?
4) Impact – did the research improve the perceived accuracy of or provide 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.

As with the previous two (2) plans, the IPHC Secretariat intends to maintain this IRMP document as a 'living plan', subject to annual reviews and updates as necessary. Revisions will reflect evolving priorities, resources available to undertake the work (e.g. internal and external fiscal resources, collaborations, internal expertise), and emerging opportunities. The IPHC Secretariat remains committed to transparency and to upholding the principles of open science in the development and implementation of this plan.

1. Introduction

The International Pacific Halibut Commission (IPHC) is a public international organisation 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 organisation 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 of 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.***

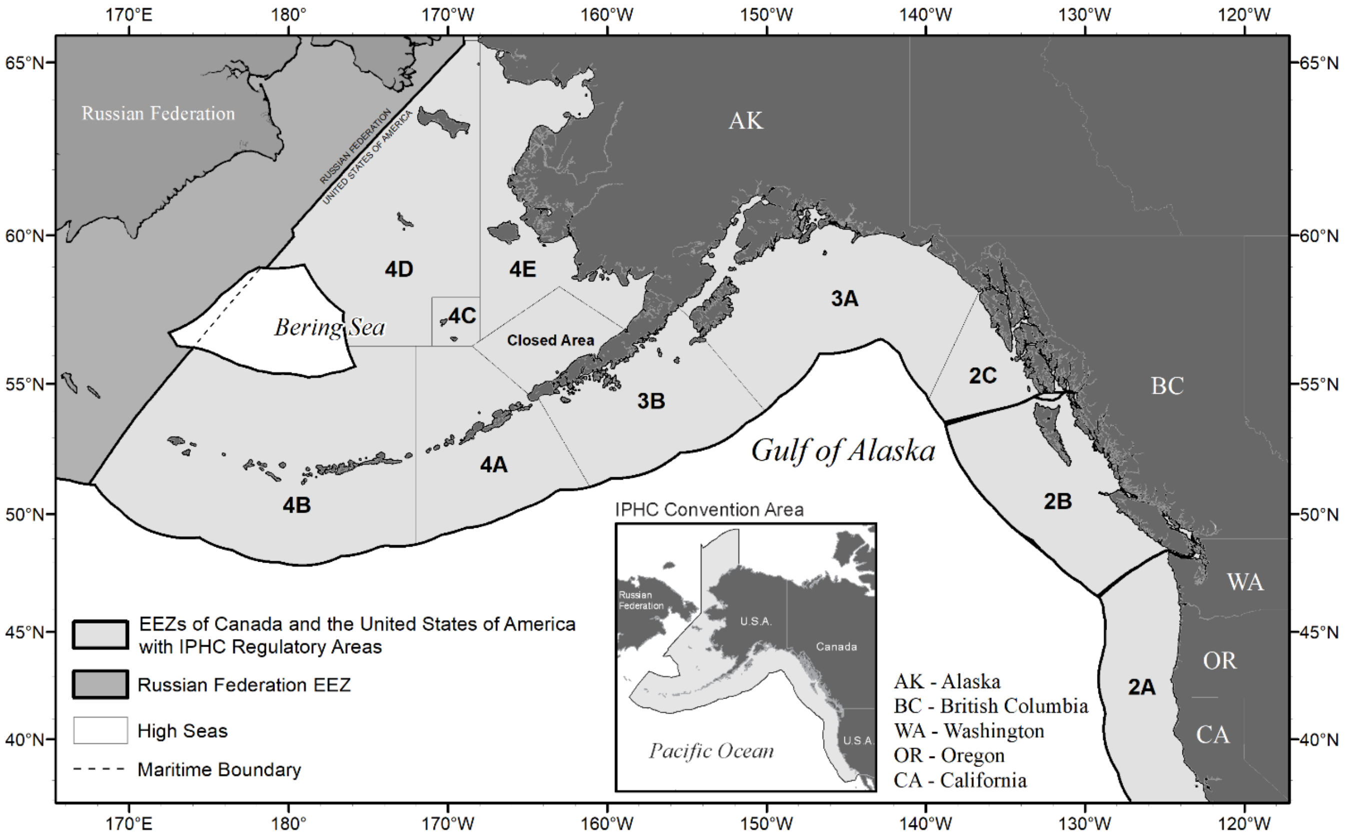


Figure 1. Map of the IPHC Convention Area (map insert) and IPHC Regulatory Areas.

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. 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 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 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 ten (10) years, the research conducted by the IPHC Secretariat has been guided by two sequential detailed plans.

- 2017-2021: 5-Year Biological and Ecosystem Science Research Plan (IPHC–2019–BESRP-5YP).
- 2022-2026: 5-Year Program of Integrated Research and Monitoring (IPHC-2023-5YPIRM)

The aim of the first plan (2017-2021) was to increase our 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 prioritisation (IPHC–2019–BESRP-5YP). The outcomes of the IPHC-2019-BESRP-5YP (summarised in Appendix I of IPHC-2023-5YPIRM) provided key inputs into stock assessment and the MSE process and, importantly, provided foundational information for subsequent plans. The first plan (2017-2021) developed into a second broader and more inclusive plan that encompassed all research and monitoring activities planned and conducted by the IPHC Secretariat as described in the 5-Year Program of Integrated Research and Monitoring (2022-2026) (IPHC-2023-5YPIRM).

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 relevant to the research and monitoring, as provided below. Of these, only recommendations 3 and 9 remain to be fully implemented and have been incorporated into this current IRMP:

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 regularized 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 Research and Monitoring Plans (IPHC–2019–BESRP-5YP; and IPHC-2023-5YPIRM), closing completed projects, extending efforts where needed, and adding new avenues in response to new information. Appendix I provides a detailed summary of the outcomes of the previous IPHC-2023-5YPIRM plan and the status of the work specifically undertaken. Key highlights relevant to the stock assessment and MSE include:

- Investigations on population genomics, including the delineation of a genetic baseline and genomic analyses of population structure (IPHC-2025-SRB026-06).
- Population-level sampling and analysis of maturity and fecundity leading to incorporation of an updated maturity ogive in the 2025 stock assessment and ongoing progress toward an updated fecundity relationship (IPHC-2025-SRB026-06).
- Investigations on methods for reducing whale depredation in the Pacific halibut commercial longline fishery (IPHC-2025-SRB026-06).

All previously described research areas continue to represent critical sources of information for the stock assessment and MSE and thus are closely linked to management performance. The previous 5-year plans were 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 current IRMP 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 this current IPHC Integrated Research and Monitoring Plan (IRMP) is to continue to integrate all research activities of the IPHC Secretariat in order to improve the Pacific halibut stock assessment and MSE process and thereby provide the best possible advice for management decision-making processes. In doing so, the Plan also responds to emerging challenges and opportunities, including those presented by advances in artificial intelligence (AI), to enhance analytical capacity, improve efficiency, and support innovation across scientific and operational domains. The intention is no longer to designate the Plan for a defined period, but rather, to annually review and update the Plan as needed, based on resources available to the IPHC, as well as new Commission directives.

Along with the implementation of the short- and medium-term activities contemplated in this IRMP and in pursuit of the overarching goal, 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 organisations and by leading international science and research collaborations;
6) effectively communicate IPHC research outcomes; and
7) incorporate talented students and early researchers in research activities.

The research and monitoring activities conducted by the IPHC Secretariat are organized into the following five (5) areas: stock assessment, MSE, biology and ecology, monitoring, and additional management support. The overall aim is to provide integrated research and monitoring where each area informs and benefits from the others (Fig. 2):

Research

1) **Stock assessment**: to improve the accuracy and reliability of the current stock assessment and the characterisation 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, investigate reasonable hypothetical scenarios, 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 , and ensure these data are effectively managed, quality-controlled, and maintained in accessible data systems to support timely analysis;

Integrated management support

5) **Additional management-supporting inputs**: respond to Commission requests for additional information supporting management and policy development, including the provision of technical advice, synthesis of research results, and development of analytical tools to inform decision-making.

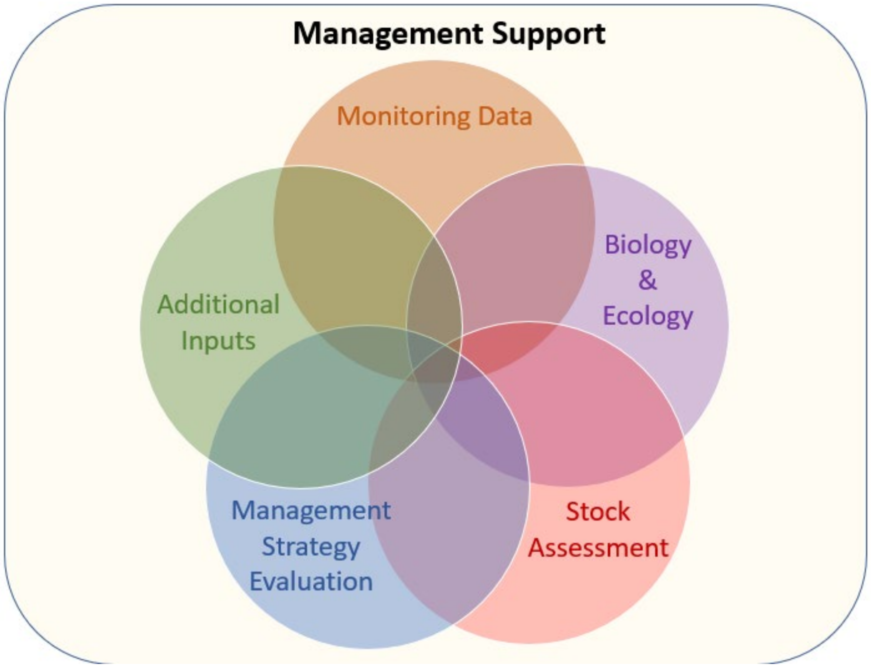
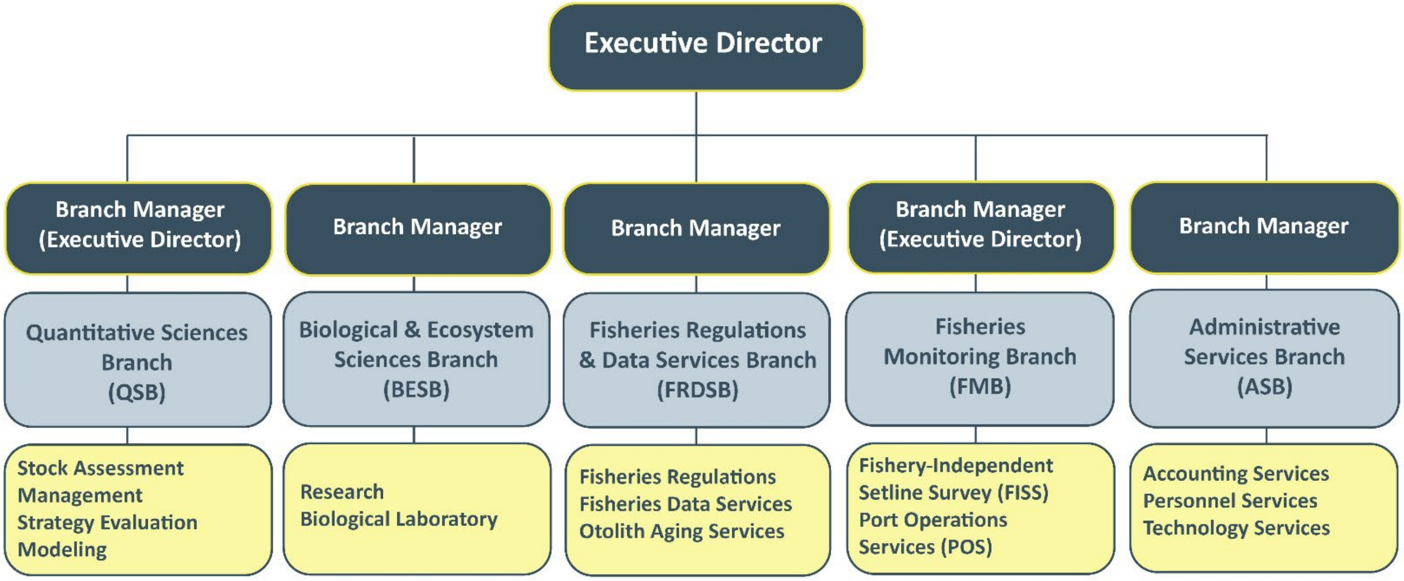


Figure 2. Core areas of the IPHC's Integrated Research and Monitoring Plan (IRMP) provide management support.

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 (2023-27)): 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, monitoring, 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, are 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.



Executive Director

Branch Manager (Executive Director)

Quantitative Sciences Branch (QSB)

Stock Assessment
Management Strategy Evaluation
Modeling

Branch Manager

Biological & Ecosystem Sciences Branch (BESB)

Research
Biological Laboratory

Branch Manager

Fisheries Regulations & Data Services Branch (FRDSB)

Fisheries Regulations
Fisheries Data Services
Otolith Aging Services

Branch Manager (Executive Director)

Fisheries Monitoring Branch (FMB)

Fishery-Independent Setline Survey (FISS)
Port Operations Services (POS)

Branch Manager

Administrative Services Branch (ASB)

Accounting Services
Personnel Services
Technology Services

Figure 3. IPHC Secretariat organisation chart (2025).

4. *Measures of Success*

The Secretariat's success in implementing the IRMP 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, analysed, 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** - was the information used to inform decisions made by the Commission?
4) **Impact** – did the research improve the perceived accuracy of or provide 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 and decision points

Each project line item will contain specific deliverables that constitute useful inputs into the understanding of the Pacific halibut stock and fisheries, 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.

In addition, decision points will be developed for each project to determine whether internally funded activities continue or stop. The goal will be to ensure that none of the projects contemplated within the IRMP are open-ended, and thus, are not continued indefinitely if the question is answered sufficiently to remove it from the high-priority list. For example, questions about stock structure could be continued, but they have been sufficiently addressed that the possibility of stock structure is no longer a high-priority risk.

Cost-benefit analysis: innovation and emerging scientific methods will undergo a cost-benefit analysis before implementation, where feasible.

4.2 Communication

The IPHC Secretariat will disseminate information about the activities contemplated in the IRMP 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), including through the development of a Stock Status Dashboard;
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) Posts on social media platforms;
7) Informal presentations and interactions with partners, stakeholders, and decision-makers at varied times and venues when needed;
8) Accessible and plain-language summaries of key findings, where appropriate, to facilitate broader stakeholder engagement and understanding.

4.3 External research funding

The Secretariat has set a funding goal of at least 20% of the funds for our research and monitoring activities, to be sourced from external funding bodies on an annual basis. Continuing the successful funding-recruitment strategy adopted during the previous plans (Appendix II), the Secretariat will target available external funding opportunities that are timely and that aim at addressing key research objectives 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 capitalise 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. While the external funding environment has changed substantially in recent years, we will continue with this goal and adapt accordingly.

4.4 Peer-reviewed journal publication

Publication of research outcomes in peer-reviewed journals will be clearly documented and monitored as a primary 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 main activities of the IRMP involve 1) monitoring (fisheries-dependent and –independent data collection), 2) research (biological, ecological), and 3) modelling (FISS, stock assessment, and MSE), as outlined in the following sub-sections. These components are closely linked to one another, have goals that are integrated across the organisation, and all feed into management decision-making (Fig. 4). Additionally, management-supporting information constitutes a range of additional decision-making inputs 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 previous two (2) plans, and which are summarised in IPHC-2023-5YPIRM and Appendix I, respectively.

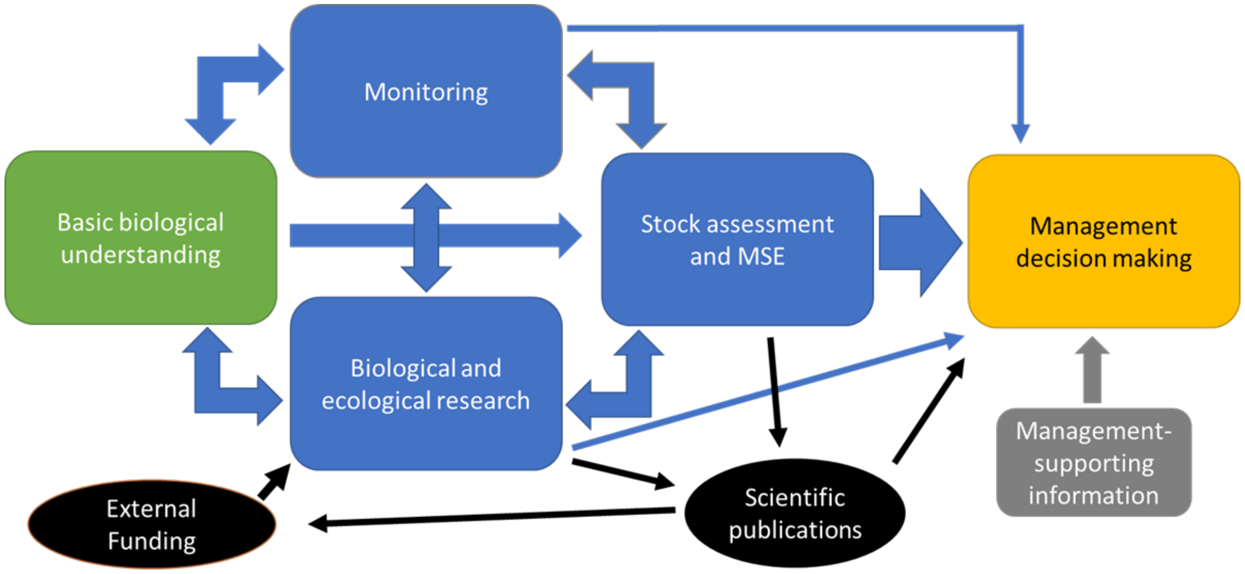


Figure 4. Flow of information from basic biological understanding of the Pacific halibut resource, through IPHC research components (monitoring, biological and ecological research, stock assessment, and MSE) to management decision-making. Management-supporting information (grey) constitutes a range of 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 the accuracy and reliability of the current stock assessment and the characterisation 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 directed and non-directed fisheries, as well as biological information from its research program and programs from other fisheries agencies. 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.

All recent stock assessments have 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. 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 three categories:

1) Assessment data collection and processing;
2) technical development;
3) biological understanding and fishery yield

It is important to note that ongoing monitoring, including the annual FISS and directed commercial landings sampling activities, 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 characterise uncertainty, investigate reasonable hypothetical scenarios, 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 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. An additional benefit of MSE is the potential to analyse scenarios that define a specific portion of the uncertainty or may be outside of the identified uncertainty to understand the management implications if the future did not follow past realizations.

The MSE uses an operating model that includes each part of the management cycle: the population and all fisheries, management decisions, the monitoring program, the estimation model, and potential ecosystem effects using a closed-loop simulation.

MSE is a simulation technique based on modelling the population and fisheries with closed-loop feedback from each part of the management cycle. An operating model (OM) represents aspects that are not controlled by management, such as fishery behavior, recruitment into the population, natural sources of mortality, and potential environmental and ecosystem effects. The management procedure (MP) represents the elements of the decision-making process, including data collection, estimation models (e.g. stock assessment), and harvest rules such as fishing intensity. The MP also characterizes uncertainty in the decision-making process through sampling error, estimation error, and decision-making variability.

MSE reveals the trade-offs among a range of possible management decisions, given alternative harvest strategies, preferences, and attitudes to risk. The MSE was an essential part of the process of developing, evaluating, and adopting the IPHC Harvest Strategy Policy, and is now used to maintain and update that Harvest Strategy Policy.

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 research priorities that would continue to improve the MSE framework and the presentation of future results to the Commission; they can be divided into five general categories:

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, specification of uncertainty, and the identification of scenarios.
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 inform the Commission on updates to the Harvest Strategy Policy.

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/research/biological-and-ecosystem-science-research/

Since its inception, the IPHC has had a long history of research activities devoted to describing and understanding the biology of and fisheries for the Pacific halibut. At present, the main objectives of the Biological and Ecosystem Science Research activities at the 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 fisheries; and 3) apply the resulting knowledge to reduce uncertainty in the stock assessment and MSE.

The primary biological research activities at the IPHC follow Commission objectives, are selected for their important management implications, and are identified and described in this current IRMP. An overarching goal of the IRMP 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 IRMP are therefore aligned and integrated with the IPHC stock assessment and MSE processes.

The biological research activities contemplated in the IRMP 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 and fecundity, skipped spawning, reproductive migrations); and 3) resulting changes in population structure and dynamics. Furthermore, the research activities of IPHC also aim to develop and evaluate methods for estimating and reducing incidental mortality of Pacific halibut, to investigate modifications of fishing gear and/or methods to reduce whale depredation and bycatch of non-targeted species, and to investigate changes in the directed Pacific halibut fishery in response to environmental, biological, and technological drivers.

5.2 Monitoring

Focal Area Objective	To collect representative fishery-dependent and fishery-independent data on the distribution, abundance, biology, and demographics of Pacific halibut through ongoing monitoring activities. Monitoring also includes the management and stewardship of these data to ensure their quality, accessibility, and effective use in research and management.
IPHC Website portal	***Fishery-dependent data:*** • https://www.iphc.int/data/time-series-datasets/ • https://www.iphc.int/fisheries/commercial-fisheries/ • https://www.iphc.int/fisheries/recreational-fisheries/ • https://www.iphc.int/fisheries/subsistence-fisheries/ • https://www.iphc.int/fisheries/non-directed-commercial-discard-mortality-fisheries/ ***Fishery-independent data:*** • https://www.iphc.int/data/fishery-independent-setline-survey-fiss/

	• https://www.iphc.int/data/water-column-profiler-data/

5.2.1 Fishery-dependent data

The IPHC estimates the magnitude and demographics of all Pacific halibut removals within the IPHC Convention Area and uses this information in its annual stock assessment and other analyses. These data are collected and compiled by the IPHC Secretariat and include information provided by 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). For each IPHC Regulatory Area, a sampling rate is determined by port and calculated annually based on the current year's mortality limits and the estimated proportion of Pacific halibut weight landed and sampled in each port. This ensures that an adequate number of biological samples is collected by IPHC Regulatory Area.

Details on the data collected and sampling methods are provided in the annually updated *IPHC Directed Commercial Landings Sampling Manual* (e.g. for 2026: IPHC-2026-PSM01). Complementary to these efforts, the IPHC provides training to Tribal commercial fishery stakeholders in IPHC Regulatory Area 2A that supply additional data. In addition, the IPHC Secretariat summarises annually directed commercial fishery landings recorded by Federal and State agencies of each Contracting Party. Discard mortality for the directed commercial fishery is currently estimated using a combination of logbook, research survey, and observer data.

5.2.1.2 Recreational fisheries data

Recreational removals of Pacific halibut, including estimated recreational discard mortality, as well as demographic information (otoliths, sex-length-weight) where available, are provided by Federal and State agencies of each Contracting Party. These data are compiled annually for use in the stock assessment and other analyses.

5.2.1.3 Subsistence fisheries data

Subsistence fisheries refer to non-commercial, customary, and traditional use of Pacific halibut for direct personal, family, or community consumption, sharing as food, or customary trade. The primary subsistence fisheries include:

- 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 in Alaska (USA), carried out by rural residents and federally recognised Native Tribes under the Subsistence Halibut Registration Certificate (SHARC) program.

Subsistence fishery removals of Pacific halibut, including estimated subsistence discard mortality, are provided by State and Federal agencies of each Contracting Party. These data are compiled annually for use in the stock assessment and other analyses.

5.2.1.4 Non-directed commercial discard mortality data

Non-directed commercial discard mortality estimates and associated demographic data (primarily length frequencies) by IPHC Regulatory Area and sector are provided by State and Federal agencies of each Contracting Party and compiled annually for use in the stock assessment and other analyses.

Non-directed commercial discard mortality of Pacific halibut is estimated because Pacific halibut are encountered in fisheries that do not permit their retention, and not all discarded Pacific halibut are assumed to die. In most fisheries, non-directed commercial discard mortality is estimated directly using data from observer programs operated by Contracting Party agencies. In cases where observer data are unavailable, estimates are based on non-IPHC research surveys or other sources.

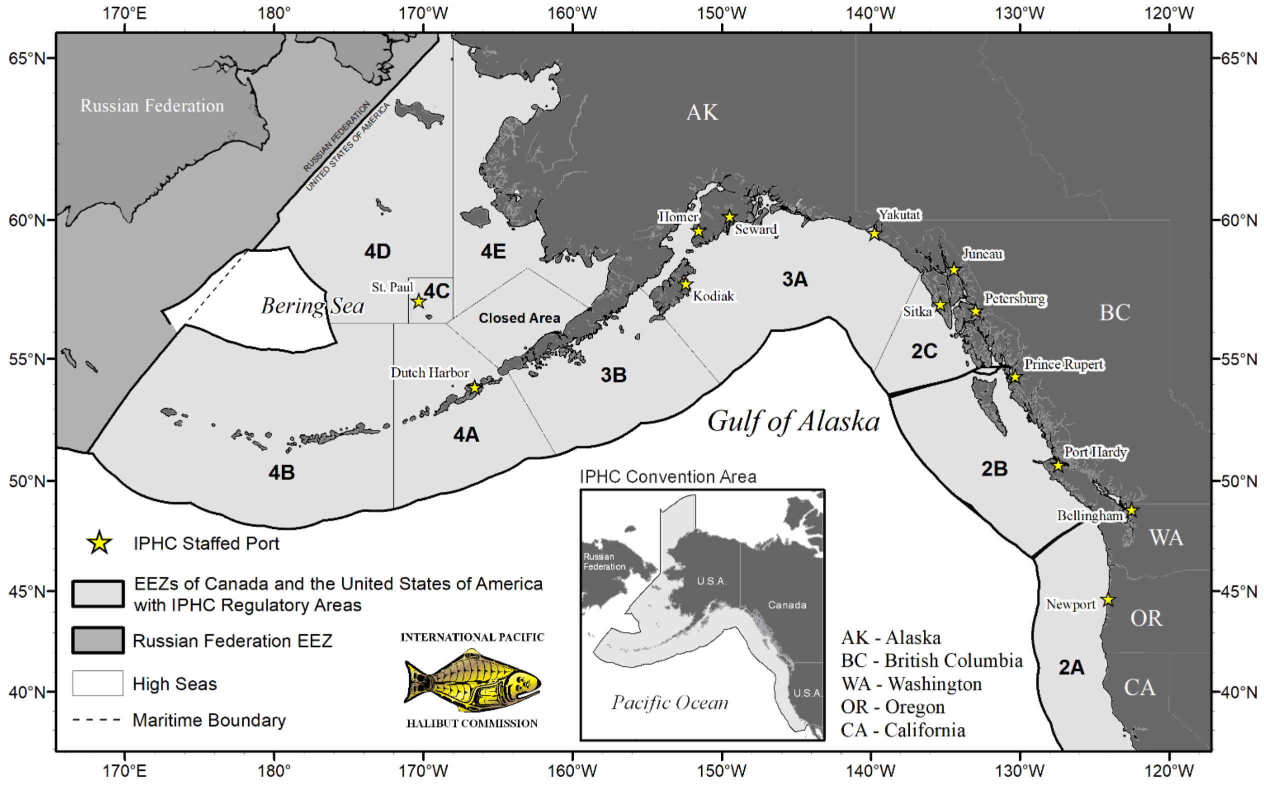


Figure 5. Ports where the IPHC has sampled directed commercial landings throughout the fishing period in recent years (note: ports sampled may change from year to year for operational reasons).

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 fisheries. These data, collected using standardised 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 almost all known Pacific halibut habitat in Convention waters outside the Bering Sea, including the commercial fishing grounds in the Pacific halibut fishery. The standard FISS grid totals 1,890 stations from which a subset is sampled each year (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 year-class strength, biomass, growth, and mortality. Tissue samples are collected from all Pacific halibut sampled by the FISS for use in genetic and other analyses. In addition, records of non-target species caught during FISS operations provide the basis for estimating bait competition and are used to index species 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 covariates in space-time modeling used in the stock assessment. An example of the data collected and the methods used is provided in the annually updated FISS sampling manual (e.g. IPHC FISS Sampling Manual 2025: IPHC-2025-VSM01).

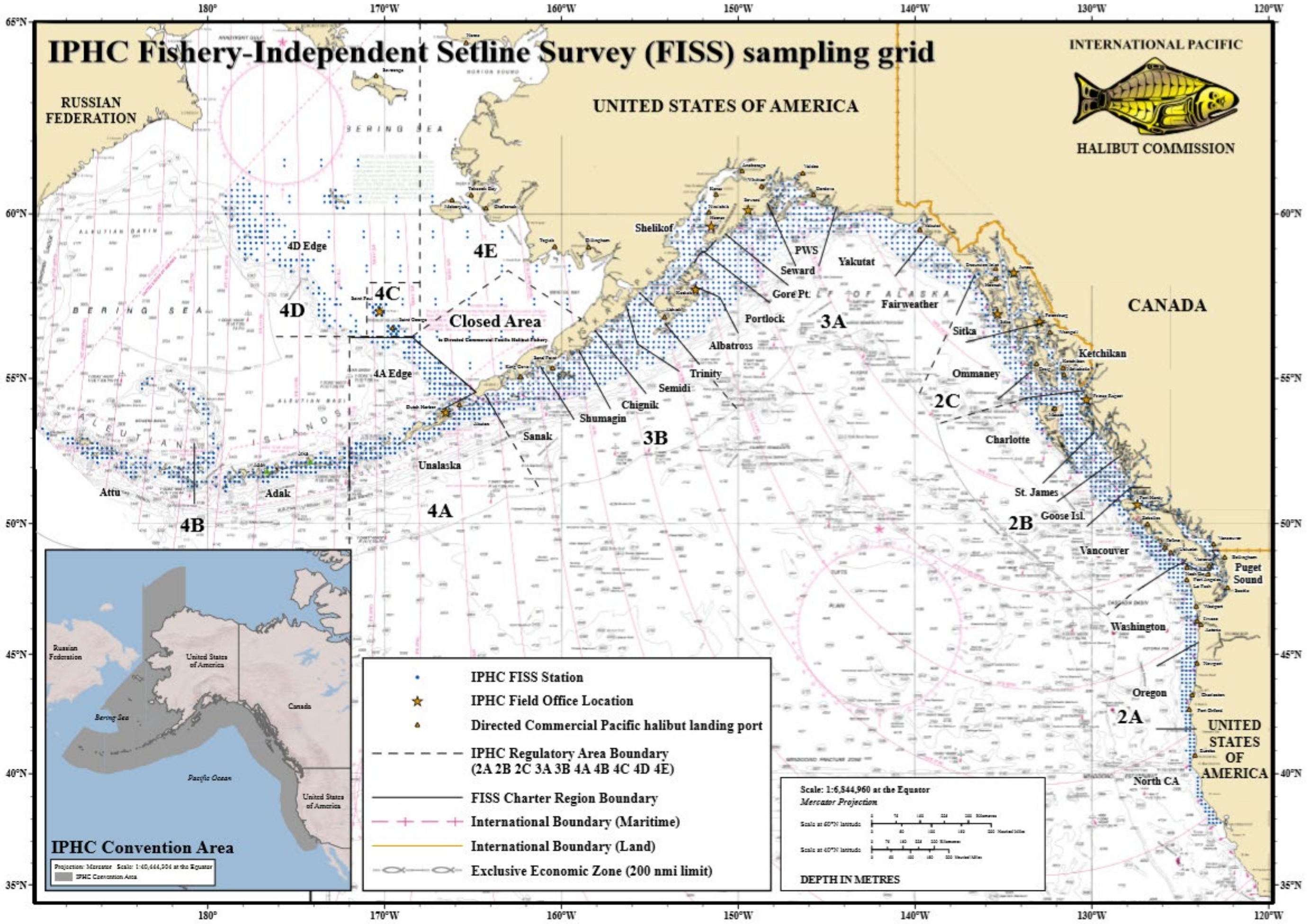


Figure 6. IPHC Fishery-Independent Setline Survey (FISS) with full sampling grid and charter regions.

Following a program of planned FISS expansions from 2014-19, a process of rationalisation of the annual FISS designs was undertaken. Currently, sampled stations are prioritised each year so that coastwide, Biological Region- and IPHC Regulatory Area-specific density indices will be estimated with high precision and low potential for bias. Based on funding and previous FISS results, potential FISS designs for the subsequent three years are evaluated. The resulting proposed designs and their evaluation are presented for review at the June Scientific Review Board (SRB) meetings and modified following SRB input and in-year FISS sampling results 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 relies on the NOAA Fisheries trawl surveys operating in the Bering Sea (Fig. 7), Aleutian Islands and Gulf of Alaska. The information collected from Pacific halibut caught on the Bering Sea trawl survey, together with data from the IPHC Fishery-Independent Setline Survey (FISS) is used in estimating indices of abundance, while data from all three trawl surveys are used to monitor population demographics.

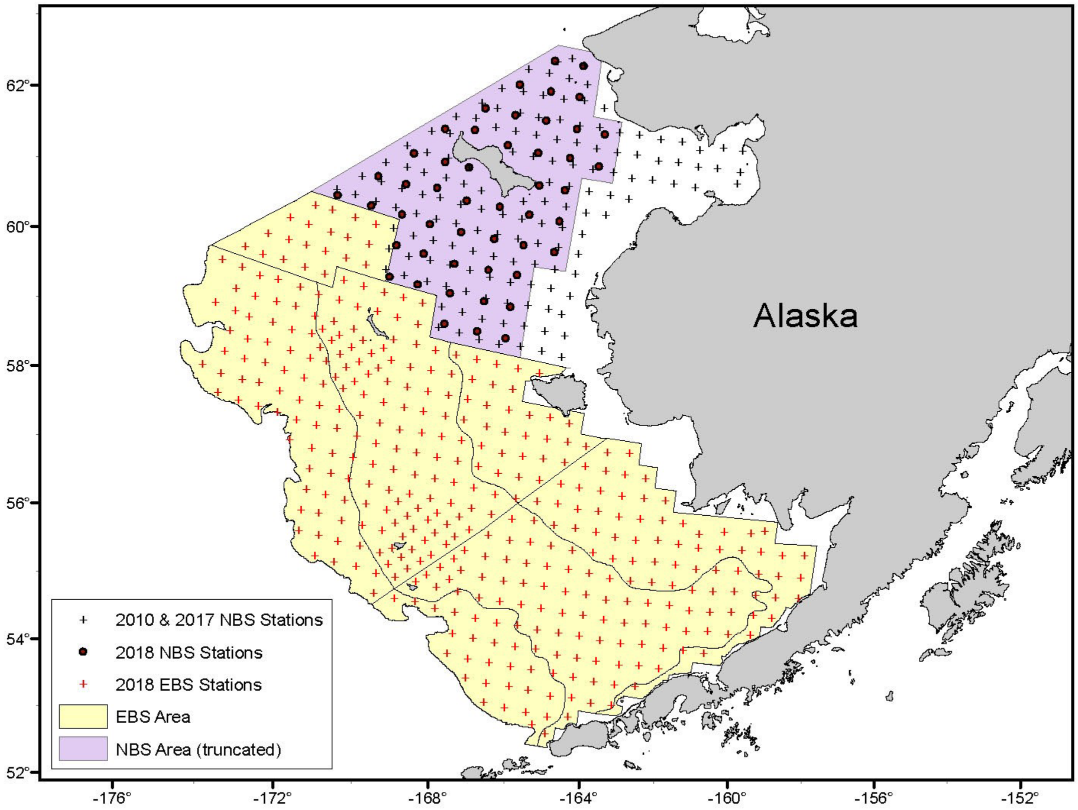


Figure 7. Representative sampling design for the NOAA Bering Sea bottom trawl survey. Black dots are stations sampled in the 2018 Northern Bering Sea trawl survey and black plus signs are stations sampled in prior Northern Bering Sea trawl surveys.

5.2.2.3 Norton Sound trawl survey

The Alaska Department of Fish and Game's annual Norton Sound trawl survey data are also used in the estimation of Pacific halibut indices of abundance in IPHC Regulatory Area 4CDE.

5.2.3 Age composition data (both fishery-dependent and fishery-independent)

Biological samples collected annually from commercial fisheries and FISS include otoliths, crystalline calcium carbonate structures found in the inner ear of fish whose growth patterns can be analysed to estimate the age of fish. Fish age is a key input to stock assessment models that inform management decisions related to fish exploitation and harvest strategies. Since its inception, the IPHC has aged over 1.5 million otoliths by trained readers under the stereoscopic microscope.

The IPHC Secretariat continues to age otoliths manually to provide the high-quality age estimates for the stock assessment. However, substantial progress has now been made toward an AI-assisted workflow. A deep-ensemble convolutional neural network (CNN) model has been developed and trained on otolith images. Through an iterative fine-tuning process, the model progressively improves predictive accuracy. The deep ensemble approach also provides uncertainty estimates, allowing low-confidence predictions to be flagged for expert review. This facilitates a mixed-method protocol where high-confidence estimates are fast-tracked while manual verification is retained for the remainder.

In addition to AI-based methods, the IPHC is exploring epigenetic ageing that may offer comparable precision to traditional human-read methods, potentially expanding the toolkit for robust and scalable age estimation in the future.

5.2.4 Data management and storage

Monitoring data collected through the IPHC's programs are subject to standardised data management procedures, including quality assurance and quality control, documentation, and secure storage. These procedures ensure that fishery-dependent and fishery-independent datasets are accurate, consistent, and traceable over time. Data are maintained in IPHC databases and are curated to support ongoing monitoring activities, stock assessment, and other scientific analyses.

Where appropriate, datasets and derived products are made available through IPHC data portals, reports, and other dissemination mechanisms. Effective data stewardship supports transparency, facilitates collaboration with Contracting Party domestic agencies and research partners, and ensures that monitoring data remain accessible and usable for scientific research and fisheries management decision-making.

5.3 Management-supporting information

To support science-based decision-making and advance the Commission's objective of developing the Pacific halibut stock to the level that permits the optimum yield from the fishery over time, the IPHC Secretariat undertakes a range of supplementary analyses that provide direct input into management procedures and policy evaluations. These efforts complement the stock assessment and biological data streams by addressing specific questions raised by the Commission, domestic agencies, and other stakeholders.

In recent years, the IPHC Secretariat has undertaken a project evaluating Pacific halibut multiregional economic impact, illustrating 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. Other work has focused on regulatory questions, such as evaluating size limits and associated tradeoffs between yield optimisation, reducing discards, and economic outcomes, as well as assessing the socioeconomic and logistical challenges of implementing year-round fishing.

The IPHC Secretariat remains well-positioned to respond to requests from the Commission or Contracting Parties for technical support on a broad range of management-relevant topics. These may include, among others, socioeconomic considerations, community development, political constraints, or logistical feasibility analyses to inform emerging policy needs. Such analyses are developed collaboratively, leverage a range of available data sources and partners, and can be tailored to specific regulatory or planning contexts.

6. Core focal areas – Planned and opportunistic activities

The IPHC Secretariat works with IPHC advisory bodies and the Commission to identify research priorities and refine hypotheses. This process occurs via an annual schedule of meetings, as shown in Fig. 8. The Management Strategy Advisory Board (MSAB) typically meets once a year. Recommendations related to the MSE and the Harvest Strategy Policy are then directed to the Commission. The SRB holds two meetings each year: one in June, where requests are typically directed to the 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 to allow the 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 commercial fishing period 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.

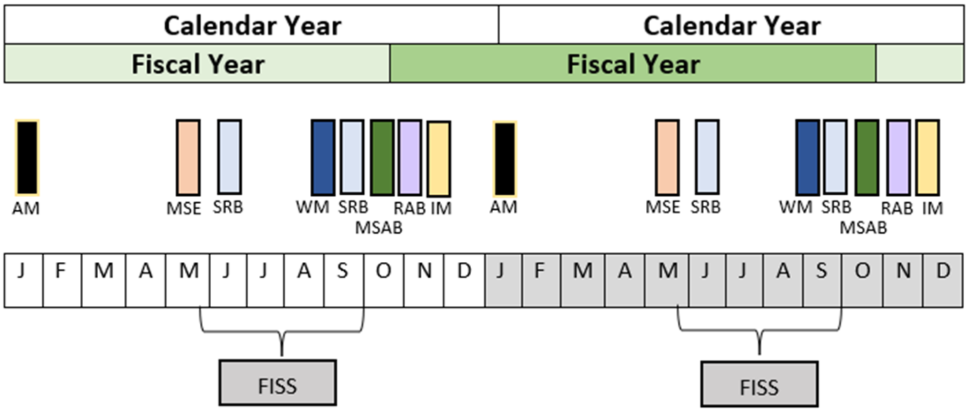


Figure 8. The typical IPHC annual meeting schedule with the calendar year and fiscal year shown. The meetings, shown in the middle row are: Annual Meeting where the Commission makes many final decisions for that year (AM), an MSE informational session (MSE), Scientific Review Board meetings (SRB), the 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 prioritise 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 motivates 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 be used to identify priority research topics for any core areas by simulation testing hypotheses 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 can be found in recent meeting documents related to each core focal area.

6.1 Research

6.1.1 Stock Assessment

Within the three 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. More extensive lists of research topics are produced every three years as part of each full stock assessment analysis.

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 through sensitivity analyses 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 a short time-series (2017-24) of commercial sex-ratio-at-age information available for the 2025 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. 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 represents a source of unobserved and unaccounted-for mortality in the assessment and management of Pacific halibut. Stock assessment sensitivity analyses have shown that unobserved mortality can result in stock assessment bias and that trends in unobserved mortality may affect current status estimates. Reduction of depredation mortality through improved fishery avoidance and/or catch protection would be a preferable extension and/or solution to methods for estimation. As such, research to provide the fishery with tools to reduce depredation is considered a high priority. This assessment priority directly informs *6.1.3.4.2 Fishing Innovations* 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 stock similarly and provide consistent and useful advice for tactical and strategic decision-making.

6.1.1.2.2 Estimation of natural mortality

The stock assessment has been shown to be extremely sensitive to the value of natural mortality. The current approach uses four separate models to estimate management quantities, with three of these models estimating natural mortality directly from the data and one using a fixed historical assumption. Further work to determine the conditions under which natural mortality is estimable in the fourth model and plausible ranges of values for this parameter could reduce perceived and actual uncertainty in the stock assessment and the management information arising from it. 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 better integrate this source of uncertainty into the stock assessment ensemble.

6.1.1.2.3 Development of state-space models

The IPHC has relied on statistical catch-at-age models for most of its stock assessment history (Stewart and Martell 2014). New programming environments (e.g., TMB; Kristensen et al. 2016) have led to an increased use of state-space models for stock assessment (e.g. SAM, WHAM; Nielsen and Berg 2014; Nielsen et al. 2021; Stock and Miller 2021). These models provide extremely efficient capabilities for modelling random effects and sparse matrices. As the Pacific halibut stock assessment models include time-varying processes (i.e. recruitment, selectivity, and catchability), it would be ideal to treat them as random effects, rather than using the penalised likelihood approach currently employed. Although few such applications include sex-specific dynamics that can accommodate the necessary dimorphic growth capability to be applicable to Pacific halibut, development of a state-space model for Pacific halibut is prioritised in this research plan.

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). Building on the success of the previous research plan, we now have an updated maturity relationship included in the 2025 stock assessment. Moving forward, we will extend that research to include an updated fecundity relationship and an investigation of the potential for skip-spawning. After updated 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 Factors affecting size-at-age

Changes in size-at-age, along with recruitment, have been the largest contributors to the historical trends in biomass and fishery yield from the Pacific halibut stock. The relative role of potential factors underlying changes in size-at-age is not currently understood. Delineating between competition, density dependence, environmental effects, size-selective fishing, and other factors could allow improved prediction of size-at-age under future conditions and a better understanding of how management can adapt to changing trends.

6.1.2 Management Strategy Evaluation

MSE priorities have been subdivided into three categories: 1) biological parameterisation, 2) fishery parameterisation, 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 parameterisation

6.1.2.1.1 Movement, distribution of life stages, and spatial spawning patterns

Research topics in this category will mainly inform parameterisation of movement in the OM but will also provide further understanding of Pacific halibut movement, connectivity, and temporal variability. This knowledge may also be used to refine specific MSE objectives. For example, further research into sub-population structure and connections between those sub-populations would provide an understanding of the importance of spatial heterogeneity in the Pacific halibut population. This includes the identification of important spawning locations, connections between spawning areas, spawning area contributions to juvenile distribution, temporal variability in spawning and recruitment, ontogenetic movement, and the importance of spawning locations to a sustainable population and efficient fisheries across the IPHC Convention Area. Larval and juvenile distribution is a main source of uncertainty in the OM and continued research in this area will improve the OM and provide justification for parameterising temporal variability. Outcomes may also provide information on recruitment strength and the relationship with environmental factors. For example, recent work by Sadorus et al (2021) used biophysical and spatio-temporal models to examine connectivity across the Bering Sea and Gulf of Alaska. Furthermore, improved understanding of the distribution of adults resulting from ontogenetic movement 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. Research under Section 6.1.3.1 will inform this MSE priority.

6.1.2.1.2 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.

6.1.2.1.3 Understanding the effects of productivity scenarios

Pacific halibut have experienced a wide range of productivity scenarios, mainly influenced by average recruitment and size-at-age. Understanding the consequences of productivity scenarios on management outcomes will help to understand past observed trends and current experiences, and to identify optimal harvest strategies for the future. Using the MSE to simulate scenarios assuming different productivity regimes can test alternative management procedures to identify a robust management procedure, or possibly differences between them given different productivity. The MSE scenarios would be informed by research described in Sections 6.1.3.1 and 6.1.3.3.

6.1.2.2 MSE fishery parameterisation

The definition of fisheries and their parameterisations in the MSE operating model involved consultation with Pacific halibut stakeholders, but some aspects of those parameterisations would 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 Section 6.1.3.4 will inform this MSE priority.

6.1.2.3 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 and support of the Harvest Strategy Policy. 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 MSE operating model, which will then inform management and stock assessment development through investigations using the closed-loop simulation framework. MSE development, simulations, and outcomes may also inform further development of the stock assessment. Conducting assessments at intervals longer than annually may allow for additional opportunity to coordinate between stock assessment and MSE.

6.1.2.3.1 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 an ensemble stock assessment, which is difficult to mimic as an 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 model accurately represents the stock assessment now and in the future, and incorporate efficiencies to speed up the simulation process.

6.1.2.3.2 Incorporate additional sources of implementation uncertainty

Implementation uncertainty consists of three subcategories: 1) decision-making uncertainty, 2) realised 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 implemented in the MSE framework but improvements could be made. Realised uncertainty is the difference between the mortality limit set by the Commission and the actual mortality realised by the various fisheries. This type of uncertainty is currently partially implemented in the MSE framework. Finally, perceived uncertainty is the difference between the realised 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 and relies on improvements to the estimation model (Section 6.1.2.3.1). Improving the implementation of decision-making uncertainty is a priority for the MSE and will assist in understanding the performance of management procedures given the flexibility desired by the Commission.

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 research priorities focus on technical development, but various elements of Management Procedures will likely be of interest once technical improvements are made. 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

Capitalising on the outcomes of the first 5-year plan (IPHC–2019–BESRP-5YP), the second 5-year plan (IPHC-2022-5YPIRM) developed five research areas to provide key inputs for stock assessment and the MSE process. In addition to linking genetics and genomics with migration and distribution studies in the area of Migration and Population Dynamics, a novel research area on Fishing Technology was incorporated in the IPHC-2023-5YPIRM. The outcomes of IPHC-2023-5YPIRM are provided in Appendix I, and the resulting peer-reviewed publications are provided in Appendix III. The present plan (IPHC-2026-5YPIRM) describes the continuation of these five research areas into the next phase of management-serving research goals, with Fishing Technology being incorporated into a new research area that includes Mortality Estimations and Fishery Practices and Behavior. A series of key objectives for each of the five research areas has been identified that integrate with specific needs for stock assessment and MSE processes and that are ranked according to their relevance (Appendix IV and Appendix V, respectively). To further describe the IPHC Secretariat's rationale for establishing research priorities, a ranked list of biological uncertainties and parameters for stock assessment and the MSE process, and their links to research activities and outcomes derived from the IRMP are also provided.

6.1.3.1 Migration and Population Dynamics

Studies aimed at improving current knowledge of Pacific halibut distribution and population dynamics throughout all life stages in order to achieve a complete understanding of stock structure and distribution across the entire range of Pacific halibut in the North Pacific Ocean and the biotic and abiotic factors that influence it through multiple approaches. Specific objectives in this area include:

- Integrate analyses of Pacific halibut population dynamics, connectivity, and distribution changes by incorporating genomic 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.
- Improve our understanding of migration and basin-wide population structure between the Eastern and Western components of the Pacific halibut stock in the North Pacific Ocean.
- Improve our understanding of the contribution of known and putative (e.g. Washington coast) spawning areas to nursery/settlement areas in relation to year-class, recruit survival and strength, juvenile genetic diversity, and environmental conditions in the North Pacific Ocean.
- Improve our understanding of the relationship between the presence of juveniles in mapped nursery/settlement areas and adult distribution and abundance over temporal and spatial scales.
- Build upon the current conceptual model of Pacific halibut movement through a synthetic analysis of existing tagging data.
- Apply methods for individual identification based on computer-assisted tail image matching systems as an alternative for traditional mark and recapture tagging.

Horizon scan:

- Evaluate the potential use of environmental DNA (eDNA) for improving current understanding of Pacific halibut distribution and assist with mapping of juvenile habitat.
- Examine the feasibility of close-kin mark-recapture-based approaches to improve estimates of population size, migration rates among geographical regions, and demographic parameters (e.g. fecundity-at-age, natural mortality).

6.1.3.2 Reproduction

Studies aimed primarily at addressing several critical issues for stock assessment analysis based on estimates of female spawning biomass: 1) the sex ratio of the commercial catch; 2) revised maturity estimates, and 3) fecundity estimates. Specific objectives in this area include:

- Continued temporal and spatial analysis of female histology-based maturity-at-age estimates: identification of potential drivers (e.g. environmental, etc.) of temporal and spatial changes in maturity schedules.
- Develop and validate methods for fecundity estimations based on the auto-diametric method applied to other species.
- Provide estimates of fecundity-at-age and fecundity-at-size.
- Investigate the possible presence of skip spawning in Pacific halibut females.
- Improve accuracy in the 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 the genetic basis of variation in age and/or size-at-maturity, fecundity, and spawning timing, by conducting genome-wide association studies.

