INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC–2026–SRB029–00

Last Update: 22 August 2026

29th Session of the IPHC Scientific Review Board (SRB029) – *Compendium of meeting documents*

22-24 September 2026, Seattle, WA, USA

Commissioners

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

Executive Director

David T. Wilson, Ph.D.

DISTRIBUTION: IPHC WEBSITE
LAST UPDATE: 22 August 2026

BIBLIOGRAPHIC ENTRY
IPHC 2026. 29th Session of the IPHC Scientific Review Board (SRB029) - Compendium of meeting documents. Int. Pac. Halibut Comm.

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 29th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB029)

Date: 22-24 September 2026
Location: Hybrid - Seattle, WA, USA & Electronic
Venue: IPHC HQ (for SRB and Science advisors only) & Adobe Connect (observers)
Time: 09:00-17:00 (22-23rd), 09:00-12:00 (24th) PDT
Chairperson: Dr. Olaf Jensen (USA)

1. OPENING OF THE SESSION

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 28th Session of the SRB (SRB028) (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 29th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB029)

SCHEDULE FOR THE 29th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB029)

Tuesday, 22 September 2026		
Time	**Agenda item**	**Lead**
09:00-09:05	1. OPENING OF THE SESSION	O. Jensen (Chairperson)
09:05-09:10	2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION	O. Jensen (Chairperson)
09:10-09:30	3. IPHC PROCESS 3.1 SRB annual workflow (D. Wilson) 3.2 Update on the actions arising from the 28th Session of the SRB (SRB028) 3.3 Outcomes of the 102nd Session of the IPHC Annual Meeting (AM102) 3.4 Observer updates (e.g. Science Advisors)	D. Wilson
09:30-10:30	4. INTERNATIONAL PACIFIC HALIBUT COMMISSION INTEGRATED RESEARCH AND MONITORING PLAN 4.1 RESEARCH 4.1.1 Biology and ecology	J. Planas
10:30-11:00	Break	
11:00-12:30	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, 23 September 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)	R. Webster
10:30-11:00	Break	
11:00-12:00	4.2.2 (cont.)	R. Webster
12:00-12:30	4.2.3 Age composition data (both fishery-dependent and fishery-independent)	B. Hutniczak
12:30-13:30	Lunch	
13:30-16:00	*Offline collaborative work session*	SRB
16:00-17:00	SRB drafting session	SRB members
Thursday, 24 September 2026		
Time	**Agenda item**	**Lead**
09:00-10:30	*Offline collaborative work session*	SRB
10:30-11:00	Break	
11:00-11:30	5. OTHER BUSINESS	Chairperson

11:30-12:30	6. ADOPTION OF THE REPORT OF THE 29th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB029)	Chairperson
12:30-13:30	Lunch and departure	

INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC-2026-SRB029-02

Last updated: 22 August 2026

LIST OF DOCUMENTS FOR THE 29th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB029)

Document	Title	Availability
IPHC-2026-SRB029-01	Agenda & Schedule for the 29th Session of the Scientific Review Board (SRB029)	✓ 28 May 2026
IPHC-2026-SRB029-02	List of Documents for the 29th Session of the Scientific Review Board (SRB029)	✓ 28 May 2026 ✓ 22 Aug 2026
IPHC-2026-SRB029-03	Update on the actions arising from the 28th Session of the SRB (SRB028) (IPHC Secretariat)	✓ 22 Aug 2026
IPHC-2026-SRB029-04	Outcomes of the 102nd Session of the IPHC Annual Meeting (AM102) (D. Wilson)	✓ 28 May 2026
IPHC-2026-SRB029-05	Report on current and future biological and ecosystem science research activities (J. Planas, C. Dykstra, A. Jasonowicz, & C. Jones)	✓ 13 Aug 2026
IPHC-2026-SRB029-06	Development of the 2026 Pacific halibut (*Hippoglossus stenolepis*) stock assessment (I. Stewart & A. Hicks)	✓ 18 Aug 2026
IPHC-2026-SRB029-07	An update of the IPHC Secretariat MSE Program of Work for 2026-2028 (A. Hicks & I. Stewart)	✓ 20 Aug 2026
IPHC-2026-SRB029-08	2027-31 FISS design evaluation and modelling updates (R. Webster, I. Stewart, K. Ualesi, & D. Wilson)	✓ 22 Aug 2026
Information papers		
IPHC-2026-SRB029-INF01	International Pacific Halibut Commission Integrated Research and Monitoring Plan (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, & B. Hutniczak)	✓ 28 May 2026
IPHC-2026-SRB029-INF02	Using artificial intelligence (AI) for supplementing Pacific halibut age determination from collected otoliths - project update (B. Hutniczak)	Due: 21 Sept 2026

INTERNATIONAL PACIFIC HALIBUT COMMISSION

UPDATE ON THE ACTIONS ARISING FROM THE 28TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB028)

PREPARED BY: IPHC SECRETARIAT (22 AUGUST 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 SRB028.

BACKGROUND

At the SRB028, the members recommended/requested a series of actions to be taken by the IPHC Secretariat, as detailed in the SRB026 meeting report (IPHC-2026-SRB028-R) available from the IPHC website, and as provided in Appendix A.