- Characterise the temporal progression of reproductive development and gamete production throughout an entire annual reproductive cycle in male Pacific halibut.

6.1.3.3 Growth and size-at-age

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:

- Investigate the effects of environmental and ecological conditions driving size-at-age and somatic growth in Pacific halibut.
- Investigate the influence of early growth (e.g. juveniles) in determining growth patterns during adulthood. Analysis of NMFS trawl data and investigation of potential early life regulatory mechanisms (e.g. epigenetic, etc.) that direct adult growth patterns.
- Investigate variation in somatic growth patterns in Pacific halibut as informed by physiological growth markers, physiological condition, energy content, and dietary influences.
- Evaluate the relationship between somatic growth, temperature, and trophic histories in Pacific halibut through the integrated use of physiological growth markers (e.g. gene expression, stable isotope profiles).
- Develop a non-invasive alternative method for aging Pacific halibut based on genetic analyses of DNA methylation patterns in tissues (fin clips). Development of an epigenetic clock and possible insights into the aging process/senescence in Pacific halibut.
- Improve our understanding of the genetic basis of variation in somatic growth and size-at-age by conducting genome-wide association studies.
- Explore emerging technological advances in genome sequencing that produce genomic and epigenetic data (e.g. PacBio, Oxford Nanopore) to assist in understanding the genetic and epigenetic basis of growth.
- Investigate the feasibility of otolith (or eye lens lamina) growth increment analyses for reconstructing individual growth histories in Pacific halibut.

Horizon scan:

- Investigate dietary composition in stomachs through metabarcoding (i.e. molecular identification of prey items in stomach contents).
- Investigate liver parasite loading and its effect on physiological conditions in Pacific halibut

6.1.3.4 Fishery dynamics and fishing technology

6.1.3.4.1. Mortality estimations. Studies aimed at developing and evaluating methods for estimating and reducing incidental mortality of Pacific halibut. Specific objectives in this area include:

- Incorporate experimentally-derived discard mortality rate data in the recreational fishery (based on research conducted under IPHC-2023-5YPIRM) into management.
- Review status of discard mortality rate (DMR) research conducted by the IPHC: synthesis paper of experimentally-derived DMR for Pacific halibut in different fisheries, with future research avenues and management recommendations.
- Investigate the application of electronic monitoring and AI-based analyses of discards for mortality estimations.

- Investigate new methods (e.g. AI-based) for improved estimation of depredation mortality from marine mammals.
- Support and collaborate in efforts to reduce Pacific halibut bycatch in other fisheries
- Investigate potential biological and ecological causes of mortality in Pacific halibut.

6.1.3.4.2. Fishing innovations. Studies investigating modifications of fishing gear/methods with the purpose of reducing depredation of Pacific halibut by toothed whales and reducing bycatch of non-targeted species. Specific objectives in this area include:

- Prepare a review paper summarising past and present directed (fixed) gear-related research by the IPHC.
- Investigate methods for whale avoidance and/or deterrence for the reduction of Pacific halibut depredation by whales (e.g. catch protection methods, pots).
- Investigate physiological and behavioral responses of Pacific halibut to fishing gear in order to increase the catch and reduce bycatch of non-targeted species: influence of lights on fishing gear, hook size, design or modification, pots, etc.

6.1.3.4.3. Fishery practices and behavior. Studies aimed at investigating changes in the directed Pacific halibut fishery in response to environmental, biological, and technological drivers. Specific objectives in this area include:

- Investigations into the interaction between climate change and fishing patterns
- Evaluations of the effects of sand fleas- and dogfish-prevalent areas on longline fisheries
- Tradeoffs of snap, fixed, and Autoline gear use on fishery efficiency.

6.2 Monitoring

The Commission's monitoring programs continue to include both direct data collection by the IPHC Secretariat and coordination with domestic agencies to generate comprehensive fishery-dependent and fishery-independent information on Pacific halibut stock and fishery trends. These critical sources include estimates of fishing mortality across 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 will continue to underpin the stock assessment and MSE process, support numerous biological research studies, and inform the decision-making process (Fig. 4).

Over the coming years, monitoring activities will also focus on strengthening data management systems, improving data accessibility, and ensuring that monitoring programs remain aligned with emerging research priorities and management needs. Periodic reviews of monitoring programs and associated data systems will support the identification of gaps, the prioritization of improvements, and the integration of new technologies and analytical approaches.

6.2.1 Fishery-dependent data

The IPHC Secretariat will continue collecting fishery-dependent data from the directed commercial fishery, with a focus on maintaining adequate spatial and temporal coverage of catch, effort, and biological data. Coordination with Tribal, State and Federal agencies will continue to support the standardisation of data collection protocols, increase data collection capacity, improve reporting consistency, and help identify and fill data gaps that may impact stock assessment and management.

Collaborative work with commercial stakeholders will continue to advance the use of electronic logbooks, which were introduced in 2023, to enhance the accuracy, timeliness, and efficiency of data submission. Further development of digital quality assurance and quality control (QA/QC) systems will strengthen data integrity, ease operational demands, and increase the capacity of IPHC Secretariat for other advancements.

Future efforts will also include a comprehensive review and audit of existing monitoring databases and associated workflows. This work will aim to modernise data storage structures, improve interoperability among datasets, and implement new tools that reduce the potential for reporting errors while facilitating more efficient data access and analysis. These improvements will support more timely data availability for stock assessment, MSE analyses, and other research applications.

Annual reviews of sampling distribution across ports, data collection methods, sampling rates, and QA/QC procedures will continue, including in-season evaluations of port sampling coverage. These initiatives aim to ensure that data collection continues to support stock assessment, MSE, and management needs, while integrating relevant research findings into long-term monitoring strategies.

6.2.2 *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 the 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.

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 the point of data collection and during post-sampling review) will ensure high-quality data from the FISS program.

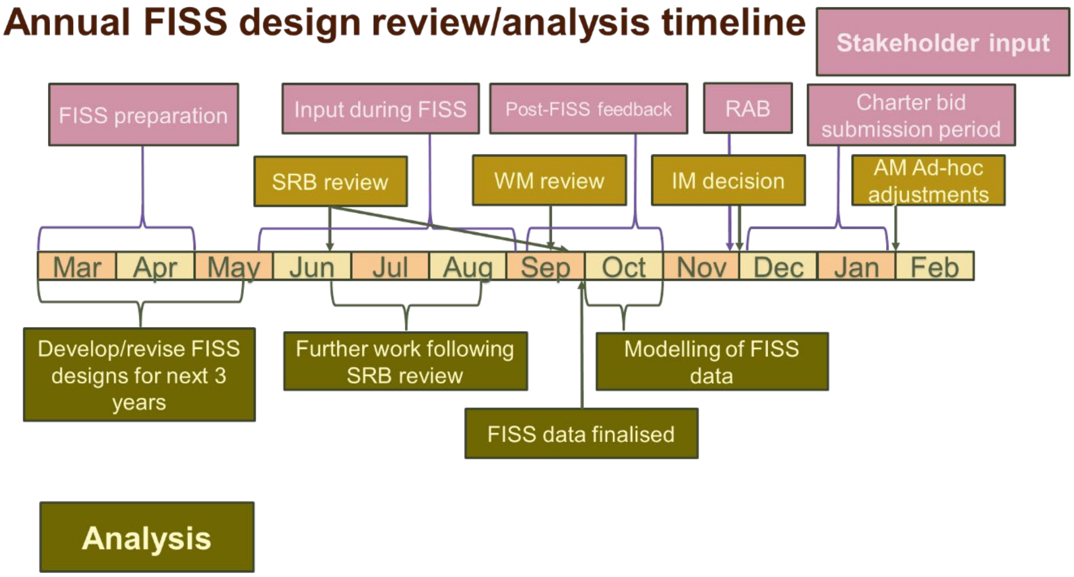


Figure 9. Timeline of annual FISS design review process.

6.2.2.1 *Fishery-independent Trawl Survey (FITS)*

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

6.2.3 Ageing methods (both fishery-dependent and fishery-independent)

6.2.3.1. Application of artificial intelligence (AI) for determining the age of fish from images of collected otoliths.

Progress in applying AI for determining the age of Pacific halibut from images of collected otoliths presents both opportunities and challenges, particularly in balancing gains in efficiency with the need to maintain data integrity and spatiotemporal consistency.

Future development will include the evaluation of candidate AI-based ageing methods that combine automated predictions with varying levels of manual verification. These approaches may differ in the proportion of AI-derived ages accepted without review or subjected to manual confirmation. A cost-benefit analysis will compare these candidate protocols with the current manual ageing process, considering labor requirements, processing time, operational costs, and implications for age composition estimates used in the stock assessment.

Before AI-derived ages can be incorporated into routine assessment inputs, additional methodological work will be required to develop imprecision matrices for candidate AI ageing approaches and compare them with existing break-and-bake and surface ageing matrices. These matrices will allow evaluation of the accuracy and precision of AI-based age estimates relative to traditional ageing methods and will support development of a testing framework for assessing their performance within the stock assessment model.

Testing within the stock assessment will likely involve split-sample or hybrid approaches in which AI-derived ages are incorporated alongside manually aged samples. Alternative scenarios may evaluate different proportions of AI-derived ages and different durations of AI-based ageing within the time series. This approach will help determine how varying levels of AI integration influence estimated year-class strength, population trends, and management quantities used to inform mortality limit decisions.

Further research will also evaluate the spatial and temporal generalization of AI models, particularly when predictions are applied to regions or years that are underrepresented in the training dataset. Additional improvements may be achieved through the incorporation of relevant covariates, such as fish sex, location, or date collected, to improve model performance and reduce prediction uncertainty. Maintaining a subset of manually aged otoliths will remain important during this transition period to support model validation, maintain training datasets, and ensure continuity with the historical age series.

Through continued development, testing, and review in collaboration with the Scientific Review Board, AI-assisted ageing methods may provide a scalable and efficient complement to traditional ageing protocols while maintaining the reliability of age data used in Pacific halibut stock assessment and management.

6.2.3.2. Application of an epigenetic clock for aging Pacific halibut using fin clips.

Epigenetic aging is a genetic method for aging that is based on the fact that methylation patterns on genomic DNA change predictably with age. Therefore, age-associated DNA methylation patterns can be modelled to generate molecular (i.e., epigenetic) age predictors capable of estimating chronological age with high accuracy. These are referred to as "epigenetic clocks" and can be developed from DNA isolated from any tissue, including non-lethal biological samples, such as a fin clip.

The objective of this project is to develop an epigenetic clock for Pacific halibut using fin clips from Pacific halibut of known ages. The specific objectives are (1) to identify DNA methylation signals in Pacific halibut fin tissue, (2) to develop an age prediction model based on age-associated DNA methylation patterns, and (3) to develop a targeted assay with selected age-associated epigenetic markers for cost-effective, high-throughput age estimations in Pacific halibut. Once this objective is met, this IRMP will be updated to describe how this ageing method would be investigated for potential inclusion into the stock assessment, similar to that described for AI ageing above.

6.3 Management-supporting information

6.3.1 Potential of integrating human dynamics into management decision-making

Effective Pacific halibut management requires understanding not only biological stock dynamics, but also the human dimensions that shape fishery outcomes (Lane and Stephenson 1995). As new technologies such as AI, digital logbooks, and real-time monitoring evolve, so too does the potential to integrate human behavior, economic dependencies, and community-level impacts into the management framework.

Recent socioeconomic analyses conducted by the IPHC highlight disparities in how different regions and user groups benefit from Pacific halibut fisheries, and how external forces such as shifting markets and climate change can amplify these differences (Cheung and Frölicher 2020). Recognising these factors can improve both the fairness and resilience of fishery policies.

Looking ahead, the IPHC Secretariat aims to be prepared to integrate human dynamics, such as fleet behavior, market access, or social vulnerability, into stock assessment and MSE, where such complementary analyses may add value to the decision-making process (Lynch et al. 2018). This may include linking fishery performance metrics to socioeconomic indicators or exploring how alternative management scenarios affect community and fisher behavior. These efforts will ensure that science-based advice not only supports biological sustainability but is also responsive to the evolving realities of people and communities who depend on the resource.

7. Amendment

As with the previous two (2) plans, the IPHC Secretariat intends to maintain this IRMP document as a '*living plan'*, subject to annual reviews and updates as necessary. Revisions will reflect evolving priorities, resources available to undertake the work (e.g. internal and external fiscal resources, collaborations, internal expertise), and emerging opportunities. The IPHC Secretariat remains committed to transparency and to upholding the principles of open science in the development and implementation of this plan.

8. References

Bravington, M.V., Skaug, H.J., and Anderson, E.C. 2016. Close-Kin Mark-Recapture. Statistical Science 31(2): 259-274. doi:10.1214/16-sts552.

Cheung, William W.L., and Thomas L. Frölicher. 2020. "Marine Heatwaves Exacerbate Climate Change Impacts for Fisheries in the Northeast Pacific." Scientific Reports 10 (1): 1–10. https://doi.org/10.1038/s41598-020-63650-z.

Clark, W.G., Hare, S.R., Parma, A.M., Sullivan, P.J., and Trumble, R.J. 1999. Decadal changes in growth and recruitment of Pacific halibut (*Hippoglossus stenolepis*). Canadian Journal of Fisheries and Aquatic Sciences 56: 242-252.

Drinan, D.P., Galindo, H.M., Loher, T., and Hauser, L. 2016. Subtle genetic population structure in Pacific halibut Hippoglossus stenolepis. J Fish Biol 89(6): 2571-2594. doi:10.1111/jfb.13148.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68: 1124-1138.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B.M. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software 70(5). doi:10.18637/jss.v070.i05.

Lane, Daniel E, and R L Stephenson. 1995. "Fisheries Management Science: The Framework to Link Biological, Economic, and Social Objectives in Fisheries Management." Aquatic Living Resources 8 (3): 215–21.

Leaman, B.M., and Stewart, I.J. 2017. 2.12 Research basis for estimated discard mortality rates used for Pacific halibut in longline and trawl fisheries. IPHC Report of Assessment and Research Activities 2016: 133-172.

Lynch, Patrick D, Richard D Methot, and Jason S Link. 2018. “Implementing a Next Generation Stock Assessment Enterprise: Policymakers’ Summary.” NOAA Technical Memorandum NMFS-F/SPO-183.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.R., and Francis, R.C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78(6): 1069-1079.

Nielsen, A., and Berg, C.W. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries Research **158**: 96-101. doi:10.1016/j.fishres.2014.01.014.

Nielsen, A., Hintzen, N.T., Mosegaard, H., Trijoulet, V., Berg, C.W., and Subbey, S. 2021. Multi-fleet state-space assessment model strengthens confidence in single-fleet SAM and provides fleet-specific forecast options. ICES Journal of Marine Science **78**(6): 2043-2052. doi:10.1093/icesjms/fsab078.

Sadorus, Lauri L., Esther D. Goldstein, Raymond A. Webster, William T. Stockhausen, Josep V. Planas, and Janet T. Duffy-Anderson. 2021. "Multiple life-stage connectivity of Pacific halibut (*Hippoglossus stenolepis*) across the Bering Sea and Gulf of Alaska." Fisheries Oceanography 30 (2): 174-193. https://doi.org/10.1111/fog.12512

Stewart, I.J., and Martell, S.J.D. 2014. A historical review of selectivity approaches and retrospective patterns in the Pacific halibut stock assessment. Fisheries Research **158**: 40-49. doi:10.1016/j.fishres.2013.09.012.

Stock, B.C., and Miller, T.J. 2021. The Woods Hole Assessment Model (WHAM): A general state-space assessment framework that incorporates time- and age-varying processes via random effects and links to environmental covariates. Fisheries Research **240**. doi:10.1016/j.fishres.2021.105967.

Webster, R.A., Clark, W.G., Leaman, B.M., and Forsberg, J.E. 2013. Pacific halibut on the move: a renewed understanding of adult migration from a coastwide tagging study. Canadian Journal of Fisheries and Aquatic Sciences 70(4): 642-653. doi:10.1139/cjfas-2012-0371.

ACKNOWLEDGEMENTS

This updated document was developed by Dr. David Wilson, Dr. Josep Planas, Dr. Ian Stewart, Dr. Allan Hicks, Dr. Ray Webster, and Dr. Basia Hutniczak, in collaboration with other current members of the IPHC Secretariat and under advice of the IPHC Scientific Review Board.

APPENDICES

Appendix I:	Outcomes of IPHC-2023-5YPIRM
Appendix II:	External funding received by the IPHC
Appendix III:	Publications arising
Appendix IV:	List of ranked research priorities for stock assessment
Appendix V:	List of ranked research priorities for management strategy evaluation

APPENDIX I
OUTCOMES OF THE IPHC-2023-5YPIRM

1. Biology and Ecology

A. Outcomes by Research Area:

1. Migration and Population Dynamics

1.1. <u>Development and application of genomic approaches</u>. Planned research outcomes: generation of genomic resources for Pacific halibut that will support genomic research.

<u>Main results</u>:

- Sequencing of the Pacific halibut genome.
- Generation of a high-quality chromosome-level genome assembly for Pacific halibut and full characterisation of the genome
- Complete sequencing and annotation of the Pacific halibut genome into a publicly available online resource
- Identification of the sex determining region of the Pacific halibut genome in Chromosome 9.
- Successful mapping of single nucleotide polymorphisms used for genetic sexing into the sex determining region of the Pacific halibut genome.
- Generation of tissue-specific transcriptomes and combined transcriptome for Pacific halibut. Identification of tissue-specific transcriptomic characteristics.

1.2. <u>Population genomic studies</u>. Planned research outcomes: delineation of population structure within Convention Waters.

<u>Main results</u>:

- Application of low-coverage whole-genome resequencing to screen genomic variation at very high resolution.
- Development of a bioinformatic platform to process and analyse high-throughput whole genome sequencing data.
- Establishment of a baseline of genetic diversity by whole genome resequencing of genetic samples from spawning individuals collected from the main five spawning areas within Convention Waters.
- Lack of evidence for population structure, as evidenced by the inability of high-resolution genomics techniques to identify discrete genetic groups.
- Low ability to assign individuals back to the location in which they were sampled.
- Lack of population structure supports the modeling of the Pacific halibut stock as a single coastwide stock

1.3. Environmental influences on Pacific halibut distribution. Planned research outcomes: relationship between Pacific halibut distribution and environmental variables.

Main results:

- Establishment of baseline environmental data for Pacific halibut habitat for older juvenile and adult individuals in different Biological Regions.
- Application of environmental profiler data in spatio-temporal modeling.
- Identification of changes in Pacific halibut density and distribution of Pacific halibut in Biological Region 2 associated with low near-bottom dissolved oxygen levels. These hypoxic events are the result of seasonal upwelling.

Publications:

Jasonowicz, A.J., 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. 22: 2685–2700. https://doi.org/10.1111/1755-0998.13641.

Jasonowicz, A.J., Simchick, C., Planas, J. V. Tissue-specific and reference transcriptomes for Pacific halibut (*Hippoglossus stenolepis*). 2025. In Preparation.

Jasonowicz, A.J., Simchick, C., Dawson, L., Spies, I., Larson, W., Planas, J.V. Genomic support for a single stock of Pacific halibut (*Hippoglossus stenolepis*) in the Northeastern Pacific Ocean. 2025. In Preparation.

Planas, J.V., Rooper, C.N., Kruse, G.H. Integrating biological research, fisheries science and management of Pacific halibut (Hippoglossus stenolepis) across the North Pacific Ocean. *Fisheries Research*. 2023. 259: 106559. https://doi.org/10.1016/j.fishres.2022.106559.

Sadorus, L.L., Webster, R.A. and Sullivan, M.E. Environmental conditions on the Pacific halibut (Hippoglossus stenolepis) fishing grounds obtained from a decade of coastwide oceanographic monitoring, and the potential application of these data in stock analyses. *Marine and Freshwater Research*. 2024. 75: MF23175. https://doi.org/10.1071/MF23175.

Integration with Stock Assessment and MSE: The relevance of research outcomes from activities in this research area for stock assessment is in evaluating the biological support for modeling the Pacific halibut stock as a coastwide stock and 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. Additionally, current assumptions of stock structure used in the current stock assessment will be tested by these research activities. The relevance of these research outcomes for MSE is in the improvement of the parametrisation of the Operating Model and represent the top ranked biological input into the MSE.

2. Reproduction

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

Main results:

- Sex ratio information for the 2017-2024 commercial landings.

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

Main results:

- Application of histological ovarian development classification criteria to revise female maturity and establishment of criteria to identify immature versus mature females.
- Successful staging of ovarian samples collected in the FISS from 2022 to 2024.
- Testing of various types of models (i.e. generalised linear models (GLMs) and generalised additive models (GAMs)) to fit maturity data.
- Application of best-fit GAM models to estimate maturity ogives by Biological Region and year.
- Generation of a coastwide maturity ogive using weighed Biological Region ogives for the period 2022-2024.
- Development of a calibration factor between histology- and field (visual)-based maturity estimates.
- Integrate the calibration factor to revise FISS historical maturity data with which to investigate decadal changes in female maturity.
- Description of endocrine parameters that are associated with female developmental stages and identification of potential physiological markers for maturity.
- Collection of samples in the summers of 2023-2025 and fall of 2024 for the development of the fecundity estimation method and for generating the first estimates of fecundity.

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.

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.

Simchick, C., Simeon, A., Bolstad, K., Planas, J.V. Endocrine patterns associated with ovarian development in female Pacific halibut (*Hippoglossus stenolepis*). *General and Comparative Endocrinology*. 2024. 347: 114425. https://doi.org/10.1016/j.ygcen.2023.114425

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 to monitor somatic growth variation in Pacific halibut.

Main results:

- Transcriptomic profiling by RNA sequencing of white skeletal muscle from juvenile Pacific halibut subjected to temperature-induced growth manipulations.
- Identification of a set of genes that change their expression levels in response to growth suppression and to growth stimulation: growth marker identification.
- Proteomic profiling by LC-MS/MS of white skeletal muscle from juvenile Pacific halibut subjected to temperature-induced growth manipulations.
- Identification of a set of proteins that change their abundance in response to growth suppression and to growth stimulation: growth marker identification.
- Application of putative growth marker genes in the characterisation of somatic growth variation in Pacific halibut juveniles collected in the Eastern Bering Sea by the NMFS Trawl Survey.
- Transcriptomic profiling by RNA sequencing of white skeletal muscle from juvenile Pacific halibut subjected to density- and stress-induced growth manipulations under experimental conditions.

Publications:

Planas, J.V., Jasonowicz, A.J., Simeon, A., Simchick, C., Timmins-Schiffman, E., Nunn, B.L., Kroska, A.C., Wolf, N., and Hurst, T.P. Molecular mechanisms underlying thermally induced growth plasticity in juvenile Pacific halibut. *Journal of Experimental Biology*. 2025. 228 (19): jeb251013. https://doi.org/10.1242/jeb.251013.

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: full characterisation of discarded Pacific halibut in the longline fishery.

Main results:

- Hook release methods strongly influence the viability category assigned to discarded Pacific halibut in the longline fishery, with careful shaking and gangion cutting resulting in >75% of fish being assigned to the excellent viability category.
- The use of the hook stripper results in >85% of the fish being classified in the moderate and poor viability categories, and sustained injuries of medium and high severity particularly among

smaller fish. These results support minimising the use of hook strippers in non-directed fisheries to optimise survival of discarded Pacific halibut.

- High lactate plasma levels and low hematocrit were characteristic of fish assigned to the dead viability category, and were attributed to sand flee intrusion.
- Reducing the use of hook strippers and limiting soak times in areas of known sand flea activity are likely to improve viability outcomes of Pacific halibut released from commercial longline gear.

Publications:

Dykstra, C., Wolf, N., Harris, B.P., Stewart, I.J., Hicks, A., Restrepo. F., Planas, J.V. Relating capture and physiological conditions to viability and survival of Pacific halibut discarded from commercial longline gear. *Ocean & Coastal Management*. 2024. 249: 107018. https://doi.org/10.1016/j.ocecoaman.2024.107018.

4.2 Discard mortality rate estimation in the guided recreational Pacific halibut fishery. Planned research outcomes: experimentally-derived discard mortality rate, full characterisation of discarded Pacific halibut and assessment of best handling practices.

Main results:

- The mortality rate estimated from Pacific halibut captured and released in excellent viability category is 1.35%.
- The size of circle hooks (12/0 and 16/0) does not affect the size of the catch nor the types of injuries incurred by captured fish, with torn cheek being the predominant injury for both hook sizes.
- The levels of stress indicators in the blood (glucose and lactated, and cortisol to a lesser extent) increase with fight time.
- Our results on the low level of mortality associated with the release of Pacific halibut in excellent viability category is consistent with current discard mortality estimates.

Publications:

Dykstra, C.L., Wolf, N., Harris, B.D., Stewart, I.J., Hicks, A., Planas, J.V. Discard mortality rates of recreationally caught Pacific halibut (*Hippoglossus stenolepis*). 2026. In Preparation for submission to *Fisheries Management and Ecology*.

Integration with Stock Assessment and MSE: The relevance of research outcomes from these activities for stock assessment resides in their ability to accurately capture 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 parametrisation

5. Fishing Technology

5.1 Investigations on new methods for whale avoidance and/or deterrence for the reduction of Pacific halibut depredation by whales (e.g. catch protection methods). Planned research outcomes: information on feasibility, and performance of catch protection devices.

Main results:

- A virtual International Workshop (link) was organised in 2022 on protecting fishery catches from whale depredation with industry (affected fishers, gear manufacturers), gear researchers and scientists to identify methods to protect fishery catches from depredation.
- Development of two catch protection designs stemming from the outcomes of the International Workshop into functional prototypes.
- Successful initial testing of two selected catch protection devices (underwater shuttle and branch gear with sliding shroud system) in the field.
- As a catch protection device, the shuttle is a safe and effective gear type that entrained comparable quantities, sizes and types of fish as control (i.e. longline) gear.
- Additional testing in the presence of whales was conducted in May of 2025.

5.2 Investigate physiological and behavioral responses of Pacific halibut to fishing gear in order to reduce bycatch. Planned research outcomes: effective ways to reduce Pacific halibut bycatch and bycatch of non-targeted species.

Main results:

- Hook size did not significantly affect the catch efficiency of Pacific halibut or yelloweye rockfish.
- Circle hooks with a 45° appendage angle caught fewer yelloweye rockfish than hooks without an appendage, irrespective of hook size, and did not affect the catch efficiency of Pacific halibut.
- Hook appendages could have potential use in reducing catch rates on yelloweye rockfish in Pacific halibut longline fisheries.

Publications:

Lomeli, M.J.M., Wakefield, W.W., Abele, M., Dykstra, C.L., Herrmann, B., Stewart, I.J., and G.C. Christie. Testing of hook sizes and appendages to reduce yelloweye rockfish bycatch in a Pacific halibut longline fishery. *Ocean & Coastal Management*. 2023. 241: 106664. https://doi:10.1016/j.ocecoaman.2023.106664.

Heppell, D.S., Lomeli, M.J.M., Wakefield W.W., Herrmann, B., Dykstra, C.L., and Stewart, I.J. Hook modification to reduce rockfish and Pacific spiny dogfish bycatch in the U.S. West Coast Pacific halibut longline fishery. *Reviews in Fish Biology and Fisheries*. 2026. 36: 38. https://doi.org/10.1007/s11160-026-10042-7.

Integration with Stock Assessment and MSE: The relevance of research outcomes from these activities for stock assessment resides in the improvement of mortality accounting through a reduction of depredation mortality, thereby increasing the available yield for directed fisheries. Depredation mortality can also be included as another explicit source of mortality in the stock assessment and mortality limit setting process, depending on the estimated magnitude.

APPENDIX II
EXTERNAL FUNDING RECEIVED BY THE IPHC

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 characterisation 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 minimising 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

9	**Bycatch Reduction Engineering Program - NOAA**	Full scale testing of devices to minimize whale depredation in longline fisheries (NA23NMF4720414)	IPHC	NOAA Fisheries -Alaska Fisheries Science Center (Seattle)	$199,870	Mortality estimations due to whale depredation	November 2023 – April 2026
10	**Alaska Sea Grant**	Development of a non-lethal genetic-based method for aging Pacific halibut (R/2024-05)	IPHC, Alaska Pacific Univ. (APU)	Alaska Fisheries Science Center-NOAA (Juneau)	$60,374	Stock structure	January 2025-December 2026
Total awarded ($)					**$1,281,045**		

APPENDIX III
PUBLICATIONS ARISING

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.

Stewart, I.J., Hicks, A.C., and Carpi, P. 2021. Fully subscribed: Evaluating yield trade-offs among fishery sectors utilizing the Pacific halibut resource. Fisheries Research **234**. doi:10.1016/j.fishres.2020.105800.

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. Canadian Journal of Fisheries and Aquatic Sciences **77**: 1421–1432.

Forrest, R.E., Stewart, I.J., Monnahan, C.C., Bannar-Martin, K.H., and Lacko, L.C. 2020. Evidence for rapid avoidance of rockfish habitat under reduced quota and comprehensive at-sea monitoring in the British Columbia Pacific halibut fishery. Canadian Journal of Fisheries and Aquatic Sciences **77**: 1409–1420.

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.

Stewart, I.J., Scordino, J.J., Petersen, J.R., Wise, A.W., Svec, C.I., Buttram, R.H., Monette, J.L., Gonzales, M.R., Svec, R., Scordino, J., Butterfield, K., Parker, W., and Buzzell, L.A. 2021. Out with the new and in with the old: reviving a traditional Makah halibut hook for modern fisheries management challenges. Fisheries **46**(7): 313–320. doi:10.1002/fsh.10603.

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. 22: 2685–2700. doi: https://doi.org/10.1111/1755-0998.13641.

Loher, T., McCarthy, O., Sadorus, L.L., Erikson, L.M., Simeon, A., Drinan, D.P., Hauser, L., Planas, J.V., and Stewart, I.J. 2022. A Test of Deriving Sex-Composition Data for the Directed Pacific Halibut Fishery via At-Sea Marking. Marine and Coastal Fisheries **14**(4). doi:10.1002/mcf2.10218.

Loher, T., Dykstra, C.L., Hicks, A., Stewart, I.J., Wolf, N., Harris, B.P., Planas, J.V. Estimation of post release 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.

2023:

Lomeli, M.J.M., Wakefield, W.W., Abele, M., Dykstra, C.L., Herrmann, B., Stewart, I.J., and G.C. Christie. Testing of hook sizes and appendages to reduce yelloweye rockfish bycatch in a Pacific halibut longline fishery. *Ocean & Coastal Management* .2023. 241: 106664. https://doi:10.1016/j.ocecoaman.2023.106664.

Planas, J.V., Rooper, C.N., Kruse, G.H. Integrating biological research, fisheries science and management of Pacific halibut (Hippoglossus stenolepis) across the North Pacific Ocean. *Fisheries Research*. 2023. 259: 106559. https://doi.org/10.1016/j.fishres.2022.106559.

2024:

Dykstra, C., Wolf, N., Harris, B.P., Stewart, I.J., Hicks, A., Restrepo. F., Planas, J.V. Relating capture and physiological conditions to viability and survival of Pacific halibut discarded from commercial longline gear. *Ocean & Coastal Management*. 2024. 249: 107018. https://doi.org/10.1016/j.ocecoaman.2024.107018.

Hutniczak, B., Wilson, D.T., Stewart, I.J., and Hicks, A.C. 2024. A hundred years of Pacific halibut management in the context of global events and trends in fisheries management. Frontiers in Marine Science **11**. doi:10.3389/fmars.2024.1424002.

Sadorus, L.L., Webster, R.A. and Sullivan, M.E. Environmental conditions on the Pacific halibut (Hippoglossus stenolepis) fishing grounds obtained from a decade of coastwide oceanographic monitoring, and the potential application of these data in stock analyses. *Marine and Freshwater Research*. 2024. 75: MF23175. https://doi.org/10.1071/MF23175

Simchick, C., Simeon, A., Bolstad, K., Planas, J.V. Endocrine patterns associated with ovarian development in female Pacific halibut (*Hippoglossus stenolepis*). *General and Comparative Endocrinology*. 2024. 347: 114425. https://doi.org/10.1016/j.ygcen.2023.114425

2025:

Adams, G.D., Holsman, K., Rovellini, A., Stewart, I.J., Privitera-Johnson, K., Wassermann, S.N., and Punt, A.E. 2025. Implications of predator–prey dynamics for single species management. Canadian Journal of Fisheries and Aquatic Sciences 82: 1–19. doi:10.1139/cjfas-2024-0225.

Planas JV, Jasonowicz AJ, Simeon A, Simchick C, Timmins-Schiffman E, Nunn BL, Kroska AC, Wolf N, Hurst TP. Molecular mechanisms underlying thermally induced growth plasticity in juvenile Pacific halibut. Journal of Experimental Biology. 2025. 228 (19): jeb-251013. https://doi.org/10.1242/jeb.251013

Ritchie, BA, Smeltz, TS, Stewart, IJ, Harris, BP, and N. Wolf. 2025. Exploring Spatial and Temporal Patterns in the Size-At-Age of Pacific Halibut in the Gulf of Alaska. Fisheries Management and Ecology. doi:10.1111/fme.12814.

Stewart, I.J., and Monnahan, C.C. 2025. Diagnosing common sources of lack of fit to composition data in fisheries stock assessment models using One-Step-Ahead (OSA) residuals. Canadian Journal of Fisheries and Aquatic Sciences. http://dx.doi.org/10.1139/cjfas-2025-0158.

2026*:*

Heppell, D.S., Lomeli, M.J.M., Wakefield, W.W., Herrmann, B., Dykstra, C.L., and Stewart, I.J. 2026. Hook modification to reduce rockfish and Pacific spiny dogfish bycatch in the U.S. West Coast Pacific halibut longline fishery. Reviews in Fish Biology and Fisheries **36**(1). doi:10.1007/s11160-026-10042-7.

Submitted peer-reviewed journal papers – In review

Larson, S., Lowry, D., Andrews, K., Dykstra, C.L., Juanes, F., Timmer, B., and May, S. Molecular relatedness-based analyses reveal breeding site philopatry in female bluntnose sixgill sharks (*Hexanchus griseus*). Frontiers of Marine Science.

McGilliard, C.R., Ianelli, J., Cunningham, C., Hicks, A., Hanselman, D., Stram, D., Henry, A. Evaluating Bering Sea Pacific halibut bycatch management options using closed-loop simulations in a dynamic, multi-agency setting. Canadian Journal of Fisheries and Aquatic Sciences.

APPENDIX IV
LIST OF RANKED RESEARCH PRIORITIES FOR STOCK ASSESSMENT

Research priorities for the Pacific halibut stock assessment are delineated into three broad categories: improvements in basic biological understanding (including fishery dynamics), investigation of existing data series and collection of new information, and technical development of models and modelling approaches. The highest priority items in each of these categories are highlighted in the 5YPIRM and are expected to be the primary focus of ongoing efforts. However, it is helpful to maintain a longer list of items to inform future prioritization, to create a record of data and research needs, and to foster opportunistic and/or collaborative work on these topics when possible.

Biological understanding and fishery yield:

- *Highest priority*: Updating the fecundity-weight relationship and the presence and/or rate of skip spawning.
- *Highest priority*: The relative role of potential factors underlying changes in size-at-age is not currently understood. Delineating between competition, density dependence, environmental effects, size-selective fishing and other factors could allow improved prediction of size-at-age under future conditions.
- Movement rates among Biological Regions at the adult, juvenile and larval stages remain uncertain and likely variable over time. Long-term research to inform these rates could lead to a spatially explicit stock assessment model for future inclusion into the ensemble.
- Improved understanding of recruitment processes and larval dynamics could lead to covariates explaining more or the residual variability about the stock-recruit relationship than is currently accounted for via the binary indicator used for the Pacific Decadal Oscillation.

Potential projects relating to existing and new data sources that could benefit the Pacific halibut stock assessment:

- *Highest priority*: Continued collection of sex-ratio from the commercial landings will provide valuable information for determining relative selectivity of males and females, and therefore the scale of the estimated spawning biomass, and the level of fishing intensity as measured by SPR.
- *Highest priority*: Evaluation of the magnitude of marine mammal depredation and tools to reduce it.
- A space-time model could be used to calculate weighted FISS and/or commercial fishery age-composition data. This might alleviate some of the lack of fit to existing data sets that is occurring not because of model misspecification but because of incomplete spatial coverage in the annual FISS sampling which is accounted for in the generation of the index, but not in the standardization of the composition information.
- The work of Monnahan and Stewart (2015) modelling commercial fishery catch rates could be used to provide a standardized fishery index for the recent time-series that would be analogous to the space-time model used for the FISS.
- There is a vast quantity of archived historical data that is currently inaccessible until organized, electronically entered, and formatted into the IPHC's database with appropriate meta-data. Information

on historical fishery landings, effort, and age samples would provide a much clearer (and more reproducible) perception of the historical period.

- Additional efforts could be made to reconstruct estimates of subsistence harvest prior to 1991.
- Discard mortality estimates for the IPHC Regulatory Area 2B recreational fishery are currently unavailable, but there is an estimation system in place. Further work to develop these estimates would be preferable to the use of proxy rates from IPHC Regulatory Area 2C.
- NMFS observer data from the directed Pacific halibut fleet in Alaska could be evaluated for use in updating discard mortality rates and the age-distributions for discard mortality. This may be more feasible if observer coverage is increased and if smaller vessels (< 40 feet LOA, 12.2 m) are observed in the future. Post-stratification and investigation of observed vs. unobserved fishing behavior may be required.
- Historical bycatch length frequencies and mortality estimates should be reanalyzed accounting for sampling rates in target fisheries and evaluating data quality over the historical period.
- There are currently no comprehensive variance estimates for the sources of mortality used in the assessment models. In some cases, variance due to sampling and perhaps even non-sampling sources could be quantified and used as inputs to the models via scaling parameters or even alternative models in the ensemble.

Technical explorations and improvements that could benefit the stock assessment models and ensemble framework:

- *Highest priority*: Maintaining consistency and coordination between MSE, and stock assessment data, modelling and methodology.
- *Highest priority*: Exploration of state-space models for Pacific halibut allowing for direct estimation of the variance in time-varying processes.
- *Highest priority*: Continued exploration into the estimation of *M* in the short coastwide model.
- Continued refinement of the ensemble of models used in the stock assessment. This may include investigation of alternative approaches to modelling selectivity that would reduce relative down-weighting of certain data sources (see section above), evaluation of additional axis of uncertainty (e.g., steepness, as explored above), or others.
- Exploration of methods for better including uncertainty in directed and non-directed discard mortalities in the assessment (now evaluated only via alternative mortality projection tables or model sensitivity tests) in order to better include these sources uncertainty in the decision table. These could include explicit discard/retention relationships, including uncertainty in discard mortality rates, and allow for some uncertainty directly in the magnitude of mortality for these sources.
- Bayesian methods for fully integrating parameter uncertainty may provide improved uncertainty estimates within the models contributing to the assessment, and a more natural approach for combining the individual models in the ensemble (see section above).

- Alternative model structures, including a growth-explicit statistical catch-at-age approach and a spatially explicit approach may provide avenues for future exploration. Efforts to develop these approaches thus far have been challenging due to the technical complexity and data requirements of both. Previous reviews have indicated that such efforts may be more tractable in the context of operating models for the MSE, where conditioning to historical data may be much more easily achieved than fully fitting an assessment model to all data sources for use in tactical management decision making.

Summary table of top ranked biological research priorities for stock assessment (SA)

SA Rank	Research outcomes	Relevance for SA	Specific analysis input	Research Area	Research activities
1. Biological input	Fecundity-at-age and -size information	Scale biomass and reference point estimates	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	Reproduction	Fecundity 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
	Revised temporal and spatial maturity schedules		Will be used to revise the maturity schedule used in stock assessment		Continued temporal and spatial analysis of female histology-based maturity-at-age estimates
	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	Understanding the role of factors driving size-at-age	Improve estimates of biomass and fishery yield	Will be used to identify contributors to historical trends in biomass and fishery yield	Growth and size-at-age	Studies on growth and size-at-age
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 and/or reduction of depredation	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	Fishing innovations	Whale depredation accounting and tools for avoidance

APPENDIX V
LIST OF RANKED RESEARCH PRIORITIES FOR MANAGEMENT STRATEGY EVALUATION

Summary table of top ranked biological research priorities for management strategy evaluation (MSE)

MSE Rank	Research outcomes	Relevance for MSE	Research Area	Research activities
1. Biological parameterization: Movement and distribution of life stages	Improved understanding of larval and juvenile distribution	Improve parametization of the Operating Model and provide justification for parametising temporal variability. Assist with conditioning the OM, very patterns simulated from the OM, and provide information to develop reasonable sensitivity scenarios to test the robustness of MPs	Migration and population dynamics	Larval and juvenile connectivity studies
	Ontogenetic movement and resulting adult distribution			Population structure and dynamics
	Genomic analysis of population size and connectivity			Genomic and Close-Kin Mark-Recapture studies (Horizon Scan)
2. Biological parameterization: spatial spawning patterns and connectivity between spawning populations	Information on spatial heterogeneity in the Pacific halibut population	Information on spatial heterogeneity can be incorporated directly into the OM, and/or into an objective to maintain spatial heterogeneity.		Population structure and dynamics
	Information on temporal and spatial maturity and spawning patterns	Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model	Reproduction	Temporal and spatial analyses of maturity and spawning activity
3. Biological parameterization of growth variation	Environmental and ecological influences on growth patterns	Improve simulation of variability in weight-at-age and allow for scenarios investigating influence of population size or environmental factors	Growth and size-at-age	Evaluation of somatic growth variation as a driver for changes in size-at-age

Report on Current and Future Biological and Ecosystem Science Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, C. DYKSTRA, A. JASONOWICZ, C. JONES, 15 APRIL 2026)

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

1) Migration and Population Dynamics. Studies are 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.
2) Reproduction. Studies are aimed at providing information on the sex ratio of the commercial catch and to improve current estimates of maturity and fecundity.
3) Growth. Studies are 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.
4) Mortality and Survival Assessment. Studies are aimed at providing updated estimates of discard mortality rates in the guided recreational fisheries and at evaluating methods for reducing mortality of Pacific halibut.
5) Fishing Technology. Studies are aimed at developing methods that involve modifications of fishing gear with the purpose of reducing Pacific halibut mortality due to depredation and bycatch.

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

SRB RECOMMENDATIONS AND REQUESTS

The SRB issued the following recommendation in their report of SRB027 (IPHC-2025-SRB027-R) in relation to presentation IPHC-2025-SRB027-06:

SRB027–Rec.01 (para. 14). The SRB ***RECOMMENDED*** *that that evaluation of epigenetic aging be expanded from random selection of cross-validation samples to include testing out-of-sample interannual predictive performance. That is, how well can an epigenetic aging method trained on data from one set of years predict age of individuals sampled in other years?*

The IPHC Secretariat has selected a set of genetic samples separate from those used for the epigenetic clock development to test out-of-sample interannual predictive performance, as detailed in section 1.2.1.2.

UPDATE ON PROGRESS ON THE MAIN RESEARCH ACTIVITIES

1. Migration and Population Dynamics.

The IPHC Secretariat is currently focusing on studies that incorporate genomics approaches in order to produce useful information on population structure, 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 MSE process is in biological parameterization and validation of movement estimates, on one hand, and of recruitment distribution, on the other hand (Appendix III).

1.1. Population genomics. The primary objective of these studies is to investigate the genetic structure of the Pacific halibut population and to conduct genetic analyses to inform on Pacific halibut population dynamics and distribution within the Convention Area

1.1.1. Population genetic structure. Details on sample collection, sequencing, bioinformatic processing and proposed analyses utilizing low-coverage whole genome sequencing (lcWGR) to investigate Pacific halibut population structure were provided in documents IPHC-2021-SRB018-08, IPHC-2022-SRB021-09, IPHC-2023-SRB022-09, IPHC-2024-SRB024-09 and IPHC-2025-SRB026-06. Results from these studies are currently being prepared for publication in a leading peer-reviewed journal.

1.1.2. Development of a novel method for estimating genetic differentiation from genotype likelihoods. As part of IPHC's research on population genetic structure, the IPHC Secretariat has developed a bioinformatic method (named *fst-gl*) designed to estimate F_{ST} using low-coverage whole genome resequencing (lcWGR) data from multiple populations. F_{ST} (Weir and Cockerham, 1984) is a widely used measure of population differentiation that is applied in the identification of SNPs or localized regions of the genome that show high levels of differentiation for the purposes of SNP panel development, identification of genomic signals of natural selection or local adaptation, identification of sex-associated genomic regions (Pacific halibut: Jasonowicz et al. 2022), etc.

Current available bioinformatic methods for estimating F_{ST} require hard-called genotypic data generated at high-coverages (> 10x) using methods such as restricted site associated DNA (RAD)-seq or whole genome sequencing (WGS) to obtain accurate estimates of F_{ST}. When sequencing at lower coverages (< 5x), uncertainty arises at the level of individual genotypes; therefore, accounting for this uncertainty is necessary when analyzing lcWGR data. The estimation of F_{ST} from lcWGR data or genotype likelihoods is complicated by the very limited number of available bioinformatic methods (e.g. *angsd*) that only estimate pairwise F_{ST} between two populations from low-coverage sequencing data (Korneliussen et al. 2014; Rasmussen et al. 2022) at a high computational cost.

The IPHC Secretariat has developed a bioinformatic method (*fst-gl*) and applied it to estimate F_{ST} values that were used to select the top SNPs for assignment testing, detailed in IPHC-2024-SRB024-09. *fst-gl* offers substantial performance improvements over existing methods implemented in *angsd* and enabled the IPHC Secretariat to test different training-set and SNP panel designs for assignment testing. *fst-gl* enables the estimation of F_{ST} among any number of populations and implements resampling routines to provide bootstrapped significance values for estimates of F_{ST}.

1.1.2.1. Methods.

1.1.2.1.1. Implementation. *fst-gl* was written in the *nim* programming language and leverages the *hts-nim* (Pedersen and Quinlan 2018) library for efficient parsing of variant call format (VCF) (Danecek et al. 2011) and the binary compressed version of VCF (BCF) files by exposing the low level HTSlib to *nim*. *fst-gl* also leverages the OpenMP API to implement multicore processing to further improve performance. At the core of *fst-gl* is an expectation maximization (EM) algorithm for estimating allele and genotype frequencies from genotype likelihoods for each population and then those estimates are used to calculate Weir and Cockerham's (1984) $\hat{\theta}$, a widely used estimator of F_{ST}. We reimplemented the EM algorithm for estimating allele frequencies from the software *vt* (Tan et al. 2015) in the *nim* programming language for *fst-gl.*

1.1.2.1.2. Performance evaluation. We used both simulated and empirical data to evaluate the performance of *fst-gl* compared to existing methods for estimating F_{ST} from lcWGR data. We used *SLiM* (v4) (Haller and Messer 2023), an individual based, forward in time simulation framework to simulate individual level genetic data under different levels of migration expected to generate varying levels of population differentiation and F_{ST} levels at individual SNPs ranging from 0 to 1. Briefly, we simulated two, three, and five population scenarios, where each population contains 1,000 individuals with a sex ratio of 0.5, under four different migration rates; 0 (no migration), 0.01, 0.05, and 0.1 for 10,000 generations using a Wright-Fisher based model in *SLiM*. Each scenario (migration rate x number of populations) was simulated 10 times.

At the end of each *SLiM* simulation, we randomly sampled 50 individuals from each population and extracted their simulated (true) genotypes and used this individual level variation to simulate Illumina sequence data using *reseq* (v1.1) (Schmeing and Robinson 2021). A sequencing error profile was obtained from https://github.com/schmeing/ReSeq-profiles to generate raw sequence data similar to what might be observed when using Illumina's TruSeq chemistry on the NovaSeq 6000 platform. We simulated reads to an approximate sequencing depth of 20x, and processed them similarly to the bioinformatic methods provided in IPHC-2023-SRB022-09. Following sequence read alignment, *samtools* (v1.22.1) (Li et al. 2009) was used to down sample the aligned reads to average sequencing depths of 0.1x, 0.5x, 2.5x, 5x, 10x, and 15x, to evaluate performance of *fst-gl* under varying levels of uncertainty due to low sequencing depth.

For each simulation, we first obtained estimates of F_{ST} at each SNP position using the simulated genotypes of the individuals subsampled at the end of each simulation using *vcftools* (v0.1.14) (Danecek et al. 2011) and compared these to estimates obtained from the down sampled alignments using genotype likelihood-based methods (*fst-gl* and *angsd*) and hard-called genotypes.

After estimates of F_{ST} were obtained using each method, we calculated bias at each SNP position as $\hat{F}_{st} - F_{ST}$. To evaluate the performance of *fst-gl* in a real-world use case, we also applied the newly developed method to the task of identifying a sex-associated region of the Pacific halibut (*Hippoglossus stenolepis*) chromosome 9 (Chr09) (NCBI: NC_061491.1). This analysis was previously carried out using pool-seq data (Jasonowicz et al. 2022) and provides a simple real-world application for *fst-gl* that we can compare to existing results and possibly gain new insights. We matched our use case to the study design of the pool-seq analysis presented in Jasonowicz et al. (2022) by analyzing lcWGR sequence reads from 30 adult female and 30 adult male Pacific halibut collected by a chartered commercial longline vessel near the Portlock Bank region of the Gulf of Alaska (56°59'N- 58°55'N, 148°41'W-152°44'W) and included in the previously reported study of Pacific halibut population structure (IPHC-2025-SRB026-06).