DISCUSSION

During the 29th Session of the SRB (SRB029), 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-SRB029-03, 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 (SRB028).
2) **AGREE** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB029.

APPENDICES

Appendix A: Update on actions arising from the 28th Session of the IPHC Scientific Review Board (SRB028).

APPENDIX A

Update on actions arising from the 28th Session of the IPHC Scientific Review Board (SRB028)

RECOMMENDATIONS

Action No.	Description	Update
SRB028–Rec.01 (para. 27)	***Management strategy evaluation*** The SRB **NOTED** that a single control rule based on relative biomass is unlikely to reach the ramp (descending limb) where reduction in F are triggered. Therefore, the SRB **RECOMMENDED** investigating HCRs based on absolute biomass.	***In Progress*** **Update**: This work will continue following the conditioning of the OM.
SRB028–Rec.02 (para. 35)	**Age composition data (both fishery-dependent and fishery-independent)** **NOTING** that the Secretariat has developed multiple aging methods (epigenetic, AI-based, traditional break and burn otolith aging), the SRB **RECOMMENDED** that a table be developed – with a column for each method - describing: a) the different anticipated use cases; b) the relative costs (split into development and production) and benefits of these approaches; c) timelines for development; and d) decision points that will determine future allocation of effort to this method.	***Completed & Ongoing*** **Update**: Preliminary tables will be included in: **IPHC-2026-SRB029-05**, and **IPHC-2026-SRB029-INF02**.

REQUESTS

Action No.	Description	Update
SRB028–Req.01 (para. 16)	***Biology and ecology*** The SRB **REQUESTED** an analysis that separates year and biological region effects on maturity ogives. This would answer whether variation in age at maturity is driven by variation in the spatial distribution of the	***Completed & Ongoing*** **Update**: The IPHC Secretariat has conducted analyses of histology-based maturity data separating year and biological region using best-fit logistic GAM. These data were provided in **IPHC-2025-**

	stock or by interannual variation in environmental conditions.	**SRB026-06**. Potential drivers of variation in age at maturity are being investigated.
SRB028–Req.02 (para. 17)	The SRB **REQUESTED** that the Secretariat investigate: a) environmental predictors of interannual variation in maturity ogives; and b) the potential to include time-varying maturity ogives in the stock assessment.	***In Progress*** **Update**: The IPHC Secretariat is investigating potential predictors of interannual variation in maturity ogives during the period of time (2002-2024) during which visual maturity was calibrated by applying the calibration using histological and visual data (2022-2024).
SRB028–Req.03 (para. 18)	The SRB **REQUESTED** that, as more epigenetic aging data become available, a more systematic approach to cross-validation be developed in which performance is evaluated across space and time. For example, applying a model trained on samples from all but one area to the withheld area and applying a model trained on samples from all but one year to the withheld year. Ideally, a full factorial approach could be used to determine whether any training-test combinations perform inadequately.	***In Progress*** **Update**: The IPHC Secretariat is investigating approaches to cross-validate epigenetic data across sampled areas (space) and (years) time.
SRB028–Req.04 (para. 21)	***Pacific halibut stock assessment*** **NOTING** the progress presented in IPHC-2026-SRB028-07 on assembling a list of state space modelling platforms and their associated features, the SRB **REQUESTED** an update at SRB029 on progress to develop initial models, including approaches to mimic essential features of the Pacific halibut assessment (e.g. sex specific modelling) using other means (e.g. the spatial area features in multi-WHAM).	***In Progress*** **Update**: Progress to date is summarized in **IPHC-2026-SRB029-06** and will be presented during the meeting.
SRB028–Req.05 (para. 23)	***Management strategy evaluation*** The SRB **REQUESTED** that the Secretariat investigate, via the MSE, control rules based on changes to the risk of overfishing (often referred to as p*, see Shertzer et al. 2008[1]).	***In Progress*** **Update**: This work will continue following the conditioning of the OM.

SRB028–Req.06 (para. 25)	**RECALLING** that at SRB026, the SRB made the following recommendation, IPHC-2025-SRB026-R, SRB026–Rec.07 (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.*" and **NOTING** the update provided by the Secretariat at SRB028, the SRB **REQUESTED** an analysis of projecting recruitment via projections in environmental drivers (Pacific Decadal Oscillation) in addition to autocorrelated recruitment, which tends to rapidly revert to the mean.	***Completed & Ongoing*** **Update**: The IPHC Secretariat has described the challenges with linking PDO projections to environmental drivers and described some alternatives in **IPHC-2026-SRB029-07**.

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

PREPARED BY: IPHC SECRETARIAT (D. WILSON; 28 MAY 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-SRB029-04 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).