We used both *fst-gl* and *angsd* to obtain pairwise estimates of F_{ST} between males and females and calculate windowed estimates of weighted F_{ST} (50 kb window, 1000 bp step) to facilitate a direct comparison to the F_{ST} estimates obtained by Jasonowicz et al. (2022). Since *fst-gl* also produces estimates of heterozygosity, we were able to compare heterozygosity levels between the sexes which was not possible in the pool-seq analysis (Jasonowicz et al. 2022).

1.1.2.1.3. Performance Benchmarks. We also compared various performance metrics (run time and memory usage) between the *angsd* and *fst-gl* analysis workflows for our real-world use case scenario. *snakemake* (v8.10.7) (Mölder et al. 2025) was used to run our workflow and the benchmarking directive was used to gather performance statistics for each step of the analysis.

1.1.2.2. Results & Discussion. We observed that sequencing depth has a strong influence on the accuracy of the F_{ST} estimates obtained across all methods compared in our analysis, with increases in accuracy observed as sequencing depth increases (Figure 1). Our analysis of simulated data reinforces that using genotypes called from lcWGR data to estimate population parameters introduces bias into results, resulting in less accurate estimates than methods that account for uncertainty in individual genotypes (Figure 1). Even at higher sequencing depths (≥ 10x) where levels of bias were very small for all methods, estimates from *fst-gl* produced slightly more accurate estimates compared to those obtained from called genotypes (Figure 1).

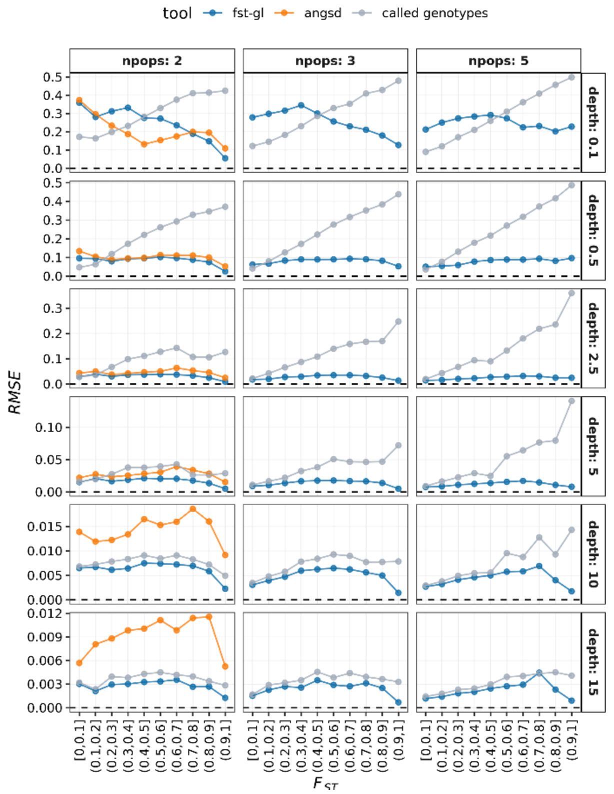


Figure 1. Comparison of RMSE observed at different simulated sequencing depths, number of populations, and methods for obtaining F_{ST} estimates from low-coverage sequence data. Note different y-axis scales for each level of sequencing depth and that angsd can only estimate pairwise F_{ST} between two populations.

When applied to our empirical data, *fst-gl* and *angsd* produced very similar estimates of F_{ST} across Chr09 (Figure 2A). Both methods captured a region of elevated differentiation from 14–26 Mbp on Chr09, with the largest peak of F_{ST} observed just downstream of the putative sex determining gene *bmpr1ba*, similar to Jasonowicz et al. (2022). Pacific halibut exhibit a ZZ/ZW system where females are the heterogametic sex (Drinan et al. 2018), and our analysis supports this notion as shown by the different levels of heterozygosity observed in this region of the genome, with many SNPs fully heterozygous in females (Figure 2B).

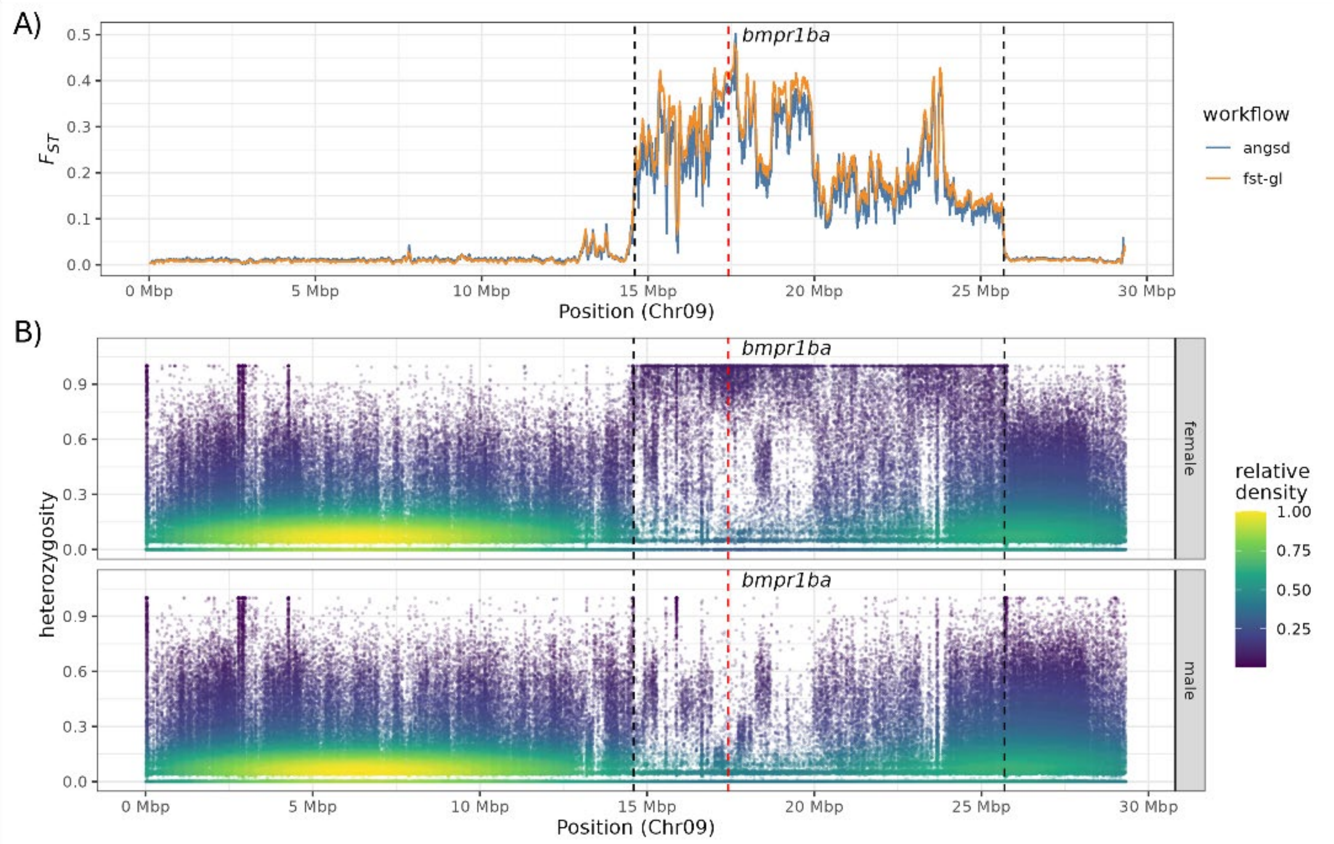


Figure 2. Windowed estimates of pairwise F_{ST} (50kb window, 100 bp step) between male and female Pacific halibut using lcWGR sequence data (2.9x) obtained using methods implemented in angsd and fst-gl (A). Estimates of heterozygosity at individual SNPs obtained from low-coverage sequence data for female (top) and male (bottom) Pacific halibut using fst-gl (B). Vertical dashed lines indicate the sex-linked region (black lines) and the location of bmpr1ba (red line), a candidate master-sex determining gene for Pacific halibut identified by Jasonowicz et al. (2022) using pool-seq.

Finally, we observed a substantial performance improvement of *fst-gl* over *angsd* in terms of both run time and memory usage. In our real-world example that analyzed a single 29.3 million base pair chromosome (Chr09), the total wall time for the *angsd* workflow was 32.53 mins and 19.74 mins for the *fst-gl* workflow, resulting in a 39.3% reduction in total wall time. After genotype likelihoods were obtained, *fst-gl* took only 11.23 seconds to run.

1.1.2.3. Conclusion. Through analysis of simulated and empirical data, we have shown that *fst-gl* reduces bias when estimating F_{ST} from low-coverage sequence data. Furthermore, *fst-gl* offers an improvement in performance over existing methods, especially if genotype likelihoods have already been estimated at SNPs of interest. In addition to developing a method for obtaining estimates of global F_{ST}, we have also added additional functionality that may be useful to future research in this area. First, this new method allows resampling routines to establish significance values under the null hypothesis of no differentiation Second, the ability to query genomic regions for indexed bcf and vcf.gz files enable targeted investigation of genomic regions. Third, this second feature can also be used to achieve high levels of parallelism by partitioning the analysis into smaller units, further improving efficiency, particularly when working in high performance computing environments. This work is currently being prepared for publication in a leading peer-reviewed journal.

1.2. Genomics-based method for estimating age of Pacific halibut. The primary objective of this project is to develop a genetic method for aging Pacific halibut using fin tissue, a sample that can be easily collected from either live or dead individuals. This method is based on the identification of DNA methylation patterns in fin tissue that are associated with age through the development of an age estimation model (i.e., an epigenetic clock) for Pacific halibut. The first epigenetic clock was developed for humans in 2013 (Horvath, 2013), and it predicted age with great accuracy (r = 0.96) and with a mean aging error (MAE) of 3.6 years. Subsequently, epigenetic clocks have been developed for several fish species that demonstrated improved accuracy (r between 0.84 and 0.99) and lower average MAE (0.87 years, or 3.5% of the total lifespan of the species examined) (reviewed in Piferrer and Anastasiadi, 2023).

Patterns of DNA methylation (i.e. a natural process of regulation of gene expression that consists in the covalent modification of the nucleobase cytosine) in Pacific halibut will be investigated by performing genome-wide DNA methylation at single base-pair resolution using reduced representation bisulfite sequencing (RRBS) by leveraging the high-quality genome assembly available for Pacific halibut (Jasonowicz et al. 2022). This is an efficient and cost-efficient method to identify methylation patterns (i.e., CpG sites) in DNA because it targets bisulfite sequencing to a well-defined set of genomic regions with high CpG density that can be sequenced at high read depth. Age-associated DNA methylation patterns will be modelled to generate an epigenetic age predictor (i.e., epigenetic clock) for Pacific halibut constructed using elastic net penalized regression models that select a group of CpG sites that have a monotonically increasing relationship with age in the selected training data set. By implementing these linear models that select and weight age-correlated CpG sites, chronological age of Pacific halibut will be estimated based on the percentage methylation at these key CpG sites in fin tissue samples.

1.2.1. Methods.

1.2.1.1. Genetic samples used in the development of the epigenetic clock. For developing an epigenetic clock, we selected genetic samples (fin clips) from 249 individual Pacific halibut collected during IPHC's Fishery Independent Setline Survey (FISS) from 2021 to 2024 throughout IPHC Convention Waters (Figure 3) and covering most of IPHC's Regulatory Areas (Table 1). These genetic samples correspond to fish with known ages (read twice by the traditional break and bake aging method) between 6 to 30 years and include 6-10 individual samples (aiming at equal number of males and females) per year of age (Figure 4).

Table 1. Number of FISS samples by year and IPHC Regulatory Area with RRBS sequence data generated for the development of the Pacific halibut epigenetic clock.

Year	2A	2B	2C	3A	3B	4A	4B	4D	Total
2021	1	12	12	3	0	3	1	0	32
2022	2	22	17	20	2	2	3	1	69
2023	16	32	25	14	10	0	0	0	97
2024	0	15	26	7	1	0	0	2	51
Total	**19**	**81**	**80**	**44**	**13**	**5**	**4**	**3**	**249**

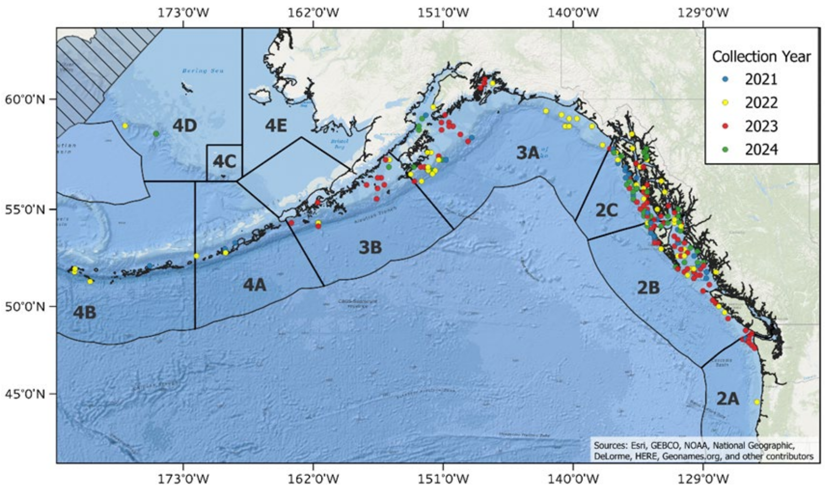


Figure 3. Map showing the collection locations of the samples with RRBS sequence data generated for the development of the Pacific halibut epigenetic clock.

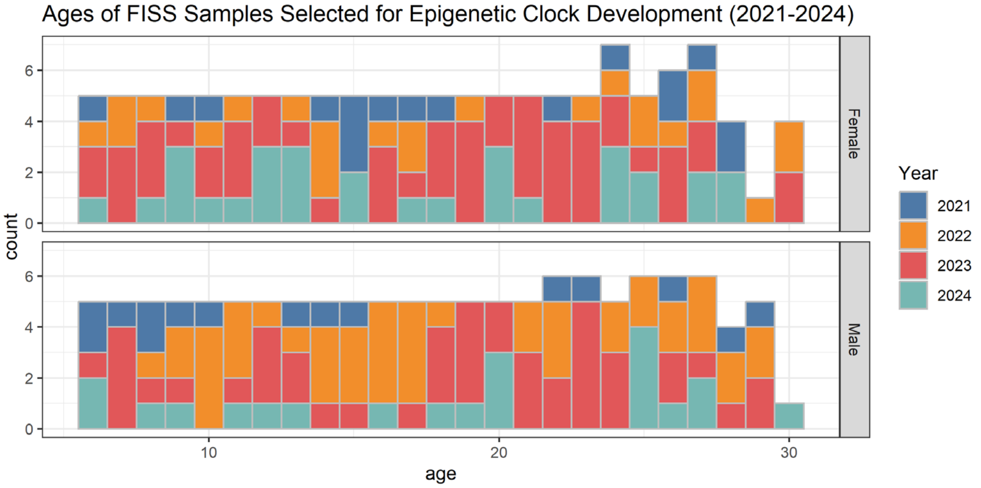


Figure 4. Histograms showing the number of female (top) and male (bottom) genetic samples with RRBS sequence data generated for the development of the Pacific halibut epigenetic clock.

1.2.1.2. Genetic samples used in testing out-of-sample interannual predictive performance. For testing out-of-sample interannual predictive performance of the epigenetic clock, we selected genetic samples (fin clips) from 46 individual Pacific halibut collected in commercial landings from 2017 to 2020 covering most of IPHC's Regulatory Areas (Table 2). These genetic samples correspond to fish with known ages (read twice by the traditional break and bake aging method) between 6 to 27 years (Figure 5).

Table 2. Number of market samples by year and IPHC Regulatory Area submitted for RRBS sequencing on the Aviti sequencing platform for out-of-sample validation of the Pacific halibut epigenetic clock.

Year	2C	3A	3B	4A	4B	4C	4D	Total
2017	0	0	0	4	4	0	4	12
2018	1	3	2	0	5	0	1	12
2019	0	3	2	3	2	1	0	11
2020	3	4	4	0	0	0	0	11
Total	**4**	**10**	**8**	**7**	**11**	**1**	**5**	**46**

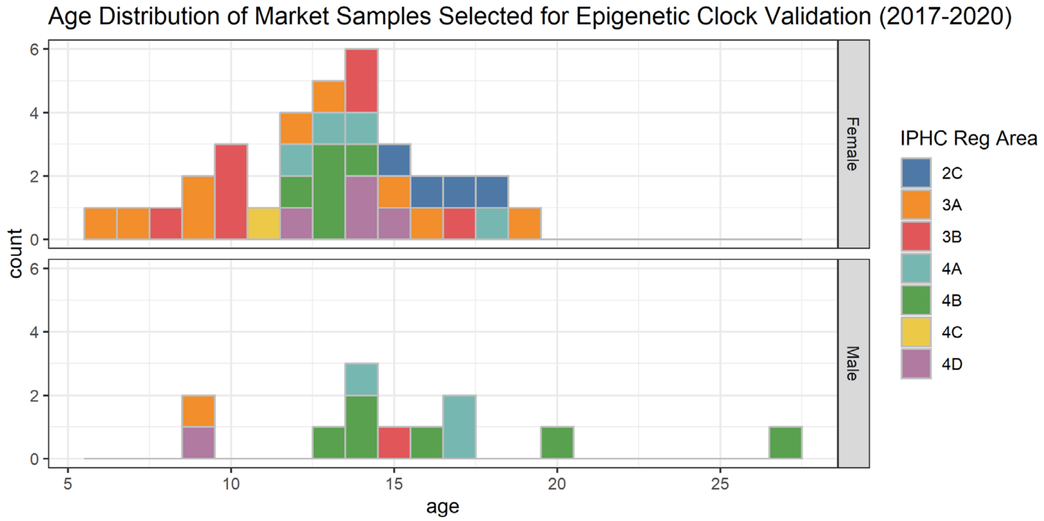


Figure 5. Age distribution of genetic samples from commercial landings ("market samples") selected for out-of-sample validation of the Pacific halibut epigenetic clock.

1.2.1.3. Development of a bioinformatic workflow. A bioinformatic workflow was developed to process reduced representation bisulfite sequencing (RRBS) data in house (Figure 6). Prior to start processing the raw sequence data, a reference genome was prepared for bisulfite alignments with the Pacific halibut reference genome (Jasonowicz et al., 2022; GCF_022539355.2) and control methylated and unmethylated sequences (see below) using the software Bismark.

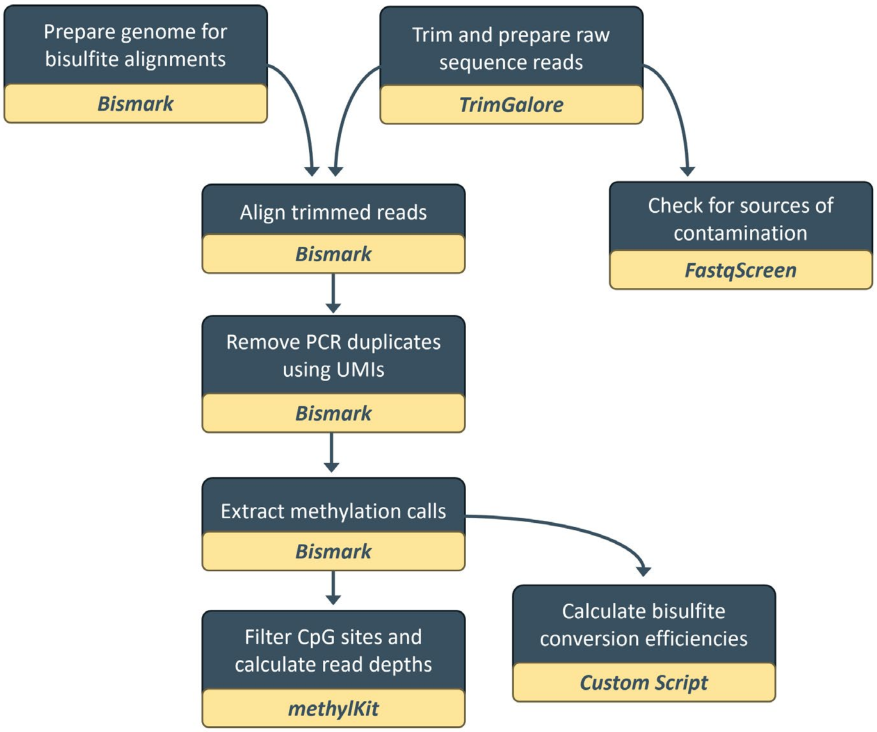


Figure 6. Basic bioinformatic workflow for processing RRBS data. The blue boxes describe each step and the software used is indicated in the yellow boxes.

1.2.1.4. Reduced representation bisulfite sequencing: library preparation and sequencing. High-quality genomic DNA was extracted from individual fin clips and purified using the DNeasy Blood and Tissue Kit (Qiagen). Genomic DNA was used to construct individual RRBS libraries using the Premium RRBS Kit V2 (Diagenode) following the manufacturer's specifications. In brief, RRBS libraries were prepared by digesting genomic DNA with the methylation sensitive restriction enzyme MspI, and the resulting DNA fragments were treated with bisulfite to convert non-methylated cytosines into uracils through chemical deamination, leaving methylated cytosines unaffected. A subsequent PCR amplification step converted uracils into thymines. Constructed RRBS libraries were first assessed for concentration and fragment size distribution by TapeStation (Agilent). Subsequently, individual libraries used for the development of the epigenetic clock were pooled and sequenced on an Illumina NovaSeq-X sequencing platform in 1.5B flow cells at 2 x 50PE at the Functional Genomics Facility at the University of Chicago (Chicago, IL). In addition, individual libraries used for the out-of-sample validation of the epigenetic clock were pooled and sequenced on an Element Aviti sequencing platform at 2 x 75PE at the Functional Genomics Facility at the University of Chicago (Chicago, IL).

1.2.1.5. Sequencing data analysis and methylation calling. Prior to analysis, raw sequence reads will be quality checked using *FastQC* (Andrews et al., 2015) to ensure consistent quality across sequencing runs and to 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. The raw sequence reads will then be processed to remove Illumina adapter sequences and low quality reads using *Trim Galore!* (https://github.com/FelixKrueger/TrimGalore), a trimming tool designed specifically for RRBS data. Trimmed sequence reads will be aligned to a bisulfite converted index of the Pacific halibut reference genome (RefSeq assembly accession: GCF_022539355.2) excluding the sex chromosome (Chr09; Jasonowicz et al., 2022) to discard possible sex-associated methylation signals, using *bismark* (Krueger and Andrews, 2011) allowing for one mismatch. Having a high-quality reference genome available for Pacific halibut is a major benefit to this study as constructing one is costly and time consuming. Furthermore, the Pacific halibut genome has been annotated so that the locations and identity of genes are known, enabling the functional significance of methylated CpG sites present in protein coding gene regions to be inferred. 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 methylation module in *BS-Seeker2* (Guo et al., 2013) with default settings will be used for methylation calling. For all identified CpG sites, percentage methylation will be calculated as the percentage of the number of methylated reads over the number of total reads with a 95% confidence interval. Typically, RRBS produces in the order of hundreds of thousands of CpGs (Anastasiadi and Piferrer, 2023). CpG sites with at least 20x coverage and with methylation levels in > 90% of the samples will be used for downstream analyses.

1.2.1.6. Development of an age predicting model for Pacific halibut. The sequenced genetic samples will be randomly assigned to a training (200 samples) or a testing data set (50 samples) following an 80/20 data split. Sample assignments will be conducted using *caret* to maintain equal sex ratios in each data set. The training set will be used to fit the model and the testing set will be an independent set of data that will be used to evaluate the model fit.

The relationship between otolith-derived age and percent methylation across age-correlated CpG sites in the training data set will be characterized by performing elastic net penalized regression analysis using the R package *glmnet* (Friedman et al., 2010) set to a 10-fold cross validation with an α-parameter of 0.5 and automatically selecting the optimal penalty parameter (λ). We expect that the age-predicting model will retain in the order of a few hundred CpG sites with a low λ value. The performance of the model in the training and testing data set will be evaluated using Pearson correlations (i.e. measuring the degree of correlation between chronological and estimated age) as a measure of accuracy, MAE as a measure of precision (i.e., how well the model fits the actual data), and relative error rates (Piferrer and Anastasiadi, 2023). Comparison of MAE between the training and testing data sets will inform on the potential overfit of the model constructed using the training data set. The linear relationship between predicted and chronological (i.e., otolith-derived) age will be visually represented and additional patterns in the data will be visualized using principal component analysis (PCA).

1.2.1.7. Identification of the genomic location of age markers. The Pacific halibut genome annotation (NCBI link) will also be used to determine if any functional genes are located within 400 bp of model selected CpG sites. This will inform whether clock CpG sites are proximal to specific annotated genes and whether methylation at those particular sites could have functional significance.

1.2.2. Results.

All aged fin clips used for the construction of the epigenetic clock have been processed for DNA extraction. The obtained genomic DNA was quantified, and all samples yielded enough high-quality genomic DNA to proceed with individual library construction. Library preparation was successfully completed for all 249 individual aged samples. RRBS libraries were combined into 6 pools of 41-42 libraries each and sequenced.

Based on initial processing of the six sequenced library pools, the average PCR duplication percentage was 43.08% across all pools, ranging from 33.77% to 64.82%. The average number of deduplicated reads per individual sample ranged from 5,288,760 reads to 7,264,685 reads. Average methylated controls were 1.58% across all libraries, ranging from 1.40% to 1.86%. Average methylated levels in the control samples below 2% indicate minimal false detection of unmethylated cytosines. On the other hand, average unmethylated controls were 99.25% across all libraries, ranging from 98.95% to 99.44%, providing a positive control to assess the efficiency of bisulfite conversion of DNA. The total number of obtained deduplicated reads that will be used for downstream analyses was 1,590,925,852 (i.e. over 1.5 billion reads) (Table 3).

Table 3. Initial metrics for all six library pools composed of individual libraries from project samples that will be used to develop an epigenetic clock.

Pool	Number of samples processed	Average PCR duplication rate (%)	Average number of remaining reads/sample	Average of methylated control (%)	Average of unmethylated control (%)	Sum of deduplicated reads (reads remaining)
1	42	64.82	5,288,760	1.40	98.95	222,127,927
2	41	49.56	6,506,924	1.65	99.20	266,783,900
3	42	34.99	7,264,685	1.64	99.37	305,116,779
4	42	38.35	6,509,939	1.86	99.44	273,417,435
5	41	33.77	6,443,062	1.41	99.29	270,608,611
6	41	36.99	6,167,590	1.51	99.25	252,871,200
Total	**249**	**43.08**	**-**	**1.58**	**99.25**	**1,590,925,852**

Current work is focused on processing the sequence data through the bioinformatic workflow depicted in Figure 6.

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 some of 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 is finalizing the processing of genetic samples from the 2025 aged commercial landings.

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

2.2.1. Update of maturity schedules based on histology and calibrated visual data. The IPHC Secretariat provided an update on spatial and temporal patterns in maturity ogives by Biological Region from 2022 to 2024, and a revised coastwide maturity ogive using histological based data in IPHC-2025-SRB026-06. At present, the IPHC Secretariat is preparing a manuscript for publication in a peer-reviewed journal describing the temporal and spatial changes in histology-derived maturity ogives and ovarian developmental stages. Furthermore, the IPHC Secretariat developed a calibration between histological and visual maturity ogives from the 2022-2024 data and produced calibrated maturity ogives based on FISS visual maturity data from 2002-2024. During this 23-year period, we observe significant shifts in the age at 50% (A_{50}) maturity (Figure 7). These results evidence two temporal shifts, one characterized by a gradual increase in the A_{50} (i.e. females maturing at a later age) from 2004 to 2016, and a second one characterized by a sharp decrease in A_{50} from 2017 to 2022 (i.e. females rapidly maturing at an earlier age). Studies are planned to identify possible drivers of these temporal shifts in maturity-at-age in female Pacific halibut.

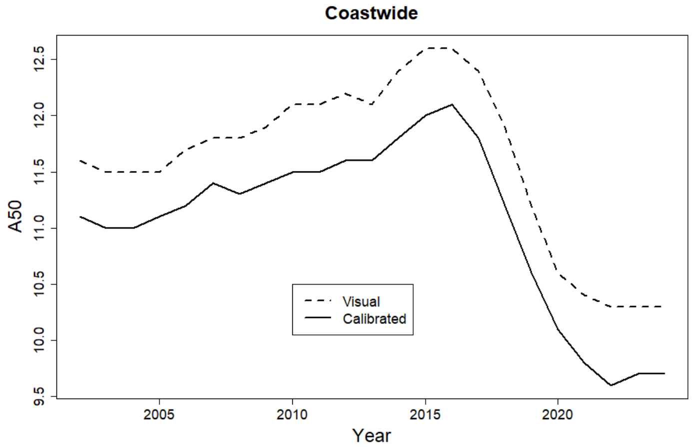
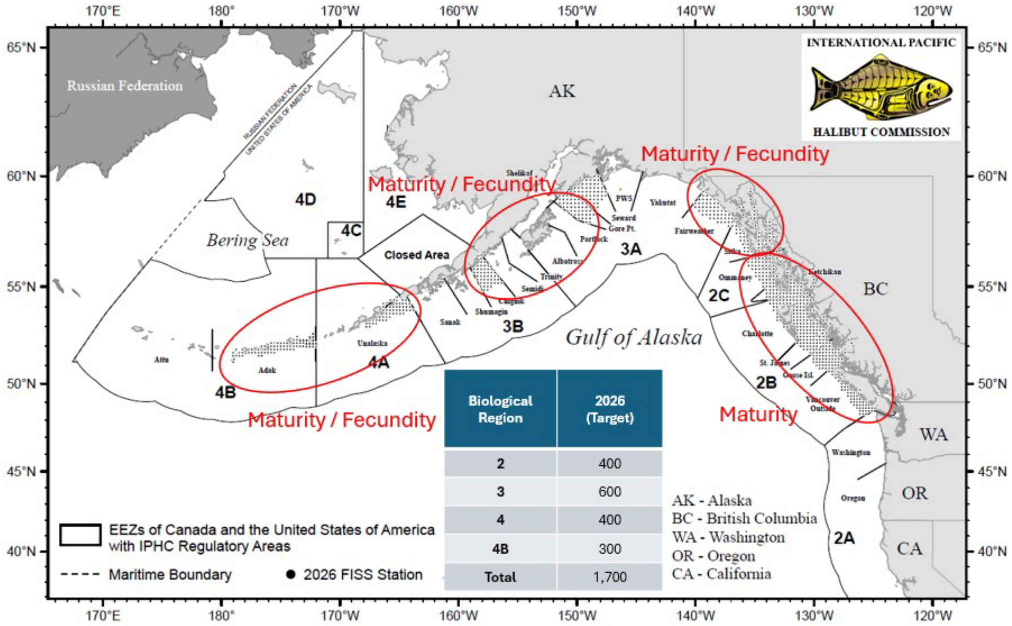


Figure 7. Coastwide A_{50} calculated from visual and calibrated maturity ogives from 2002 to 2024.

The IPHC Secretariat continued to collect ovarian samples for maturity in the 2025 FISS. 2025 FISS sampling resulted in the successful collection of 1,276 ovarian samples from all four Biological Regions: 275 samples in Biological Region 2, 380 samples in Biological Region 3, 355 samples in Biological Region 4, and 266 samples in Biological Region 4B. These samples will allow us to further investigate both spatial and temporal differences in histological-based female Pacific halibut maturity. In 2026, the IPHC Secretariat will continue to collect maturity samples across the entirety of the FISS by targeting the collection of 400 ovarian samples in Biological Region 2, 600 samples in Biological Region 3, 400 samples in Biological Region 4, and 300 samples in Biological Region 4B (Figure 8).



Biological Region	2026 (Target)
2	400
3	600
4	400
4B	300
Total	1,700

Figure 8. Coastwide map of sample areas and targets for maturity and fecundity collection in 2026 FISS.

2.2.2. Fecundity estimates. The IPHC Secretariat has initiated studies that are aimed at improving our understanding of Pacific halibut fecundity. These studies will allow us to estimate fecundity-at-size and -age and could be used to replace spawning biomass with egg output as the metric for reproductive capability in SA and management reference points. Fecundity determinations will be conducted using the auto-diametric method (Thorsen and Kjesbu, 2001; Witthames et al., 2009) and IPHC Secretariat staff received training on this method by experts in the field (NOAA Fisheries, Northeast Fisheries Science Center, Wood Hole, MA) in May 2023. Ovarian samples for the development and application of the auto-diametric method to estimate fecundity in female Pacific halibut have been collected during the FISS in 2023, 2024 and 2025, as well as two special collections in IPHC Regulatory Area 2B in 2024 and 2025 (Figure 9). In 2023, sampling was conducted only in Biological Region 3, with a total of 452 fecundity samples collected. In 2024, sampling was conducted in Biological Regions 2 and 4, with 149 and 359 fecundity samples collected, respectively. In the Fall (Oct/Nov) of 2024, 271 additional fecundity samples targeting large females (85-200+ cm in fork length) were collected in Biological Region 2. This sampling was conducted to collect later developing females to help build the auto-diametric curve for fecundity estimations. For 2025, in addition to 878 samples collected in all four Biological Regions in the FISS, 242 fecundity samples were collected in Biological Region 2 in a special project targeting large females during the late summer months. This comprehensive collection of ovarian samples will be used initially for the development of the auto-diametric method, followed by actual fecundity estimations by age and by size (length and weight).

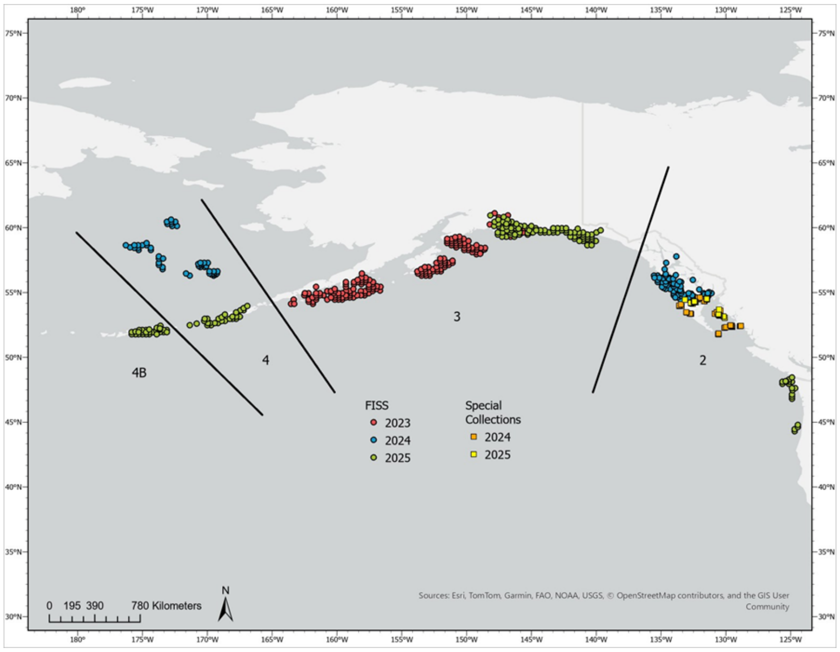


Figure 9. Coastwide map of 2023, 2024 and 2025 samples for fecundity collected in FISS (circle colors), and 2024 and 2025 special collection fecundity samples in IPHC Regulatory Area 2B (square colors).

To examine potential indicators of increased reproductive output of female Pacific halibut, IPHC Secretariat calculated gonadosomatic index (GSI) values for all fecundity samples that have been histologically staged. This includes all FISS samples in 2023 and 2024, as well as the special collection samples in Regulatory Area 2B in 2024 and 2025. GSI was calculated as $GSI = \frac{G}{W} x\ 100$. Where G = total gonad weight (kg), and W = dressed weight (kg). We compared GSI to age (Figure 10) and weight (Figure 11) across four different female ovarian developmental stages (Vtg1, Vtg2, Vtg3, and GVM).

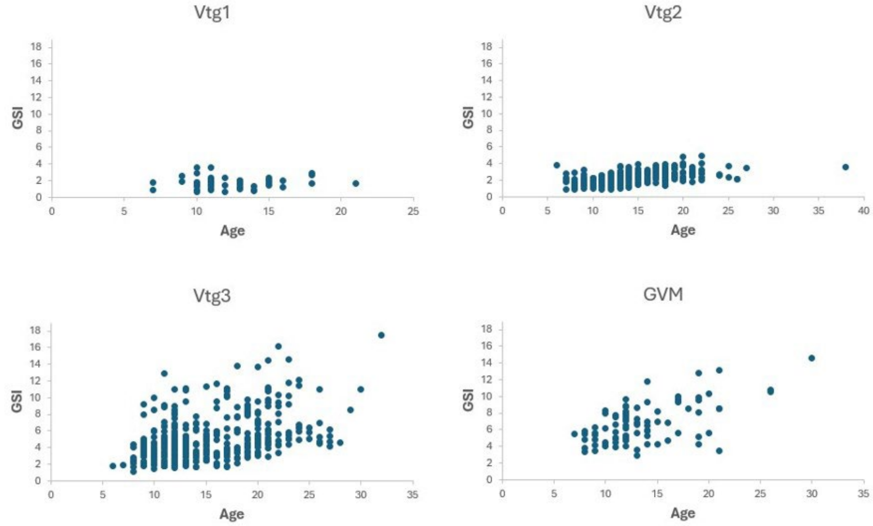


Figure 10. Gonadosomatic index (GSI) of female Pacific halibut according to age and female developmental stage (Vitellogenic 1, Vtg1; Vitellogenic 2, Vtg2; Vitellogenic 3, Vtg3; Germinal Vesicle Migration, GVM).

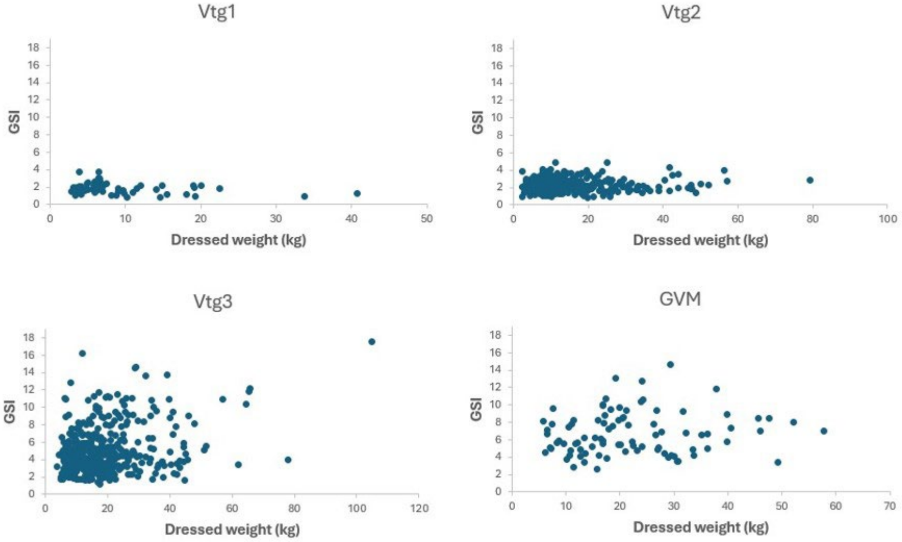


Figure 11. Gonadosomatic index (GSI) of female Pacific halibut according to weight and female developmental stage.

Our preliminary results show no increase in GSI with age for earlier developing females (e.g. Vtg1 and Vtg2), and a slight trend towards an increase in GSI with older females as they progress to the Vtg3 and GVM stages. When comparing GSI to weight, there is no indication of increasing gonad size with overall body weight, with higher variability in later stage developing females (Vtg3 and GVM). These preliminary results suggest that egg output might follow an isometric relationship with weight, which is the current assumption in the Pacific halibut SA.

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. A manuscript describing the results of these studies has been published (Planas et al., 2025).

4. Mortality 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, constitute 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 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).

4.1. Estimation of discard mortality rates in the charter recreational sector. Results from a recently completed study investigating discard mortality rates and characteristics of fish captured and released using guided recreational fishery practices are currently being prepared for publication in a peer-reviewed journal.

5. Fishing technology.

The IPHC Secretariat has determined that research to provide the Pacific halibut fishery with tools to reduce whale depredation is considered a high priority (Appendix I). 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 been investigating gear-based approaches to catch protection as a means for minimizing whale depredation in the Pacific halibut and other longline fisheries with funding from NOAA's Bycatch Research and Engineering Program (BREP) (NOAA Awards NA21NMF4720534 and NA23NMF4720414; Appendix IV). The results and outcomes of the initial pilot phase of this project were reported in the documentation provided for the previous SRB meetings: IPHC-2022-SRB020-08 and IPHC-2024-SRB024-09.

The second phase of this project focused on further refinement and performance characterization of the shuttle device (Figure 12A) in the presence of toothed whales in IPHC Regulatory Area 4A. Field operations occurred from 21-28 May 2025 aboard the F/V Oracle (17.5 m, 58 ft) in the Bering Sea and Aleutian Islands off Alaska in known depredation hotspots and with higher expected Pacific halibut catch rates than seen in the pilot testing.

Eighteen sets were successfully completed, generating 15 sets of shuttle and control catch comparison data. Depredating orcas (identified by eaten or damaged Pacific halibut and by orca presence (Figure 12B, C)) were present at 6 of the paired sets. Camera systems developed by project participants were successfully deployed both on the control gear and on the shuttle itself (exterior and interior forward and reverse views), generating approximately 80 hours of underwater footage combined, enabling us to better quantify shuttle performance and retention rates (Figure 12D). Approximately 70 hours (10/15 paired sets) of the footage has been reviewed in detail, and 4,863 hook status observations have been recorded across all four cameras.

Preliminary results from data comparisons from 10 sets with completed video review suggest that the shuttle achieved good retention of Pacific halibut, and lower rates of retention for other frequently encountered fish (Table 4). Species morphology was likely the predominant reason for this observation and simple modifications to the entry tines and to optimal stopper fit should easily achieve much higher retention rates for these other species. Auto-removal of fish resulted in more severe hook release damage (compared to careful release by fishers at the vessel), which is expected to negatively affect survival outcomes of non-retained specimens.

Table 4. Numbers of fish encountered by the shuttle device that were either excluded, entered and escaped, entered and passed through still on the hook, and/or finally retained on 10 of 15 sets with video footage analyzed to date.

Common Name	Encountered	Excluded	Entered and Escaped	Entered and Passed Through	Retained
Pacific halibut	89	1 (1.1%)	0	8 (9.1%)	80 (90.9%)
Sablefish	160	2 (1.3%)	45 (28.5%)	30 (19.0%)	83 (52.5%)
Pacific cod	124	3 (2.4%)	13 (10.7%)	6 (5.0%)	102 (84.3%)
Rockfish	16	7 (43.8%)	2 (22.2%)	1 (11.1%)	6 (66.7%)
Skate	18	3 (16.7%)	0	2 (13.3%)	13 (86.7%)

Preliminary catch rate comparisons between protected and unprotected skates were mixed, and initial estimates of variability among catch rates within treatments were large. Overall, the shuttle demonstrated good retention capacity (up to 500 kg (1,000 lb) in the trials, with capacity for higher weights). Incidentally, rare footage of Orcas around the groundline at depth was captured.

Further testing of the shuttle device was conducted under typical commercial fishing conditions in the Bering Sea in October 2025 on the same fishing vessel with an IPHC field specialist aboard to assist with data collection. No cameras were used during this phase. The shuttle was only deployed for a total of 4 sets over this effort due to weather challenges and lack of whales present on many fishing days. Upon compilation, data from these sets will be included in the overall catch data analysis.

Data analysis and video review are ongoing. These preliminary results suggest potential for this approach to interrupt the reward cycle underpinning toothed whale depredation.

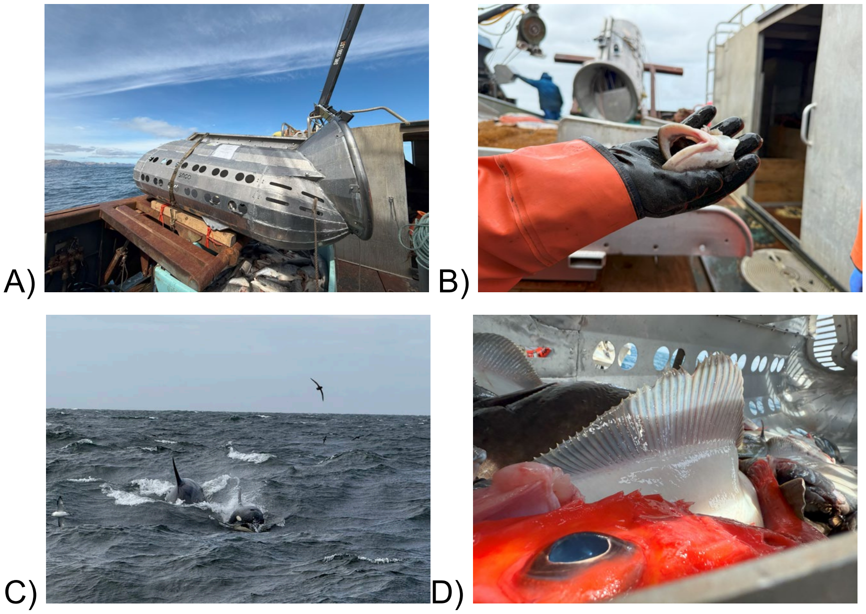


Figure 12. A) Shuttle device in transport. B) Typical evidence (lips only) of depredation. C) Killer whales rapidly approaching the hauling site. D). Catch retained within the shuttle.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2026-SRB028-06 which provides a response to Recommendations and Requests from SRB027, and a report on current biological research activities contemplated within the IPHC's five-year Program of Integrated Research and Monitoring (2022-26).

REFERENCES

Anastasiadi, D. and Piferrer, F., 2023. Bioinformatic analysis for age prediction using epigenetic clocks: Application to fisheries management and conservation biology. Frontiers in Marine Science, 10.

Andrews, S., Krueger, F., Seconds-Pichon, A., Biggins, F. and Wingett, S., 2015. FastQC. A quality control tool for high throughput sequence data. Babraham Bioinformatics. Babraham Institute, 1(1): 1.

Danecek, P., Auton, A., Abecasis, G., Albers, C.A., Banks, E., DePristo, M.A., Handsaker, R.E., Lunter, G., Marth, G.T., Sherry, S.T., McVean, G., and Durbin, R. 2011. The variant call format and VCFtools. Bioinformatics **27**(15): 2156—2158. doi:10.1093/bioinformatics/btr330.

Drinan, D.P., Loher, T., and Hauser, L. 2018. Identification of Genomic Regions Associated With Sex in Pacific Halibut. Journal of Heredity **109**(3): 326–332. doi:10.1093/jhered/esx102.

Friedman, J., Hastie, T. and Tibshirani, R., 2010. Regularization Paths for Generalized Linear Models via Coordinate Descent. J Stat Softw, 33(1): 1-22.

Guo, W., Fiziev, P., Yan, W., Cokus, S., Sun, X., Zhang, M.Q., Chen, P.-Y. and Pellegrini, M., 2013. BS-Seeker2: a versatile aligning pipeline for bisulfite sequencing data. BMC Genomics, 14(1): 774.

Haller, B.C., and Messer, P.W. 2023. SLiM 4: Multispecies Eco-Evolutionary Modeling. The American Naturalist **201**(5): E127–139. doi:10.1086/723601.

Horvath, S., 2013. DNA methylation age of human tissues and cell types. Genome Biology, 14(10): 3156.

Jasonowicz, A.J., 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. and Planas, J.V. 2022. Generation of a chromosome-level genome assembly for Pacific halibut (Hippoglossus stenolepis) and characterization of its sex-determining genomic region. Molecular Ecology Resources, 22(7): 2685-2700. https://doi.org/10.1111/1755-0998.13641

Korneliussen, T.S., Albrechtsen, A., and Nielsen, R. 2014. ANGSD: Analysis of Next Generation Sequencing Data. BMC Bioinformatics **15**(1). doi:10.1186/s12859-014-0356-4.

Krueger, F. and Andrews, S.R., 2011. Bismark: a flexible aligner and methylation caller for Bisulfite-Seq applications. Bioinformatics, 27(11): 1571-1572.

Li, H., Handsaker, B., Wysoker, A., Fennell, T., Ruan, J., Homer, N., Marth, G., Abecasis, G. and Durbin, R. 2009. The Sequence Alignment/Map format and SAMtools. Bioinformatics, 25(16): 2078-2079.

Mölder, F., Jablonski, K.P., Letcher, B., Hall, M.B., Tomkins-Tinch, C.H., Sochat, V., Forster, J., Lee, S., Twardziok, S.O., Kanitz, A., Wilm, A., Holtgrewe, M., Rahmann, S., Nahnsen, S., and Kster, J. 2025. Sustainable data analysis with Snakemake [version 3; peer review: 2 approved]. F1000Research **10**. doi:10.12688/f1000research.29032.3.

Pedersen, B.S., and Quinlan, A.R. 2018. hts-nim: scripting high-performance genomic analyses. Bioinformatics **34**(19): 3387–3389. doi:10.1093/bioinformatics/bty358.

Piferrer, F. and Anastasiadi, D. 2023. Age estimation in fishes using epigenetic clocks: Applications to fisheries management and conservation biology. Frontiers in Marine Science, 10.

Planas, J.V., Jasonowicz, A.J., Simeon, A., Simchick, C., Timmins-Schiffman, E., Nunn, B.L., Kroska, A.C., Wolf, N., Hurst, T.P. 2025. Molecular mechanisms underlying thermally induced growth plasticity in juvenile Pacific halibut. Journal of Experimental Biology. 228 (19):jeb251013. https://doi.org/10.1242/jeb.251013

Rasmussen, M.S., Garcia-Erill, G., Korneliussen, T.S., Wiuf, C., and Albrechtsen, A. 2022. Estimation of site frequency spectra from low-coverage sequencing data using stochastic EM reduces overfitting, runtime, and memory usage. Genetics **222**(4). doi:10.1093/genetics/iyac148.

Schmeing, S., and Robinson, M.D. 2021. ReSeq simulates realistic Illumina high-throughput sequencing data. Genome Biology **22**(1): 67. doi:10.1186/s13059-021-02265-7.