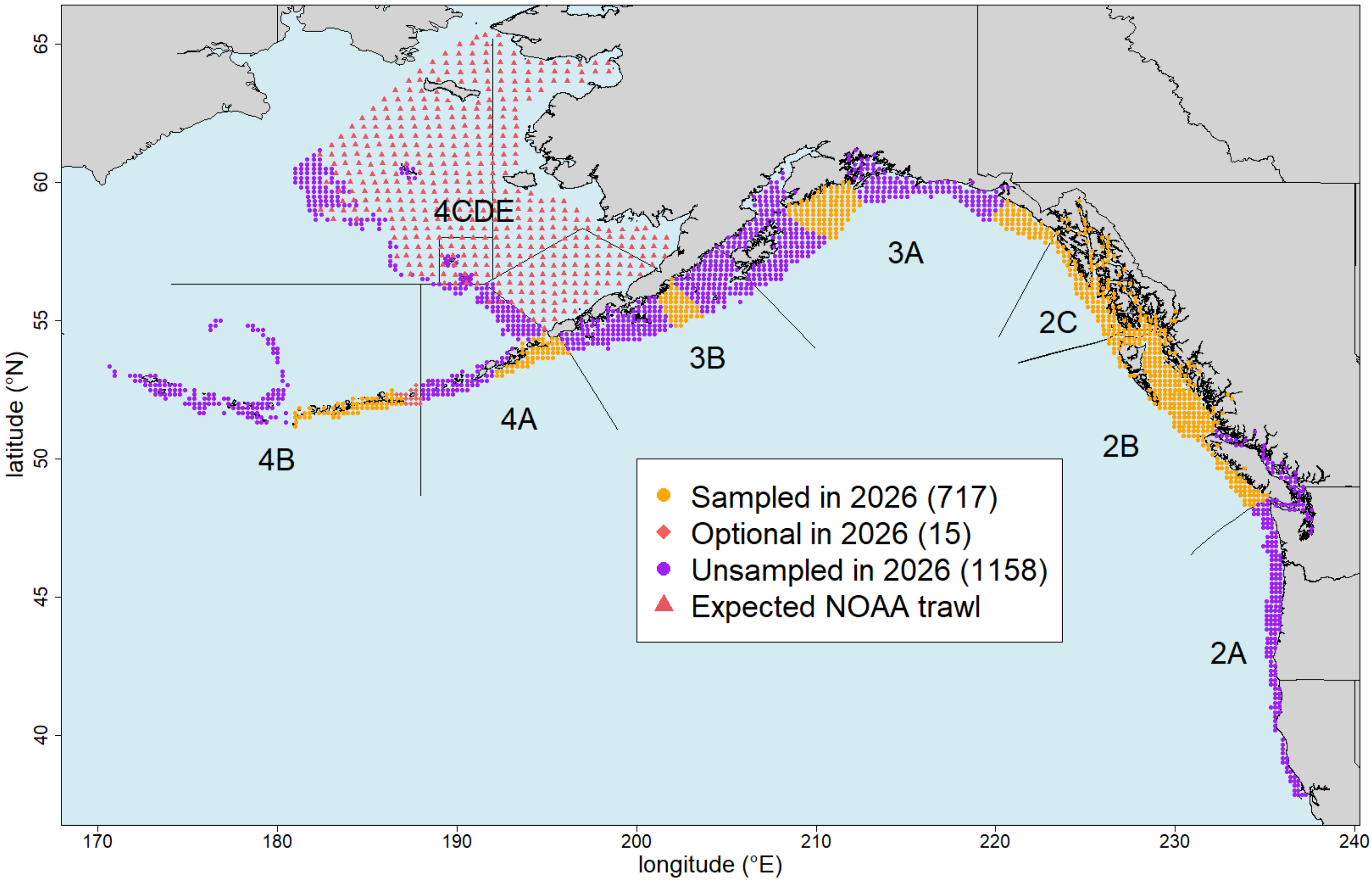


Figure 6. The AM102 approved 2026 FISS design (orange circles).

Report on Current and Future Biological and Ecosystem Science Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, C. DYKSTRA, A. JASONOWICZ, C. JONES, 13 AUGUST 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 REQUESTS AND RECOMMENDATIONS

The SRB issued the following recommendation in their report of SRB028 (IPHC-2025-SRB028-R) in relation to presentation IPHC-2026-SRB028-06:

*SRB028–Req.01 (para. 16) The SRB **REQUESTED** an analysis that separates year and biological region effects on maturity ogives. This would answer whether variation in age at maturity is driven by variation in the spatial distribution of the stock or by interannual variation in environmental conditions.*

The IPHC Secretariat has conducted analyses of histology-based maturity data separating year and biological region using best-fit logistic GAM. These data were provided in IPHC-2025-SRB026-06. Potential drivers of variation in age at maturity are being investigated.

*SRB028–Req.02 (para. 17) The SRB **REQUESTED** that the Secretariat investigate:*
- a) *environmental predictors of interannual variation in maturity ogives; and*
- b) *the potential to include time-varying maturity ogives in the stock assessment.*

The IPHC Secretariat is investigating potential predictors of interannual variation in maturity ogives during the period of time (2002-2024) during which visual maturity was calibrated by applying the calibration using histological and visual data (2022-2024).

*SRB028–Req.03 (para. 18) The SRB **REQUESTED** that, as more epigenetic aging data become available, a more systematic approach to cross-validation be developed in which performance is evaluated across space and time. For example, applying a model trained on samples from all but one area to the withheld area and applying a model trained on samples from all but one year to the withheld year. Ideally, a full factorial approach could be used to determine whether any training-test combinations perform inadequately.*

The IPHC Secretariat is investigating approaches to cross-validate epigenetic data across sampled areas (space) and (years) (time).