Stewart, I., and Hicks, A. 2018. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2017. Int. Pac. Halibut Comm. Annual Meeting Report: IPHC-2018-AM094-10

Tan, A., Abecasis, G.R., and Kang, H.M. 2015. Unified representation of genetic variants. Bioinformatics **31**(13): 2202–2204. doi:10.1093/bioinformatics/btv112.

Thorsen, A., and Kjesbu, O.S. 2001. A rapid method for estimation of oocyte size and potential fecundity in Atlantic cod using a computer-aided particle analysis system. Journal of Sea Research, 46: 295-308.

Weir, B.S., and Cockerham, C.C. 1984. Estimating F-statistics for the analysis of population structure. Evolution **38**(6): 1358-1370. doi:10.2307/2408641.

Witthames, P.R., Greenwood, L.N., Thorsen, A., Dominguez, R., Murua,H., Korta,M., Saborido-Rey, F., Kjesbu, O.S. 2009. Advances in methods for determining fecundity: application of the new methods to some marine fishes. Fishery Bulletin, 107, 148–164.

APPENDIX I

Integration of biological research, stock assessment (SA) and management strategy evaluation (MSE): rationale for biological research prioritization

Research areas	Research activities	Research outcomes	Relevance for stock assessment	Relevance for MSE	Specific analysis input	SA Rank	MSE Rank	Research priorization
Migration and population dynamics	Population structure	Population structure in the Convention Area	Altered structure of future stock assessments	Improve parametization of the Operating Model	If 4B is found to be functionally isolated, a separate assessment may be constructed for that IPHC Regulatory Area	2. Biological input	1. Biological parameterization and validation of movement estimates and recruitment distribution	2
	Distribution	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	3. Biological input		2
	Larval and juvenile connectivity studies	Improved understanding of larval and juvenile distribution	Improve estimates of productivity		Will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region	3. Biological input	1. Biological parameterization and validation of movement estimates	2
Reproduction	Histological maturity assessment	Updated maturity schedule	Scale biomass and reference point estimates	Improve simulation of spawning biomass in the Operating Model	Will be included in the stock assessment, replacing the current schedule last updated in 2006	1. Biological input		1
	Examination of potential skip spawning	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			1
	Fecundity assessment	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			1
	Examination of accuracy of current field macroscopic maturity classification	Revised field maturity classification			Revised time-series of historical (and future) maturity for input to the stock assessment			1
Growth	Evaluation of somatic growth variation as a driver for changes in size-at-age	Identification and application of markers for growth pattern evaluation	Scale stock productivity and reference point estimates	Improve simulation of variability and allow for scenarios investigating climate change	May inform yield-per-recruit and other spatial evaluations of productivity that support mortality limit-setting		3. Biological parameterization and validation for growth projections	5
		Environmental influences on growth patterns			May provide covariates for projecting short-term size-at-age. May help to delineate between effects due to fishing and those due to environment, thereby informing appropriate management response			5
		Dietary influences on growth patterns and physiological condition			May provide covariates for projecting short-term size-at-age. May help to deleineate between effects due to fishing and those due to environment, thereby informing appropriate management response			5
Mortality and survival assessment	Discard mortality rate estimate: longline fishery	Experimentally-derived DMR	Improve trends in unobserved mortality	Improve estimates of stock productivity	Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits	1. Fishery yield	1. Fishery parameterization	4
	Discard mortality rate estimate: recreational fishery				Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits			4
	Best handling and release practices	Guidelines for reducing discard mortality			May reduce discard mortality, thereby increasing available yield for directed fisheries	2. Fishery yield		4
Fishing technology	Whale depredation accounting and tools for avoidance	New tools for fishery avoidance/deterence; improved estimation of depredation mortality	Improve mortality accounting	Improve estimates of stock productivity	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	1. Assessment data collection and processing		3

APPENDIX II

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

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 links to biological research areas and research activities

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 current external research grants

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**Bycatch Reduction Engineering Program - NOAA**	Full scale testing of devices to minimize whale depredation in longline fisheries (NA23NMF4720414)	IPHC	NOAA Fisheries - Alaska Fisheries Science Center (Seattle)	$199,870	Mortality estimations due to whale depredation	November 2023 – April 2026
2	**Alaska Sea Grant**	Development of a non-lethal genetic-based method for aging Pacific halibut (R/2024-05)	IPHC, Alaska Pacific Univ. (APU)	Alaska Fisheries Science Center-NOAA (Juneau)	$60,374	Stock structure	December 2024-January 2027
Total awarded ($)					**$260,244**		

IPHC-2026-SRB028-07

Development of the 2026 Pacific halibut (*Hippoglossus stenolepis*) stock assessment

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 15 APRIL 2026)

PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with a response to recommendations and requests from SRB026 (IPHC-2025-SRB026-R) and SRB027 (IPHC-2025-SRB027-R) and to provide the Commission with an update on progress toward the 2026 stock assessment update.

INTRODUCTION

The International Pacific Halibut Commission (IPHC) conducts an annual coastwide stock assessment of Pacific halibut (*Hippoglossus stenolepis*). The most recent full assessment was completed in 2025 (IPHC-2026-SA01, IPHC-2026-SA02, and detailed model evaluation presented during SRB026: IPHC-2025-SRB026-07). That analysis followed updates in 2023 (IPHC-2024-SA01) and 2024 (IPHC-2025-SA01). The 2026 stock assessment is planned as an update analysis, updating data sources but not revisiting all data processing and model development.

Major topics explored during the 2025 full assessment included:

1) updating the time-series information for the Pacific Decadal Oscillation, used as a covariate to the stock-recruitment relationship,
2) improving the bootstrapping approach to pre-model calculation of maximum effective sample sizes to include ageing imprecision (Hulson and Williams 2024),
3) re-tuning the process and observation error components of assessment models to achieve internal consistency,
4) and updating the maturity ogive to reflect the recent histology-based estimates produced by the IPHC's Biological and Ecosystem Sciences Branch.

The results of the final 2025 assessment (IPHC-2026-AM102-10), including stock projections and the harvest decision table (IPHC-2026-AM102-12), were generally consistent with those from previous stock assessments.

Starting from the final 2025 stock assessment, this document addresses requests and recommendations made during SRB026 and SRB027 and prepares for the 2026 updated analysis.

TIME-SERIES AND SOFTWARE UPDATES

In order to provide comparability between the final 2025 results and all subsequent steps working toward the final 2026 stock assessment, this evaluation began with a bridging analysis. First, each of the four assessment models was extended by one year, including projected 2026 mortality from all sources based on the mortality limits set during AM102 (IPHC-2026-AM102-R). Extending the time-series without adding any new data does not affect the historical time-series' estimates but allows for a simple stepwise evaluation of the effects of adding data (including updating from the projected to actual fishery harvest) and any other changes to the models prior to the final version used for management.

Next, the Stock Synthesis (SS) software was updated from the version used for the 2025 stock assessment (3.30.23.1; Methot Jr 2024) to the newest release available (3.30.24.2; Methot Jr et al. 2026). The changes to the software between these two versions had no effect on the Pacific halibut stock assessment (the results were identical to the final 2025 assessment). There was a small improvement in run time for each model (in both safe and optimized modes) but no changes were noted in convergence performance, or other technical aspects of the software update relevant to this assessment.

SRB REQUESTS AND RECOMMENDATIONS

There are two pending SRB recommendations specific to the stock assessment from SRB026 and SRB027:

1) SRB026 (para. 26):

   *"The SRB **RECOMMENDED** that a candidate state space assessment model (e.g. WHAM) be developed for Pacific halibut and presented by SRB032, tentatively scheduled for June 2028. Progress toward this modelling framework may also be presented at interim SRB meetings."*

2) SRB027 (para. 16):

   *"The SRB **RECOMMENDED** that the analysis of projection performance be expanded to include plotting receiver operating characteristic (ROC) curves and evaluating the area under the curve (AUC) to understand the predictive performance of probabilistic advice from the stock assessment projections. This approach is commonly used as a threshold-independent metric of performance in applications such as species distribution modelling."*

Request 1 – State space model development

As discussed in previous documents, the IPHC continues to rely on SS for its annual tactical stock assessment modelling; however we recognize that future development of this software will be limited. During 2024, Secretariat staff explored the capabilites of R-Template Model Builder (RTMB; Kristensen et al. 2016), via a training course hosted by Fisheries and Oceans Canada. TMB forms the basis of most state-space models currently used for stock assessment (e.g., SAM, WHAM; Nielsen and Berg 2014; Nielsen et al. 2021; Stock and Miller 2021), provides a more efficient Auto-Differentiation (AD) algorithm than Automatic Differentiation Model Builder (ADMB; Fournier et al. 2012) and extremely efficient capabilities for modelling random effects and sparse matrices. As the Pacific halibut stock assessment models include time-varying processes (i.e. recruitment, selectivity, and catchability) it would be ideal to treat them as random effects, rather than using the penalized likelihood curently employed.

The IPHC development and review process benefits from the use of a generalized software platform that is widely used and tested, rather than a customized platform that may have more features but may be much more difficult to maintain and review effectively. Secretariat staff followed the December 2025 Center for the Advancement of Population Assessment Modelling (CAPAM) workshop on developing the next generation of tuna models. This workshop comprised an extensive discussion of needed model features for those species, but also included extensive consideration of exisiting stock assessment software used around the world. The requirements for a Pacific halibut modelling platform are reletively complex compared to many stock assessments and not all features are supported by all exisiting state-space platforms (Table 1). Assessment development in prepartion for the next full stock assessment (2028) will include monitoring of development and testing of each of the platforms currently in mangement use.

Table 1. Generalized state-space stock assessment platforms and existing capabilities for features needed in the Pacific halibut assessment.

Model	Reference	Sex-specific dynamics	Multiple aging error matrices	Environmental covariates to S-R function	Time varying selectivity	Prior distribution for M	Used for assessments informing management
SAM	Nielsen and Berg 2014	No	No	Yes	Yes	Yes	Yes
WHAM	Stock and Miller 2021	No	No	Yes	Yes	No	Yes
FIMS[1]	None	No	No	No	No	Yes	No
SPoRC	Cheng et al. 2026	Yes	No	No	Yes	Yes	No
CEATTLE	Adams et al. 2022	Yes	Yes	Yes	Yes	Yes	Yes

[1] FIMS is the generalized NOAA Fisheries stock assessment platform currently under development and intended to replace stock synthesis at some point in the future (https://noaa-fims.github.io/about/).

Development of the IPHC's stock assesment is highly dependent on the type of management procedure in use by the Commission. Currently, the IPHC Harvest Strategy Policy requires an full stock assessment every three years with an update stock assessment occurring in intervening years. The stock assesment analysis conducted each fall in order to provide annual management information is based on the current year's data and must be stable and simple enough to be completed in less than two weeks. If a management procedure based on modelled survey trends, or a multi-year procedure was to be adopted in the future, it may be unneccesary to conduct annual stock assessments. That type of procedure and timeline could allow for the development of more complex stock assessment ensembles/models (including fully Bayesian analyses), given extended development time between assessments. Therefore, any updates to the current IPHC management procedure, developments in the MSE process, and strategic planning for the stock assessment modelling platform should be considered together: the long-term focus should be on selecting the most efficient tools to meet management needs as they continue to evolve and ensuring that the IPHC relies on appropriate models that can be efficiently applied and reviewed and would remain stable for any future transitions in secretariat staff.

Recommendation 2 – ROC curves

IPHC decision making since 2013 has been informed by a 'Harvest decision table' illustrating the risk-benefit trade-off between fishery yield and a suite of stock and fishery metrics (Table 2). An emerging question after 14 years of this process is "How have the estimated risk probabilities in the table performed?". The only metric that has been maintained through every year of the decision table and the one most frequently evaluated as part of the decision-making process is the probability of stock decline in the next year (row a). Therefore, we focused the receiver-operating characteristic (ROC) performance analysis on that metric.

Table 2. Harvest decision table provided for AM102 to inform mortality limits for 2026-2028. Columns correspond to yield alternatives and rows to risk metrics. Values in the table represent the probability, in “times out of 100” (or percent chance) of a particular risk.

2026 Alternative					***Status quo -10%***	***Status quo -5%***	***Status quo***	***Status quo +5%***	***Status quo +10%***	***$F_{46\%}$***	***3-Year Surplus / $F_{43\%}$***	***MEY proxy***	***Overfishing limit***	
Total mortality (M lb)			**0.0**	**21.9**	**28.6**	**30.1**	**31.6**	**33.1**	**34.6**	**37.0**	**40.8**	**45.1**	**53.7**	
TCEY (M lb)			**0.0**	**20.0**	**26.8**	**28.2**	**29.7**	**31.2**	**32.7**	**35.1**	**39.0**	**43.3**	**51.9**	
2026 fishing intensity			$F_{100\%}$	$F_{62\%}$	$F_{54\%}$	$F_{52\%}$	$F_{51\%}$	$F_{49\%}$	$F_{48\%}$	$F_{46\%}$	$F_{43\%}$	$F_{40\%}$	$F_{35\%}$	
Fishing intensity interval			--	47-77%	39-71%	37-70%	36-69%	34-68%	33-67%	31-65%	28-62%	26-59%	22-54%	
Stock Trend (spawning biomass)	**in 2027**	**is less than 2026**	**<1**	**3**	**10**	**12**	**15**	**18**	**22**	**28**	**40**	**54**	**80**	a
		is 5% less than 2026	**<1**	**<1**	**1**	**1**	**2**	**2**	**3**	**4**	**8**	**14**	**32**	b
	in 2028	**is less than 2026**	**<1**	**2**	**8**	**10**	**13**	**16**	**19**	**26**	**38**	**54**	**82**	c
		is 5% less than 2026	**<1**	**<1**	**2**	**3**	**4**	**5**	**7**	**10**	**17**	**28**	**55**	d
	in 2029	**is less than 2026**	**<1**	**3**	**11**	**14**	**18**	**22**	**27**	**35**	**50**	**68**	**91**	e
		is 5% less than 2026	**<1**	**1**	**5**	**6**	**8**	**11**	**13**	**19**	**30**	**46**	**77**	f
Stock Status (Spawning biomass)	**in 2027**	**is less than 30%**	**24**	**25**	**26**	**26**	**26**	**26**	**26**	**26**	**26**	**26**	**27**	g
		is less than 20%	**<1**	**<1**	**<1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	h
	in 2028	**is less than 30%**	**14**	**22**	**23**	**24**	**24**	**24**	**24**	**25**	**25**	**26**	**27**	i
		is less than 20%	**<1**	**<1**	**<1**	**<1**	**<1**	**1**	**1**	**1**	**1**	**2**	**3**	j
	in 2029	**is less than 30%**	**5**	**17**	**20**	**21**	**22**	**22**	**23**	**23**	**24**	**25**	**27**	k
		is less than 20%	**<1**	**<1**	**<1**	**<1**	**1**	**1**	**1**	**1**	**2**	**3**	**6**	l
Fishery Trend (TCEY)	**in 2027**	**is less than 2026**	**0**	**<1**	**11**	**16**	**20**	**25**	**30**	**37**	**49**	**60**	**75**	m
		is 10% less than 2026	**0**	**<1**	**4**	**9**	**10**	**14**	**18**	**25**	**35**	**47**	**65**	n
	in 2028	**is less than 2026**	**0**	**<1**	**11**	**15**	**20**	**24**	**29**	**37**	**50**	**61**	**78**	o
		is 10% less than 2026	**0**	**<1**	**4**	**10**	**10**	**14**	**18**	**25**	**36**	**49**	**68**	p
	in 2029	**is less than 2026**	**0**	**1**	**11**	**15**	**10**	**25**	**30**	**39**	**53**	**65**	**82**	q
		is 10% less than 2026	**0**	**<1**	**5**	**10**	**11**	**15**	**19**	**26**	**39**	**53**	**73**	r
Fishery Status (Fishing intensity)	**in 2026**	**is above $F_{43\%}$**	**0**	**<1**	**13**	**18**	**23**	**27**	**32**	**39**	**50**	**60**	**73**	s

ROC curves are used in a wide range of fields to determine the performance of testing or detection methods (e.g. Zweig and Campbell 1993). In the context of spawning biomass trends, we are interested in the frequency of accurately projecting a decline in the next year’s spawning biomass (true positive; P_t) vs the frequency of projecting a decline when it does not occur (false positive; P_f). Possible outcomes are illustrated in Table 3.

Table 3. Frequency table of projected and actual estimated trends used to calculate the receiver-operating characteristic curves.

		Spawning biomass projection	
		Declining	Not declining
Actual SB trend	Declining	P_t	N_f
	Not Declining	P_f	N_t

Following the standard approach for ROC calculations, two quantities are needed for comparison: 1) the proportion of years with true positive projections of declining spawning biomass are calculated as:

$$\boldsymbol{Proportion\ true\ postive} = \frac{\boldsymbol{P_t}}{(\boldsymbol{P_t} + \boldsymbol{N_f})}$$

and 2) the proportion of years with false positive projections of declining spawning biomass are calculated as:

$$\boldsymbol{Proportion\ false\ postive} = \frac{\boldsymbol{P_f}}{(\boldsymbol{P_f} + \boldsymbol{N_t})}$$

Since the harvest decision table does not represent a strict “test” but rather reports the estimated probability of spawning biomass decline, we compare incremental values (from 5% to 95%) for the estimated probability of decline as different testing/detection methods. Further, we differentiate among actual spawning biomass declines (any decline, >1% decline, >2% decline, >3% decline). Interpretation of ROC curves is based on the area-under-the-curve (AUC), integrating over the proportion of true positive outcomes on the y-axis and the proportion of false positive outcomes on the x-axis. The relative importance of detection of true positive outcome and false negative outcomes is a value judgement that depends on the application. However, a value of 0.5 represents a random outcome and a value of 1.0 a perfect test.

We use the estimated time-series of spawning biomass from the 2025 stock assessment as the ‘true’ trend and compare that to the projected probability of decline reported in the decision tables created in each year from 2013 through 2025 (both the decision making and the spawning biomass estimate occur at the beginning of the year; Table 4).

Table 4. Current estimated spawning biomass (SB) time-series compared to probability of decline estimated at the time for each year from 2013-2026.

Year	Current estimated SB (Mlb)	Percent change to next year	Estimated probability of decline at the time
2013	216.5	1.8%	84%
2014	220.4	3.0%	67%
2015	227.1	1.9%	30%
2016	231.4	-1.3%	29%
2017	228.3	-6.0%	71%
2018	214.7	-5.8%	93%
2019	202.2	-9.6%	84%
2020	182.9	-7.4%	95%
2021	169.4	-6.0%	65%
2022	159.2	-2.9%	59%
2023	154.7	-1.0%	38%
2024	153.2	1.3%	40%
2025	155.1	7.0%	25%
2026	166.0	NA	14%

The Pacific halibut spawning biomass is estimated to have increased over 2013-2016, declined over 2017-2024 and then increased to 2026. The annual decision table generally favored a higher probability for stock decline when that was the subsequent outcome (2017-2022) but sometimes estimated a relatively high probability when the stock did not decline (2013-2014). All annual spawning biomass changes have been less than 10%, with about half (6/13) greater than 5%.

Based on estimated ROC curves, the harvest decision table is generally a reliable tool to project spawning biomass trends with skill well above random for all 4 levels of decline evaluated (Figure 1). At a 50% estimated probability of any decline, the true positive frequency is 0.75 and the false positive frequency is 0.4 (Figure 1; red point). For a decline greater than 1%, the true positive frequency goes up to 0.86 and the false positive frequency goes down to 0.33 (Figure 1; green point). For a decline greater than 2%, the true positive frequency goes up again to 1.00 (all declines of this magnitude were projected with at least 50% probability) and the false positive frequency goes down to 0.29 (Figure 1; blue point). For a decline greater than 3%, the true positive frequency remains at 1.00 but the false positive frequency goes up slightly to 0.38 (Figure 1; purple point). If an estimated probability threshold of at least 60% is used, the true positive frequency remains at 1.00 and the false positive frequency goes down to 0.25 (Figure 1; open purple point); this represents the best performance of any threshold evaluated. In simple terms, if at least a 3% decline in spawning biomass is considered important, a high probability of stock decline (> 50/100) estimated in the harvest decision table has correctly identified this in all years it has occurred.

While it would be helpful to have a larger sample size for this type of analysis, the stock assessment models themselves are changing over time such that even comparisons made across the existing time series may not accurately reflect the performance of future stock assessments and harvest decision tables.

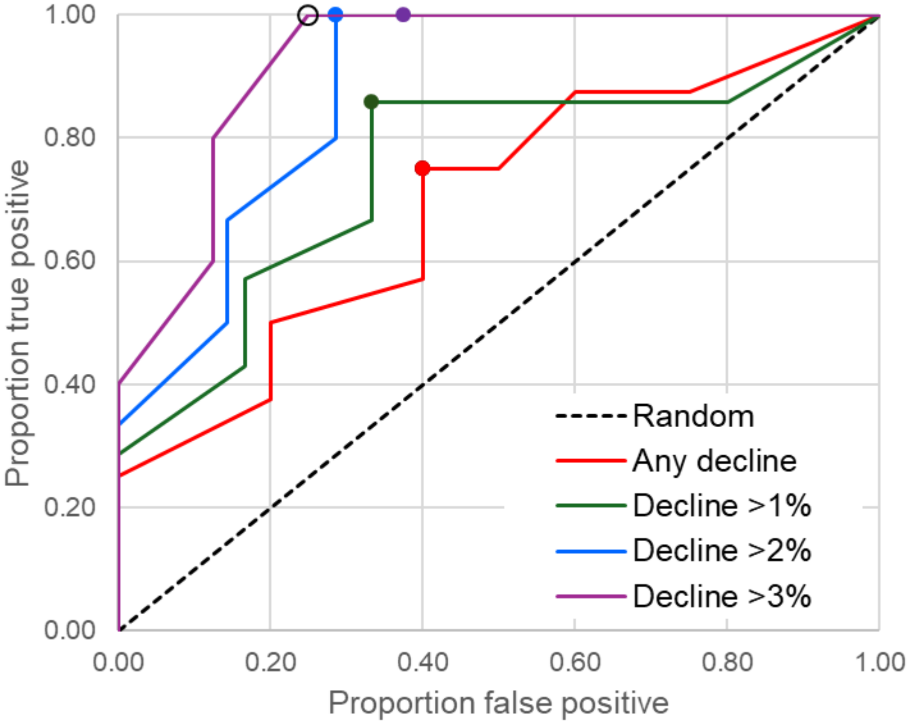


Figure 1. ROC curves for different levels of spawning biomass decline (colors) and different estimated probability of decline cutoffs (points defining each line). Solid circles represent an estimated probability of decline for each curve of 50%. Open circle indicates the best performing cutoff for declines of >3% decline (highest true positive rate and lowest false positive rate; probability of decline of 60%).

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2026-SRB028-07 which provides a response to requests from SRB026 and SRB027, and an update on model development for 2026.

b) **REQUEST** any analyses to support the final 2026 stock assessment.

c) **REQUEST** any analyses to be provided at future SRB meetings as part of the longer-term stock assessment development.

REFERENCES

Adams, G.D., Holsman, K.K., Barbeaux, S.J., Dorn, M.W., Ianelli, J.N., Spies, I., Stewart, I.J., and Punt, A.E. 2022. An ensemble approach to understand predation mortality for groundfish in the Gulf of Alaska. Fisheries Research **251**. doi:10.1016/j.fishres.2022.106303.

Cheng, M.L.H., Goethel, D.R., Cunningham, C.J., Hulson, P.J.F., Ianelli, J.N., and Omori, K.L. 2026. The SPoRC Stock Assessment Package: A Generalized Next-Generation Platform to Assess Spatial, Age and Sex-Structured Populations. Fish and Fisheries. doi:10.1111/faf.70082.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., and Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software **27**(2): 233–249.

Hulson, P.-J.F., and Williams, B.C. 2024. Inclusion of ageing error and growth variability using a bootstrap estimation of age composition and conditional age-at-length input sample size for fisheries stock assessment models. Fisheries Research **270**. doi:10.1016/j.fishres.2023.106894.

IPHC. 2025a. Report of the 26th session of the IPHC Scientific Review Board (SRB). Meeting held in Seattle, WA, USA, 10-12 June 2025. IPHC-2025-SRB026-R. 17 p.

IPHC. 2025b. Report of the 27th session of the IPHC Scientific Review Board (SRB027). IPHC-2025-SRB027-R. 18 p.

IPHC. 2026. Report of the 102nd session of the IPHC annual meeting (AM102). Bellevue, WA, USA 19-22 January 2026. IPHC-2026-AM102-R. 54 p.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B.M. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software **70**(5). doi:10.18637/jss.v070.i05.

Methot Jr, R.D. 2024. Stock Synthesis User Manual Version 3.30.23.1. NOAA Fisheries. Seattle, WA. December 5, 2024. 272 p.

Methot Jr, R.D., Wetzel, C.R., Taylor, I.G., and Doering, K. 2026. Stock synthesis user manual version 3.30.24.2. NOAA Fisheries. Seattle, WA. 264 p.

Nielsen, A., and Berg, C.W. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries Research **158**: 96–101. doi:10.1016/j.fishres.2014.01.014.

Nielsen, A., Hintzen, N.T., Mosegaard, H., Trijoulet, V., Berg, C.W., and Subbey, S. 2021. Multi-fleet state-space assessment model strengthens confidence in single-fleet SAM and provides fleet-specific forecast options. ICES Journal of Marine Science **78**(6): 2043–2052. doi:10.1093/icesjms/fsab078.

Stewart, I., and Hicks, A. 2024. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2023. IPHC-2024-SA-01. 37 p.

Stewart, I., and Hicks, A. 2025. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2024. IPHC-2025-SA-01. 40 p.

Stewart, I., and Webster, R. 2026. Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses. IPHC-2026-SA-02. 59 p.

Stewart, I., and Hicks, A. 2026a. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2025. IPHC-2026-SA-01. 38 p.

Stewart, I., and Hicks, A. 2026b. Stock projections and the harvest decision table for 2026-2028. IPHC-2026-AM102-12. 6 p.

Stewart, I., Hicks, A., Webster, R., and Wilson, D. 2026. Data overview and stock assessment for Pacific halibut (*Hippoglossus stenolepis*) at the end of 2025. IPHC-2026-AM102-10. 17 p.

Stock, B.C., and Miller, T.J. 2021. The Woods Hole Assessment Model (WHAM): A general state-space assessment framework that incorporates time- and age-varying processes via random effects and links to environmental covariates. Fisheries Research **240**. doi:10.1016/j.fishres.2021.105967.

Zweig, M.H., and Campbell, G. 1993. Receiver-operating characteristic (ROC) plots: a fundamental tool in clinical medicine. Clinical Chemistry **39**(4): 561–577.

An update of the IPHC Secretariat MSE Program of Work

Prepared by: IPHC Secretariat (A. Hicks, I. Stewart; 16 April & 5 May 2026)

PURPOSE

To provide the Scientific Review Board (SRB) with the MSE Program of Work for 2026–2027 and an overview of work done since the 27th Session of the Scientific Review Board (SRB027) using the IPHC Management Strategy Evaluation (MSE) framework.

UPDATES IN REV_1 (5 MAY 2026)

Additional work conditioning the operating model (OM) was completed after the first posting of this document. This revised document updates Section 2.1.1 with a final conditioned OM representing historical uncertainty determined from 1000 simulated trajectories for each individual model.

1 INTRODUCTION

The SRB made a number of recommendations at SRB027 (IPHC-2025-SRB027-R) for investigation with the MSE framework for Pacific halibut (*Hippoglossus stenolepis*), of which many were related to updating the draft IPHC Harvest Strategy Policy (HSP). After incorporating those recommendations, the IPHC HSP was adopted by the Commission in December 2025. Other tasks are better done after the MSE Operating Model is conditioned following the full 2025 stock assessment. The conditioning of the operating model is part of the 2026–2027 Program of Work and began in early 2026 using the 2025 full stock assessment to reflect new understanding of the Pacific halibut population and fishery dynamics. This document presents the MSE Program of Work for 2026–2027 along with currently available results.

2 MSE PROGRAM OF WORK FOR 2026–2027

The IPHC HSP defines a 3-year timeline for the MSE process. The Operating Model (OM) is updated every third year, following the full stock assessment. After updating the OM, management procedures (MPs) are re-evaluated to ensure that they continue to meet the objectives of the Commission. Other tasks, pending the updated OM, are also described below.

The Commission noted prioritised topics for the 2026–2027 MSE Program or Work at the 102nd Session of the IPHC Annual Meeting (AM102).

> **IPHC-2026-AM102-R, para. 56**. *The Commission NOTED that the 2026 MSE and HSP Program of Work will include the following high priority topics:*
>
> *a) Update and recondition the MSE Operating Model in accordance with the schedule defined in the Harvest Strategy Policy;*
>
> *b) Evaluate a range of SPR values to determine if the optimal reference coastwide fishing intensity is different than the current reference fishing intensity (F43%) defined in the HSP;*

c) *Investigate productivity regimes to determine how the Pacific halibut population and fisheries respond to different productivity regimes, if the optimal reference fishing intensity differs across productivity regimes, and how productivity regimes may be incorporated into a Management Procedure;*

d) *Further develop the Depleted concept and identify a limit reference point below which recovery of the Pacific halibut population would be uncertain.*

IPHC-2026-AM102-R, para. 57. *The Commission NOTED that the 2026 MSE and HSP Program of Work will include the following low priority topics, which may not be completed before AM103:*

a) *Improve the estimation model used in the MSE framework to better characterize the stock assessment in the simulations;*
b) *Evaluate potential management actions to invoke when approaching a depleted limit reference point;*
c) *Evaluate additional elements of Management Procedures which may include a triennial assessment frequency, constraints and smoothers on the interannual change in the TCEY, and empirical rules to determine the reference TCEY in years without a stock assessment;*
d) *Determine reference points using the updated MSE Operating Model (e.g. FMSY and MSY);*
e) *Develop guidance documents for the Harvest Strategy Policy (e.g. specifications of a rebuilding plan).*

IPHC-2026-AM102-R, para. 58. *The Commission NOTED that the 2026 MSE and HSP Program of Work should not include topics related to the distribution of the TCEY, as this is part of the decision-making process and not part of the management procedure, as described in the Harvest Strategy Policy.*

IPHC-2026-AM102-R, para. 59. *The Commission NOTED that outcomes of the 2026 MSE workplan (e.g. an optimal fishing intensity) may be used to update the Harvest Strategy Policy in the future.*

2.1 High priority tasks

The Commission identified four high priority tasks for the MSE Program of Work, which are either defined by the HSP or essential to ensuring that the HSP reflects the current knowledge of the Pacific halibut stock and fisheries.

2.1.1 Condition the MSE Operating Model

Immediately following a full stock assessment, which occurs every three years, the MSE operating model is conditioned using updated data streams, newly estimated parameters from the stock assessment, and an improved understanding of processes driving Pacific halibut population dynamics and fisheries. This is also an opportunity to implement improved and updated OM code incorporating current best practices. Once the OM is conditioned, the process does not need to be repeated until after the next full stock assessment, or an exceptional circumstance occurs (see Section 3.8 of the IPHC HSP). However, after each update stock assessment, mortality, weight-at-age, and other data or inputs may be updated to reflect recent realizations (steps 3–6).

The conditioning process is time-consuming and involves the following workflow.

1. Outcomes of each individual model of the 2025 ensemble stock assessment are summarized.
2. Parameters and assumptions in each individual model of the OM are linked to each individual model of the 2025 ensemble stock assessment and updated to match those in the stock assessment.
3. Mortality and weight-at-age for each fishery is extended to the most recent year.
4. Weight-at-age for the survey and population is updated and extended to the most recent year.
5. The Pacific Decadal Oscillation (PDO) is updated to the most recent year (and revised for this development cycle based on the new series used in the 2025 stock assessment).
6. An optimized OM executable is compiled and a directory structure for each individual model is created.
7. Parameters for each individual model (e.g. movement, recruitment distribution, average recruitment, initial fishing mortality) are estimated based on fits to regional stock distribution, regional indices of abundance, age compositions, and the estimated spawning biomass from the linked individual stock assessment model.
8. Individual historical trajectories are created for each individual model of the OM using estimated uncertainty and correlations between parameters.
9. Inputs and outputs for each individual trajectory is saved to the appropriate directory and a reduced set of necessary inputs is saved to GitHub for distribution among computers and for record keeping.

2.1.1.1 Conditioning the Operating Model

The four individual models of the OM (OM1_longAAF, OM2_shortAAF, OM3_longCW, and OM4_shortCW) were conditioned through all steps above. The conditioning process balanced the fits to the four sources of information (stock distribution, regional indices of abundance, age compositions, and the estimated spawning biomass from the stock assessment) in an ad hoc manner by determining the best parameter values when fitting to each source alone, and then adjusting weights of the likelihood component for each source such that no one source showed a severe lack of fit. Stock distribution and recent years of estimated spawning biomass were given the highest priority for good fits. The age compositions were given a low weight due to the number of observations potentially overwhelming the likelihood and less importance for evaluating coastwide management procedures (MPs).

Each model starts in 1958, even those based on the short assessment models, with estimated recruitment deviations from the long assessment models and an average fishing mortality informing the initial population. The population trajectory was then derived through 2025 based on the parameter set. Estimated parameters included the proportion of recruitment in each region for low and high PDO regimes, a scalar for the initial average fishing mortality, and movement parameters from Region 4 to 3 and 3 to 2 for low and high PDO regimes. Movement between other adjacent regions was fixed at empirical rates determined from historical data and it was assumed that movement did not occur between non-adjacent regions in an annual time-step (see the MSE Technical document).

The individual models of the OM are shown in each section below. These include uncertainty for each model.

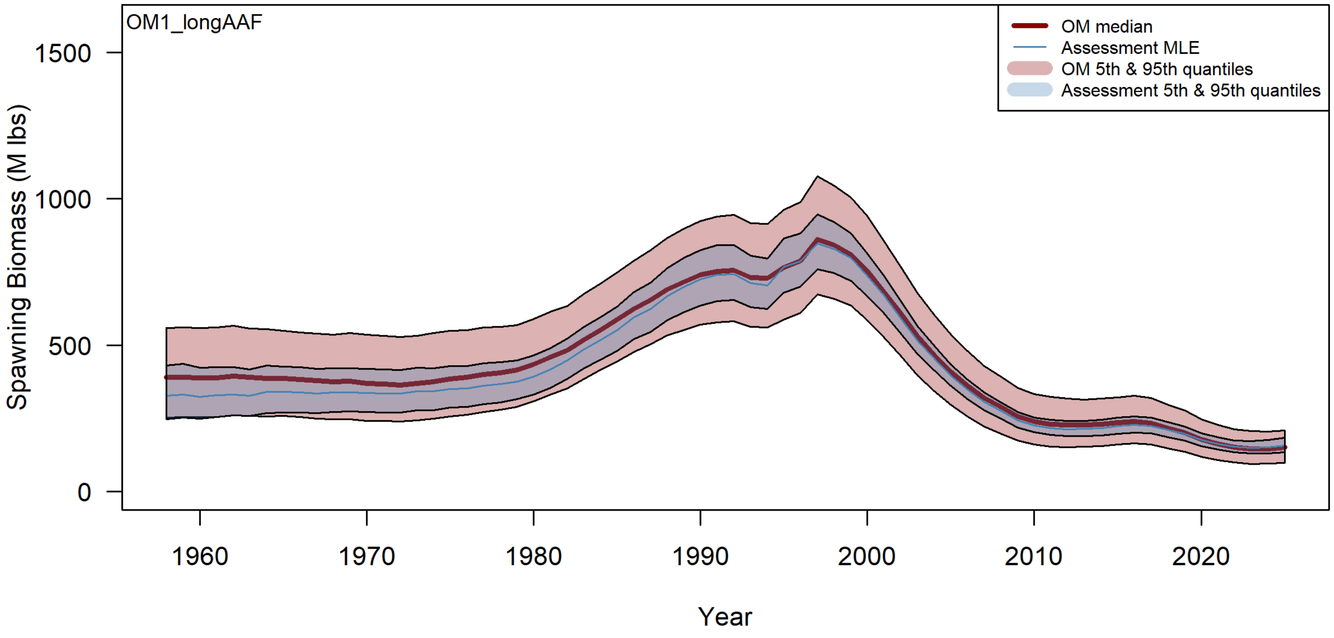
OM1_longAAF

OM1_longAAF is based on the parameters and estimated spawning biomass of the long areas-as-fleets (AAF) stock assessment model. This included natural mortality rates for age 3+ female and male Pacific halibut equal to 0.181 and 0.164, respectively.

The OM1_longAAF model closely matched the spawning biomass for the long AAF assessment model (Figure 1). The distribution of 'all sizes' (those selected by the FISS) biomass was also fit well except for Region 3 in recent years (Figure 2). This overprediction in Region 3 was a result of a slight underfitting in all other Regions. The FISS index fit reasonably well although showed departures in the 1990s in Regions 2, 4, and 4B (Figure 3). The index was closely matched in recent years for all Regions.

A large proportion of the recruitment was distributed to Region 4 and was higher when the PDO was in a positive regime (Figure 3). Approximately 70% of the age-0 fish settled in Region 4 in low PDO regimes and nearly 80% in high PDO years. A very small proportion was distributed to Region 4B.

Movement was only estimated from Region 4 to Region 3 and from Region 3 to Region 2 (Figure 3). Movement probabilities were similar across PDO regimes for Region 4 to 3, but was shifted to younger ages in the high PDO regime. Fewer Pacific halibut moved from Region 3 to 2 in the high PDO regime. A very small proportion of Pacific halibut 6 years and older moved from either of these regions.



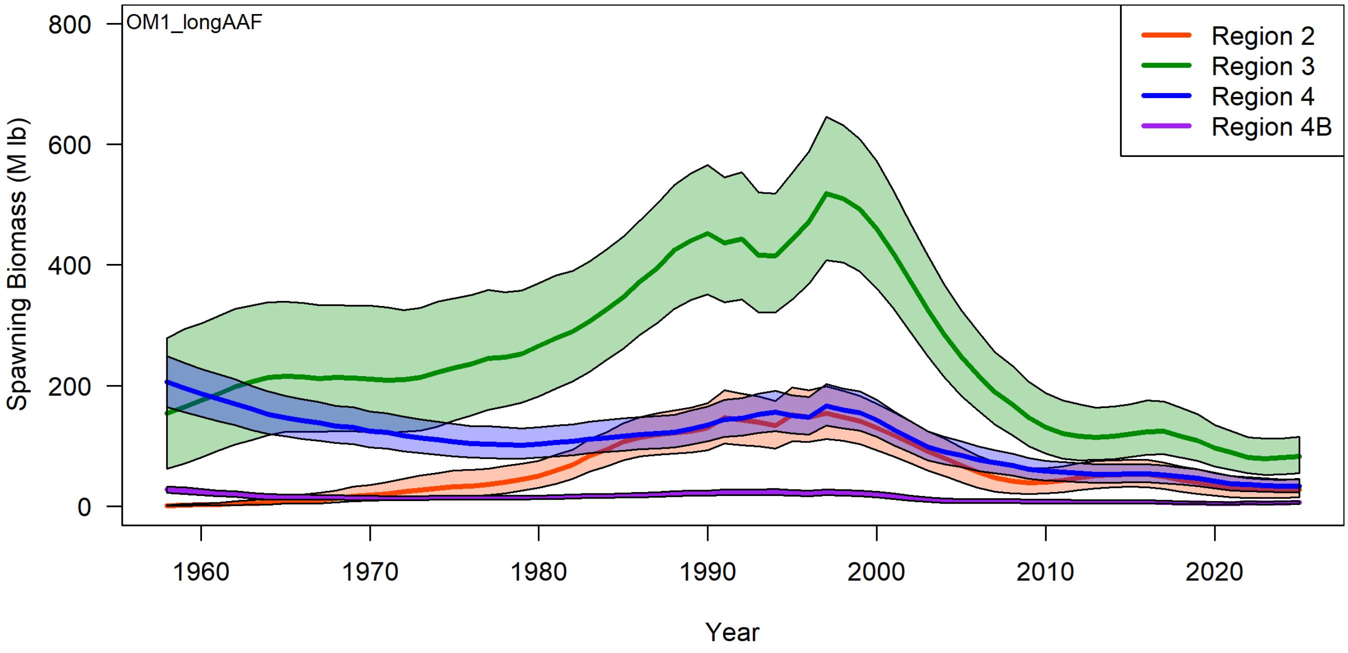


Figure 1. The spawning biomass from the OM1_longAAF model compared to the estimated spawning biomass from the long AAF assessment model (top). The bottom plot shows the spawning biomass in each Region from the OM1_longAAF model.

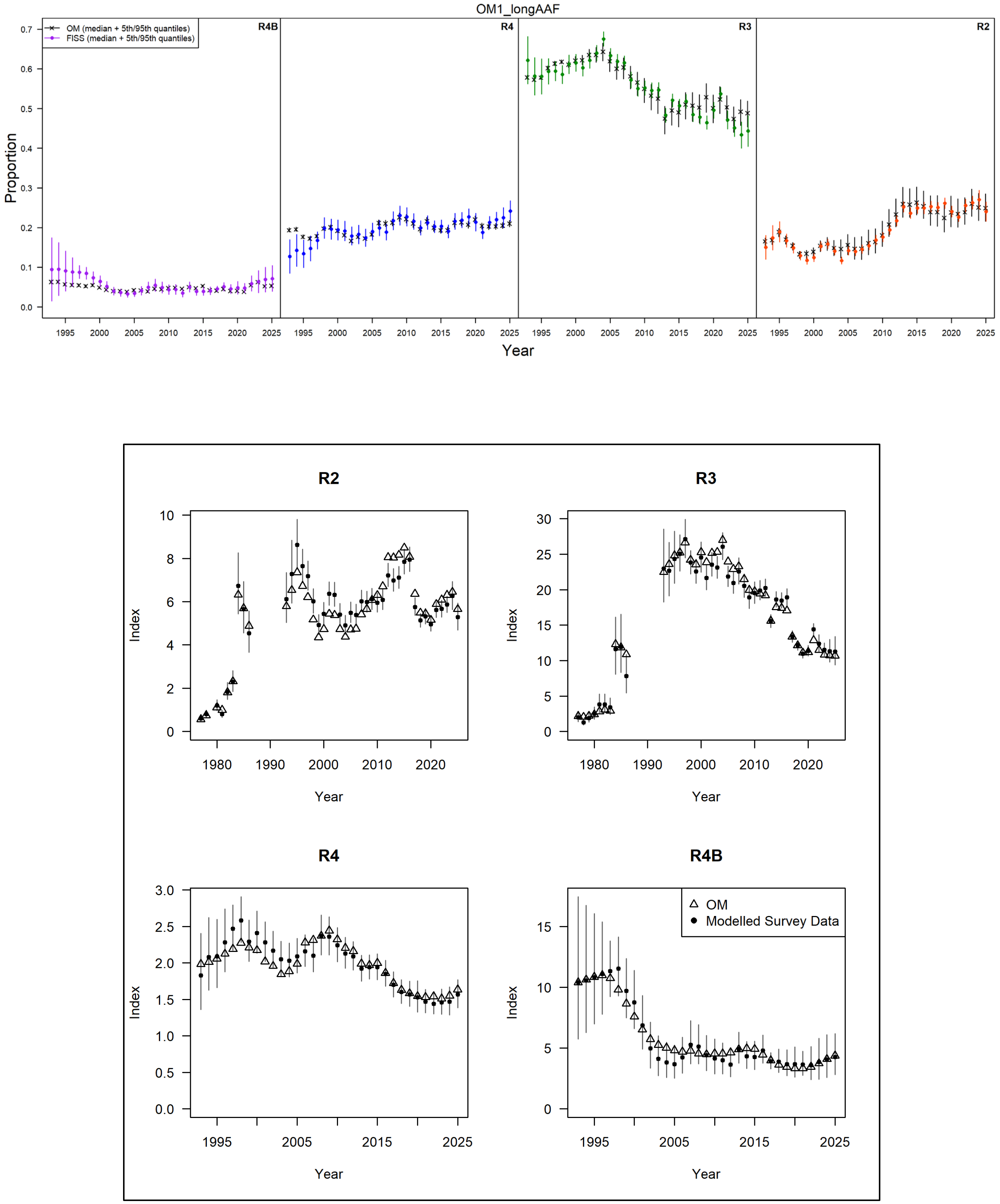


Figure 2. The top plots show the proportion of all sizes biomass in each Region from the OM1_longAAF model (triangles) and the FISS modelled output with 95% credible intervals (circles). The bottom plots show the predicted index from the OM1_longAAF model (triangles) and the FISS index (circles).

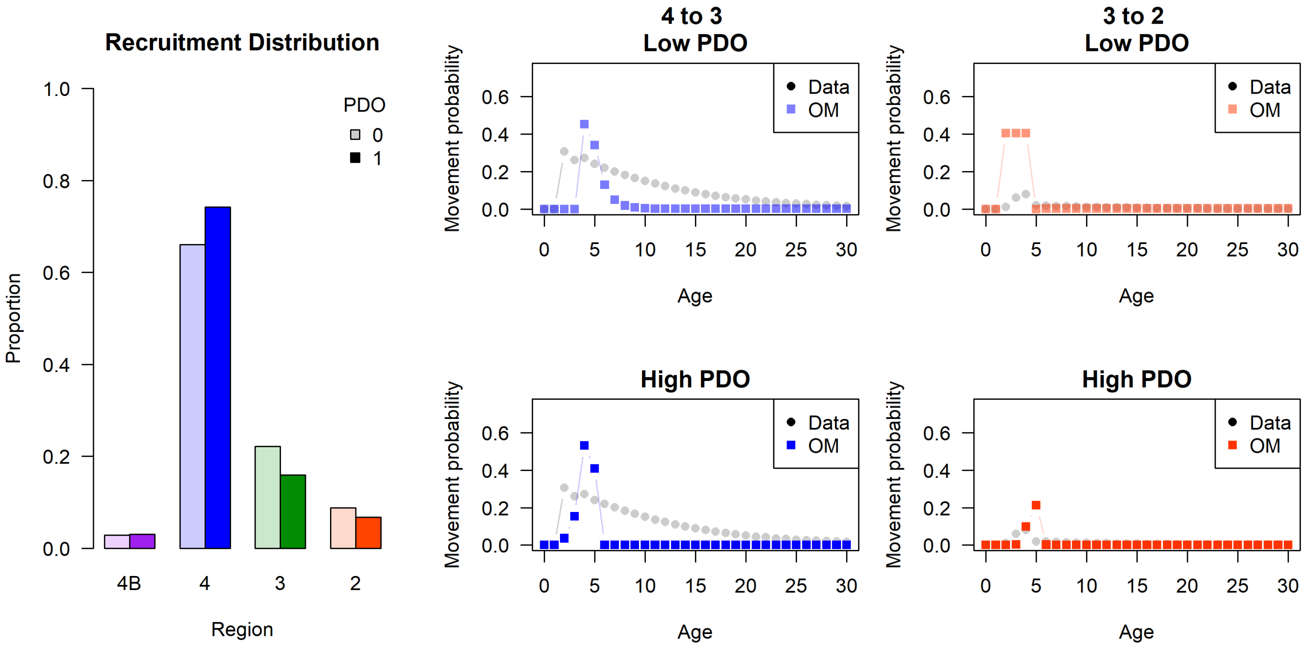


Figure 3. Distribution (proportion) of coastwide recruitment to each Region (leftmost plot) estimated in the OM1_longAAF model. The proportion of numbers of Pacific halibut estimated in OM1_longAAF that move from Region 4 to 3 (center) and from Region 3 to 2 (right) for low PDO regimes (top) and high PDO regimes (bottom). Light grey dots are movement probabilities inferred from empirical observations.

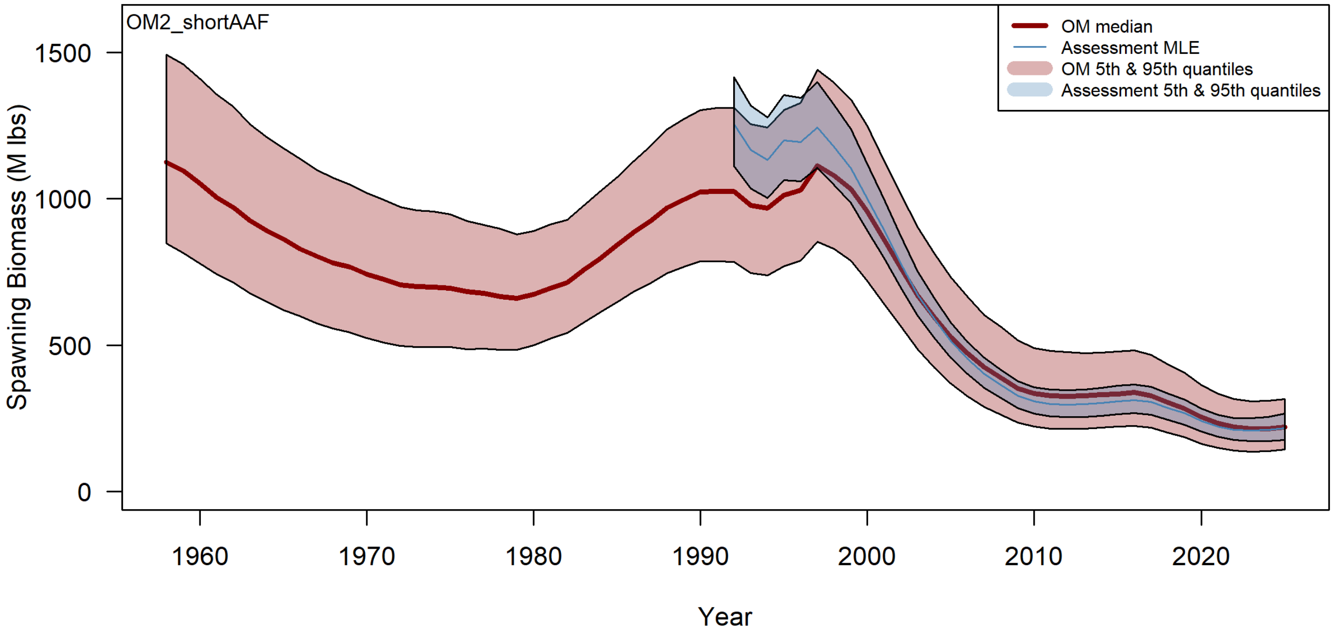
OM2_shortAAF

OM2_shortAAF is based on the parameters and estimated spawning biomass of the short AAF stock assessment model. This included natural mortality rates for age 3+ female and male Pacific halibut equal to 0.214 and 0.180, respectively.

The OM2_short AAF model closely matched the spawning biomass for the short AAF assessment model, except for the beginning of the assessment time-series, which is not well estimated in the stock assessment (Figure 4). The distribution of ‘all sizes’ biomass was also fit well except for Regions 3, 4, and 4B in recent years (Figure 5). The overprediction in Region 3 was a result of a slight underfitting in all other Regions. The FISS index fit reasonably well although showed departures in the 1990s in Regions 2, 4, and 4B (Figure 5). The index was closely matched in recent years for Regions 3 and 4B.

A large proportion of the recruitment was distributed to Region 4 and was higher when the PDO was in a positive regime (Figure 6). Approximately 85% of the age-0 fish settled in Region 4 in low PDO regimes and over 95% in high PDO years. A very small proportion was distributed to Region 4B.

Movement was only estimated from Region 4 to Region 3 and from Region 3 to Region 2 (Figure 6). Movement probabilities were similar across PDO regimes for Region 4 to 3, but peaked slightly higher in the high PDO regime. A smaller proportion of Pacific halibut moved from Region 3 to 2 in the high PDO regime when compared to the low PDO regime. A very small proportion of Pacific halibut 8 years and older moved from either of these regions.



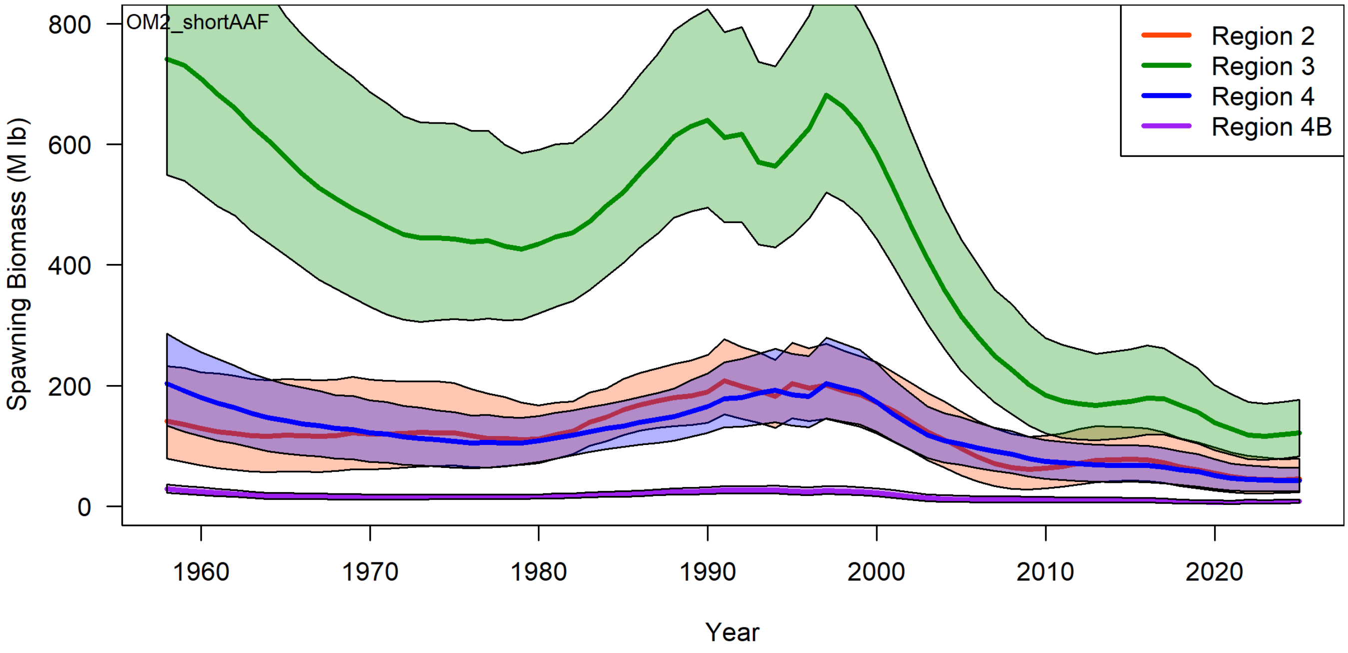
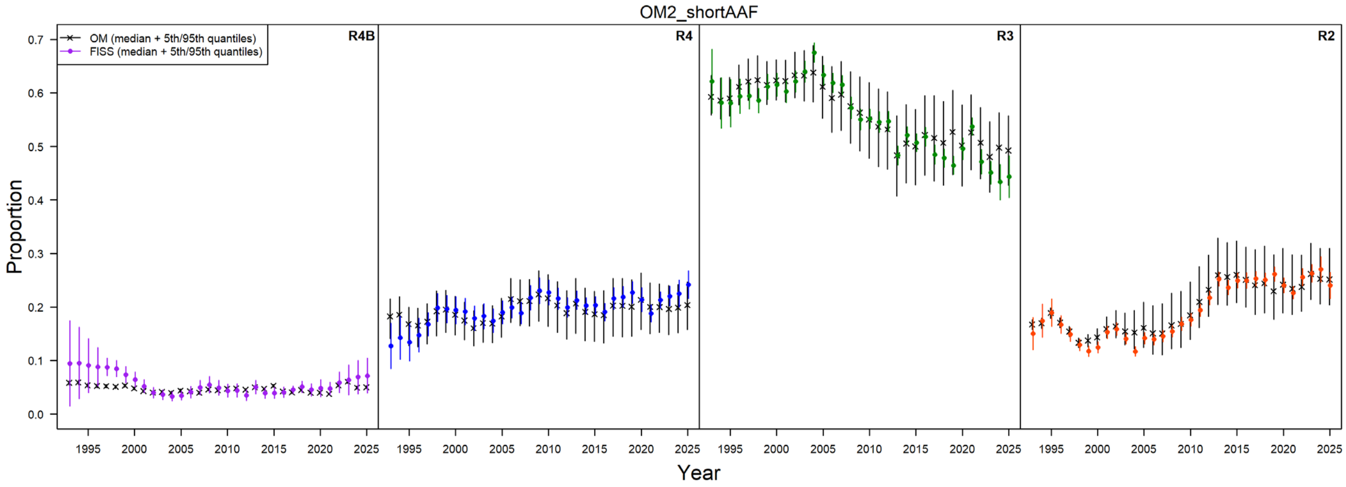


Figure 4. The spawning biomass from the OM2_shortAAF model compared to the estimated spawning biomass from the long AAF assessment model (top). The bottom plot shows the spawning biomass in each Region from the OM2_shortAAF model.



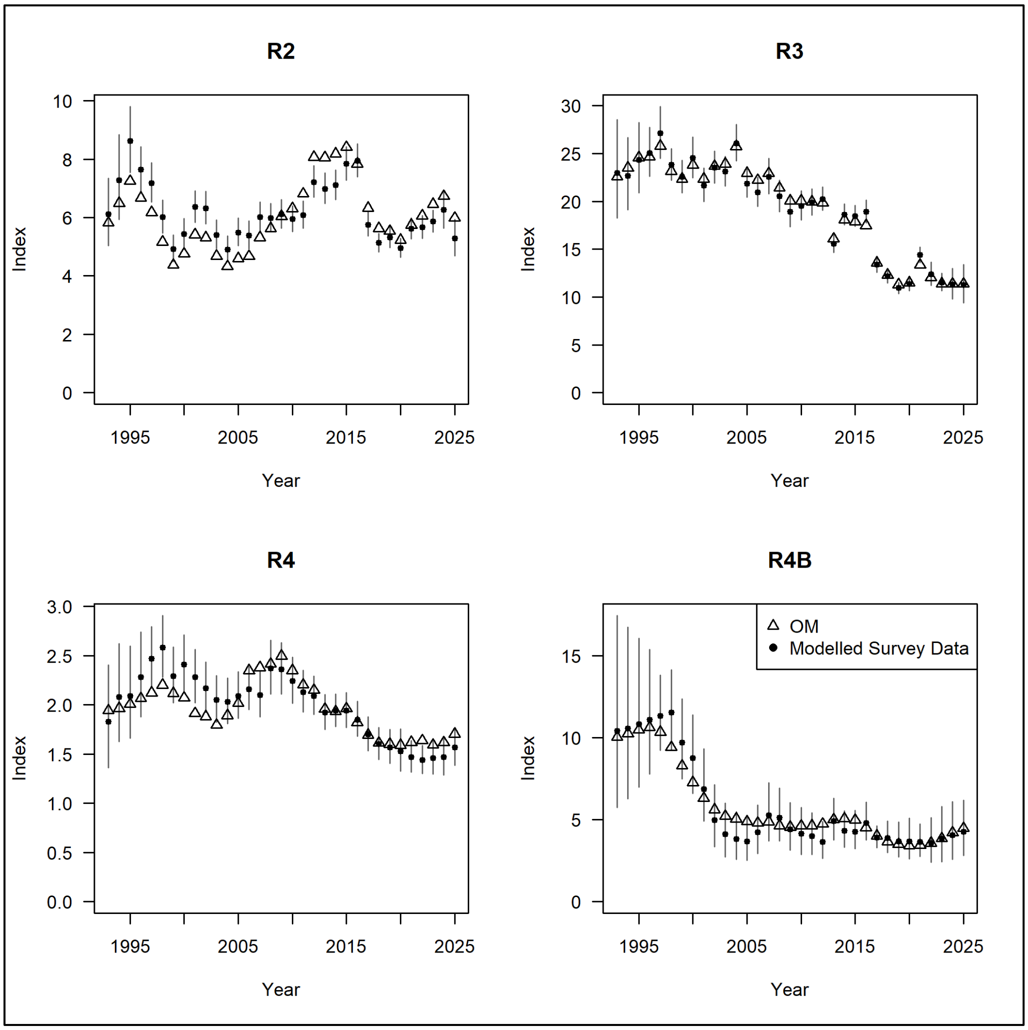


Figure 5. The top plots show the proportion of all sizes biomass in each Region from the OM2_shortAAF model (triangles) and the FISS modelled output with 95% credible intervals (circles). The bottom plots show the predicted index from the OM2_shortAAF model (triangles) and the FISS index (circles).

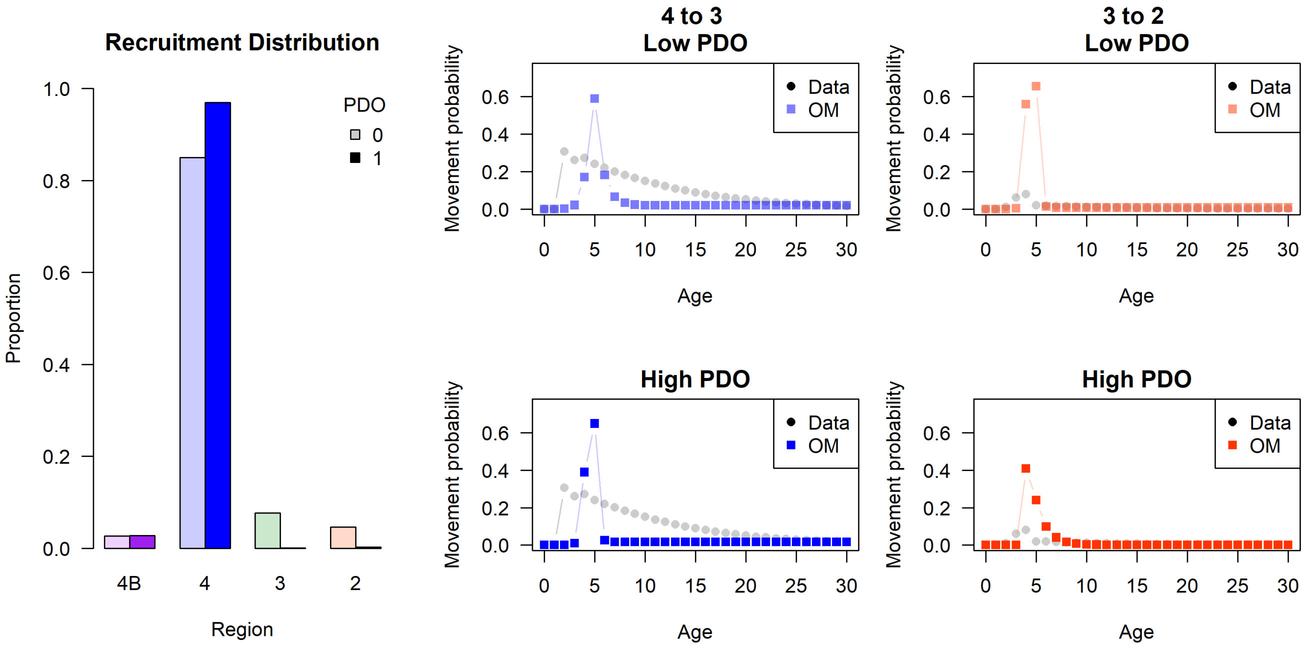


Figure 6. Distribution (proportion) of coastwide recruitment to each Region (leftmost plot) estimated in the OM2_shortAAF model. The proportion of numbers of Pacific halibut estimated in OM2_shortAAF that move from Region 4 to 3 (center) and from Region 3 to 2 (right) for low PDO regimes (top) and high PDO regimes (bottom). Light grey dots are movement probabilities inferred from empirical observations.

OM3_longCW

OM3_longCW is based on the parameters and estimated spawning biomass of the long coastwide stock assessment model. This included natural mortality rates for age 3+ female and male Pacific halibut equal to 0.229 and 0.199, respectively.

The OM3_longCW model closely matched the spawning biomass for the long coastwide assessment model (Figure 7) with a slight departure at the beginning of the series. The distribution of 'all sizes' biomass was also fit well except for Region 3 in recent years (Figure 8). The overprediction in Region 3 was a result of a slight underfitting in all other Regions. The FISS index fit reasonably well although showed departures in the 1990s in Regions 2, 4, and 4B (Figure 8). The index was closely matched in recent years for all Regions.

A large proportion of the recruitment was distributed to Region 4 and was higher when the PDO was in a positive regime (Figure 9). Slightly less than 80% of the age-0 fish settled in Region 4 in low PDO regimes and just over 80% in high PDO years. Very small proportions of recruitment were distributed to Regions 2 and 4B, except that a larger proportion was in Region 2 in low PDO years.

Movement was only estimated from Region 4 to Region 3 and from Region 3 to Region 2 (Figure 9). Movement probabilities were similar across PDO regimes for Region 4 to 3 with a broader range of ages moving in low PDO regimes. Higher movement across ages 2-4 was seen in from Region 3 to 2 in low PDO years. A very small proportion of Pacific halibut 6 years and older moved from either of these regions, except that from 4 to 3 in the low PDO higher movement rates were observed for Pacific halibut up to 9 years old.

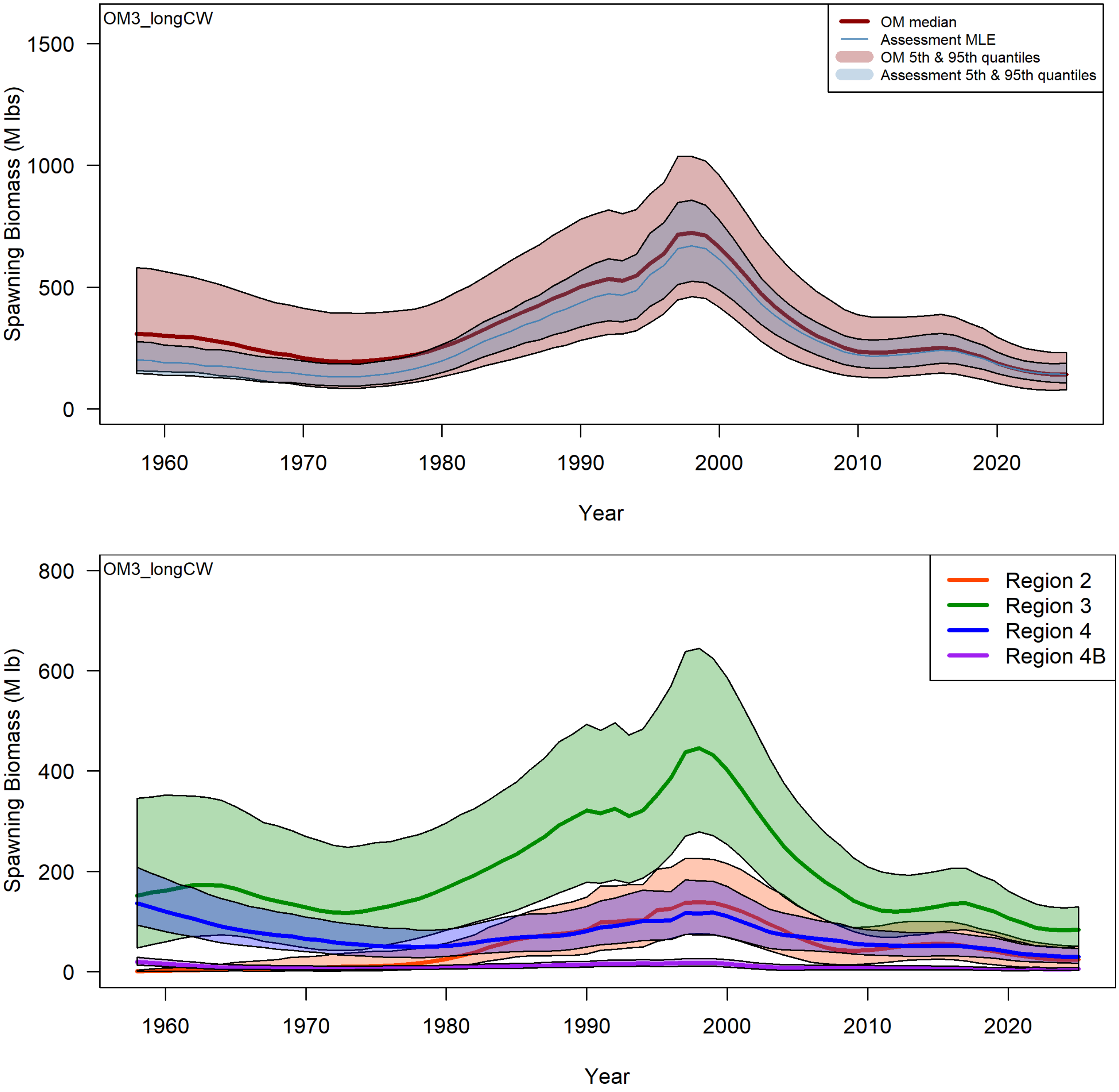


Figure 7. The spawning biomass from the OM3_longCW model compared to the estimated spawning biomass from the long AAF assessment model (top). The bottom plot shows the spawning biomass in each Region from the OM3_longCW model.

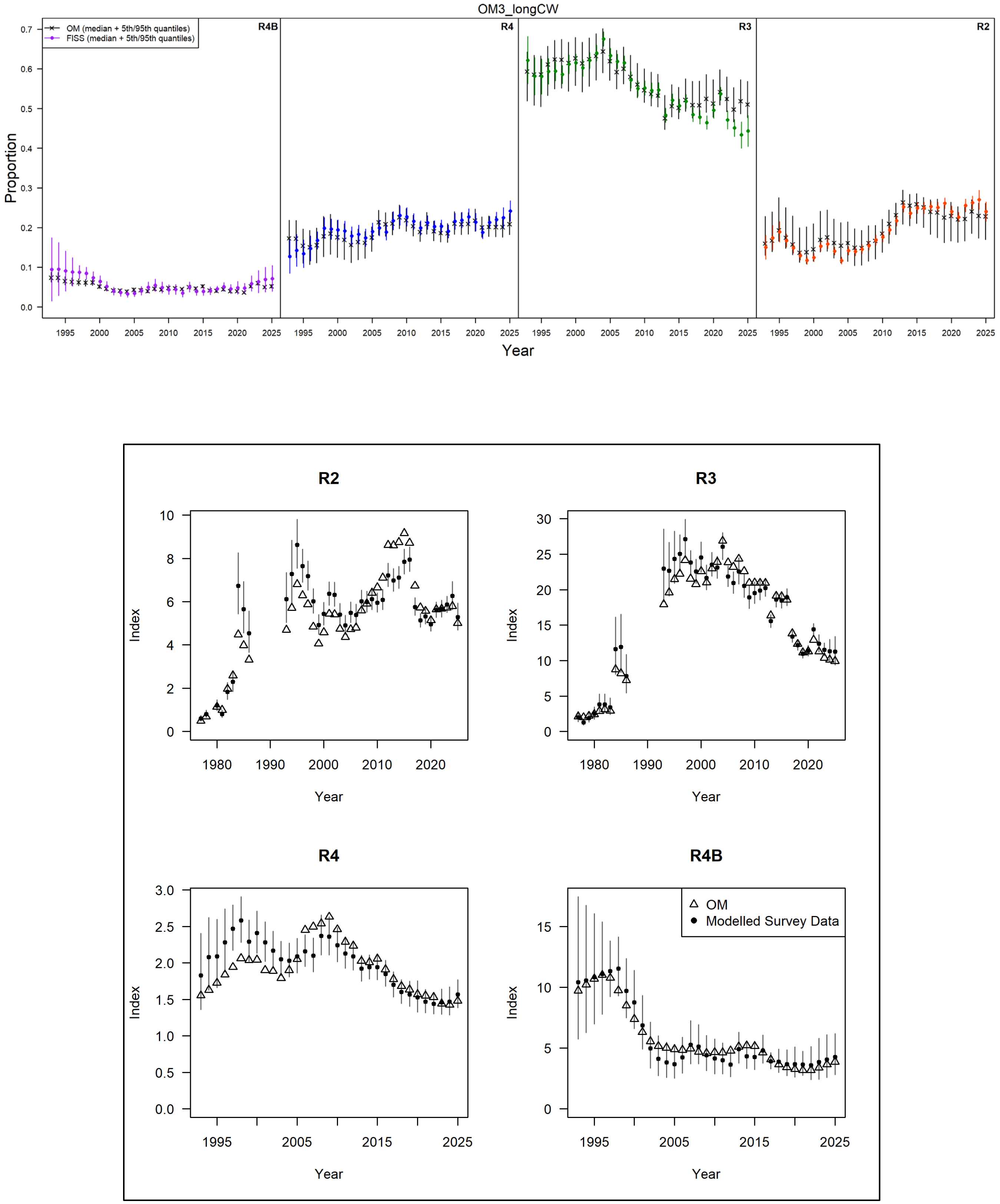


Figure 8. The top plots show the proportion of all sizes biomass in each Region from the OM3_longCW model (triangles) and the FISS modelled output with 95% credible intervals (circles). The bottom plots show the predicted index from the OM3_longCW model (triangles) and the FISS index (circles).

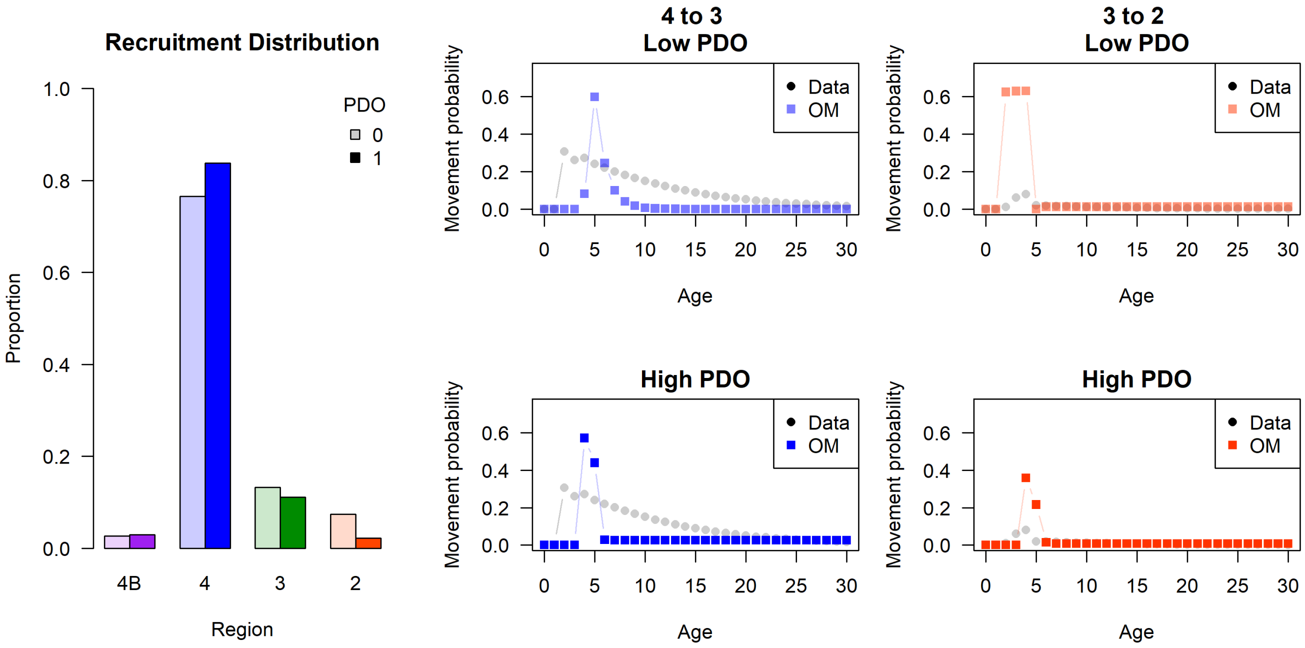


Figure 9. Distribution (proportion) of coastwide recruitment to each Region (leftmost plot). The proportion of numbers of Pacific halibut estimated in OM3_longCW that move from Region 4 to Region 3 (center) and from Region 3 to Region 2 (right) for low PDO regimes (top) and high PDO regimes (bottom). Light grey dots are movement probabilities inferred from empirical observations.

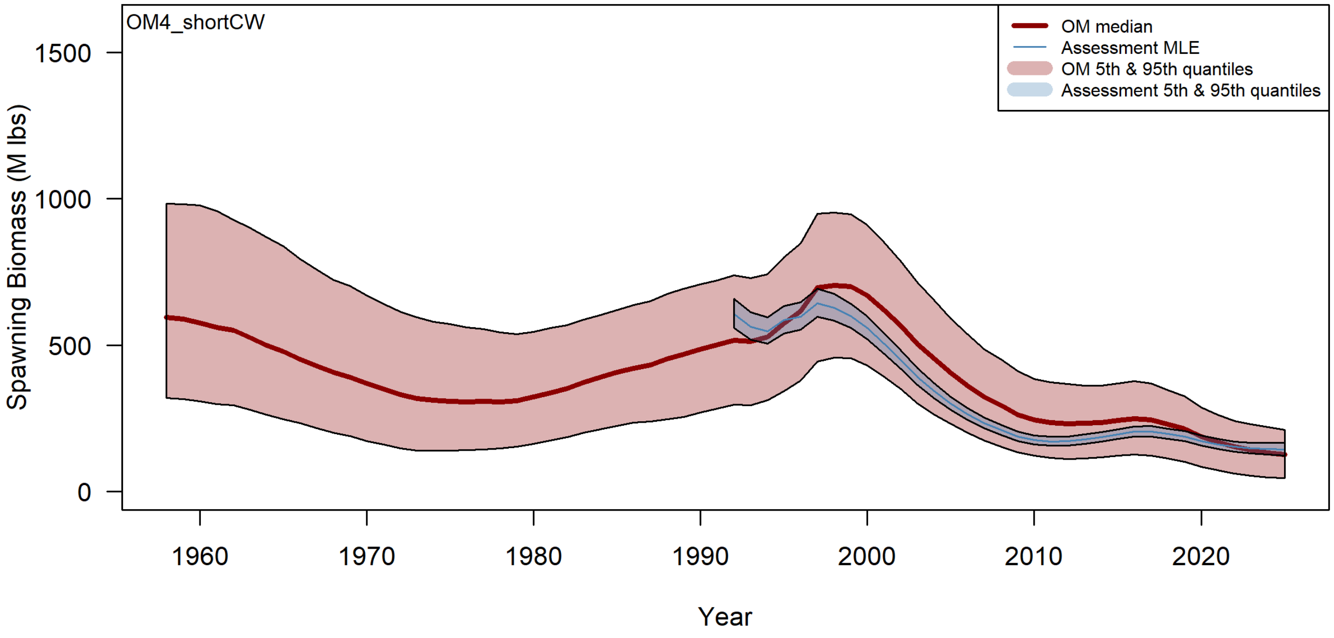
OM4_shortCW

OM4_shortCW is based on the parameters and estimated spawning biomass of the short coastwide stock assessment model. This included natural mortality rates for age 3+ female and male Pacific halibut equal to 0.150 and 0.163, respectively.

The OM4_shortCW model spawning biomass was similar to the short coastwide assessment model spawning biomass, but showed overfitting in the 1990s and a downward trend in recent years (Figure 10). The distribution of ‘all sizes’ biomass was also fit well except for Region 3 in recent years (Figure 11). The overprediction in Region 3 was a result of slight underfitting in all other Regions. The FISS index fit was not as good as other models and showed departures throughout the time-series in all regions (Figure 11). Overall, the OM4_shortCW model was unable to fit the data as well as the other models.

Similar proportions of recruitment were distributed to Regions 4 and 3, but was slightly higher in Region 4 (and thus lower in Region 3) (Figure 12). Very small proportions were distributed to Regions 2 and 4B.

Movement was only estimated from Region 4 to Region 3 and from Region 3 to Region 2 (Figure 12). Movement probabilities were similar across PDO regimes for Region 4 to 3, but peaked slightly higher in high PDO regimes. Fewer Pacific halibut moved from Region 3 to 2 in the high PDO regime. A very small proportion of Pacific halibut 6 years and older moved from either of these regions.



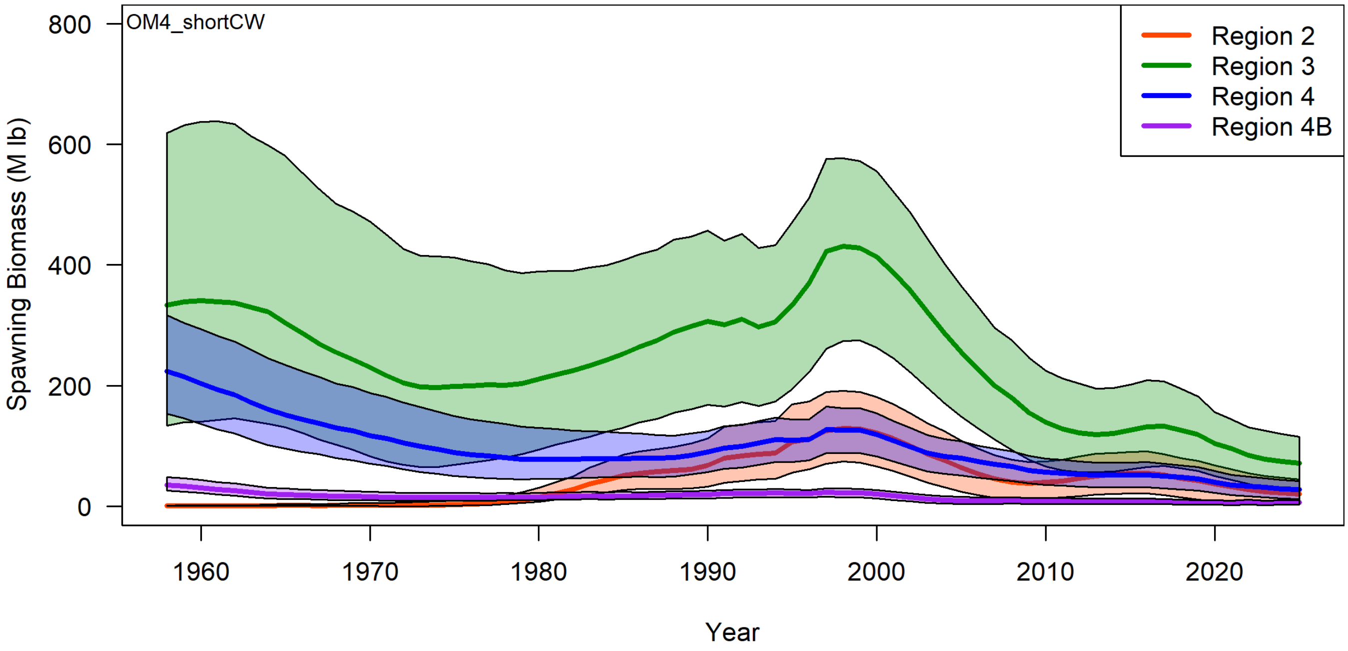


Figure 10. The spawning biomass from the OM4_shortCW model compared to the estimated spawning biomass from the long AAF assessment model (top). The bottom plot shows the spawning biomass in each Region from the OM4_shortCW model.

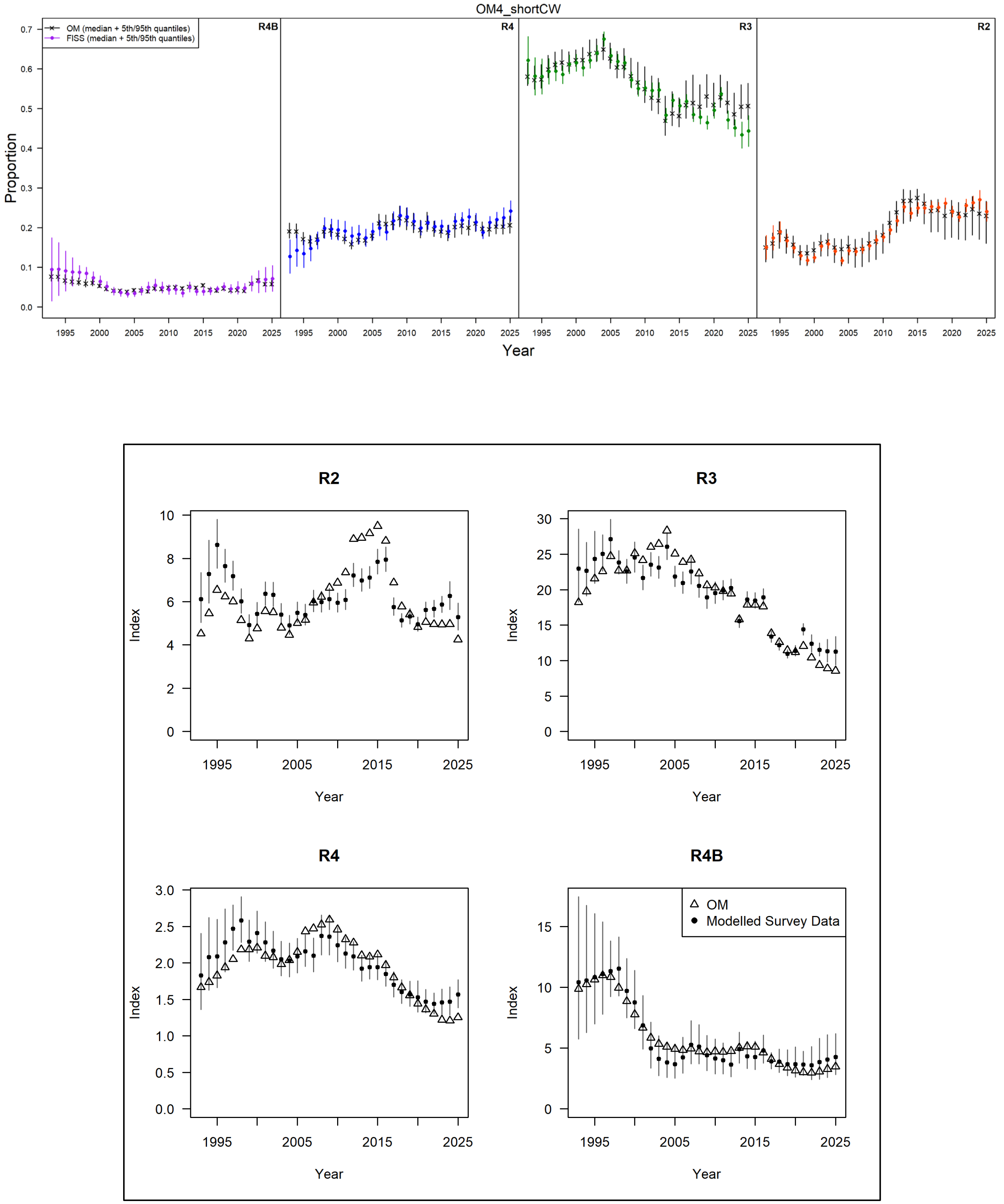


Figure 11. The top plots show the proportion of all sizes biomass in each Region from the OM4_shortCW model (triangles) and the FISS modelled output with 95% credible intervals (circles). The bottom plots show the predicted index from the OM4_shortCW model (triangles) and the FISS index (circles).

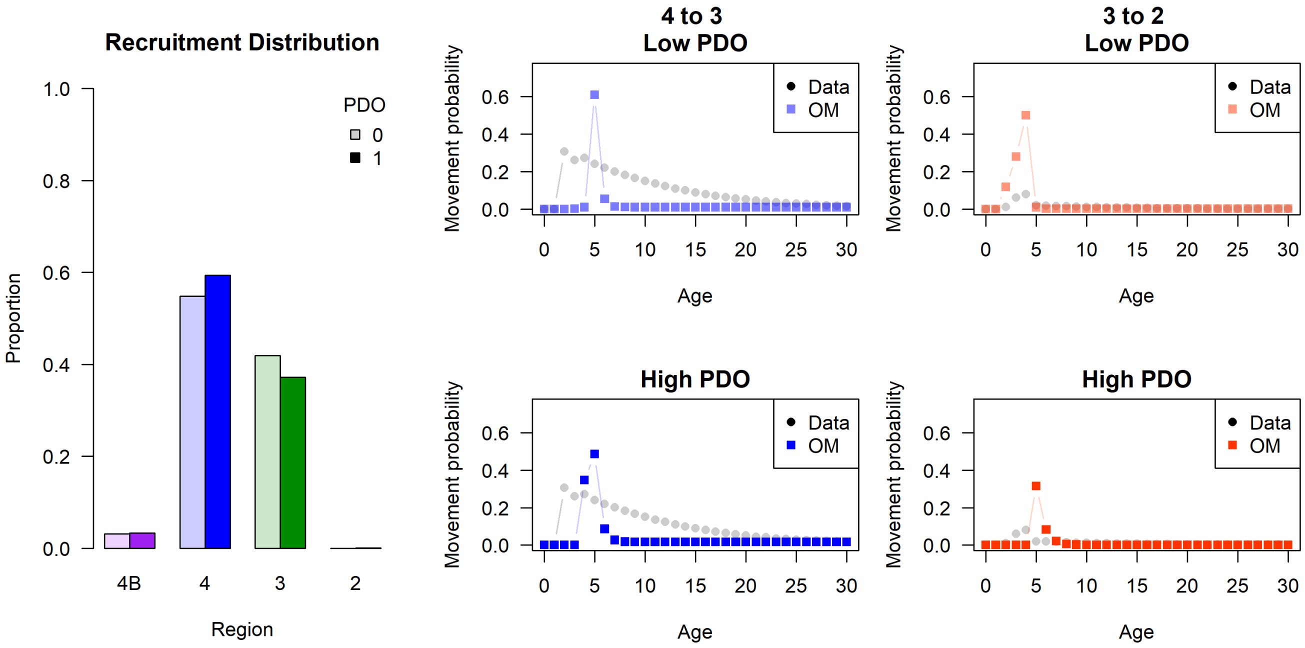


Figure 12. Distribution (proportion) of coastwide recruitment to each Region (leftmost plot). The proportion of numbers of Pacific halibut estimated in OM4_shortCW that move from Region 4 to Region 3 (center) and from Region 3 to Region 2 (right) for low PDO regimes (top) and high PDO regimes (bottom). Light grey dots are movement probabilities inferred from empirical observations.

2.1.1.2 Discussion of conditioning

All of the models captured the recent trends in the spawning biomass but showed consistent overfitting to the distribution in Region 3 in recent years. It is not certain why this occurs, and no combination of parameters could be found that rectified this while simultaneously fitting all the data sources reasonably well. For example, fitting to only stock distribution data with the OM1_longAAF model still showed this overfitting (Figure 13). It is possible that the response of Pacific halibut dynamics to the environment (e.g. PDO) has changed in recent years, whether through movement, recruitment distribution, or some other factor. The 2025 stock assessment has classified the PDO in a low regime since 1998, and recent years have seen the lowest annual average PDO in the entire time-series (Figure 14). However, the North Pacific Ocean has been recently experiencing warmer regional temperatures and novel relationships between climate variables and the PDO (Litzow et al. 2020). It is possible that these novel processes are causing a change in population parameters that the OM models are unable to capture. It will be important to capture this uncertainty when determining variability in the OM.

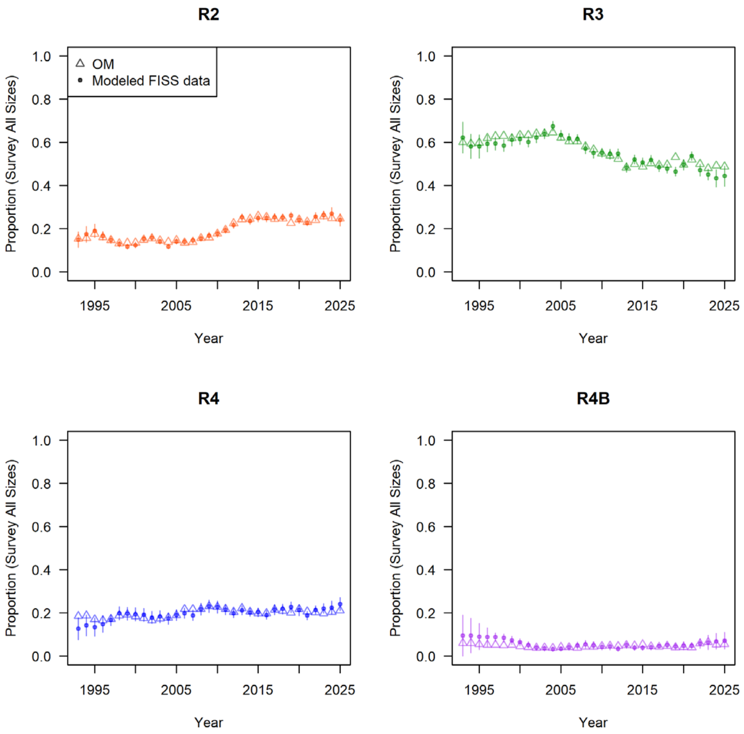


Figure 13. Results of fits to stock distribution in each Region when fitting to only stock distribution data using the OM1_longAAF model. This model is not considered for use as a conditioned model in the MSE framework but is useful to understand model fitting.

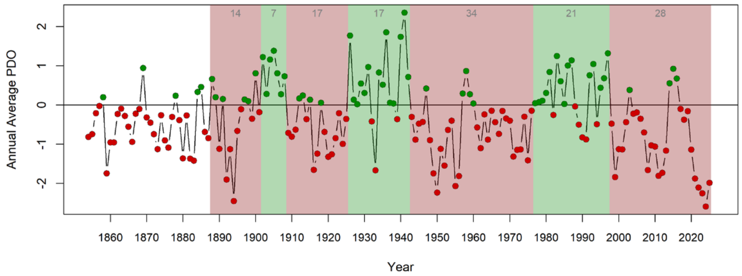


Figure 14. Annual PDO determined by averaging monthly values as of April 2026 (https://www.ncei.noaa.gov/pub/data/cmb/ersst/v5/index/ersst.v5.pdo.dat). Red and green shaded areas indicate low and high regimes, respectively, as used in the 2025 stock assessment and OM. Numbers in the shaded areas indicate the number of years for that regime.

A goal of the MSE is to capture the variability and uncertainty in the population dynamics, therefore determining uncertainty is an important part of the conditioning process. Using OM1_longAAF, one-hundred (100) trajectories were determined via parametric bootstrap using covariance matrices estimated in the 2025 long AAF stock assessment model (with the addition of steepness) and during the OM conditioning process. The final OM models will each use 1000 samples.

The median spawning biomass estimated from OM1_longAAF was slightly higher than the estimate from the 2025 long AAF stock assessment model and the estimate when conditioning OM1_longAAF, showing the asymmetry in the uncertainty interval (Figure 15). The uncertainty in the OM was slightly greater than the uncertainty in the ensemble stock assessment because additional parameters were modelled and considered when determining the overall uncertainty (e.g. steepness, movement, and recruitment distribution).

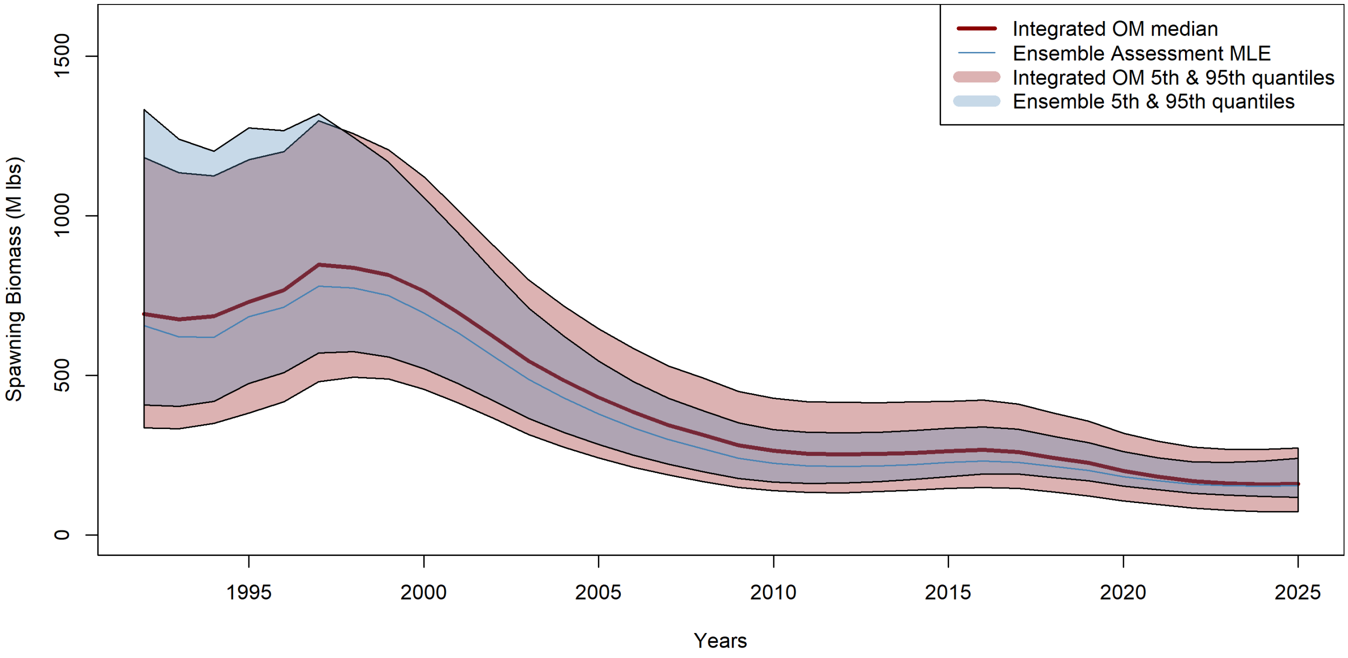


Figure 15. Estimated spawning biomass from the 2025 ensemble stock assessment model with a 90% credible interval (blue) and from the Integrated OM with bootstrapped 5th and 95th quantiles (red).

2.1.2 Evaluate a range of SPR values

The IPHC HSP defines a reference fishing intensity ($F_{SPR=43\%}$) that was determined to meet the Commission's objectives using past MSE simulations. With an updated OM, it is useful to ensure that the reference fishing intensity continues to be the optimal fishing intensity to meet those objectives. Therefore, a range of fishing intensities (i.e. SPR values) should be evaluated.

At MSAB021 a recommendation was made to evaluate a range of SPR values.

> **IPHC-2025-MSAB021-R, para. 36**: *The MSAB REQUESTED further evaluations of the following MP elements, after the OM is conditioned following the full 2025 stock assessment:*
>
> *a) fishing intensities including, but not limited to, SPRs of 40%, 43%, 46%, 52%, 55%, and 100% (no directed fishing); …*

This is a reasonable range to determine an optimal reference fishing intensity, and additional values will be added if necessary.

2.1.3 Investigate productivity regimes

Recent MSE work has involved investigating the effects of low or high productivity on management outcomes (see IPHC-2025-AM102-11 and IPHC-2026-MSAB022-06), and has found that the range of productivity historically observed for Pacific halibut has profound effects on the magnitude of biomass and mortality limits (Figure 16). Weight-at-age and average recruitment are currently identified as the two major components influencing historical productivity. Low and high PDO regimes have been linked to low and high average recruitment, respectively, and are modelled in the OM. PDO regimes are also parameterized to change the distribution of age-0 recruits and movement of all ages in the OM. Environmental or density-dependent linkages have not been determined for weight-at-age, but low, current, and high periods have been identified from historical observations. There are three main concepts to explore when investigating productivity regimes: determine 1) how the Pacific halibut population and fisheries respond to different productivity regimes, 2) if the optimal reference fishing intensity differs across productivity regimes, and 3) how productivity regimes may be incorporated into a Management Procedure.

Pacific halibut have been in what can be called a low productivity period (e.g. low weight-at-age and low recruitment) for at least the last 15 years. MSE simulations integrating across the full range of observed biological characteristics for Pacific halibut assume that weight-at-age will likely increase and the PDO will soon switch to a positive regime, therefore spawning biomass and the TCEY have a high probability of increasing in the simulated future. However, previous simulations assuming that weight-at-age remains similar to the recent 5 years (current weight) and the PDO remains in a negative regime (low recruitment) show a potential further decline in the spawning biomass (Figure 17).