*SRB028–Rec.02 (para. 35) **NOTING** that the Secretariat has developed multiple aging methods (epigenetic, AI-based, traditional break and burn otolith aging), the SRB **RECOMMENDED** that a table be developed – with a column for each method - describing:*
- *a) the different anticipated use cases;*
- *b) the relative costs (split into development and production) and benefits of these approaches;*
- *c) timelines for development; and*
- *d) decision points that will determine future allocation of effort to this method.*

The IPHC Secretariat has incorporated information related to epigenetic aging into a table that includes multiple aging methods for comparison.

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 developed bioinformatic method (*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}, as previously detailed in document IPHC-2026-SRB028-06. A manuscript describing the development and validation of this new method has been submitted for publication to the journal *Bioinformatics* (Jasonowicz and Planas, in review).

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 1) 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 2).

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**

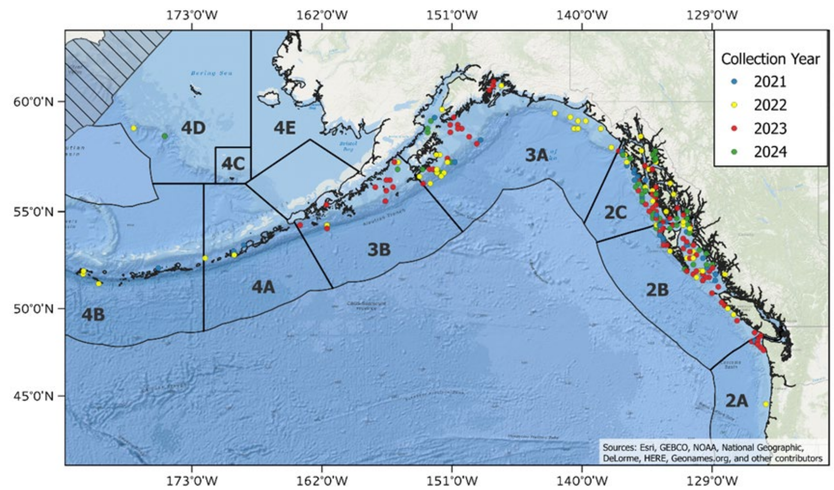


Figure 1. Map showing the collection locations of the samples with RRBS sequence data generated for the development of the Pacific halibut epigenetic clock.

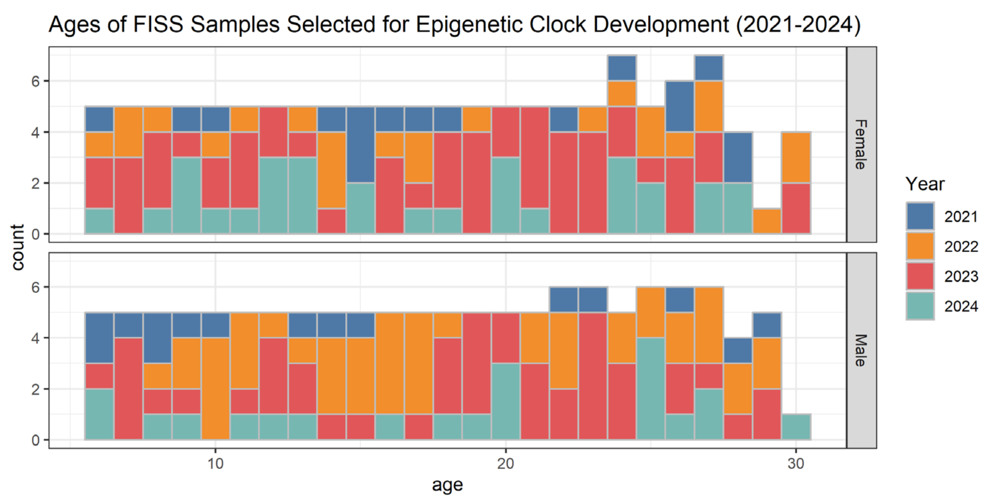


Figure 2. Histograms showing the number of female (top) and male (bottom) genetic samples with RRBS sequence data generated for the development of the Pacific halibut epigenetic clock.

1.2.1.2. <u>Genetic samples used in testing out-of-sample interannual predictive performance</u>. 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 3).

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**

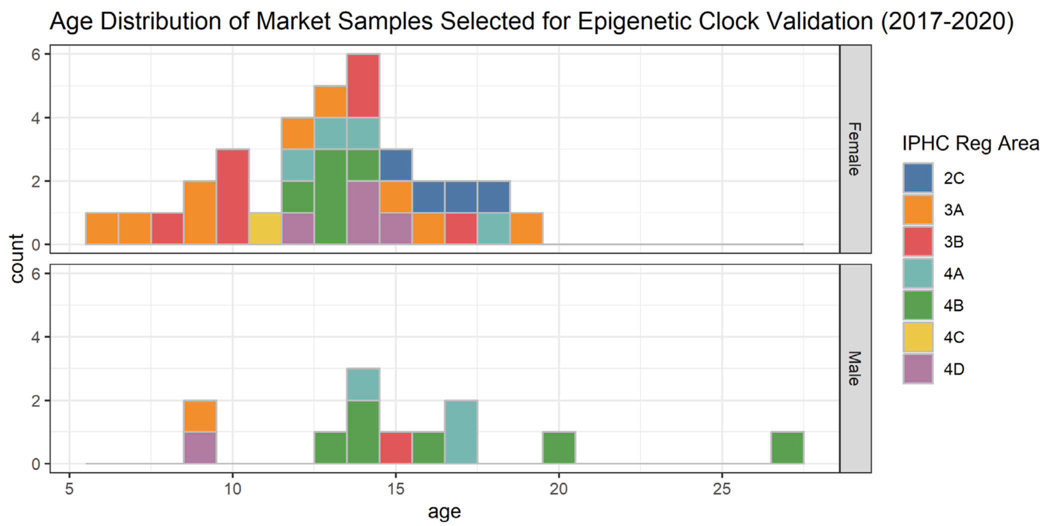


Figure 3. Age distribution of genetic samples from commercial landings ("market samples") selected for out-of-sample validation of the Pacific halibut epigenetic clock.

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 4). 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.

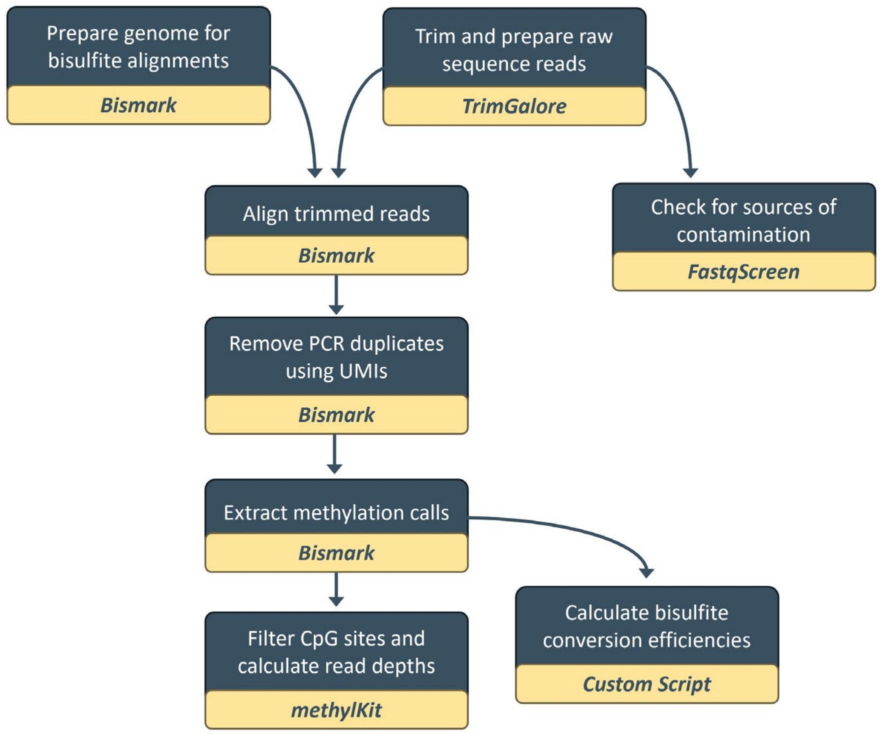


Figure 4. Basic bioinformatic workflow for processing RRBS data. The blue boxes describe each step and the software used is indicated in the yellow boxes.

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 were 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 were used to identify samples that were poorly sequenced and should be omitted from downstream analyses. The raw sequence reads were then 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 were 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. Following alignment, polymerase chain reaction (PCR) duplicates were removed using unique molecular index (UMI) information using by supplying the --barcode --bclconvert options to *bismark's deduplicate_bismark* utility. Lastly, methylation levels were extracted using the *bismark_methylation_extractor* utility provided with *bismark.* For all identified CpG sites, percentage methylation was calculated as the percentage of the number of methylated reads over the number of total reads. Typically, RRBS produces in the order of hundreds of thousands of CpGs (Anastasiadi and Piferrer, 2023). Methylation levels at CpG sites for each sample were processed using the *methylKit* package (v1.24.0) (Akalin et al. 2012) in R (v4.2.3) (R Core Team 2023). To remove CpG sites covered by too few or too many reads, we retained CpG sites that were covered by at least 10 reads and did not exceed the 99.9th percentile of coverage distribution for reach sample. Next, we selected CpG sites that did not have any missing data across all the samples. For each aged individual, we calculated levels of global methylation as the mean methylation percentage across the shared CpG sites identified and summarized these values for each age class using a boxplot.

1.2.1.6. <u>Development of an age predicting model for Pacific halibut</u>. 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. 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 were 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 4, with a specific focus on evaluating CpG site filtering choices that will determine which CpGs are available for the modelling step. Our current filtering process yielded 2,823,114 CpG sites per sample on average and 1,055,430 CpGs per sample on average after additional filtering based on sequence read depth (Figure 5).