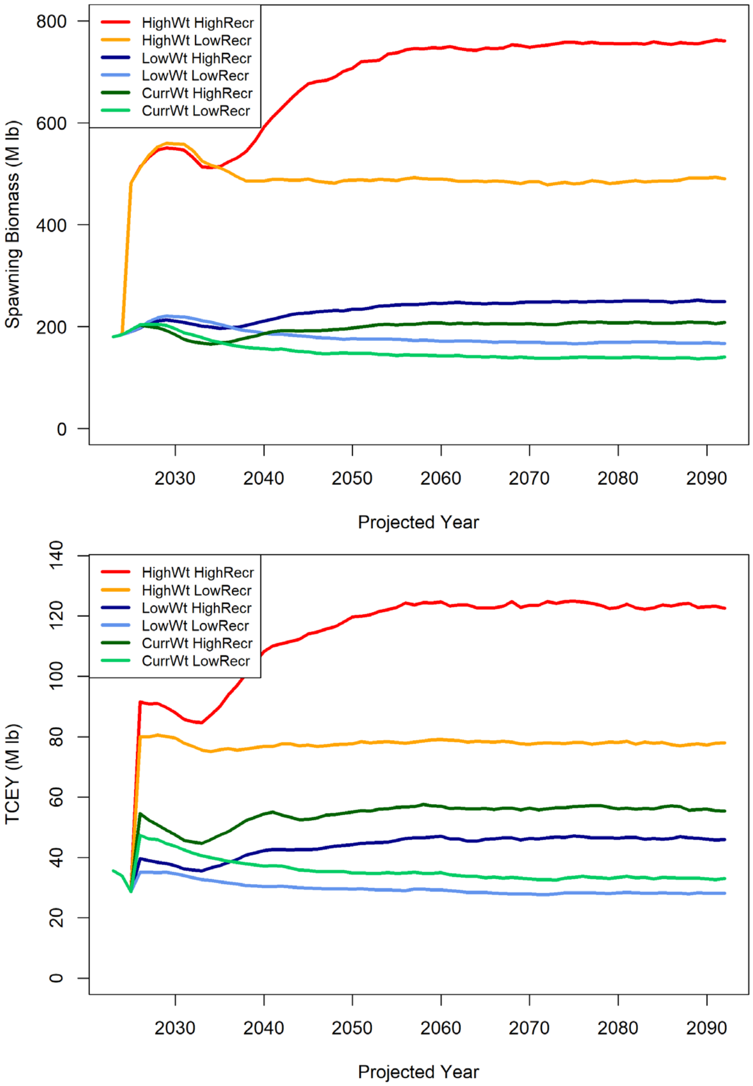


Figure 16. Simulated projections, using the OM from 2025, of spawning biomass (left) and TCEY (right) assuming six different regimes for combinations of weight-at-age and recruitment and an SPR of 43%. Each projection held the weight-at-age and average recruitment at the defined level for all projected years.

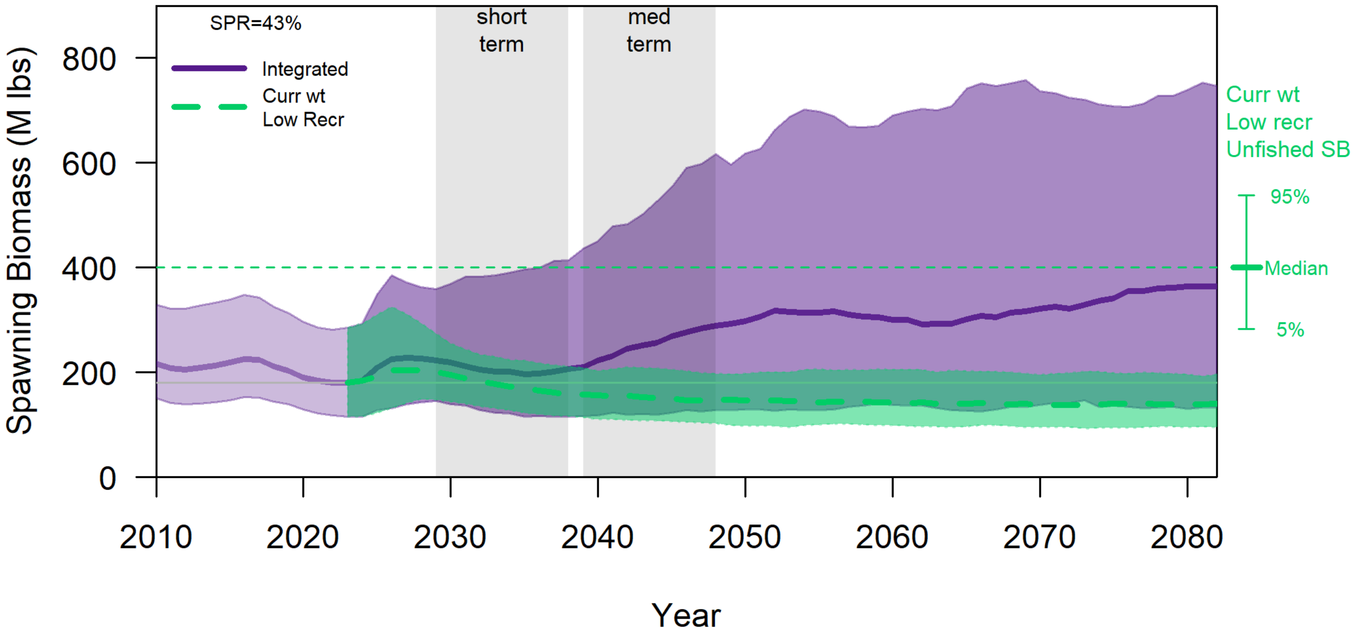


Figure 17. Simulated spawning biomass, using the 2025 OM, when fishing at an SPR=43% fishing intensity for productivity integrated over low and high levels (purple) and productivity assumed to remain at recent low levels (green). The 2023 median spawning biomass is shown as a horizontal grey line for reference, and the range of unfished spawning biomass for the low productivity scenario is shown on the right.

Another interesting aspect of investigating productivity regimes is the effect of the productivity regime on the optimal fishing intensity. This was investigated by conducting MSE simulations across various SPR values assuming a low productivity scenario (i.e. current weight-at-age and negative PDO) and comparing the performance metrics associated with the four priority objectives to the simulation results integrating over changes in weight-at-age and a cyclical PDO. The probability that the short-term spawning biomass will be less than the spawning biomass in 2023 was also compared for both sets of simulations (Table 1). The median TCEY is less for the low productivity scenario and the AAVs slightly higher. The probability that the relative spawning biomass is less than 36% is also higher for the low productivity scenario and this performance metric is not met with an SPR of 40% assuming constant low productivity. The short-term probability of being below the 2023 spawning biomass is also higher for the low productivity scenario with an approximate 1 in 2 chance for the low productivity scenario with an SPR of 43% versus an approximate 1 in 3 chance with integrated productivity (i.e. simulated low and high periods of productivity).

The trade-offs between the TCEY and variability in the TCEY (AAV) are similar for the integrated productivity and low productivity scenario (Figure 18). There are slight differences between the AAVs at different fishing intensities with the lowest AAVs occurring between SPRs of 43% and 52%. The AAV increased at a faster rate for lower SPRs in the low productivity scenario compared to integrated productivity. However, the TCEY increased by approximately 1 M lbs per every 1% reduction in SPR. Further defining what an optimal fishery is would help evaluate this trade-off.

Table 1. Performance metrics for different SPR values and simulations integrating over changes in weight-at-age and cyclical PDO and assuming a recent (i.e. low) productivity scenario (i.e. current weight-at-age and negative PDO). Green colours indicate that the performance metrics passes and red indicates that it does not.

	Integrated (low & high) Productivity						
	SPR (%)	**40**	**43**	**46**	**49**	**52**	**55**
Long-term	**P(RSB<20%)**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	P(RSB<36%)	0.372	0.195	0.066	0.014	0.001	<0.001
Short-term	**Median TCEY (M lb)**	55.0	52.0	48.9	45.9	42.5	39.1
	AAV	28.5%	26.3%	25.6%	25.5%	26.0%	26.7%
	P(SB < SB_{2023})	0.401	0.350	0.297	0.254	0.214	0.179

	Recent (low) Productivity						
	SPR (%)	**40**	**43**	**46**	**49**	**52**	**55**
Long-term	**P(RSB<20%)**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	P(RSB<36%)	0.677	0.462	0.236	0.081	0.016	<0.001
Short-Term	**Median TCEY (M lb)**	43.5	41.2	38.7	36.1	33.3	30.6
	AAV	29.0%	28.3%	27.7%	28.3%	29.2%	30.3%
	P(SB < SB_{2023})	0.609	0.543	0.466	0.390	0.312	0.241

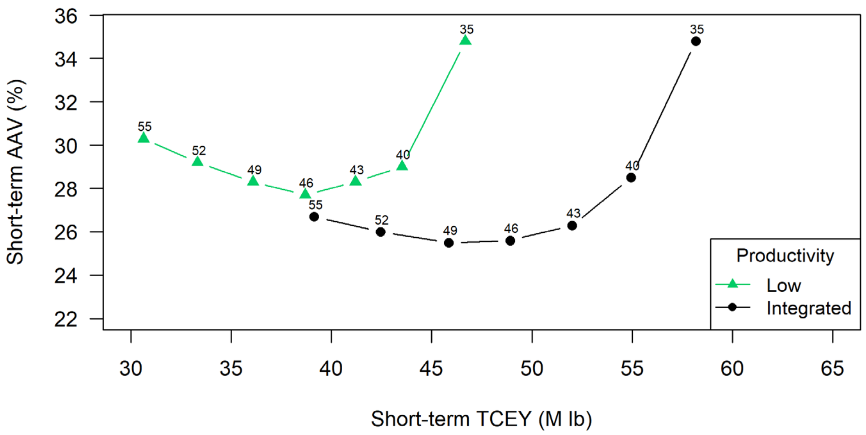


Figure 18. Trade-off between variability in the TCEY (AAV) and the TCEY for different fishing intensities (SPR labelling the points) when integrating over a range of productivity from low to high (black circles) and consistent low productivity similar to recent observations (green triangles).

Using the newly conditioned OM, productivity regimes will be defined and fixed in the projections. Projections will be used to evaluate a range of SPR values to gain an understanding of the effect of productivity on the optimal fishing intensity, and the Secretariat will work with the MSAB, SRB, and Commissioners to identify additional MPs to evaluate that directly incorporate and respond to productivity. Finally, the Secretariat will work with the MSAB and SRB to identify the most effective ways to present these results to better understand the effects that changing productivity has on the Pacific halibut population and fisheries.

2.1.4 Further develop the Depleted concept and identify a limit reference point

The IPHC HSP defines two limit biomass reference points (Figure 19) where going below either of them is to be avoided with a high probability. The first is a dynamic relative spawning biomass that measures only the effect of fishing. The second, called the Depleted limit reference point, is an absolute spawning biomass that measures the effect of fishing and the environment. The potential for recovery of the population is uncertain if it is below the Depleted limit reference point. The specific value for a Depleted reference point has not been determined.

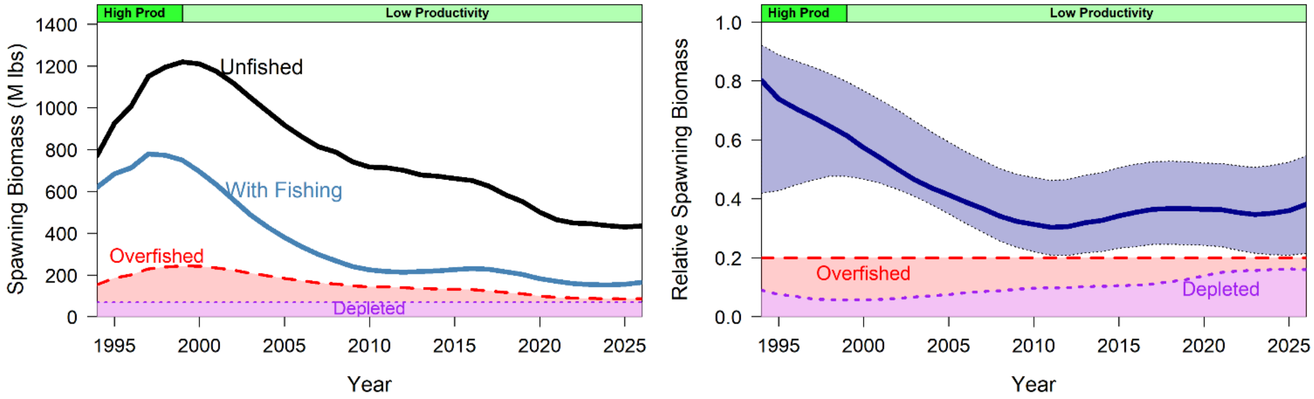


Figure 19. Estimated spawning biomass (left) if fishing had not occurred (unfished) and estimated spawning biomass from the 2025 stock assessment (with fishing). The Overfished threshold of 20% of unfished spawning biomass is shown as a dashed line and changes over time. An example "Depleted" threshold is shown as a straight horizontal line, assuming that it is defined as a constant absolute spawning biomass. The relative spawning biomass ("with fishing" divided by "unfished") is shown on the right with a 95% credible interval (accounting for the covariance in the biomass estimated with and without fishing). The Overfished threshold is shown at 20% and the example Depleted value is shown in purple.

Simulations were conducted in 2025 with the previously conditioned OM (see Section 3 of IPHC-2025-SRB027-08) to determine an absolute biomass below which the potential for recovery would be uncertain. These simulations assumed a 'worst-case' scenario of low productivity and a depensatory spawner-recruit relationship at low spawning biomass. This work was incomplete and will be expanded in 2026 using the newly conditioned OM and further determination of scenarios. The SRB suggested the following.

> **IPHC-2025-SRB027-R. para 23**. *The SRB RECOMMENDED increasing simulation sample sizes to achieve a smooth curve so that a "depleted" threshold can be identified as the lowest spawning stock biomass that results in near 100% probability of recovery.*

Furthermore, the SRB recommended defining an exceptional circumstance if the stock is estimated to be below the Depleted limit reference point because the MP determined from the MSE process should avoid this with high probability and thus would be theoretically unlikely. If the stock was depleted, it may indicate a misspecification within the MSE framework that should be investigated. A definition for this type of exceptional circumstance will be determined with assistance from the MSAB and SRB, and then presented to the Commission for adoption into the IPHC HSP.

> **IPHC-2025-SRB027-R. para 21.** *The SRB RECOMMENDED defining an "exceptional circumstance" if the stock is determined to be "depleted" as this state is unlikely to occur under the circumstances in which the HSP is implemented and may be indicative of a need for model revision*

2.2 Low priority tasks

The Commission, MSAB, and SRB identified additional tasks which are a lower priority than those defined above. These may be possible to complete in 2026 or 2027, but may also be extended into the next MSE Program of Work.

2.2.1 Improve the estimation model in the MSE framework

The closed-loop simulations in the MSE framework consist of an OM and an MP (Figure 20). Within the MP there are three subcomponents. The monitoring subcomponent determines what data are sampled and with what precision. The estimation model uses those data to determine outputs necessary for management (e.g. stock status, mortality limits, etc.). The harvest rule consists of other items necessary for the management of Pacific halibut, such as size limits, distribution of the harvest, and control rules.

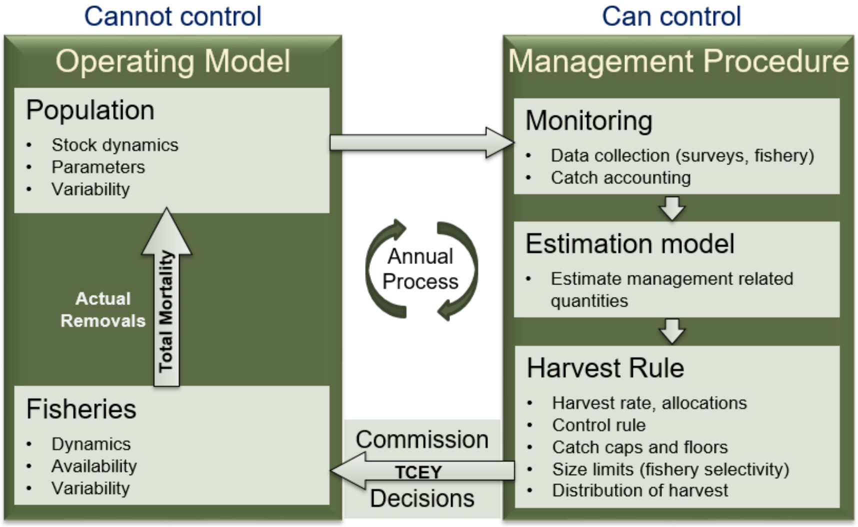


Figure 20. An illustration of the closed-loop simulation within the MSE framework.

Implementing a full ensemble stock assessment in a simulation framework is not technically feasible at this time. Therefore, estimation models in MSE frameworks are typically simplifications of the actual stock assessment to reduce the simulation time but still mimic the behaviours of the stock assessment. The current estimation model mimics the stock assessment with a simple approach of adding correlated random variability to stock status and the mortality limit, which was tuned to outputs of past stock assessments. This method, however, is not capturing potential lags and biases in estimated quantities, and cannot simulate different assumptions in the stock assessment. Following an SRB recommendation, work has begun on better mimicking the stock assessment within the MSE framework.

> **IPHC-2025-SRB027-R, para 24.** *The SRB RECOMMENDED considering the development of an assessment model within the MSE framework. This would have multiple benefits including:*
>
> *a) facilitating analysis of the economic consequences of reduced FISS sampling and the associated increased potential for bias in assessment-relevant metrics such as WPUE, the maturity schedule, size-at-age, and age composition.*
>
> *b) Understanding the impacts of uncertainty in natural mortality on management performance.*

2.2.2 Evaluate potential management actions when approaching the depleted limit reference point

Once a Depleted limit reference point is determined (see Section 2.1.4), specific management actions to incorporate into a management procedure if this reference point is reached will be evaluated using the MSE framework. This may be a control rule that reduces fishing intensity as the stock approaches a limit reference point to complement the current 30:20 control rule that uses stock status as its operational control points. Other management actions to investigate include adjusting the reference fishing intensity based on the perceived productivity regime.

2.2.3 Evaluate additional elements of Management Procedures

The MSE framework has been used to evaluate many elements of management procedures other than fishing intensity (i.e. SPR). These include constraints or smoothers on the annual change in the TCEY, assessment frequencies other than annual, and alternative control rules. The MSAB has found the investigations useful and has made a number of requests to continue evaluating these as well as new elements.

> **IPHC-2025-MSAB021-R, para 23**. *The MSAB AGREED that a constraint would help to reduce interannual variability in the TCEY when using an annual or triennial assessment frequency.*
>
> **IPHC-2025-MSAB021-R, para 36**. *The MSAB REQUESTED further evaluations of the following MP elements, after the OM is conditioned following the full 2025 stock assessment:*
>
> *a) fishing intensities including, but not limited to, SPRs of 40%, 43%, 46%, 52%, 55%, and 100% (no directed fishing);*
>
> *b) a triennial assessment frequency;*
>
> *c) various empirical rules to determine the reference coastwide TCEY in non-assessment years;*
>
> *d) control rules with triggers at higher values than $RSB_{30\%}$ or based on absolute spawning biomass relative to the spawning biomass estimated at the beginning of 2024.*
>
> **IPHC-2025-MSAB021-R, para 37**. *The MSAB REQUESTED evaluating constraints and smoothers, along with MP elements listed in para. 36, that would potentially reduce the interannual variability in the TCEY, including:*
>
> *a) a 3-year rolling average (arithmetic or geometric) on the FISS O32 WPUE used in the empirical rule in a triennial stock assessment frequency;*
>
> *b) constraints applied only to non-assessment years and/or applied only to assessment years;*
>
> *c) a phase-in approach for the change in TCEY in assessment years;*

> *d) using the trends in fishery CPUE and/or FISS WPUE to determine if a bigger reduction should be taken than suggested by the unconstrained reference TCEY to curtail further reductions in the SB.*

The Secretariat will work with the MSAB and SRB to clearly identify candidate MPs incorporating these elements for evaluation.

2.2.4 Update estimates of reference points

The Secretariat last conducted an in-depth analysis of reference points in 2019 and reported the results in IPHC-2019-SRB015-11 Rev_1. That analysis reported estimates of MSY-based reference points that were used in the development of objectives and the definition of overfishing. Since 2019, there have been many updates to the stock assessment and the OM, as well as new data available. Repeating this analysis with the updated OM and stock assessment will ensure that the HSP reflects the most up-to-date information.

2.2.5 Develop guidance documents for the Harvest Strategy Policy

The HSP document is a high-level description of the harvest strategy policy that does not describe all concepts in detail. Therefore, the development of supplementary guidance documents describing some concepts in more detail is necessary for the management of Pacific halibut. Supplementary documents to be developed may include

1. Guidelines for developing a rebuilding plan for Pacific halibut that would apply if it was determined to be overfished;
2. Other guideline documents as determined by the Commission.

Guideline documents will be developed and adopted after input from the MSAB, SRB, and Commission.

2.2.6 Incorporate autocorrelated recruitment in projections

The Secretariat reported results of investigations of autocorrelated recruitment for Pacific halibut and its use in the MSE framework in document IPHC-2025-SRB027-08. This was in response to an SRB request from the 26th Session of the SRB.

> **IPHC-2025-SRB026-R, para 24**. *The SRB RECOMMENDED that recruitment projections in the stock assessment and Management Strategy Evaluation (MSE) incorporate a random-walk starting from the most recent reliable recruitment estimate to constrain expected short-term recruitment around recent estimates rather than immediately reverting to the stock-recruitment relationship.*

These results showed some evidence of autocorrelated recruitment that may be useful to model. MSE simulations with and without autocorrelated projected recruitment showed slight differences in performance metrics. The MSE framework is capable of including autocorrelated recruitment and further discussion with the SRB will determine if this is appropriate for evaluating MPs.

2.2.7 Update objectives and performance metrics

The three priority Commission objectives are defined in the HSP and additional objectives considered by the MSAB are presented in Appendix A. It is useful to occasionally revisit objectives to clarify them or add new ones. For example, there have been recent discussions regarding the development of an objective related to absolute spawning biomass or a depleted level (see Section 2.1.4).

It is also useful to review the performance metrics related to the objectives. This ensures that MSE results are presented using applicable and understandable metrics. The SRB suggested considering fishery performance metrics.

> **IPHC-2025-SRB027-R, para 22.** *The SRB RECOMMENDED considering some fishery performance indicators that represent metrics directly observable by stakeholders, e.g. fishery CPUE.*

These types of fishery performance indicators would be best associated with general objective 2.2: Provide Directed Fishery Yield (Appendix A). Discussions with the MSAB and Commission will determine if new objectives should be adopted and new performance metrics be reported.

3 DISCUSSION

Tasks for the 2026–2027 MSE Program of Work are divided into high priority and low priority. High priority tasks are already underway, and some low priority tasks require completion of high priority tasks. A list of all tasks is provided below.

1. High priority tasks
    - 1.1. Condition the MSE Operating Model
    - 1.2. Evaluate a range of SPR values
    - 1.3. Investigate productivity regimes
    - 1.4. Further develop the depleted concept and identify a limit reference point
2. Low priority tasks
    - 2.1. Improve the estimation model in the MSE framework
    - 2.2. Evaluate potential management actions when approaching the depleted limir reference point
    - 2.3. Evaluate additional elements of the Management Procedures
    - 2.4. Update estimates of reference points
    - 2.5. Develop guidance documents for the Harvest Strategy Policy
    - 2.6. Incorporate autocorrelated recruitment in projections
    - 2.7. Update objectives and performance metrics

4 REFERENCES

Litzow, M.A., Malick, M.J., Bond, N.A., Cunningham, C.J., Gosselin, J.L., and Ward, E.J. 2020. Quantifying a Novel Climate Through Changes in PDO-Climate and PDO-Salmon Relationships. Geophysical Research Letters **47**(16). doi:10.1029/2020gl087972.

5 RECOMMENDATIONS

That the SRB:

1) **NOTE** paper IPHC-2026-SRB028-08 Rev_1 that describes tasks included in the MSE Program of Work for 2026–2027 and work towards completing those tasks.
2) **REQUEST** additional tasks to be included in the MSE Program of Work for 2026–2027.

6 APPENDICES

Appendix A: Primary objectives used by the Commission for the MSE evaluations

APPENDIX A
PRIMARY OBJECTIVES USED BY THE COMMISSION FOR THE MSE EVALUATIONS

Table A1. Primary objectives, evaluated over a simulated ten-year period, accepted by the Commission at the 7th Special Session of the Commission (SS07). Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives. Priority objectives are shown in green text.

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	MEASURABLE OUTCOME	TIME-FRAME	TOLERANCE	PERFORMANCE METRIC
1.1. KEEP FEMALE SPAWNING BIOMASS ABOVE A LIMIT TO AVOID CRITICAL STOCK SIZES AND CONSERVE SPATIAL POPULATION STRUCTURE	Maintain the long-term coastwide female relative spawning biomass above a biomass limit reference point ($RSB_{20\%}$) at least 95% of the time	*RSB* < Spawning Biomass Limit (RSB_{Lim}) RSB_{Lim}=20% unfished spawning biomass	Long-term	0.05	$P(RSB < RSB_{Lim})$ Fail if greater than 0.05
	Maintain a defined minimum proportion of female spawning biomass in each Biological Region	$p_{SB,2} > 5\%$ $p_{SB,3} > 33\%$ $p_{SB,4} > 10\%$ $p_{SB,4B} > 2\%$	Long-term	0.05	$P(p_{SB,R} < p_{SB,R,min})$
2.1 MAINTAIN SPAWNING BIOMASS AT OR ABOVE A LEVEL THAT OPTIMIZES FISHING ACTIVITIES	Maintain the long-term coastwide female relative spawning biomass at or above a biomass reference point ($RSB_{36\%}$) 50% or more of the time	*RSB*<Spawning Biomass Reference (RSB_{Thresh}) $RSB_{Thresh}=RSB_{36\%}$ unfished spawning biomass	Long-term	0.50	$P(RSB < RSB_{Thresh})$ Fail if greater than 0.5
2.2. PROVIDE DIRECTED FISHING YIELD	Optimize average coastwide TCEY	Median coastwide TCEY	Short-term		*Median* $\overline{TCEY}$
	Optimize TCEY among Regulatory Areas	Median $TCEY_A$	Short-term		*Median* $\overline{TCEY_A}$
	Optimize the percentage of the coastwide TCEY among Regulatory Areas	Median $\%TCEY_A$	Short-term		*Median* $\left(\overline{\frac{TCEY_A}{TCEY}}\right)$
	Maintain a minimum TCEY for each Regulatory Area	Minimum $TCEY_A$	Short-term		*Median Min(TCEY)*
	Maintain a percentage of the coastwide TCEY for each Regulatory Area	Minimum $\%TCEY_A$	Short-term		*Median Min(%TCEY)*
2.3. LIMIT VARIABILITY IN MORTALITY LIMITS	Limit annual changes in the coastwide TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Median coastwide Average Annual Variability (AAV)	Short-term		*Median AAV*
	Limit annual changes in the Regulatory Area TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Average AAV by Regulatory Area (AAV_A)	Short-term		*Median* AAV_A

$$AAV_t = \frac{\sum_{t+1}^{t+9} |TCEY_t - TCEY_{t-1}|}{\sum_{t}^{t+9} TCEY_t}$$

$$AC_t = \frac{|TCEY_t - TCEY_{t-1}|}{TCEY_{t-1}}$$

2027-31 FISS design evaluation

PREPARED BY: IPHC SECRETARIAT (R. WEBSTER, I. STEWART, K. UALESI, T. JACK & D. WILSON; 15 APRIL 2026)

PURPOSE

To present the Scientific Review Board with potential FISS designs for 2027-31, including a preliminary cost evaluation of the 2027 Base Block design.

BACKGROUND

The IPHC's Fishery-Independent Setline Survey (FISS) provides data used to compute indices of Pacific halibut density for use in monitoring stock trends, estimating stock distribution, and as an important input in the stock assessment. Stock distribution estimates are based on the annual mean weight per unit effort (WPUE) for each IPHC Regulatory Area, computed as the average of WPUE of all Pacific halibut and for O32 (greater than or equal to 32" or 81.3cm in length) Pacific halibut estimated at each station in an area. Mean numbers per unit effort (NPUE) is used to index the trend in Pacific halibut density for use in the stock assessment models. Annual FISS designs are developed by selecting a subset of stations for sampling from the full 1890-station FISS footprint (Figure 1).

In recent years, financial constraints due to reduced catch rates and the combined impact of factors affecting revenue and costs (FISS accounting changes, Pacific halibut sales prices, charter vessel and bait costs) have resulted in the implementation of FISS designs with reduced spatial footprints (Figure 2). Effort has been concentrated in IPHC Regulatory Areas 2B, 2C, 3A and 3B (the core of the stock), with limited sampling in other areas in most years (Figure 3).

The **Base Block design** was presented to the Commission at the September 2024 Work Meeting and the 14th Special Session of the IPHC (SS014, IPHC-2024-SS014-03) as a more efficient approach to annual sampling in the core of the stock compared to previous designs based on random selection of FISS stations. The Commission has noted that "the use of the Base Block Design will be the focus of future planning and annual FISS proposals from the Secretariat" (e.g., IPHC-2026-AM102-R, para. 72). The Base Block design ensures that all charter regions in the core areas are sampled over a three-year period, while prioritizing coverage in other areas based on minimizing the potential for bias and maintaining CVs below 25% for each IPHC Regulatory Area. The Base Block design also includes some sampling in all IPHC Biological Regions in each year, ensuring that trend and biological data from across the spatial range of Pacific halibut are available to the stock assessment and for stock distribution estimation.

Since 2016, spatio-temporal (geostatistical) modelling has been used to estimate time series of WPUE and NPUE, and to estimate the stock distribution of Pacific halibut among IPHC Regulatory Areas and Biological Regions (Webster et al. 2020). The IPHC space-time models are fitted through the R-INLA package using R (R Core Team, 2024).

FISS history 1993-2019

The IPHC has undertaken FISS activity since the 1960s. However, methods were not standardized to a degree (e.g., the bait and gear used) that allows for simple combined analyses until 1993. From 1993 to 1997, the annual design featured fishing triangular clusters of stations, with clusters located on a grid (IPHC 2012). Coverage was limited in most years and was generally restricted to IPHC Regulatory Areas 2B through 3B. The modern FISS design, based on a grid with 10 nmi (18.5 km) spacing, was introduced in 1998, and over the subsequent two years was expanded to include annual coverage in parts of all IPHC Regulatory Areas within the depth ranges of 20-275 fathoms (37-503 m) in the Gulf of Alaska and Aleutian Islands, and 75-275 fathoms (137-503 m) in the Bering Sea (IPHC 2012). Annually-fished stations were added around islands in the Bering Sea in 2006, and in the same year, a less dense grid of paired stations was fished in shallower waters of the southeastern Bering Sea, providing data for a calibration with data from the annual National Marine Fishery Service (NMFS) bottom trawl survey (Webster et al. 2020).

Through examination of commercial logbook data and information from other sources, it became clear by 2010 that the historical FISS design had gaps in coverage of Pacific halibut habitat that had the potential to lead to bias in estimates derived from its data. These gaps included deep and shallow waters outside the FISS depth range (0-20 fathoms and 275-400 fathoms), and unsurveyed stations on the 10 nmi grid within the 20-275 fathom depth range within each IPHC Regulatory Area. This led the IPHC Secretariat to propose expanding the FISS to provide coverage of the unsurveyed habitat in United States and Canadian waters. In 2011 a pilot expansion was undertaken in IPHC Regulatory Area 2A, with stations on the 10 nmi grid added to deep (275-400 fathoms) and shallow (10-20 fathoms) waters, the Salish Sea, and other, smaller gaps in coverage. The 10-fathom limit in shallow waters was due to logistical difficulties in standardized fishing of longline gear in shallower waters. The 400-fathom maximum depth is understood to cover almost all Pacific halibut summer habitat. A second expansion in IPHC Regulatory Area 2A was completed in 2013, with a pilot survey in California waters between the latitudes of 40 and 42°N.

The full expansion program began in 2014 and continued through 2019, sampling the entire FISS design of 1890 stations in the shortest time logistically possible, as well as replicating the 2006 calibration with the Bering Sea trawl survey. The FISS expansion program allowed us to build a consistent and complete picture of Pacific halibut density throughout its range in Convention waters. Sampling the full FISS design has reduced bias, and, in conjunction with space-time modelling of survey data (see below), has improved precision and fully quantified the uncertainty associated with estimates based on partial annual sampling of the species range. It has also provided us with a complete set of observations over the full FISS design (Figure 1) from which an optimal subset of stations can be selected when devising annual FISS designs. This station selection process began in 2019 for the 2020 FISS and continues with the current review of design proposals for 2027-29. Note that in the Bering Sea, the full FISS design does not provide complete spatial coverage, and FISS data are augmented with calibrated data from National Marine Fisheries Service (NMFS) and Alaska Department of Fish and Game (ADFG) trawl surveys (stations can vary by year – 2019 designs are shown in Figure 1). Both supplementary surveys have been conducted approximately annually in recent years.

Rationalized FISS, 2020-26

Following the 2011-2019 program of FISS expansions, rationalized FISS designs were approved for 2020 based on random selection of over 50% of stations in the core of the stock (IPHC Regulatory Areas 2B, 2C, 3A and 3B) and sampling of all stations in selected subareas of the remaining IPHC Regulatory Areas. For the latter areas, sampling priorities were determined based on maintaining precise estimates of area-specific indices of density and ensuring low bias in index estimators. That year, the COVID19 pandemic led to a reduced FISS with sampling only in the core areas. The 2021-22 FISS sampling proceeded largely as designed, although planned stations in western IPHC Regulatory 4B in 2022 were unsampled due to a lack of viable charter bids. In some charter regions in the core areas, 100% of stations were sampled in order to achieve revenue goals.

Four years of spatially-reduced designs followed the 2022 FISS:

2023 (IPHC-2023-AM099-R)

- Little sampling outside of the core areas due to large projected revenue losses from designs that included extensive sampling in IPHC Regulatory Areas 2A, 4A, 4B and 4CDE
- Limited sampling in northern IPHC Regulatory 2A
- Planned stations around the IPHC Regulatory Area 4A/4B boundary not sampled due to a lack of charter bids

2024 (IPHC-2024-AM100-R)

- High sampling rates in IPHC Regulatory Areas 2B and 2C
- A small number of charter regions in IPHC Regulatory Areas 3A and 3B
- Sampling of the southern shelf edge and Bering Sea islands in IPHC Regulatory Area 4CDE

2025 (Figure 2, IPHC-2025-AM101-R)

- Charter regions in IPHC Regulatory Areas 3A and 3B selected to complement coverage in recent years
- Sampled stations in IPHC Regulatory Areas 2A, 4A and 4B that had not been sampled for three or more years

2026 (Figure 4)

- Increases spatial coverage relative to 2023-25
- Complements the 2025 design by including ten charter regions not sampled last year

FISS DESIGN OBJECTIVES (Table 1)

***Primary objective**: To sample Pacific halibut for stock assessment and stock distribution estimation.*

The primary purpose of the annual FISS is to sample Pacific halibut to provide data for the stock assessment (abundance indices, biological data) and estimates of stock distribution for use in management. The priority of the current rationalized FISS is therefore to maintain or enhance data quality (precision and bias) by establishing baseline sampling requirements in terms of station count, station distribution and skates per station.

***Secondary objective**: Cost effectiveness.*

The FISS is intended to be cost-effective without compromising the scientific integrity of the design. Any implemented design must consider logistics and cost together with scientific integrity.

***Tertiary objective:** Minimise removals and assist others where feasible on a cost-recovery basis.*

Consideration is also given to the total expected FISS removals (impact on the stock), data collection assistance for other agencies, and emerging IPHC informational needs.

Table 1. Prioritized FISS objectives and corresponding design layers.

Priority	**Objective**	**Design Layer**
Primary	Sample Pacific halibut for stock assessment and stock distribution estimation	Minimum sampling requirements in terms of: • Station distribution • Station count • Skates per station
Secondary	Cost effectiveness without compromising the scientific integrity of the FISS design.	Balance operational feasibility/logistics, cost/revenue, and scientific needs. Includes an aspirational target reserve of US$2,000,000
Tertiary	Minimise removals, assist others where feasible on a cost-recovery basis, address specific Commission informational needs.	Removals: minimise impact on the stock while meeting primary priority Assist: assist others to collect data on a cost-recovery basis IPHC policies: ad-hoc decisions of the Commission regarding the FISS design

Annual design review, endorsement, and finalisation process

Since the completion of the FISS expansions in 2019, a review process has evolved for annual FISS designs created according to the above objectives:

- Step 1: The Secretariat presents preliminary design options based on the primary objective (Table 1) to the SRB for three subsequent years at the June meeting, based on analysis of prior years' data. Commencing in 2024, this has included preliminary cost projections based on prior year fiscal details (revenue) and current year vessel contract cost updates;

- Step 2: Updated design options for the following year that account for both primary and secondary objectives (Table 1) are reviewed by the Commission at the September work meeting, recognising that revenue and cost data from the current year's FISS are still preliminary at this time;
- Step 3: At their September meeting, the SRB reviews design options accounting for both primary and secondary objectives (Table 1) for comment and advice to the Commission (recommendation). FISS revenue and cost information from the current year is near-final at this time;
- Step 4: Designs are further modified to account for updates based on secondary and tertiary objectives before being finalized during the Interim and Annual meetings and the period prior to implementation:
    - Presentation of FISS designs for 'endorsement' by the Commission occurs at the annual Interim Meeting;
    - Ad-hoc modifications to the design for the current year (due to unforeseen issues arising) are possible at the IPHC Annual Meeting;
    - The endorsed design for the current year is then modified (if necessary) to account for any additional tertiary objectives or revisions to inputs into the evaluation of secondary objectives prior (i.e., updated cost estimates) and logistical considerations raised by the operators of contracted vessels prior to summer implementation (February-April).

Consultation with industry and stakeholders occurs throughout the FISS planning process, at the Research Advisory Board meeting (late November), and particularly in finalizing design details as part of the FISS charter bid process, when stations can be added and other adjustments made to provide for improved logistical efficiency. We also note the opportunities for direct stakeholder input during public meetings (Interim and Annual Meetings).

Although the review process examines designs for the next three years, revisions to designs for the second and third years are expected during subsequent review periods as additional data are collected. Having design proposals available for three years assists the Secretariat with medium-term planning of the FISS, and allows reviewers (SRB, Commission) and stakeholders to see more clearly the planning process for sampling the entire FISS footprint over multiple years.

POTENTIAL DESIGNS FOR 2027-31

BASE BLOCK DESIGN

At AM102, Secretariat staff presented the Base Block design for 2026 and subsequent years based a rotational block design (IPHC-2025-AM102-13). This design implements sampling of complete FISS charter regions (subsets of stations generally sampled by a single vessel via multiple trips) in each area rather than randomly selected stations as was previously done in the core of the stock. Sampled charter regions are rotated over two or three years depending on area. Block designs are potentially more efficient from an operational perspective than a randomized design as they involve less running time between stations, leading to cost reductions on a per station basis. The proposed Base Block designs for 2027-31 are shown in Figures 5 to 9.

Using posterior samples generated from the fitted 2025 space-time models as simulated data for 2026-29, we projected the coefficient of variation (CV, a relative measure of precision) for mean O32 WPUE for each year of the design by area. As CVs are generally greater in the terminal year of the time series and that year is usually the most relevant for informing management, the CV values in Table 2 are for the final year of the modelled time series. For example, the CVs for 2027 were projected by fitting the model to the data for 1993-2027, with simulated data used for 2026-27.

Table 2. Projected coefficients of variation (CVs, %) of mean O32 WPUE for the 2026 design and the potential 2027-29 Base Block designs by terminal year of time series and IPHC Regulatory Area and Biological Region.

Regulatory Area	**Year** 2026	2027	2028	2029
2A	27	26	16	22
2B	6	5	10	7
2C	5	6	6	6
3A	11	8	7	7
3B	17	14	12	9
4A	19	24	12	19
4B	17	16	17	14
4CDE	9	9	9	8
Biological Region				
Region 2	4	5	5	4
Region 3	9	7	6	6
Region 4	9	11	7	9
Region 4B	17	16	17	14
Coastwide	5	4	4	4

Projected terminal year CVs for the Base Block design (2027-29) are 25% or less for all IPHC Regulatory Areas except 2A, which has a 26% projected CV in 2027. In the core areas (2B, 2C, 3A and 3B), CVs are projected to be 15% or less (Table 2) following this year's FISS. All Biological Region CVs, except that of Region 4B, are at most 11%, while the coastwide CV is projected to be 4% for the 2027-29 Base Block designs. Thus, the Base Block design is expected to maintain precise estimates of indices of Pacific halibut density and abundance across the range of the stock. At the same time, the rotating nature of the sampled blocks means that almost all FISS stations will be sampled within a 5-year period (2-3 years within the core areas) resulting in low risk of missing important stock changes and therefore a low risk of large bias in estimates of trend and stock distribution. By 2030, we expect to no longer have any significant biases that resulted from unmonitored stock changes in regions that were unsampled for several years.

Preliminary Cost Projections for 2027

The 2027 Base Block design is projected to result in an operating loss close to US$1 million (Table 3). Preliminary cost and revenue projections for the Base Block design are based on the following assumptions:

1. Designs are optimised for numbers of skates, with sets of 4, 6 or 8 100-hook skates used, depending on projected catch rates and bait costs.
2. Pacific halibut sales price is unchanged from 2025 values, ranging from approximately $6 to $10/lb (coastwide average US$8.18/lb), depending on FISS charter region.
3. Pacific halibut landings remain unchanged from 2025 values.
4. The price of chum salmon bait remains at the 2026 price of US$2.40/lb.

Table 3. Preliminary projected costs and revenue for the 2027 Base Block ($US). (Totals may not equal the sum of individual rows due to rounding.)

Design		**2027 Base Block design**
Income	**Pacific halibut sales**	2,976,000
	Byproduct sales	96,000
	Total	**3,072,000**
Expenses	**Base HQ (staff salary and wages, and benefits x 4)**	(534,000)
	Vessel contracts	(1,496,000)
	Field staff (salary and wages, and benefits)	(615,000)
	Bait	(483,000)
	Non-IPHC fish sales	(346,000)
	Other expenses*	(614,000)
	Total	**(4,089,000)**
Net revenue		**($1,017,000)**

*Other costs include staff training, personnel expenses, mailing and shipping, travel, technology, gear replacement, customs fees, bait storage fees, field supplies and equipment, equipment maintenance fees, facility rental fees, and communication fees.

Note: Cost estimates are largely based on information from the 2025 FISS and outcomes of the 2026 charter bidding process, and it is important to note there is uncertainty in the catch and cost projections for 2027 and that this uncertainty increases over time. Projected income and expenses for the 2027 design will be updated once FY2026 has been reconciled (expected late October 2026) and will be used to refine the projections provided in this Briefing Note at that time.

DISCUSSION

The **Base Block** design has a projected net loss of around $1,017,000 for 2027 and therefore will rely on supplementary funding for implementation. Projected deficits for the Base Block design for 2025 and 2026 led to the adoption of reduced designs, although with reductions in spatial coverage mitigated by supplementary funding from the USA and Canada. For 2027, the Secretariat staff is working with Commissioners to secure the necessary funding to implement the full Base Block design.

RECOMMENDATION

That the Scientific Review Board **NOTE** paper IPHC-2026-SRB028-09, which presents potential Base Block designs for 2027-31, including a preliminary projection of revenue and expenses for the 2027 design.

References

IPHC (2023). Report of the 99th Session of the IPHC Annual Meeting (AM099) IPHC-2023-AM099-R. 62 p.

IPHC (2024). Report of the 100th Session of the IPHC Annual Meeting (AM100) IPHC-2024-AM100-R. 55 p.

IPHC (2025). Report of the 101st Session of the IPHC Annual Meeting (AM101) IPHC-2025-AM101-R. 52 p.

IPHC (2026). Report of the 102nd Session of the IPHC Annual Meeting (AM102) IPHC-2026-AM102-R. 54 p.

R Core Team (2024) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

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., Stewart, I., Ualesi, K., Jack, T. and Wilson, D. (2024). 2025 and 2026-29 FISS designs. IPHC-2024-SS014-03. 21 p.

Webster, R., Stewart, I., Ualesi, K., Jack, T. and Wilson, D. (2026). FISS design 2026-28. IPHC-2026-AM102-13. 23 p.

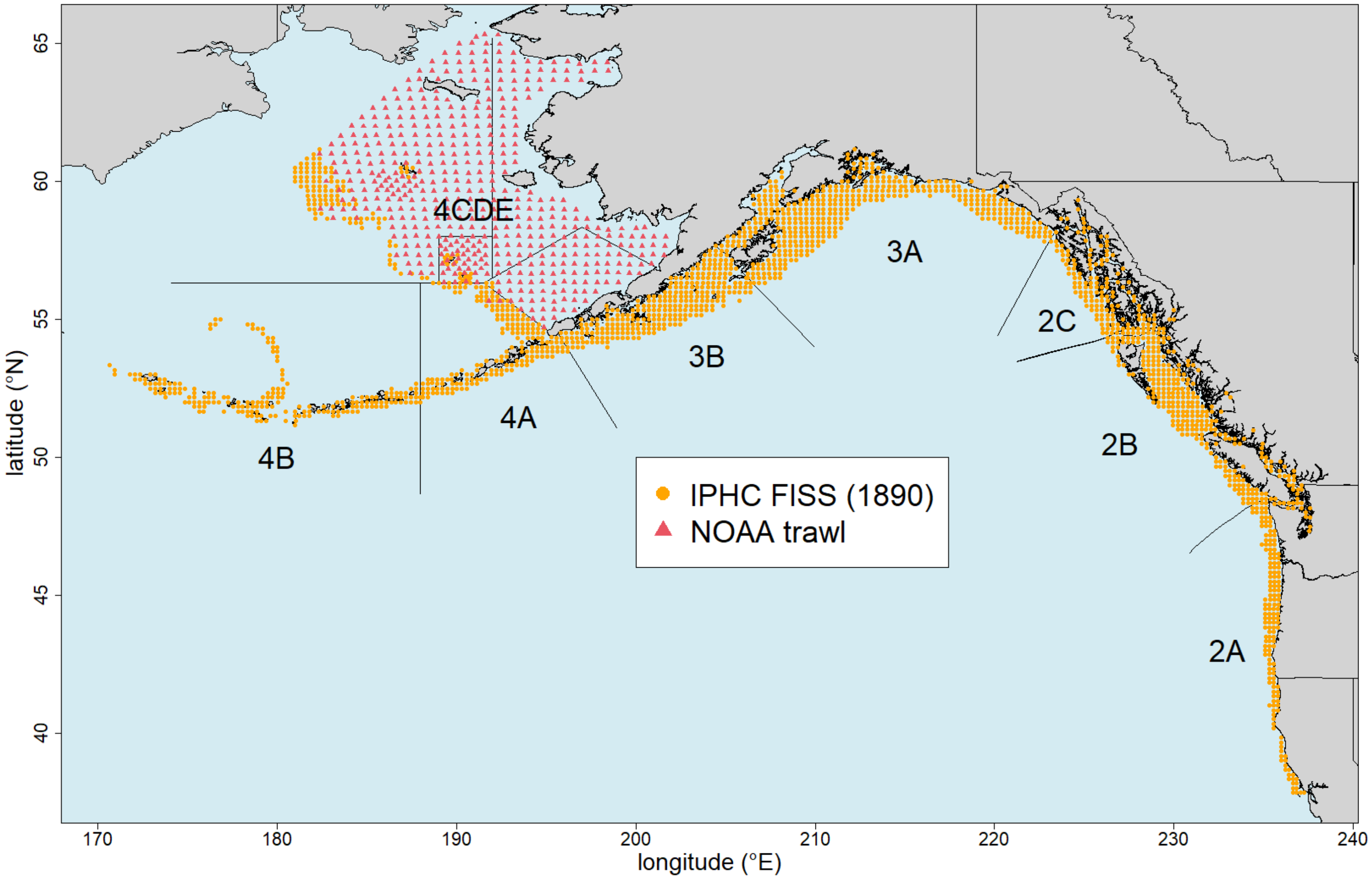


Figure 1. Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs. Red triangles represent standard locations of NOAA trawl stations used to provide complementary data for Bering Sea modelling (actual NOAA trawl design can vary year-to-year).