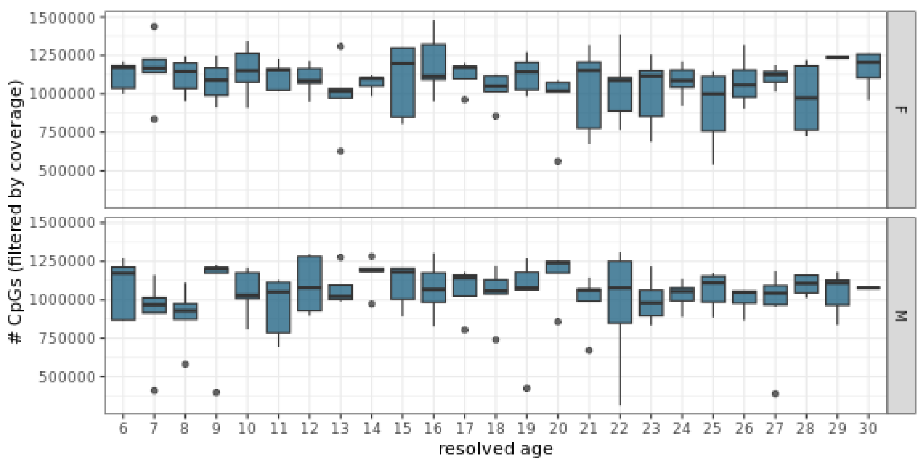


Figure 5. Number of individual CpG methylation sites by age class after filtering for sequence read depth (> 10x). Boxplots show the median (black line), 25th and 75th percentiles (box limits) and whiskers that extend to the most extreme value within 1.5x of the interquartile range.

Applying a conservative filtering approach that required complete data of all samples, 39,461 CpG sites were identified that are common to all samples. We observed a mean global methylation level of 24.6% across all aged samples (Figure 6).

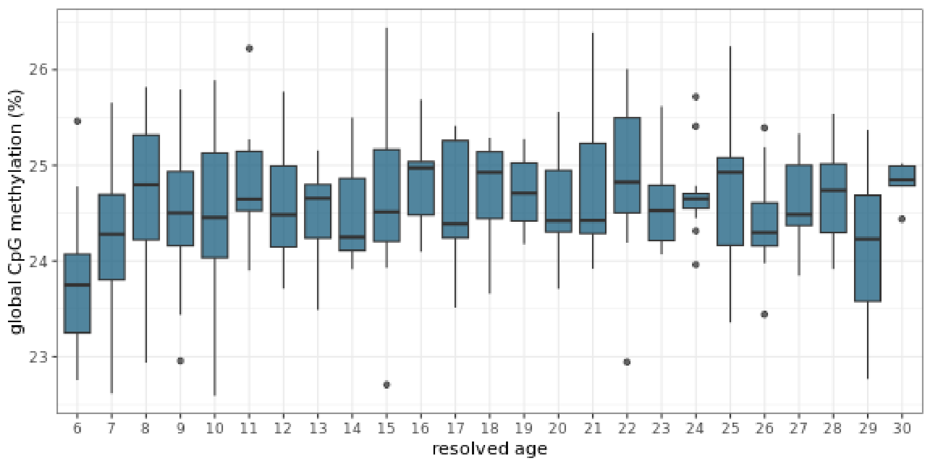


Figure 6. Individual average CpG methylation levels (%) by age class for 39,461 common CpG sites without any missing data. Boxplots show the median (black line), 25th and 75th percentiles (box limits) and whiskers that extend to the most extreme value within 1.5x of the interquartile range.

Raw sequencing data from the 46 individual libraries included in pool 7 that will be used for the out-of-sample validation of the epigenetic clock has been processed (Table 4). The average number of deduplicated reads and the total number of deduplicated reads that will be used for downstream analysis were acceptable and slightly lower than those from sequenced pools from project samples (Table 3). Bisulfate conversion efficiency was high (99.3%) and comparable to other sequenced pools.

Table 4. Initial metrics for the library pool composed of individual market samples that will be used for out-of-sample validation of the 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)
7	46	28.13	4,087,418	1.74	99.27	183,933,800

In response to SRB028–Req.03 (para. 18), the IPHC Secretariat has created a preliminary full factorial design that could be used to determine whether any training-test combinations of geographic area and year perform inadequately (Figure 7).

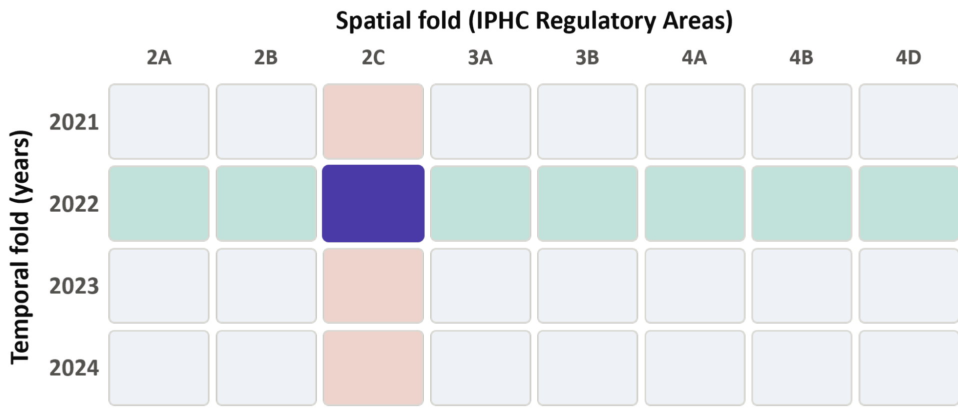


Figure 7. IPHC Regulatory Area x year holdout matrix. In this example, the model would be trained using data from every IPHC Regulatory Area and year except a specific area-year combination (blue cell: IPHC Regulatory Area 2 x Year 2022) and subsequently tested using that specific area-year combination. Alternatively, leave-on-area-out and leave-one-year-out approaches could be used to train the model with all areas (green row) or years (red column) except one (blue cell: 2C or 2022, respectively) for out-of-area and out-of-year cross validations.

In response to *SRB028–Rec.02* (*para. 35*) regarding the different aging methods that the IPHC Secretariat is currently using and developing, the IPHC Secretariat has compiled information on the epigenetic aging method in relation to anticipated use cases, relative development and production costs, benefits, timelines for development and decision point in Table 5.

Table 5. Characteristics of the epigenetic aging method.

	Epigenetic aging
Anticipated use cases	Additional source of ages for stock assessment
	Can provide insights into the biological basis of aging
	Could reduce uncertainty in natural mortality estimations in stock assessment
Relative costs	
Development costs	Sample processing ($1,859)
	Library construction ($17,450)
	Genome sequencing ($6,000)
	Cloud computing services ($3,603)
Production costs	GT-seq panel on subset of age-associated CpG sites ($1-2 per sample)
Benefits	Non-lethal aging
	Useful for species with hard structures that are hard to read Accurate alternate aging method
	Genetic samples (fin clips) are easy to collect and store
	Laboratory based method
	Low cost, high throughput production aging

Timelines for development	Epigenetic clock: 18 months
	Production panel: 6 months
Decision points	Evaluation of model performance in development of the epigenetic clock
	Evaluation of sex, maturity status and geographic origin on age predictive capabilities
	Evaluation of accuracy and precision
	Comparison with other aging methods

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 based on the calibrated maturity ogives (Figure 8; solid line). 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.

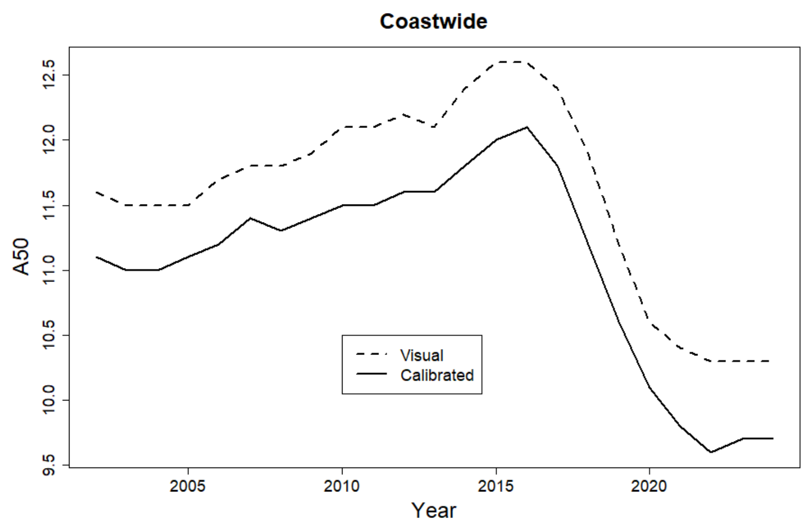


Figure 8. Coastwide A_{50} calculated from visual and calibrated maturity ogives from 2002 to 2024.

The IPHC Secretariat collected ovarian samples for maturity in the 2025 FISS, resulting in 1,276 ovarian samples collected 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. The IPHC Secretariat is currently processing the 2025 histology samples and will present preliminary spatial and temporal analyses at SRB029. In 2026, the IPHC Secretariat will continue to collect maturity samples coastwide by targeting the collection of 400 ovarian samples in Biological Region 2, 600 samples in Biological Region 3, and 400 samples in Biological Region 4 (Figure 9). Unfortunately, no samples will be collected in Biological Region 4B in 2026 due to the lack of FISS vessel bids.