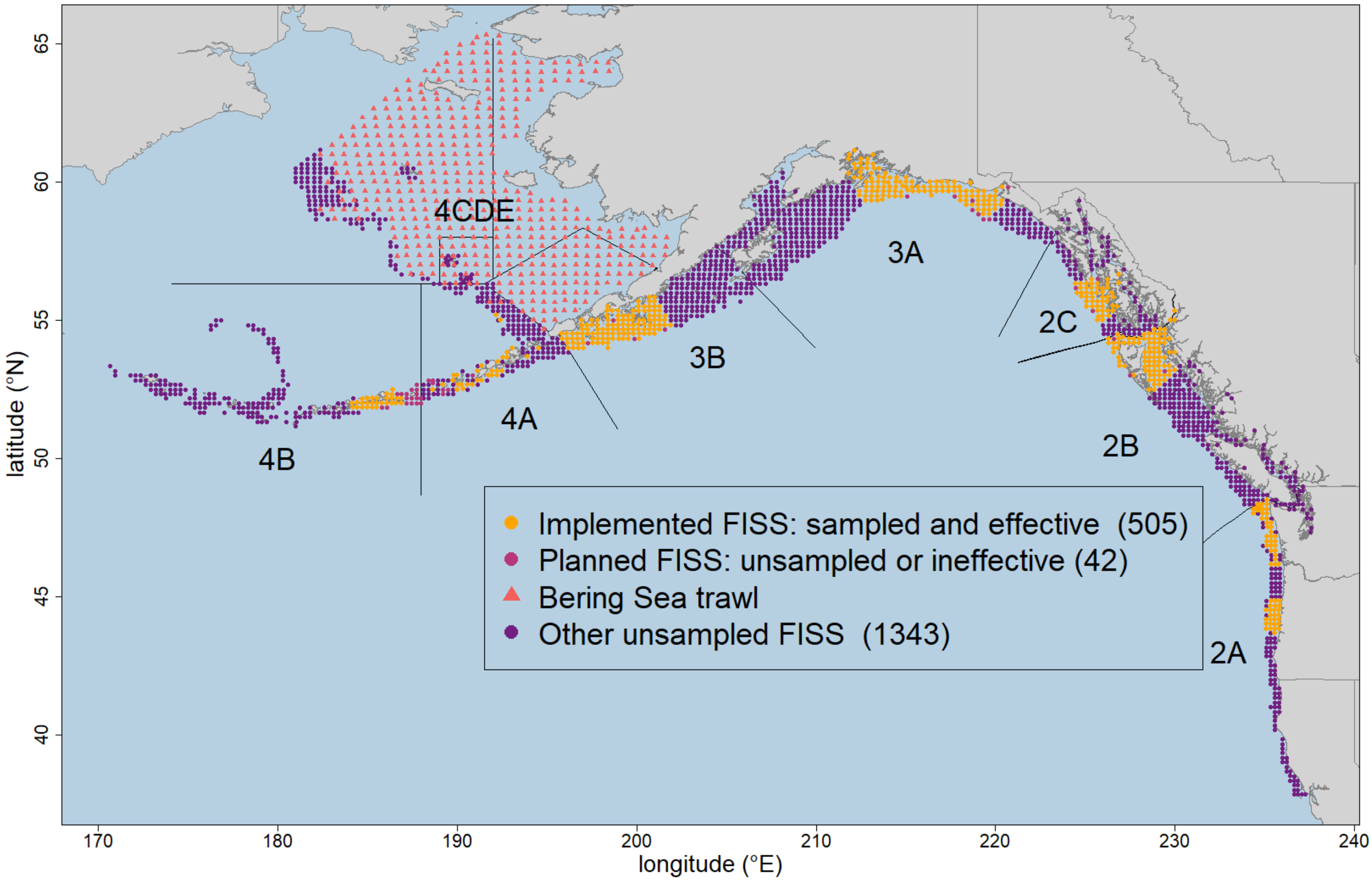


Figure 2. Map of implemented 2025 sampled FISS design showing sampled stations with data used in modelling (orange circles for FISS, red triangles for trawl), along with planned but ineffective FISS stations, FISS grid stations fished off grid as vessel captain stations and other unsampled FISS stations.

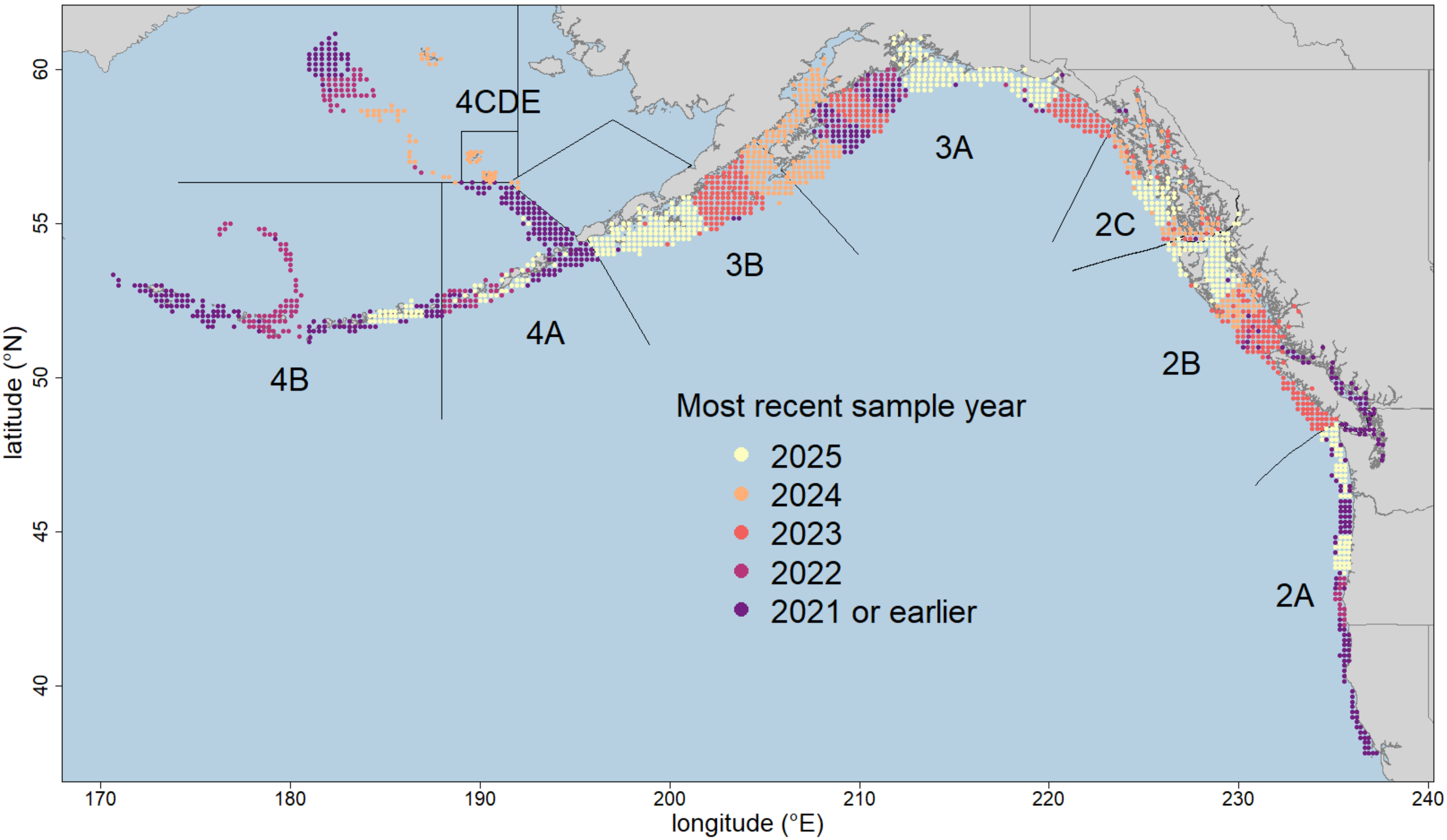


Figure 3. Map showing the most year that each station on the full FISS grid was successfully sampled.

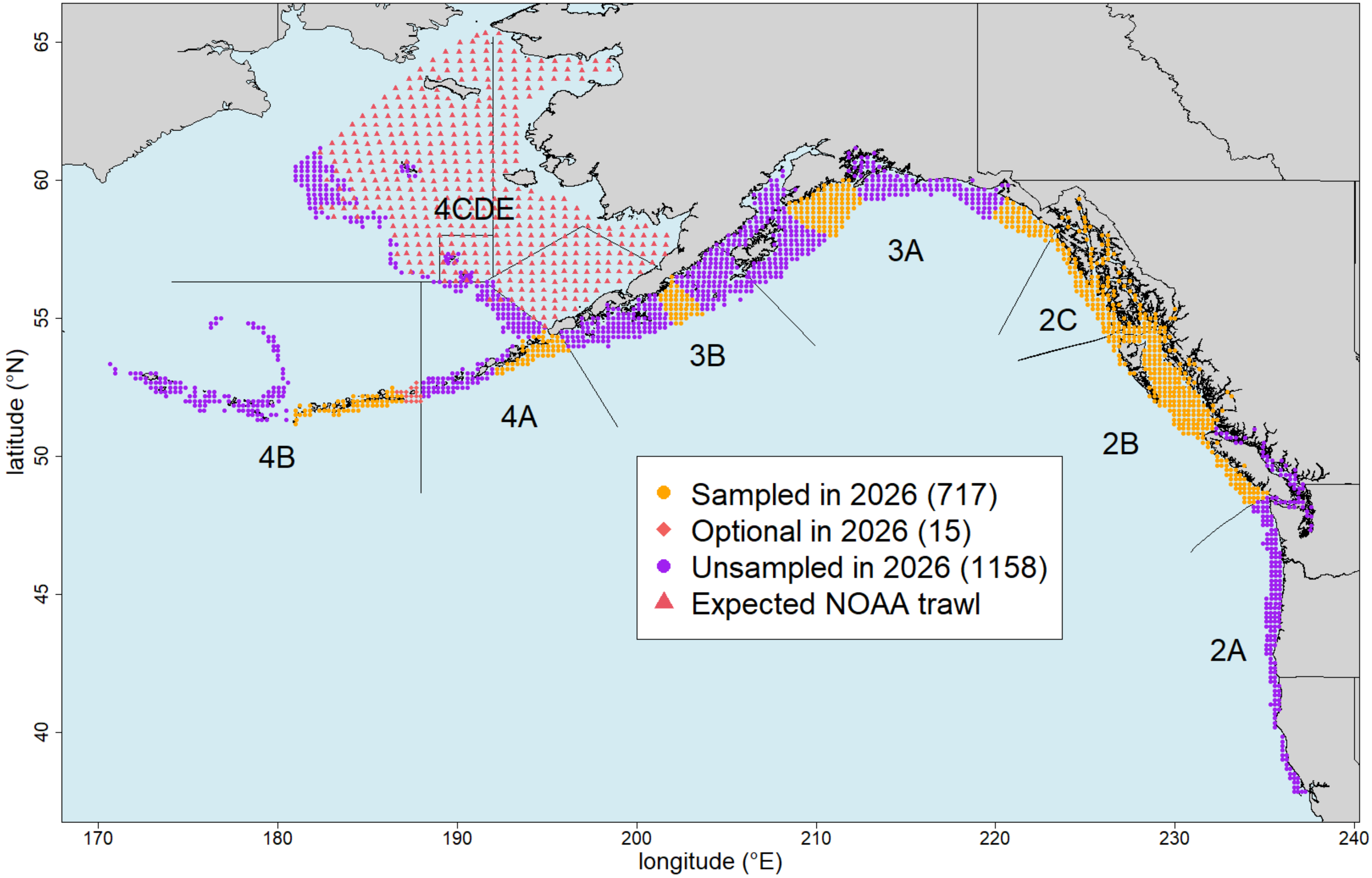


Figure 4. Adopted 2026 FISS design, with planned FISS stations shown as orange circles.

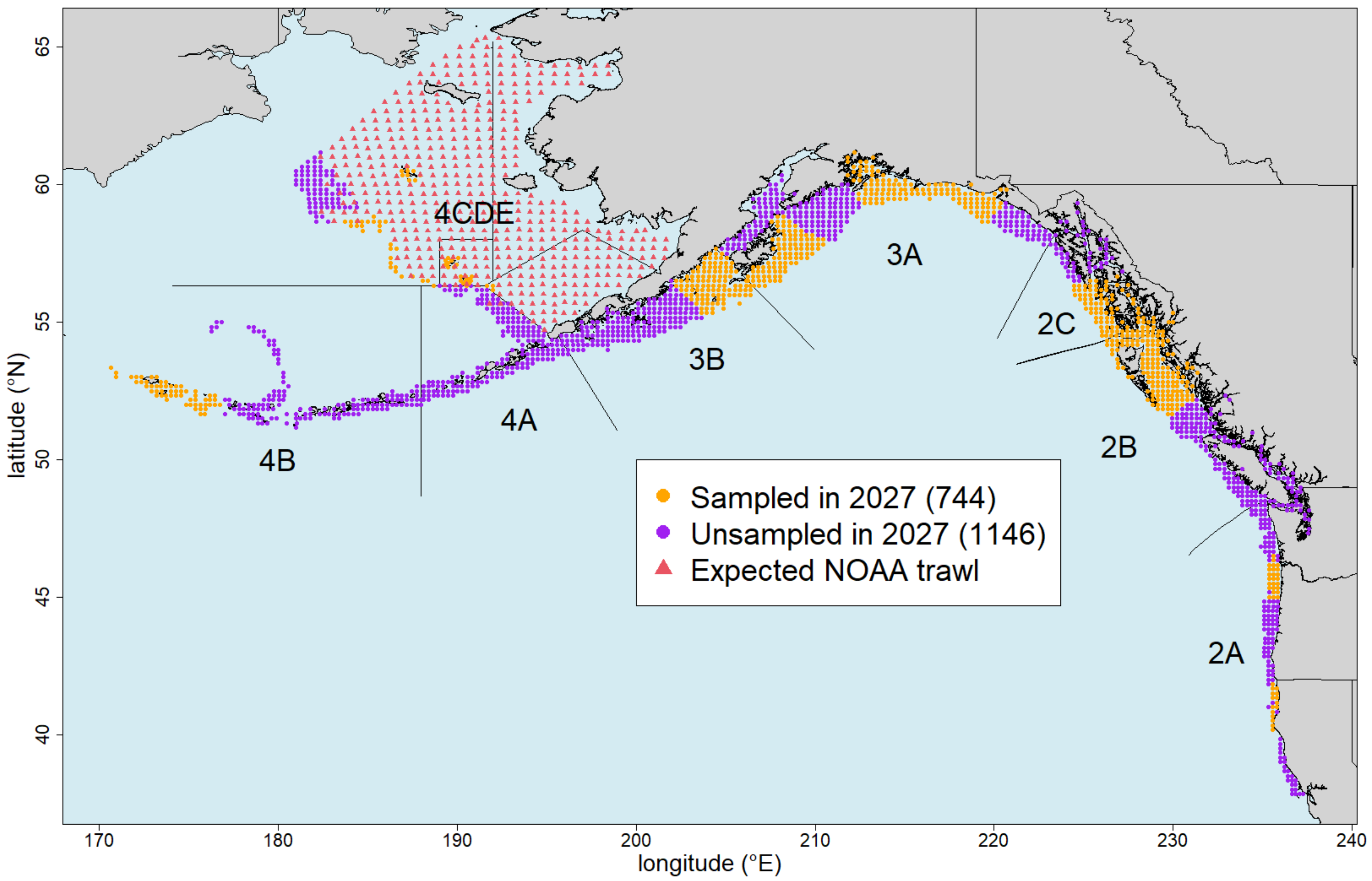


Figure 5. Base Block design for 2027 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

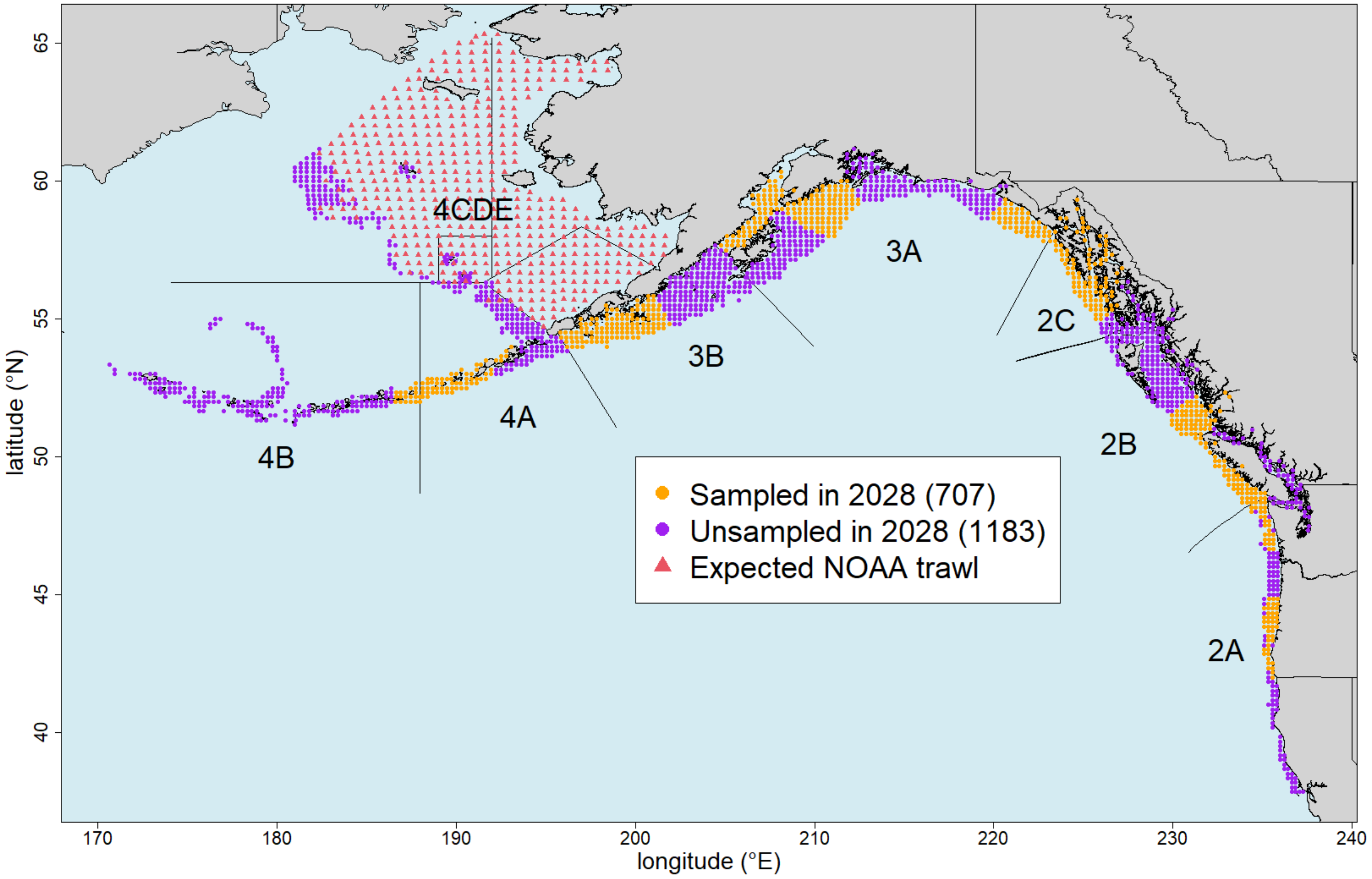


Figure 6. Base Block design for 2028 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

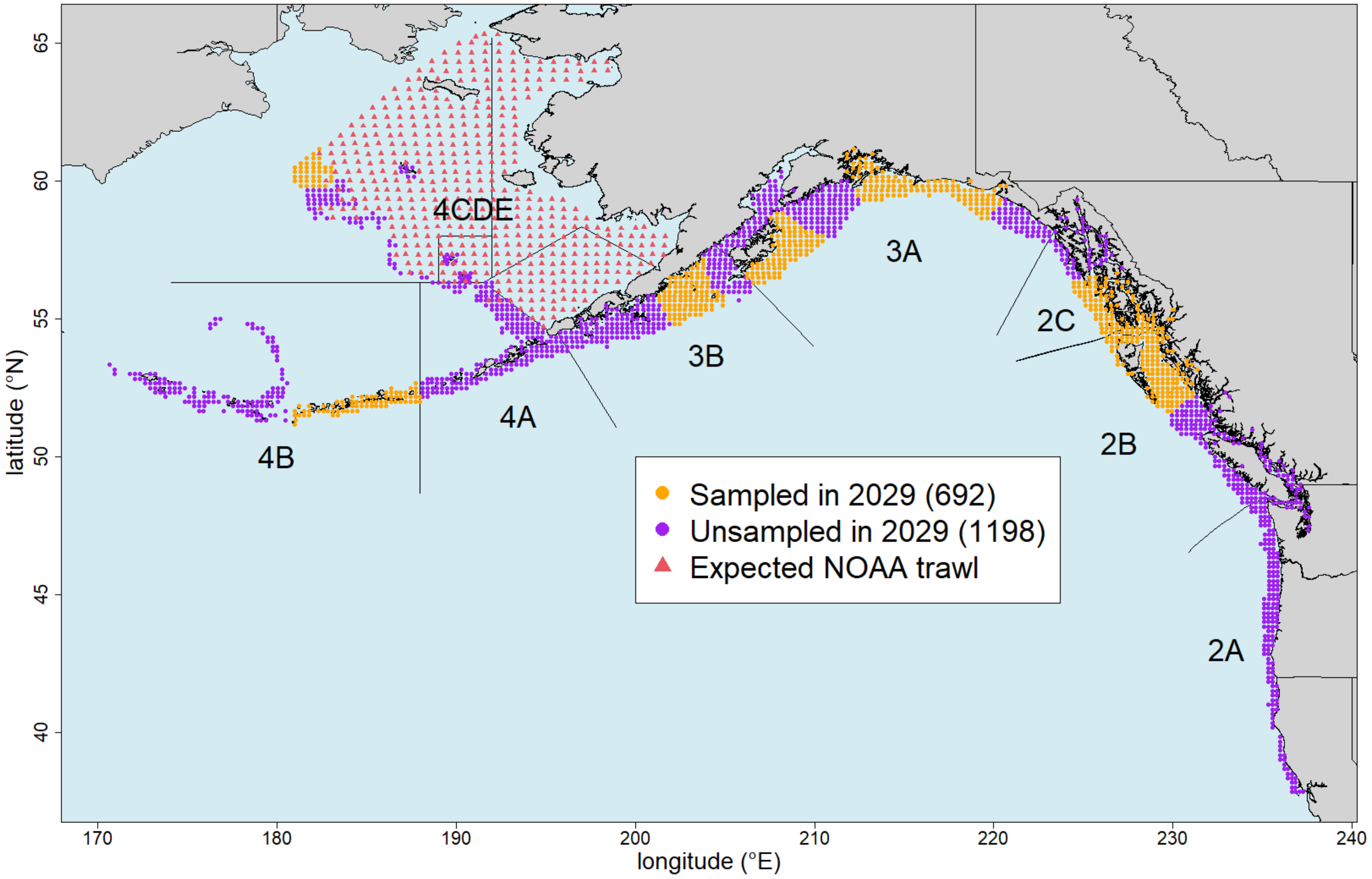


Figure 7. Base Block design for 2029 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

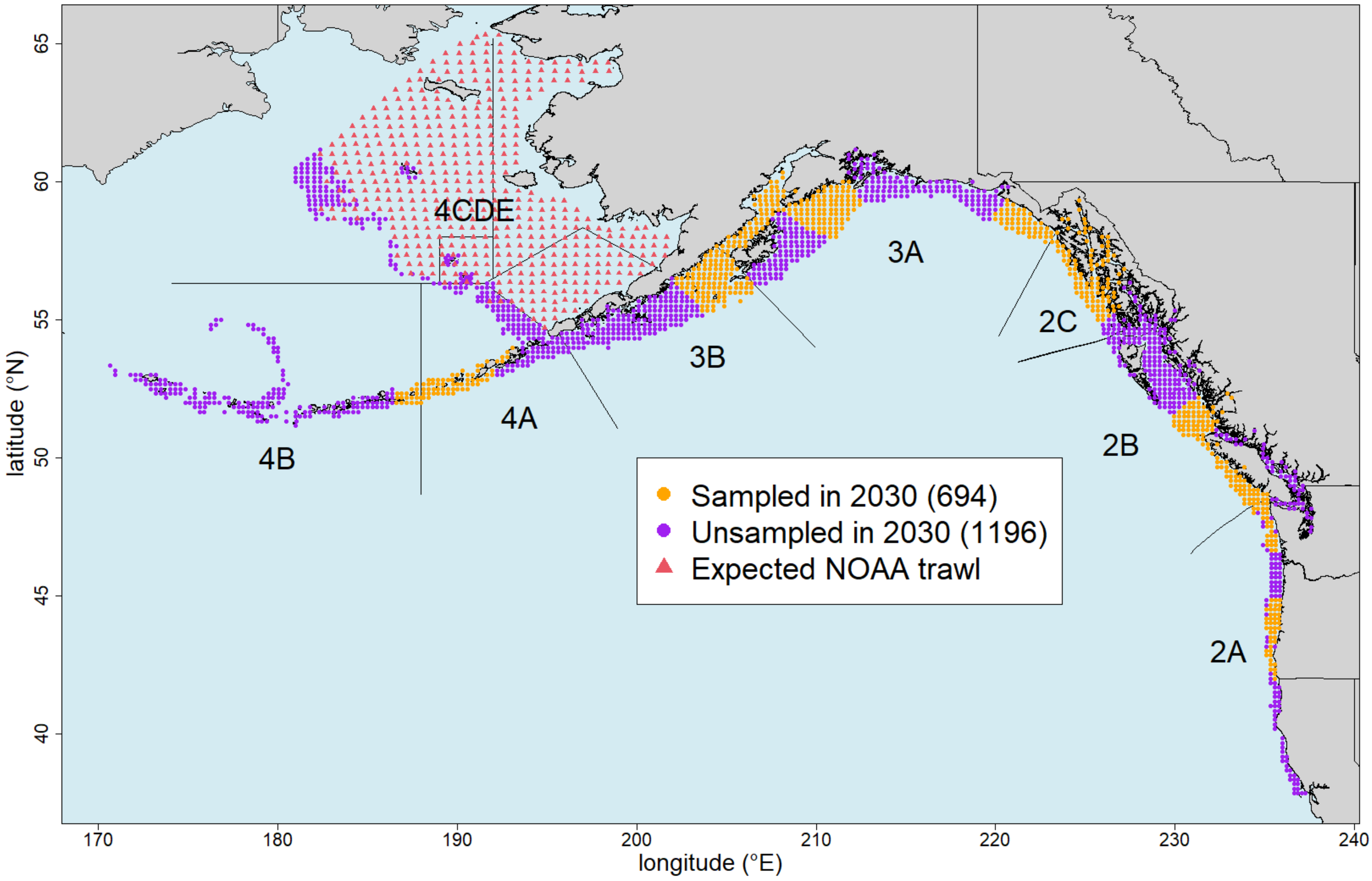


Figure 8. Base Block design for 2030 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

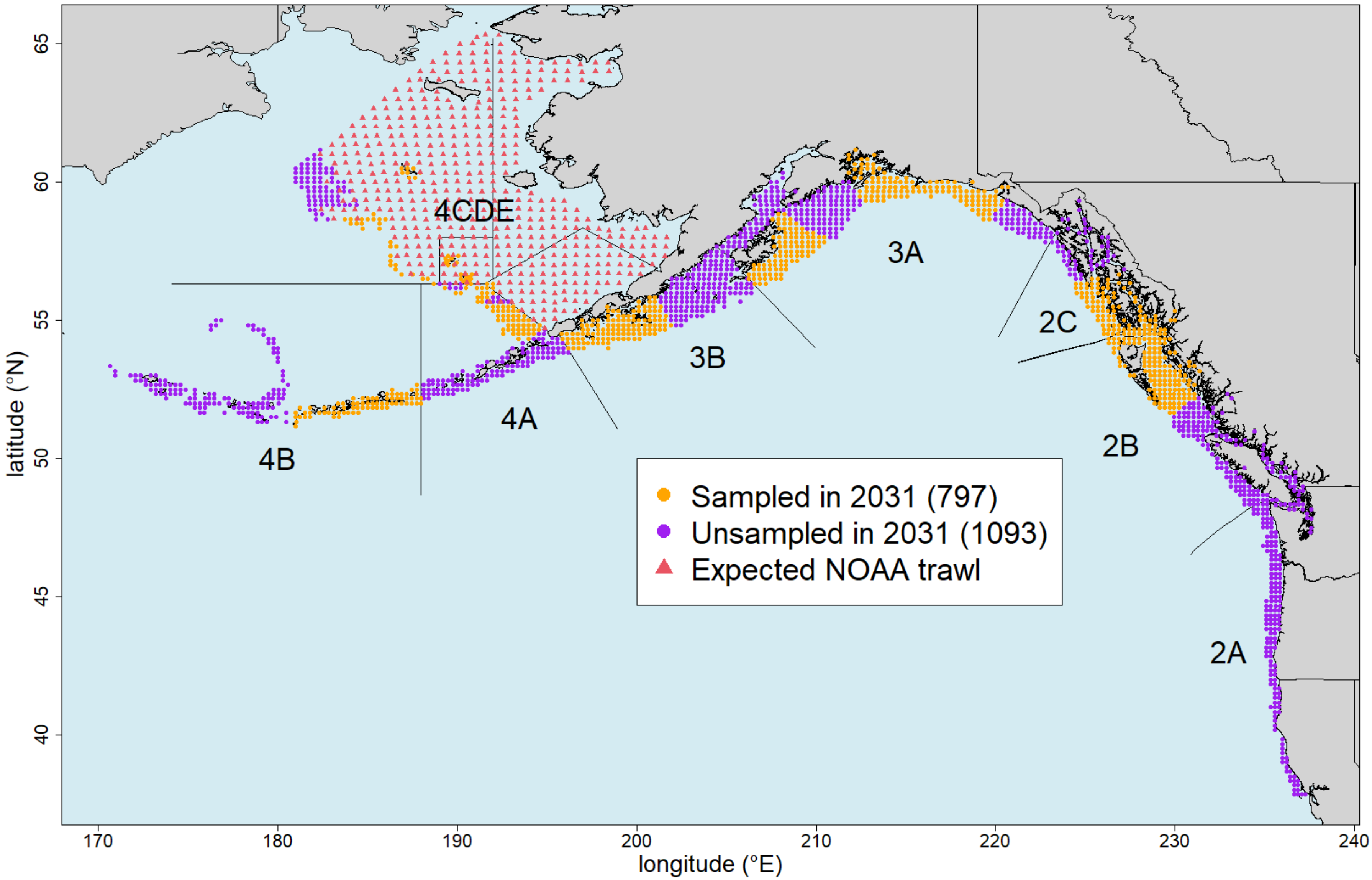


Figure 9. Base Block design for 2031 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

INTERNATIONAL PACIFIC HALIBUT COMMISSION

Using artificial intelligence (AI) for supplementing Pacific halibut age determination from collected otoliths – project update

PREPARED BY: IPHC SECRETARIAT (B. HUTNICZAK; 8 MAY 2026)

PURPOSE

This document summarizes current knowledge on the use of artificial intelligence (AI) for determining the age of fish from images of collected otoliths and provides an update on the ongoing exploratory work to develop an AI-based age determination model for Pacific halibut. The primary objective is to assess the viability of an AI-based approach as a supplement to existing Pacific halibut ageing protocols, while also identifying the remaining steps and requirements necessary for potential operational implementation.

The progress summarized in this document focuses on:

- Evaluating multiple components of the deep learning workflow for Pacific halibut age estimation, including model architectures, image preprocessing, weighting strategies, and training procedures.
- Evaluating the contribution of auxiliary biological and environmental covariates, through comparison of image-only and multi-input deep learning models integrating both visual and tabular data.
- Evaluating model temporal generalization by comparing age predictions from a model trained on images from one year to those from a different year.
- Evaluating model spatial generalization by comparing age predictions from a model trained on images from one area to those from a different area.
- Utilizing confidence intervals derived from deep ensemble techniques to assess the model's capability in identifying ambiguous or noisy samples.
- Demonstrating improvements in model performance associated with expansion of the image database from 2,799 (SRB026) to 11,107 otolith images.

UPDATES SUMMARY

Expanding image database

The IPHC continues to expand its otolith image database to support development and evaluation of deep learning approaches for Pacific halibut age estimation. Since the previous SRB meeting, the number of images available for model development has increased substantially, from 2,799 images to 11,107 otolith images used in the primary model runs. This increase in dataset size has improved representation across age classes, while also supporting more robust model training, evaluation, and testing of additional preprocessing and modelling approaches.

Cleaning pipeline

To evaluate whether removal of background information improves age prediction performance, a semi-automated image cleaning pipeline based on otolith segmentation was developed. First, a convolutional neural network with a U-Net architecture was trained to segment otolith regions from raw images using a limited set of manually annotated masks (approximately 200 images). The model was trained using a combination of binary cross-entropy and Dice loss to optimize both pixel-wise accuracy and region overlap, and standard data augmentation (including flips, rotations, and brightness variation) was applied to improve generalization.

Predicted segmentation masks were subsequently reviewed and corrected using a custom graphical interface, allowing manual refinement and exclusion of low-quality images. The final masks were then used to generate cleaned images by removing background pixels (set to white) and centering the otolith within the frame. As part of preprocessing experiments, grayscale conversion and contrast enhancement (CLAHE) were optionally applied within the segmented region. Images were finally resized to match the input resolution required by the age prediction model. This pipeline ensured that the downstream model was trained on images containing only the biologically relevant otolith structure, enabling a controlled comparison between raw and background-removed inputs.

Use of covariates

To assess the contribution of auxiliary biological and environmental information to model performance, parallel model variants were evaluated using identical image inputs. One model was trained using image data only, while a second model incorporated additional covariates alongside image features within a multi-input architecture. The covariates included geographic coordinates of capture (latitude and longitude), date of capture (expressed as day of year), and fish sex, where available. These variables were standardized prior to model input and processed through a dedicated fully connected branch, which was subsequently concatenated with features extracted from the convolutional backbone before final prediction. This design enabled joint learning from visual and tabular data while maintaining comparability between model variants. Performance differences between the image-only and image-plus-covariates models were therefore attributable to the inclusion of auxiliary information, allowing a direct evaluation of whether non-image features improved age prediction accuracy under otherwise identical training conditions.

Weights

To account for variability in the reliability of age determinations, a weighting scheme was applied during model training. Each image was assigned a weight proportional to the number of independent age readings conducted for the corresponding otolith, reflecting the confidence in the final age estimate. Higher weights were therefore assigned to samples with multiple consistent readings, while lower weights were applied to those based on fewer observations. This approach ensured that the loss function placed greater emphasis on more reliable labels, aligning model training with the underlying uncertainty in the age determination process.

Treating systematic negative bias at older age as an imbalanced-regression problem

Systematic underestimation observed in older age classes was addressed by testing an imbalanced-regression framework. Specifically, label distribution smoothing (LDS) was implemented following Yang et al. (2021), in which the empirical age distribution is smoothed using a Gaussian kernel to estimate an effective label density. Training samples are then reweighted inversely to this density, increasing the contribution of underrepresented older ages during model training.

In addition to LDS, feature distribution smoothing (FDS), as described by Yang et al. (2021), may be considered in future work for addressing imbalance. Unlike LDS, which operates on the label distribution, FDS aims to improve representation learning by smoothing feature statistics across adjacent target values during training. This is achieved by aligning feature representations of samples with similar target values using smoothed estimates of feature means and variances, thereby reducing noise and instability in sparsely populated regions of the target space.

Technical improvements

The latest model runs include a number of technical improvements. Image preprocessing was standardized through the use of model-specific normalization functions rather than simple scaling, ensuring compatibility with pretrained architectures. Additionally, data handling was refined by introducing seed-controlled shuffling and train–validation splitting, improving reproducibility across runs. The validation pipeline was also corrected by removing augmentation from the validation generator and disabling shuffling, allowing for more reliable performance assessment.

Testing spatial generalization

To evaluate the spatial generalization capability of the model, a targeted hold-out experiment was conducted using IPHC Regulatory Area as the spatial grouping variable. For each IPHC Regulatory Area, a fixed subset of 100 images was randomly selected and reserved as an independent test set. Two training scenarios were then implemented: (1) a spatial exclusion model, in which 2000 images excluding those originating from the focal IPHC Regulatory Area were randomly drawn for the training and validation sets, and (2) a control model, in which an equivalent number of images from all areas were randomly drawn for the training and validation sets to match sample size. Model performance was assessed on the held-out test subset using standard metrics including RMSE, MAE, R^2, and classification-based accuracy measures (e.g., exact match and within-one-year agreement). This design allowed for direct comparison between models trained with and without spatial representation of the test region, providing a structured assessment of the model's ability to generalize across geographic areas.

Latest results summary

Results:

1. In general, the use of covariates improved the predictive performance of the model, although the gain was relatively minor. Runs that included sex, coordinates, and date performed similarly to runs without sex, and in some cases resulted in lower MAE. Therefore, sex was not included in further testing, and variables that are readily available at the time of collection were prioritized.
2. Across RMSE, MAE, and R^2 metrics, standard images served as better inputs for training. Background cleaning, in some cases, resulted in a marginal increase in the percentage of predictions within a one-year tolerance, but grayscale conversion generally led to worse performance. Cleaned images, however, resulted in substantially faster training (24–30% reduction in runtime for runs with covariates).
3. Fine-tuning continues to provide substantial improvement to model generalization. For the selected primary run, predicting age for 2024 images using a model trained on 2019 otolith images resulted in a 24% higher RMSE. In contrast, when the model was fine-tuned on 20% of new images selected based on deep ensemble cross-validation, RMSE was only marginally higher (3%).

Results for individual model runs are available in Appendix B: Selection of model runs. Detailed evaluation and performance metrics for the selected best-performing model specification are presented in Preliminary results section and Appendix C: Deep ensemble individual results.

Spatial generalization results

The results of the spatial generalization experiment indicate that model performance is generally robust across Regulatory Areas, but the effects of excluding spatial information are not entirely consistent. In some areas (e.g., 2C, 4D, and, to a lesser extent, 3B), the control model that included data from the focal Regulatory Area in training produced slightly higher predicted ages (Figure 1) and, in many cases, marginally lower MAE (Figure 2), suggesting a modest benefit from incorporating local data. However, this pattern was not universal: in some regions (notably 2A and 3B), the spatial exclusion model performed slightly better, and differences between models were often small relative to the variability observed across training seeds. The seed-level distributions further highlight that between-run variability can overlap substantially with the effect of spatial inclusion, indicating that model uncertainty is of similar magnitude to the spatial effect itself.

This interpretation is limited by the experimental design. Only three random seeds were used per model–area combination, reflecting the large number of total runs required across nine Regulatory Areas[1] and two training scenarios. As a result, estimates of variability and central tendency are based on a limited number of realizations, and some of the observed inconsistencies may reflect stochastic variation rather than systematic spatial effects. Nonetheless, both models tended to preserve overall age structure across regions, with mean predictions remaining close to observed values, supporting the conclusion that the model captures broadly transferable otolith features. Taken together, these findings suggest that while there is some benefit to including Regulatory Area–specific data, the model demonstrates a reasonable capacity for spatial generalization, and performance degradation under complete spatial exclusion is limited and not consistently biased across all areas.

It is noted, however, that all IPHC Regulatory Areas are currently represented in the available dataset, and therefore the experimental design reflects a hypothetical scenario in which data from a given Regulatory Area are entirely absent. As such, the results should be interpreted as an assessment of potential model performance under conditions of incomplete spatial coverage, rather than a direct reflection of current operational limitations. In contrast, temporal generalization represents a more critical consideration, as models would ideally be available for routine application to new-year data for which no contemporaneous training data are available.

Figure 1: Spatial generalization results - manually derived age vs. model predictions (seed-level).

---

[1] Training data were not available for Regulatory Area 4E.

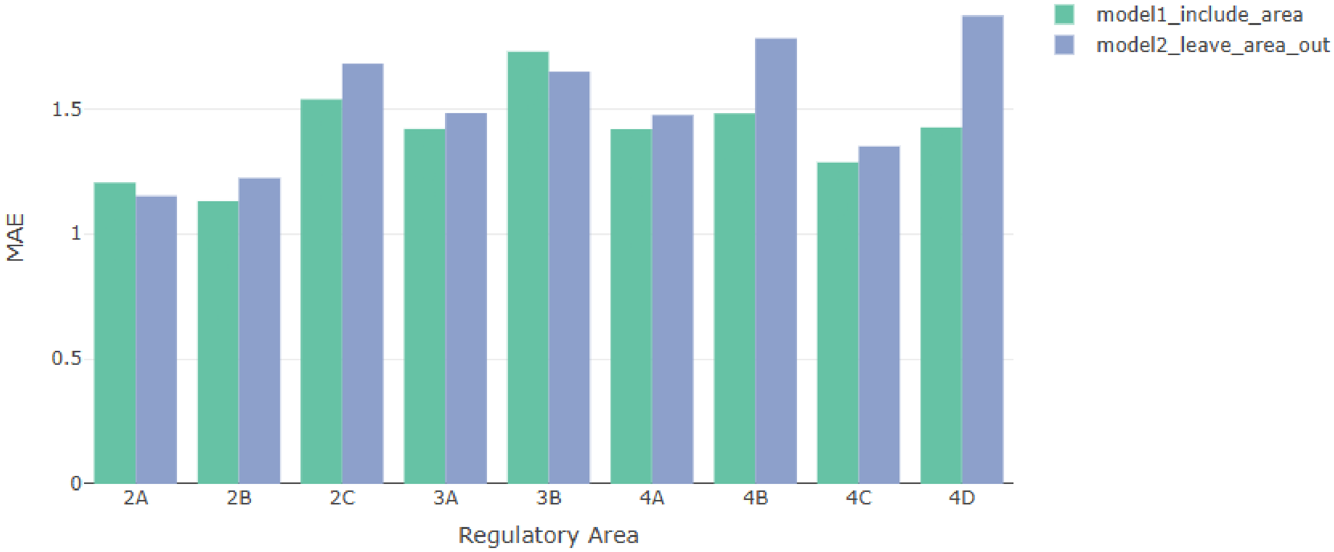


Figure 2: Spatial generalization results - mean average error (MAE) by Regulatory Area and model.

Evaluation of Label Distribution Smoothing

A model version incorporating label distribution smoothing (LDS) was evaluated in an attempt to reduce the tendency of the model to underpredict older Pacific halibut ages. The approach increased the weighting assigned to sparsely represented age classes, effectively encouraging the network to prioritize accurate prediction of relatively few older individuals during training. However, this implementation substantially reduced overall predictive performance, with test-set RMSE increasing to 5.1725 compared to 1.7921 for the standard setup using covariates. The results suggest that the LDS weighting strategy over-corrected for age imbalance, causing the model to fit a limited number of difficult and potentially noisy older-age samples at the expense of broader generalization across the dataset. Given the comparatively small sample sizes and greater uncertainty typically associated with older otolith ages, the weighting scheme likely amplified noise rather than biological signal. Consequently, the resulting performance fell outside the range considered operationally useful for ageing. Although the present implementation was unsuccessful, additional investigation of imbalance-aware learning approaches, including less aggressive weighting schemes or alternative calibration strategies, may still be warranted in future work.

BACKGROUND

Otoliths are crystalline calcium carbonate structures, mostly in the form of aragonite, found in the inner ear of fish. They contain growth rings, that are often compared to tree growth rings. By analyzing the growth patterns in otoliths, scientists estimate the age of fish (Campana, 1999; Campana & Neilson, 1985), supporting the estimation of fish population demographics and population dynamics (Campana & Thorrold, 2001). In turn, fish age is a key input to stock assessment models that inform management decisions related to fish exploitation (Methot & Wetzel, 2013). It is estimated that the number of otoliths from captured fish that are read annually worldwide is on the order of one million (Campana & Thorrold, 2001).

The current method for determining ages of most fish species relies on manually extracting, preparing (embedding, sectioning), and reading otoliths. The simplest approach to reading the otolith is to immerse it in a clear liquid, such as water or alcohol solution, illuminate it from above, and view it against a dark background, using a stereo microscope. This method is suitable only for otoliths that are relatively thin with all annual bands visible from the surface. For species such as Pacific halibut, as the growth rate of the fish slows down, the outer growth bands become increasingly compressed and difficult to read from the surface of the whole otolith. To correctly determine the number of annual bands in such cases, otoliths are typically viewed in cross section which allows viewing the bands that are not visible from the surface view. In addition, the contrast between the growth rings can be enhanced through the baking process. Pacific halibut otoliths are aged using the ‘break and bake’ technique.

This manual ageing process is expensive, time-consuming,[2] and can be subject to bias[3] as well as imprecision due to variations in age estimations between readers and within readers over time. Recent advances in imaging technologies and machine learning suggest that AI can assist in this process by automating the analysis of otolith images[4] and identifying and measuring the growth rings to determine age. AI algorithms can be trained on a large dataset of otolith images with known ages to learn the patterns and variations in growth rings. Once trained, the AI model can analyze new otolith images and predict the age of the fish based on the identified patterns in the image.

Using AI for age determination of Pacific halibut could improve consistency and replicability of age estimates, as well as provide time and cost savings to the organization, providing age data for reliable management advice. However, it's important to note that the AI model's accuracy depends on the quality and diversity of the training data, as well as the expertise of the scientists involved in training and validating the model. Regular validation and calibration with manual age determinations may be necessary to ensure the accuracy and reliability of the AI predictions. Thus, the proposed approach explores integrating AI-based age determination and traditional ageing methods for maximum accuracy of the estimates.

MODEL

Model framework

The proposed model framework (Figure *3*) includes a continuous process of training the model using available labelled data (aged otoliths), querying the model to select the next sample, labeling or relabeling the selected sample, and enriching the model with newly labelled samples.

This model relies on automatized ageing that is supplementing the expert-derived age estimates continuously improving the model in the *Label* phase and the *Enrich* phase.

---

[2] While the actual reading may account only for a fraction of the total cost and time required to process the otolith from collection to age determination, skilled readers require years of training, which should be considered when conducting a cost-benefit analysis.

[3] While the count of annual rings on Pacific halibut otoliths was found to provide unbiased age estimate using validation against bomb radiocarbon isotopes (Piner & Wischniowski, 2004), an earlier oxytetracycline (OTC) mark-recapture study indicated biases among age readers (Blood, 2003). In the 1980s, the IPHC applied injections with the antibiotic oxytetracycline (OTC) during routine tagging operations to evaluate validity of ageing method (IPHC, 1985). Upon injection, the OTC is absorbed by the fish's bony structure, including the otoliths, and leaves a mark that is easily seen when viewed under an ultraviolet light. When an OTC-injected tagged fish is recovered, the otoliths are removed and examined under the ultraviolet light. By comparing the number of annuli laid since the OTC mark to the fish recovery, the accuracy of the age readings can be determined.

[4] Although the idea of taking pictures of Pacific halibut otoliths is not new. See 1960 report by G. Morris Southward, *Photographing Halibut Otoliths for Measuring Growth Zones* (Southward, 1962).

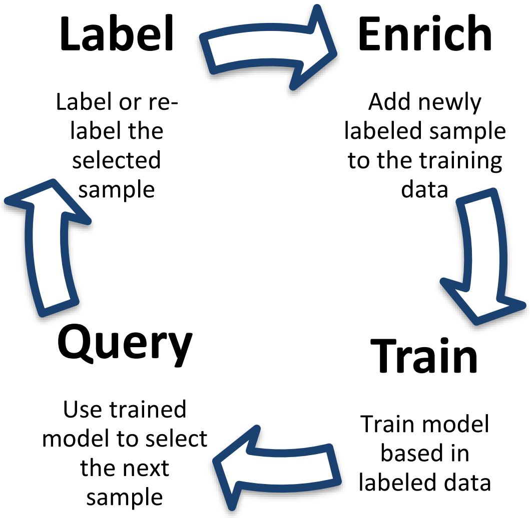


Figure 3. Model framework.

Modeling approach

Previous literature (see perspective piece by Malde et al., 2020) suggests adapting a pre-trained convolutional neural network (CNN) designed for image classification to estimate age using otolith images obtained via microscope camera. This type of model is trained on a large collection of images of otoliths previously aged by human readers. Moen et al. (2018) presents the first case of the use of deep learning and CNN to estimate age from images of whole otoliths of Greenland halibut (*Reinhardtius hippoglossoides*).[5]

Artificial neural networks (ANNs) are computational structures inspired by biological neural networks. They consist of simple computational units referred to as neurons, organized in layers. The neuron parameters (or weights) are estimated by training the model using supervised learning. This process consists of two steps: forward propagation, where the network makes a prediction based on the input; and back propagation, where the network learns from its mistake by calculating the gradient of a loss function, and then uses the gradient to update the neuron weights. The ANNs approach has been used for fish ageing by Robertson & Morison (1999) and Fablet & Le Josse (2005) with a limited success.

The neural networks approach significantly improved in recent years with the increase in the number of layers, applying an approach often referred to as deep learning. Deep learning neural networks are known for their generality. With sufficient training data, they can be used to classify raw data (e.g., an array of pixels) directly, without explicit design of low-level features. The deep learning algorithm lower layers learn to distinguish between primitive features automatically, typically identifying sharp edges or color transitions. Subsequent layers then learn to recognize more abstract features as combinations of lower layer features, and finally merge this information to provide a high-level classification.

In CNNs (LeCun et al., 1998; Simonyan & Zisserman, 2015), the layers are structured as stacks of filters, each recognizing increasingly abstract features in the data. Convolutional layers may be understood as an efficient way to transform an input image into another image, highlighting meaningful patterns, learned from data during training. The training is sequential, meaning the output of each layer is the input of the next layer, and the useful features are learned in the

---

[5] CNN was also applied for other tasks related to fisheries management, e.g. fish species identification (Allken et al., 2019).

various layers during training. This approach is very effective for many image analysis problems, where objects are often recognized independent of their location. During network training, the performance is monitored over sequential epochs. Epochs represent the number of times that the training dataset is passed forward and backward through the network to refine model weights. Whenever the validation loss decreases, the trained model is saved, ending up with the network that corresponds to the minimum loss and highest accuracy on the validation set. The trained network is then evaluated on the testing set.

In the CNN model, age prediction from otolith images can be formulated either as a classification task - where age is treated as a categorical variable - or as an image regression task, which involves predicting a continuous numerical value. Although treating fish age as a discrete parameter is a common method for identifying individual year classes, i.e., grouping fish by spawning year (Moen et al., 2018), this approach has proven less effective for Pacific halibut. As a long-lived species with a wide distribution of age classes, Pacific halibut pose a challenge for classification-based methods. The oldest Pacific halibut on record have been aged at 55 years (Keith et al., 2014).

Software and model architecture options

The proposed approach builds on prior work by Moen et al., (2018) and Moore et al., (2019), who implemented CNNs for otolith-based fish age estimation using the TensorFlow and Keras libraries. TensorFlow remains one of the most widely used and well-supported frameworks for deep learning, and Keras provides a high-level API that simplifies TensorFlow model development.

The approach utilizes a transfer-learning technique to develop a CNN for otolith age estimation. Transfer learning is the process of repurposing a machine learning model that has been pre-trained for another, related, task. Specifically, it starts with the InceptionV3 model from Google, pre-trained on the ImageNet database. ImageNet database contains over 14 million annotated images classified into 1,000 categories. By loading CNN layers with publicly available pre-trained weights rather than random initialization, transfer learning significantly enhances model performance.

To adapt this model specifically for Pacific halibut ageing, modifications included scaling the input layer to match otolith images' resolution[6] and changing the output from multi-dimensional class probabilities to a single numeric output for regression.[7] Thus, the architecture employed follows the pattern: Input → InceptionV3 (feature extractor) → Regressor → Output, optimized

---

[6] Resolution is the total number of pixels along an image's width and height, expressed as pixels per inch (PPI). The Inception v3 model processes images that are 299 x 299 pixels in size. The original images (2548 × 2548 pixels) were first resized to 400 × 400 pixels prior to input into the model. This intermediate resizing step preserves more visual detail than a direct downscaling to 299 × 299 and allows for subsequent data augmentation operations (such as cropping, flipping, or rotation) to be applied more effectively before the final resize to the model's required input size.

[7] Alternatively, Politikos et al. (2021) replaced the last layer with a feed-forward network with two hidden layers replacing the default 1000-categories output layer with a fully-connected layer with six hidden nodes, corresponding to a limited number of age categories [Age-0 – Age-5+], with the last one representing fish of age 5 and older, In this case, the network outputs probabilities using the softmax function, a function that performs multi-class classification and transforms the outputs to represent the probability distributions over a list of potential outcomes. The IPHC uses in its stock assessment bins Age-2 – Age 25+ for the current age data and Age-2 - Age-20+ for the historical surface read ages. The adoption of a larger number of age categories prompted the decision to incorporate a regression layer in place of class probabilities.

using stochastic gradient descent (SGD) to minimize mean squared error (MSE) between model predictions and expert annotations.[8]

A similar approach, although adopting classification approach, was applied for ageing Greek Red Mullet (*Mullus barbatus*) (Politikos et al., 2022) and the associated code is available on GitHub (github.com/dimpolitik/DeepOtolith). The available open-source code was adapted to test the approach for Pacific halibut.

In addition to the InceptionV3 architecture, alternative architectures continue to be explored to identify potential improvements in predictive performance and computational efficiency. These include EfficientNet variants (EfficientNetB4, EfficientNetB5, EfficientNetV2 M/L) and ConvNeXt. EfficientNet architectures are known for their balanced approach to scaling depth, width, and resolution, optimizing computational efficiency and accuracy. EfficientNetV2 further refines this by introducing progressive training and improved scaling techniques. ConvNeXt architectures, inspired by transformer models, incorporate modifications to convolutional structures, achieving competitive accuracy with a simplified design and potentially improved model interpretability.

However, given previously reported underperformance of alternative architectures (IPHC-2025-SRB026-10), the current update focuses primarily on results derived from the InceptionV3 implementation. Despite their advanced theoretical advantages - such as better scalability, computational efficiency, and deeper learning capabilities - EfficientNet and ConvNeXt models underperformed relative to the simpler InceptionV3 architecture. Several configurations of EfficientNet and ConvNeXt exhibited limited learning, with predictions regressing toward the mean age of the test dataset. This outcome suggests that these more complex models struggled to extract meaningful age-related features from the otolith images, likely due to a combination of insufficient training data and overfitting driven by model complexity.

In contrast, the InceptionV3 architecture consistently produced more accurate and stable predictions, indicating that its comparatively simpler structure may currently be better suited to the available dataset size and image variability. Furthermore, the improvements achieved through additional refinements presented in this update suggest that there remains considerable opportunity for further optimization within the InceptionV3 framework itself.

TensorFlow/Keras has been the primary framework used in the current implementation. However, future work may explore alternative frameworks such as PyTorch (originally developed by Meta), which offers flexible dynamic computation graphs and growing adoption in the deep learning research community.

Performance metrics and achieved accuracy

Performance of the CNN to correctly assign ages (rounded output of the regression layer) to otolith images in the test set is assessed via the root mean squared error (RMSE), mean average error (MAE) and the percentage of correctly predicted ages, as well as predictions within ±1 year tolerance. Moen et al., (2018) also suggest calculating coefficient of variation (CV).[9]

Moen et al., (2018), for Greenland halibut, achieved MSE for the left and right otoliths and pair of 3.27, 2.71 and 2.99, respectively. Age was correctly estimated for 48 out of the 164 tested otolith-pairs (29%). In addition, 63 cases (38%) were estimated to be one year off the read age.

---

[8] In practice, the neural network minimizes the MSE of normalized age values, i.e., age values divided by the maximum age provided as input.

[9] The CV of the predicted age at true age is the primary input to the IPHC stock assessment. It is generally modelled as a parametric function of age accounting for the complex joint probability that both estimates can be incorrect (Punt et al., 2008).

There was also a clear tendency for the system to predict a lower age for older individuals, when compared to human readers. The variance of the predictions also increased with the age of the otolith.

The model developed by Moore et al. (2019), for prediction of age of snapper using CT scans,[10] gave the same age as the human reader for 47% of otoliths in a test dataset, with a further 35% of ages estimated within 1 year of the human reader estimate of age (n=687). For hoki, the model gave the same age as the human reader for 41% of individuals (n=882).

The age model for Greenland halibut by Politikos et al., (2022) gave RMSE of 1.69 years between age prediction and age reading by experts (n=8,218, 26 age categories). For Greek red mullet, correct age was predicted for 69.2% individuals, with an additional 28.2% being within 1 year of error (n=5,027).

Benson et al., (2023), using near-infrared spectroscopy of otoliths, supplemented by geospatial and biological data routinely collected on the survey, estimated age of walleye pollock. For the optimal multimodal CNN model, an RMSE of 0.83 for the training set and an RMSE of 0.91 for the test set indicated that at least 67% of estimated ages were predicted within ±1 year of age compared to traditional microscope-based ages.

However, it should be noted that neither the traditional ageing methods for Pacific halibut are perfectly accurate. Within- and between-reader agreement in age assignment is generally 60%-70% complete agreement, 80% to 90% within one year, and 100% within 3 years. The IPHC Secretariat's publications report on % agreement (see *Technical Report No. 46* and *No. 47*).

Database

The IPHC annually ages a considerable number of otoliths (see *Appendix A* for details). Since 1925, over 1.6 million otoliths have been aged and stored for potential future use. Otoliths collected by the IPHC for ageing purposes undergo additional processing. Otoliths are sectioned (broken in half) and baked to enhance the contrast between the growth rings. These stored and previously aged otoliths serve as a valuable resource for creating a database of images for training purposes. To optimize model training, the selection of otoliths included in the model covers a broad spectrum of fish sizes, ages, sexes, and collection locations.

Before photographing, processed otoliths were placed in a monochrome tray featuring an elongated groove designed to keep the otolith upright and immersed in water. The pictures were taken with AmScope 8.5MP eyepiece cameras,[11] under consistent lighting conditions and magnification. The input database includes images of standardized size, 2,548 by 2,548 pixels, which are later resized to the desired resolution based on the model's specification.[12]

---

[10] CT scanning uses X-ray technology to produce image slices through objects, which can be reconstructed into virtual, three-dimensional (3D) images that can be rotated and viewed in any orientation (Moore et al., 2019). Such images may provide more accurate estimates, but the cost of this approach is prohibitive at (based on trial conducted in New Zealand) $1,500 per day, with scan timed for an individual otolith between 40 min to one hour. However, as the technology progresses, this approach may provide an option for fully automating the entire ageing process by scanning a whole fish (e.g., along a conveyor belt). Deep learning methods (i.e., CNN) developed for age determination from surface images could serve as a base for age determination from CT scans.

[11] The camera fits in one of the microscope eyepieces, eliminating the need to purchase a separate camera mount for the microscope.

[12] Moen et al. (2018) used images 400 by 400 pixels, which required the input layer to be scaled to match the Inception V3 requirements (299 by 299 pixels). Ordoñez et al. (2020), using the same set of images, built a CNN with images resized to 224 by 224 pixels, the default input of the VGG-19 model. Higher resolution images offer the flexibility to adapt the model in the future to more detailed and complex image analysis tasks, potentially improving the accuracy and effectiveness of image recognition capabilities.

It is important to note that it may not be necessary to image the otoliths at resolutions sufficient for human viewers to resolve, because the CNN may be able to arrive at an age estimate without directly counting bands (Moore et al., 2019).

Figure *4* shows an example of a range of images used in the CNN training dataset.

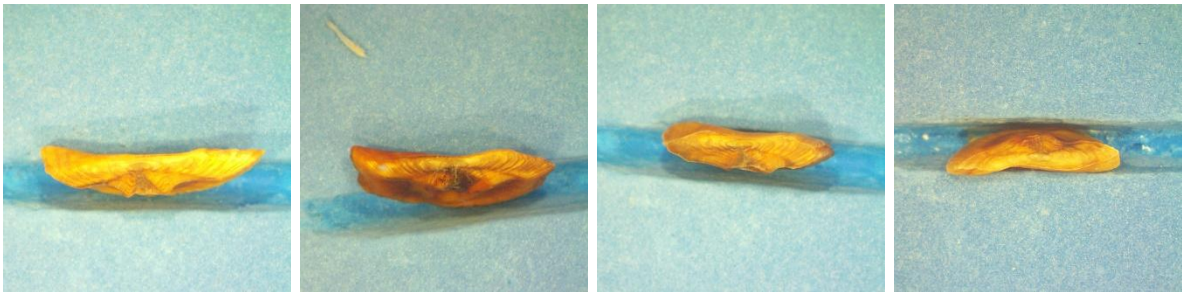


Figure 4. Examples of Pacific halibut otolith images taken for inclusion in the training set.

In addition, the IPHC is in the process of creating complementary database comprising labelled images of otoliths captured prior to processing to conduct a cost-benefit analysis of using processed versus unprocessed otoliths for AI-based age determination. Example images are provided in Figure *5*. In their research, Politikos et al. (2022) utilized digital images of otoliths that were not subject to any additional processing in the laboratory, immersed in water and placed under a stereomicroscope on a white background with transmitted light. However, it is important to note that even if results indicate that breaking and baking is not necessary for age determination using AI, a subsample chosen for the Label and Enrich phases would have to be fully processed for age determination with traditional methods by an expert reader.

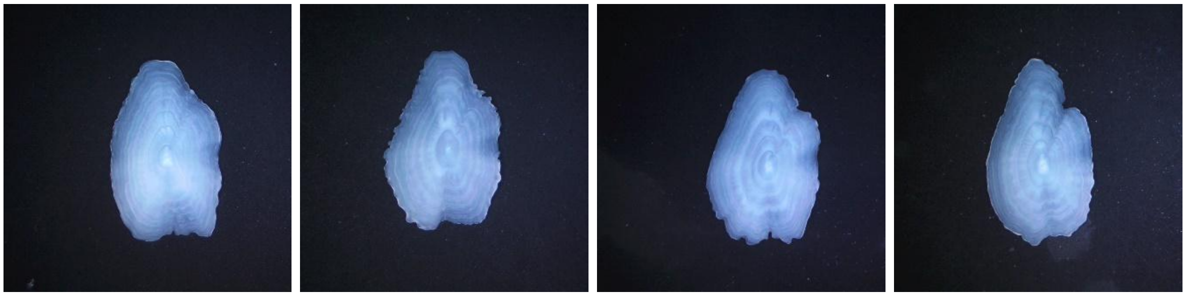


Figure 5. Examples of Pacific halibut otolith images taken for inclusion in the training set.

Presorting otoliths

The adopted procedure excludes broken otoliths, applying manual presorting at the image-taking stage. Presorting has also occurred at the collection stage when crystalized otoliths[13] are omitted when collecting samples.

Ongoing research [Dimitris Politikos, personal communication] is investigating the initial stage of the aging process, specifically assessing whether an otolith is of sufficient quality for age determination. This research is relevant for cases involving crystallized or broken otoliths and aims to potentially eliminate the need for subjective decisions by samplers regarding the usability of otoliths for age determination. This approach implements a two-stage classification system. In the first stage, the model assesses the otolith's suitability for ageing; in the second, it

---

[13] Crystalized otoliths have an altered composition – specifically, where the aragonite in the otolith is partially or mostly replaced by vaterite, a phenomenon known as otolith crystallization. Crystallized otoliths are not suitable for ageing.

determines the age. Th algorithm-driven presorting could also incorporate expert knowledge for handling problematic otoliths.

In developing the model, the training dataset can be strategically supplemented with images of samples that represent a group of otoliths with which the original model struggles the most (Query phase).[14]

Image collection

The image collection is associated with labels storing:

1. Otolith reference number – using referencing system already in place;
2. Image name and location – exact path for image access;
3. Resolved age – human reader derived age (**rsvage**);
4. Year collected – to account for variation between cohorts and prevalent environmental conditions;[15]
5. Date collected – to account for the 'edge effect' reflecting seasonal changes;
6. Geospatial characteristics of the collection site (latitude, longitude and IPHC Regulatory Area) – to capture regional variation;
7. Resolved sex – to determine whether otolith characteristics (possibly not directly visible to human eye) could be used for sex determination.[16]

Uncertainty estimates

To further refine accuracy in a production setting, a mixed-method approach can be applied. This approach involves selecting a subset of otolith images (e.g., 10%, 20% or 50%) for ageing by human experts, with selection guided by model-derived uncertainty estimates. Under this framework, images associated with high predictive uncertainty would be prioritized for expert review, while high-confidence predictions could be processed automatically. Newly validated samples could subsequently be incorporated into the training dataset for annual fine-tuning, enabling targeted and resource-efficient model improvement over time.

In practice, this strategy would allow human experts to focus on "difficult" otoliths, while automating the processing of comparatively "easy" samples with high model confidence. Such a hybrid workflow has the potential to improve throughput without compromising the accuracy and consistency necessary for applications such as stock assessment, where minimizing systematic bias is critical.[17]

Several approaches were considered for quantifying model uncertainty, including Monte Carlo dropout (Gal & Ghahramani, 2016) and deep ensemble method (Lakshminarayanan et al., 2017). Following preliminary evaluation, **deep ensemble method** was identified as the more suitable approach for the present application. Deep ensembles involve training multiple independently initialized models and aggregating their predictions to produce a consensus estimate, with prediction variance across ensemble members serving as a measure of

---

[14] About 1% of otoliths are partly crystallized and are assigned ages. The same is true for broken otoliths that are aged (1%)

[15] Year collected is currently not incorporated as a model covariate due to the limited temporal range represented within the training dataset. Future model versions may re-evaluate its inclusion as additional years of data become available.

[16] IPHC is currently using genotyping for Pacific halibut sex determination.

[17] If there is a strong junction in the relative precision between old and younger fish due to the change in methods this may require a nonparametric approach to ageing imprecision. If an AI method is biased as a function of age (standard for surface reading methods) and the break and bake method is unbiased, integrating the methods may prove challenging.

uncertainty. Compared with Monte Carlo dropout, deep ensembles generally provide more stable predictive performance, improved calibration of confidence estimates, and greater robustness to out-of-distribution or ambiguous samples. Although computationally more demanding, this approach better aligns with Pacific halibut ageing workflows, where reliable identification of uncertain predictions in a production setting will be essential for directing expert review and minimizing systematic ageing bias. This supports the development of a semi-automated, quality-controlled ageing protocol that leverages the strengths of both AI and human expertise.

PRELIMINARY RESULTS

Selected model evaluation

The selected model configuration utilized 11,107 images of otoliths collected during the 2019 IPHC fishery-independent setline survey (FISS). The 2019 FISS represents a comprehensive sampling effort expected to reflect regional variability in Pacific halibut otolith characteristics. As such, it provides a robust foundation for initial model development and evaluation.

The images were divided into training, validation, and test datasets. The training set (7,740) was used for training purposes. The validation set (1,367) was used to evaluate the model during the training process, allowing for adjustments without using the test set, which was reserved for the final evaluation. The test dataset (2,000) was used to assess the performance of the model after training, providing an unbiased evaluation of its generalization capability to new, unseen data. Additionally, a separate set of 2,931 images of otoliths collected during the 2024 FISS was used to verify model performance on additional unseen data, testing the temporal generalization of the model configurations. All images were resized to 400x400 pixels. Images of broken otoliths were excluded.

The selected model employed a maximum of 600 training epochs, with early stopping patience set to 60 epochs. A learning rate reduction was triggered if validation loss plateaued for 30 epochs, reducing the rate by a factor of 0.8. The initial learning rate was set at 0.0002, and training was performed using a batch size of 8. A comprehensive suite of image augmentation techniques (e.g., rotation, position shift, zoom, brightness variation) was applied to improve generalization and robustness.

To enhance model reliability and quantify uncertainty, a deep ensemble approach was adopted. The model was trained 5 times, each with a different random seed. Ensemble outputs were averaged to produce final predictions and calculate prediction uncertainty. Detailed results for individual ensemble members are provided in *Appendix C*.

Across ensemble runs, the model trained for an average of 183 epochs (123 effective epochs with early stopping set at 60). It achieved a normalized MSE average of 0.00114 on the validation set. When averaged across seeds results were rounded to the nearest integer age, the RMSE for the test set was 1.68 and MAE was 1.06. On average, the ensemble predicted the exact age correctly for 35.5% of test images, and an additional 41.0% were within ±1 year of the manually assigned age, resulting in a total agreement within 1 year for 76.5% of cases.

Figure *6* shows a comparison between manually derived ages and AI-predicted ages across the ensemble. Figure 7 compares the age composition estimated manually with that derived from the ensemble model predictions.

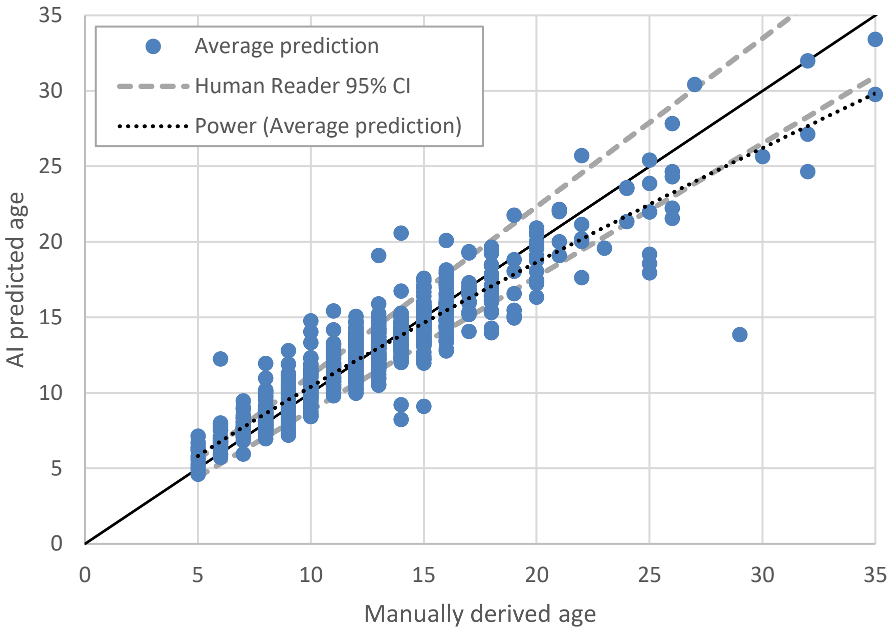


Figure 6. Comparison between manually derived age with AI predicted age.

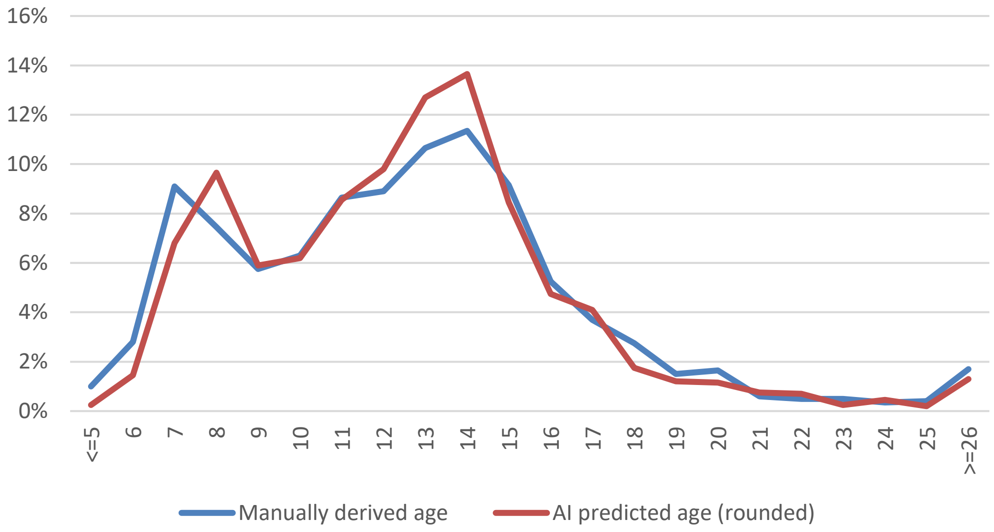


Figure 7. Comparison between manually derived age with AI predicted age – age composition.

It is important to note that although the model tends to underestimate the ages of older Pacific halibut on average, the statistically significant bias previously observed for age categories 21+ (IPHC-2025-SRB026-10) is no longer apparent. The number of observations for older age categories remains low despite an overall increase in sample size (Figure *8*). This suggests that the saturation point for achieving optimal accuracy in older age categories may not yet have been reached, and the model could benefit from further improvement by adding more images representing older age categories to the training set. Currently, only 4.1% of the otoliths used in the model were from fish aged 21 or older.

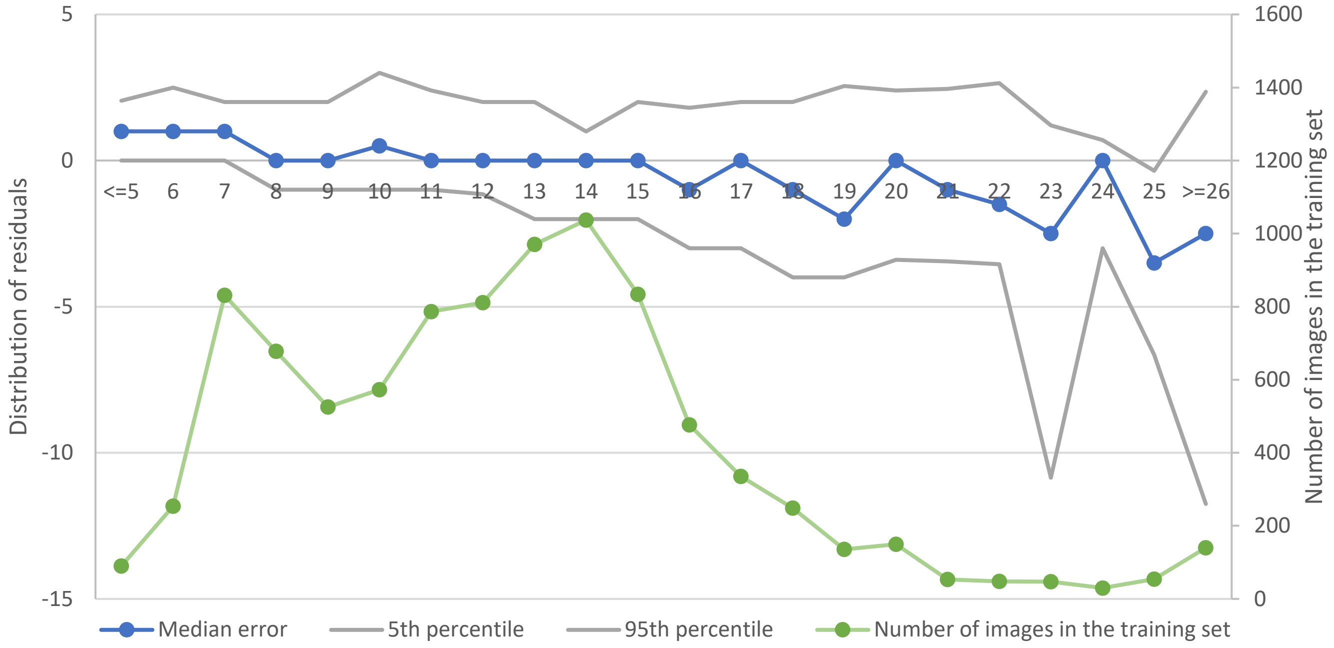


Figure 8. Distribution on residuals and number of images by age in the test set.

Testing temporal generalization

The performance of the model trained on the 2019 FISS sample declined when applied to otolith images collected during the 2024 survey, reflecting the challenges of temporal generalization. On average, the root mean squared error (RMSE) increased to 2.27, representing an approximate 35% increase compared to the 2019 test set. Furthermore, the proportion of predictions within ±1 year of the manually assigned age dropped by 16.9 percentage points, indicating a decline in predictive accuracy.

However, the use of a deep ensemble approach enabled a more nuanced evaluation of model reliability. Specifically, the ensemble framework provided per-sample uncertainty estimates (measured as the standard deviation across model predictions), which helped distinguish between confidently and less confidently predicted samples. This enabled stratification of predictions by uncertainty level.

Figure 9 shows the cumulative proportion of 2024 test samples for which the ensemble prediction falls within ±1 year of the manually assigned age, as a function of increasing prediction uncertainty (measured by the standard deviation across the ensemble). The curve confirms that predictions with lower uncertainty levels tend to be more accurate. For the least uncertain subset of the test data (e.g., the first ~20%), accuracy within ±1 year exceeds 80%, while this metric gradually declines as predictions with higher uncertainty are included. By the time the entire sample is considered, accuracy drops to approximately 59%.

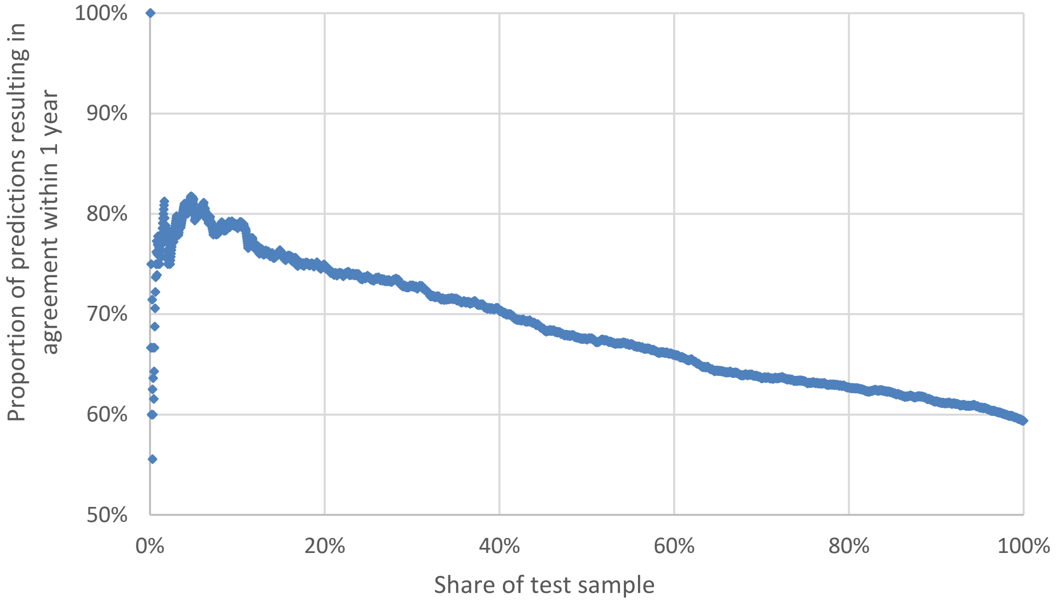


Figure 9: Proportion of ensemble predictions within ±1 year of manual age as a function of cumulative share of the test sample, ordered by prediction uncertainty (standard deviation).

Fine-tuning the model

To assess the impact of fine-tuning on model generalization across years, the ensemble originally trained on 2019 FISS images was fine-tuned using a randomly selected 20% subset of otoliths collected in 2024. The model was then evaluated on the remaining unseen 80% of 2024 images. Fine-tuning yielded measurable improvements: the average RMSE across ensemble runs decreased from 2.27 to 2.23, and the proportion of predictions within ±1 year of the manually assigned age increased from 59.6% to 66.1%.

In a separate analysis, the fine-tuning subset was selected based on uncertainty rather than random sampling. Specifically, 20% of 2024 images with the highest standard deviation across ensemble predictions - interpreted as the most ambiguous or noisy samples - were used for fine-tuning. This targeted approach led to further gains in predictive accuracy. When evaluated on the remaining 80%, the model achieved an RMSE of 1.97 and the proportion of predictions within ±1 year of the manually assigned age of 70.0%

CONCLUSIONS

The ongoing advancement of AI technologies in the field of marine science offers considerable potential to enhance the efficiency of age determination of Pacific halibut using otolith images. Preliminary results presented here suggest that convolutional neural networks (CNNs), particularly when implemented using a deep ensemble approach, could provide predictive accuracy that supports their use as a supplement - or in some cases, a potential alternative - to the current manual ageing protocol.

The results demonstrate that continued expansion of the image database improves model development and evaluation capacity. Increasing the training dataset from 2,799 to 11,107 otolith images improved representation across age classes and biological variability, supporting more robust model training and enabling evaluation of additional preprocessing, weighting, and modelling approaches. Incremental improvements were also observed through continued refinement of the modelling pipeline itself, including implementation of model-specific preprocessing, improved data handling procedures, and evaluation of auxiliary biological and environmental covariates. Although the inclusion of covariates such as capture location and collection date resulted in comparatively modest gains in predictive performance, the results suggest that non-image information can contribute additional biologically relevant context to the model under otherwise identical training conditions.

The findings also highlight the practical value of the deep ensemble framework. In addition to improving predictive performance, ensemble-based models provide per-sample uncertainty estimates that can be used to identify potentially unreliable predictions. This enables a mixed-method protocol in which low-confidence predictions, identified through high variance across ensemble members, can be flagged for expert review, while high-confidence outputs may be accepted directly. Such an approach could substantially streamline the ageing workflow while maintaining the accuracy and consistency required for stock assessment applications.

Results additionally showed that model performance deteriorates when predictions are applied to data collected in years different from those represented in the training dataset, indicating limited temporal generalization. However, modest fine-tuning using a subset of current-year images substantially improved predictive performance, reducing RMSE and increasing agreement within ±1 year of expert-derived ages. Fine-tuning focused specifically on uncertain samples identified through ensemble variance produced further improvements, suggesting that uncertainty-guided updating may represent an effective strategy for adapting models to new data while minimizing the amount of manual ageing required.

Spatial generalization experiments indicated that the model retains a reasonable ability to generalize across IPHC Regulatory Areas, with only limited and inconsistent performance degradation when data from a focal area were excluded from training. Although inclusion of area-specific data provided modest improvements in some regions, the overall results suggest that the model captures broadly transferable otolith features and is not strongly dependent on spatially localized training data.

Despite the encouraging progress, important limitations remain. Although the latest model runs showed no statistically significant bias for the oldest age categories (~21+ years), the model still tends to underestimate ages of older Pacific halibut on average. These age classes remain substantially underrepresented within the available training data, reflecting the underlying population structure. About 4.1% of otoliths included in training of the main model were from fish aged 21 years or older. Attempts to directly correct this imbalance using label distribution smoothing resulted in substantially poorer overall predictive performance, suggesting that aggressive imbalance-correction approaches may amplify label noise and reduce broader model generalization. Expanding the dataset to improve representation of older individuals will therefore remain an important priority for achieving more balanced training and improving reliability across the full biological age range.

Finally, it is important to emphasize that AI-based ageing models will continue to rely on human experts, both for validation and for generation of the high-quality training data that reflect temporal changes and environmental variability. As environmental conditions and stock structure continue to change, integrating expert oversight and continual model updating will remain a critical part of accurate AI implementation for ageing process.

LITERATURE

Allken, V., Handegard, N. O., Rosen, S., Schreyeck, T., Mahiout, T., & Malde, K. (2019). Fish species identification using a convolutional neural network trained on synthetic data. *ICES Journal of Marine Science*, *76*(1), 342–349. https://doi.org/10.1093/icesjms/fsy147

Benson, I. M., Helser, T. E., Marchetti, G., & Barnett, B. K. (2023). The future of fish age estimation : deep machine learning coupled with Fourier transform near-infrared spectroscopy of otoliths. *Canadian Journal of Fisheries and Aquatic Sciences*, *00*, 1–13. https://doi.org/dx.doi.org/10.1139/cjfas-2023-0045

Blood, C. L. (2003). I . Age validation of Pacific halibut II . Comparison of surface and break-and-burn otolith methods of ageing Pacific halibut. *IPHC Technical Report*, *47*.

Campana, S. E. (1999). Chemistry and composition of fish otoliths: Pathways, mechanisms and applications. *Marine Ecology Progress Series*, *188*, 263–297. https://doi.org/10.3354/meps188263

Campana, S. E., & Neilson, J. D. (1985). Microstructure of Fish Otoliths. *Canadian Journal of Fisheries and Aquatic Sciences*, *42*(5), 1014–1032. https://doi.org/10.1139/f85-127

Campana, S. E., & Thorrold, S. R. (2001). Otoliths, increments, and elements: keys to a comprehensive understanding of fish populations? *Canadian Journal of Fisheries and Aquatic Sciences*, *58*(1), 30–38. https://doi.org/10.1139/f00-177

Fablet, R., & Le Josse, N. (2005). Automated fish age estimation from otolith images using statistical learning. *Fisheries Research*, *72*(2–3), 279–290. https://doi.org/10.1016/j.fishres.2004.10.008

Gal, Y., & Ghahramani, Z. (2016). Dropout as a Bayesian approximation: Representing model uncertainty in deep learning. *Proceedings of the 33rd International Conference on Machine Learning*.

IPHC. (1985). Annual Report 1984. In *IPHC Annual Report*.

Keith, S., Kong, T., Sadorus, L. L., Stewart, I. J., & Williams, G. (2014). The Pacific halibut: biology, fishery, and management. *IPHC Technical Report*, *59*. https://doi.org/10.1042/bj0490062

Lakshminarayanan, B., Pritzel, A., & Blundell, C. (2017). Simple and Scalable Predictive Uncertainty Estimation using Deep Ensembles. *NIPS'17: Proceedings of the 31st International Conference on Neural Information Processing Systems*.

LeCun, Y., Bottou, L., Bengio, Y., & Haffner, P. (1998). Gradient Based Learning Applied to Document Recognition. *Proc. of the IEEE*.

Malde, K., Handegard, N. O., Eikvil, L., & Salberg, A. B. (2020). Machine intelligence and the data-driven future of marine science. *ICES Journal of Marine Science*, *77*(4), 1274–1285. https://doi.org/10.1093/icesjms/fsz057

Methot, R. D., & Wetzel, C. R. (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research*, *142*, 86–99. https://doi.org/https://doi.org/10.1016/j.fishres.2012.10.012

Moen, E., Handegard, N. O., Allken, V., Albert, O. T., Harbitz, A., & Malde, K. (2018). Automatic interpretation of otoliths using deep learning. *PLoS ONE*, *13*(12), e0204713.

Moore, B. R., Maclaren, J., Peat, C., Anjomrouz, M., Horn, P. L., & Hoyle, S. (2019). Feasibility of automating otolith ageing using CT scanning and machine learning. *New Zealand Fisheries Assessment Report*, *58*.

Ordoñez, A., Eikvil, L., Salberg, A. B., Harbitz, A., Murray, S. M., & Kampffmeyer, M. C. (2020). Explaining decisions of deep neural networks used for fish age prediction. *PLoS ONE*, *15*(6), 1–19. https://doi.org/10.1371/journal.pone.0235013

Piner, K. R., & Wischniowski, S. G. (2004). Pacific halibut chronology of bomb radiocarbon in otoliths from 1944 to 1981 and a validation of ageing methods. *Journal of Fish Biology*, *64*(4), 1060–1071. https://doi.org/10.1111/j.1095-8649.2004.0371.x

Politikos, D. V, Petasis, G., Chatzispyrou, A., Mytilineou, C., & Anastasopoulou, A. (2021). Automating fish age estimation combining otolith images and deep learning: The role of multitask learning. *Fisheries Research*, *242*, 106033. https://doi.org/https://doi.org/10.1016/j.fishres.2021.106033

Politikos, D. V, Sykiniotis, N., Petasis, G., Dedousis, P., Ordoñez, A., Vabø, R., Anastasopoulou, A., Moen, E., Mytilineou, C., Salberg, A. B., Chatzispyrou, A., & Malde, K. (2022). DeepOtolith v1.0: An Open-Source AI Platform for Automating Fish Age Reading from Otolith or Scale Images. *Fishes*, *7*(3), 1–11. https://doi.org/10.3390/fishes7030121

Punt, A. E., Smith, D. C., KrusicGolub, K., & Robertson, S. (2008). Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. *Canadian Journal of Fisheries and Aquatic Sciences*, *65*(9), 1991–2005. https://doi.org/10.1139/F08-111

Robertson, S. G., & Morison, A. K. (1999). A trial of artificial neural networks for automatically estimating the age of fish. *Marine and Freshwater Research*, *50*(1), 73–82. https://doi.org/10.1071/MF98039

Simonyan, K., & Zisserman, A. (2015). Very deep convolutional networks for large-scale image recognition. *ICLR 2015 - Conference Track Proceedings*.

Southward, G. M. (1962). Photographing Halibut Otoliths for Measuring Growth Zones. *Journal of the Fisheries Research Board of Canada*, *19*(2), 335–338. https://doi.org/10.1139/f62-018

Yang, Y., Zha, K., Chen, Y. C., Wang, H., & Katabi, D. (2021). Delving into Deep Imbalanced Regression. *Proceedings of Machine Learning Research*, *139*, 11842–11851.

APPENDIX A: COUNTS OF OTOLITHS AGED BY THE IPHC

Collection year	Ageing method	IPHC FISS*	Commercial (Market Sample)*	NOAA Trawl survey*	Tag recovery*	ADF&G recreational*	Clean collection
pre-1960	surface	70,984			10,068		
1960	surface	6,606			681		
1961	surface	4,727		4,576	842		
1962	surface	2,605		1,692	594		
1963	surface	8,257		2,209	440		
1964	surface	10,295	27,828	1,001	353		
1965	surface	5,169	27,252	1,186	493		
1966	surface	3,750	24,638	1,777	796		
1967	surface	6,325	29,797	2,271	1,151		
1968	surface	2,314	29,772	1,887	1,813		
1969	surface	1,510	23,361	1,019	1,869		
1970	surface	1,138	24,686	1,184	867		
1971	surface	2,702	16,374	2,294	732		
1972	surface	2,597	23,381	1,180	490		
1973	surface	1,747	16,683	893	244		
1974	surface	1,021	11,569	1,189	128		
1975	surface	1,212	14,128	1,136	131		
1976	surface	1,843	14,103	969	72		
1977	surface	1,853	13,514	1,102	83		
1978	surface	1,933	11,434	1,309	61		
1979	surface	2,021	7,219	730	93		
1980	surface	5,022	10,317	717	168		
1981	surface	7,942	8,267	460	129		
1982	surface	5,720	9,644	443	208		
1983	surface	5,822	9,262	1,355	286		
1984	surface	6,508	10,233	1,089	455		
1985	surface	5,872	12,986	1,192	778		
1986	surface	5,139	12,426	1,120	1,020		
1987	surface	42	16,137		859		
1988	surface	1,179	17,154	98	761		
1989	surface	6,130	14,122		710		
1990	surface	2,201	14,800	4,802	397		
1991	surface	1,315	13,461	2,598	280		
1992	surface/BB	7,530	14,564	222	182		
1993	surface/BB	3,384	13,747		147		
1994	surface/BB	2,618	13,311		99		
1995	surface/BB	4,512	12,297	433			
1996	surface/BB	10,893	13,452	2,211			
1997	surface/BB	14,784	15,501	834	148		
1998	surface/BB	8,587	14,395	1,145	98		

1999	surface/BB	11,971	12,858	3,029	70	3,672	
2000	surface/BB	14,122	13,982	1,209	46	2,706	
2001	surface/BB	14,731	13,181	2,952	27	2,609	
2002	BB	13,635	17,932	761	24	2,349	
2003	BB	12,626	13,915	3,876	79	2,754	
2004	BB	14,474	11,798	897	450	3,288	
2005	BB	12,651	14,650	2,028	643	3,183	
2006	BB	14,976	13,399	2,621	679	3,179	
2007	BB	16,285	13,964	3,930	455	3,026	
2008	BB	15,545	13,460	1,527	304	1,500	
2009	BB	15,706	13,583	4,922	276	1,500	
2010	BB	14,080	16,106	1,915	21	1,500	625
2011	BB	14,451	11,391	4,592	26	1,500	676
2012	BB	17,896	12,902	1,639	9	1,500	1164
2013	BB	12,717	11,039	2,044	19	1,503	1020
2014	BB	16,194	12,606	1,476	22	1,500	1096
2015	BB	15,815	12,312	2,133	24	1,500	1072
2016	BB	15,113	11,618	742	21	1,502	902
2017	BB	12,565	10,821	1,384	15	1,500	756
2018	BB	12,935	11,013	576	39	1,499	798
2019	BB	17,716	10,711	1,640	34	1,497	925
2020	BB	10,323	10,568	-	34	1,413	577
2021	BB	12,253	11,051	1,444	38	1,500	547
2022	BB	9,702	10,942	1,902	39	2,334	519
2023	BB	8,506	10,932	(3,147)	(48)	(1,958)	462
2024	BB	5,770	10,474[1]	1,058	(61)	1,542[2]	458
2025	BB	7,912[3]	9,740[4]	(2,379)	(35)	(1,456)	499

Notes:

- Star (*) indicates blind side otolith.
- BB stands for ‘break and bake’ approach.
- All otoliths reported in this table were aged with the exception of the clean collection.
- All aged otoliths are stored in glycerol/thymol solution.
- Some small fish from trawl survey collection are still aged by surface method; otoliths with surface age>4 are sectioned and baked.
- Sample data not entered prior to 1960 for FISS, 1964 for commercial, 1961 for NOAA trawl survey.
- Clean collection is not aged, stored dry, and include paired otoliths.
- Tribal otoliths are included in the Market Sample series.
- Additionally, there are 144 not aged 2A recreational otoliths, all from Hein Bank collected between 2004 and 2009.
- Sex information available since 2017 (typically ca. 1 year of lag).
- Trawl and recreational otoliths lag one year in ageing.
- In brackets, otoliths available for ageing but ageing not completed.

[1] Commercial otolith collection subsampled: 10,474 otoliths were collected, 7,057 were selected for ageing.

[2] 2024 ADF&G recreational otolith collection subsampled: 1,542 otoliths were collected, 819 were selected for ageing.

[3] 7,912 FISS total for 2025 includes 242 fecundity samples. Some otoliths from Area 4A were subsampled: 7,670 were selected for ageing.

[4] 2025 commercial otolith collection subsampled: 9,740 otoliths were collected, 6,723 otoliths were selected for ageing.

APPENDIX B: SELECTION OF MODEL RUNS

RunID	1	2	3	13	14	15	16	17	18	19	20	21	22	24
SETUP				**									**	
Architecture	InV3	InV3	InV3	InV3	InV3	InV3	InV3	InV3	InV3	InV3	InV3	InV3	InV3	InV3
Image mode	rgb	rgb clean	grayscale clean	rgb	rgb clean	grayscale clean	rgb	rgb clean	grayscale clean	rgb	rgb clean	grayscale clean	rgb	rgb
Covariates	-	-	-	s+c+d	s+c+d	s+c+d	-	-	-	c+d	c+d	c+d	c+d	c+d
Notes													technical improvements	LDS
RESULTS														
Validation MSE	0.0012	0.0013	0.0014	0.0011	0.0012	0.0012	0.0014	0.0012	0.0014	0.0011	0.0013	0.0013	0.0012	0.0121
Epochs trained	184	164	145	184	155	159	154	148	141	192	146	137	192	157
Test RMSE	0.00129	0.00136	0.00136	0.00125	0.00135	0.00152	0.00141	0.00132	0.00135	0.00126	0.00135	0.00148	0.00125	0.01138
Test MAE	0.0244	0.0247	0.0251	0.0245	0.0252	0.0275	0.0255	0.0243	0.0249	0.0240	0.0251	0.0268	0.0237	0.0778
Test R^2	0.84	0.83	0.83	0.85	0.83	0.81	0.83	0.84	0.83	0.84	0.83	0.82	0.85	-0.41
Correctly predicted	30.6%	29.9%	29.2%	29.6%	29.5%	26.5%	28.8%	31.5%	29.6%	31.0%	29.8%	27.0%	31.2%	9.7%
Correctly predicted with ±1 year tolerance	71.9%	72.3%	70.7%	72.0%	71.6%	67.1%	70.1%	72.2%	71.2%	72.8%	71.3%	67.6%	73.4%	28.0%
RUN parameters														
Run time in hours	15.0	12.1	10.9	15.4	11.8	11.9	11.3	10.8	10.6	15.8	11.0	10.4	15.6	12.8
RESULTS for 2024														
RMSE	*	*	*	*	*	*	*	*	*	2.24414	2.24892	2.36083	2.27066	*
MAE	*	*	*	*	*	*	*	*	*	1.5684	1.5660	1.6841	1.5844	*
R^2	*	*	*	*	*	*	*	*	*	0.795	0.793	0.772	0.791	*
Correctly predicted	*	*	*	*	*	*	*	*	*	21.9%	23.3%	20.2%	21.8%	*
Correctly predicted with ±1 year tolerance	*	*	*	*	*	*	*	*	*	60.3%	59.8%	55.3%	59.6%	*
RESULTS for 2024 (FT)														
RMSE	*	*	*	*	*	*	*	*	*	2.21941	2.22268	2.26534	2.22613	*
MAE	*	*	*	*	*	*	*	*	*	1.4614	1.4426	1.4832	1.4358	*
R^2	*	*	*	*	*	*	*	*	*	0.808	0.806	0.798	0.807	*
Correctly predicted	*	*	*	*	*	*	*	*	*	25.2%	27.6%	25.9%	26.7%	*
Correctly predicted with ±1 year tolerance	*	*	*	*	*	*	*	*	*	64.9%	65.8%	64.4%	66.1%	*
RESULTS for 2024 (FT select)														
RMSE	*	*	*	*	*	*	*	*	*	1.86369	1.98599	1.97036	1.96559	*
MAE	*	*	*	*	*	*	*	*	*	1.3488	1.3761	1.4064	1.3510	*
R^2	*	*	*	*	*	*	*	*	*	0.820	0.794	0.791	0.812	*
Correctly predicted	*	*	*	*	*	*	*	*	*	22.9%	25.0%	22.7%	24.2%	*
Correctly predicted with ±1 year tolerance	*	*	*	*	*	*	*	*	*	66.1%	65.9%	63.7%	67.0%	*

Note: Results represent averages across three individual runs using randomly selected seed values; individual run performance varied. All models utilized the InceptionV3 (InV3) architecture, with image size = 400 × 400 pixels, dropout = 0.25, and L2 regularization = 1.0×10^{-4}. Training parameters included a maximum of 600 epochs, batch size = 8, EarlyStopping patience = 60, ReduceLROnPlateau patience = 30 epochs with reduction factor = 0.8, and an initial learning rate = 0.0002. Full augmentation settings included rotation range = 360°, width shift range = 0.1, height shift range = 0.1, brightness range = [0.95, 1.05], and zoom range = [0.98, 1.02]. Covariate legend: c = coordinates, d = date collected, s = sex.

Machine setup: VM with AMD EPYC 7V12 64-Core Processor and Nvidia Tesla T4 GPU.

* Indicates values not recorded for the given run.

**Indicates model selected for further investigation.

APPENDIX C: DEEP ENSEMBLE INDIVIDUAL RESULTS

Model run	1	2	3	4	5	**AVERAGE**
Seed	11	27	42	44	51	
Epochs trained	219	156	200	194	147	183
Validation MSE	0.00106	0.00111	0.00131	0.00113	0.00111	0.00114
Rum time [h]	18.0	12.6	16.1	15.7	11.9	14.9
RESULTS – TEST SET						
Test RMSE	1.814	1.782	1.780	1.802	1.830	1.802
Test MAE	1.161	1.182	1.145	1.172	1.193	1.170
Test R^2	0.841	0.848	0.847	0.844	0.839	0.844
Correctly predicted	32.0%	29.9%	31.7%	31.9%	30.5%	31.2%
Correctly predicted with ±1 year tolerance	73.6%	72.3%	74.2%	72.7%	72.8%	73.1%
RESULTS – 2024 IMAGES						
RMSE	2.466	2.418	2.361	2.426	2.513	2.437
MAE	1.734	1.678	1.661	1.720	1.754	1.709
R^2	0.751	0.759	0.772	0.760	0.757	0.760
Correctly predicted	20.8%	22.0%	20.7%	20.6%	20.7%	21.0%
Correctly predicted with ±1 year tolerance	56.0%	58.4%	57.3%	55.8%	57.1%	56.9%
RESULTS – 2024 IMAGES – 20% FT						
RMSE	2.392	2.330	2.295	2.333	*	2.337
MAE	1.581	1.538	1.489	1.593	*	1.550
R^2	0.775	0.786	0.793	0.786	*	0.785
Correctly predicted	24.6%	25.7%	26.1%	22.6%	*	24.7%
Correctly predicted with ±1 year tolerance	61.5%	62.6%	65.1%	60.1%	*	62.3%
RESULTS – 2024 IMAGES – 20% FT select						
RMSE	2.027	2.046	1.966	*	*	2.013
MAE	1.414	1.444	1.351	*	*	1.403
R^2	0.798	0.796	0.812	*	*	0.802
Correctly predicted	23.0%	21.9%	24.2%	*	*	23.0%
Correctly predicted with ±1 year tolerance	63.2%	62.6%	67.0%	*	*	64.2%

* Indicates values not recorded for the given run.