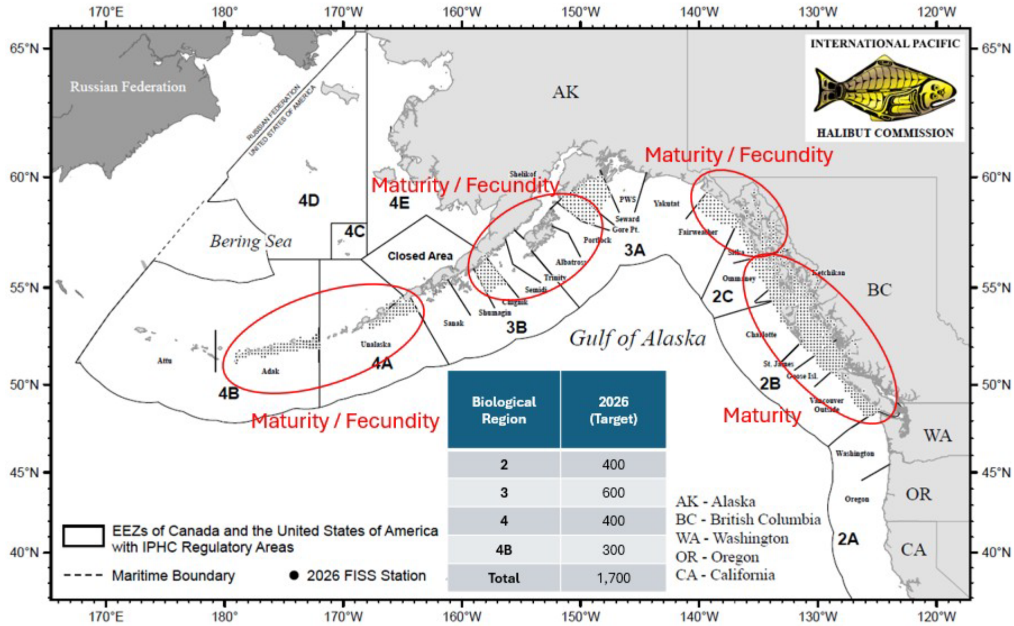


Figure 9. Coastwide map of sample areas and targets for maturity and fecundity collection in 2026 FISS.

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 10). 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).

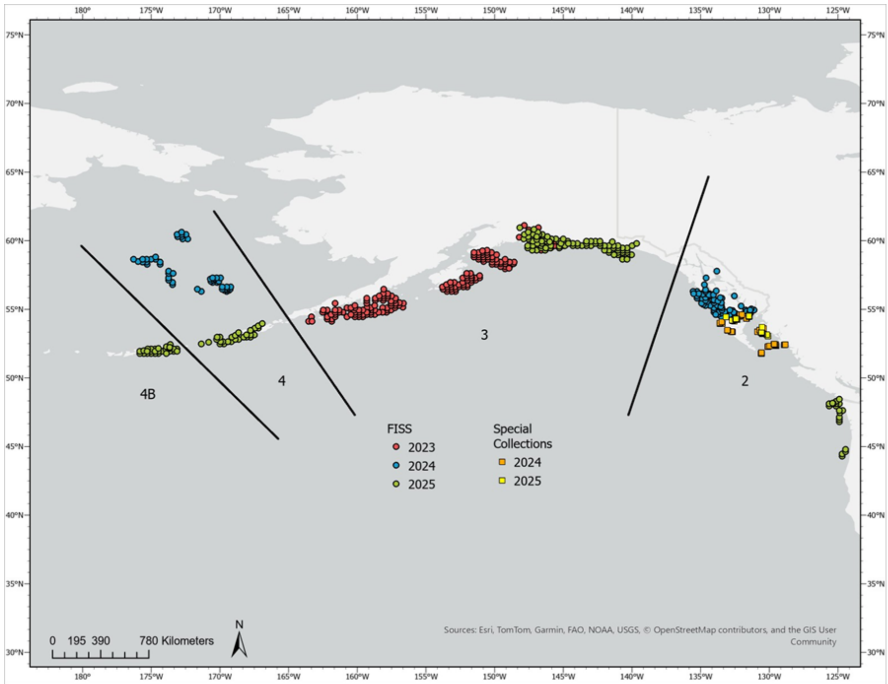


Figure 10. Coastwide map of 2023, 2024 and 2025 samples for fecundity collected in FISS (circle colors), and 2024 and 2025 special collection fecundity samples in IPHC Regulatory Area 2B (square colors).

In 2026, the IPHC Secretariat will continue to collect ovarian samples during the FISS for fecundity estimation. Specifically, whole ovary weights and samples are being collected from G2 (i.e. mature) females in Biological Region 2 (Sitka charter region), Biological Region 3 (Fairweather, Gore Pt., and Chignik charter regions), and Biological Region 4 (Unalaska charter region). The IPHC Secretariat will also be collecting fecundity samples from mid-September to October of 2026 (outside of FISS) during a special project in Biological Region 2 (Ommaney charter region) and Biological Region 3 (Gore Pt. charter region). The target sample collection for each Biological Region is 150 samples of >90cm G2 females. These samples will allow the IPHC Secretariat to spatially compare fecundity estimations among multiple Biological Regions, as previous special project collections (2024 and 2025) were conducted in Biological Region 2.
From 2023-2025, a total of 1,154 G2 ovarian samples have been collected for fecundity estimations. When examining the age and weight distribution of mature (G2) females collected for fecundity sampling (Figures 11-12), the distribution of fish appeared to be skewed to the right for both parameters, but more pronounced for weight (Figure 12). For the mature female samples collected from 2023-2025, the total range of ages was from 6 to 38 years old, and the total range of weights was from 2 to 92 kg. The largest proportion of sampled fish was from 11 to 13 years old, and from 3 to 9 kg in weight.

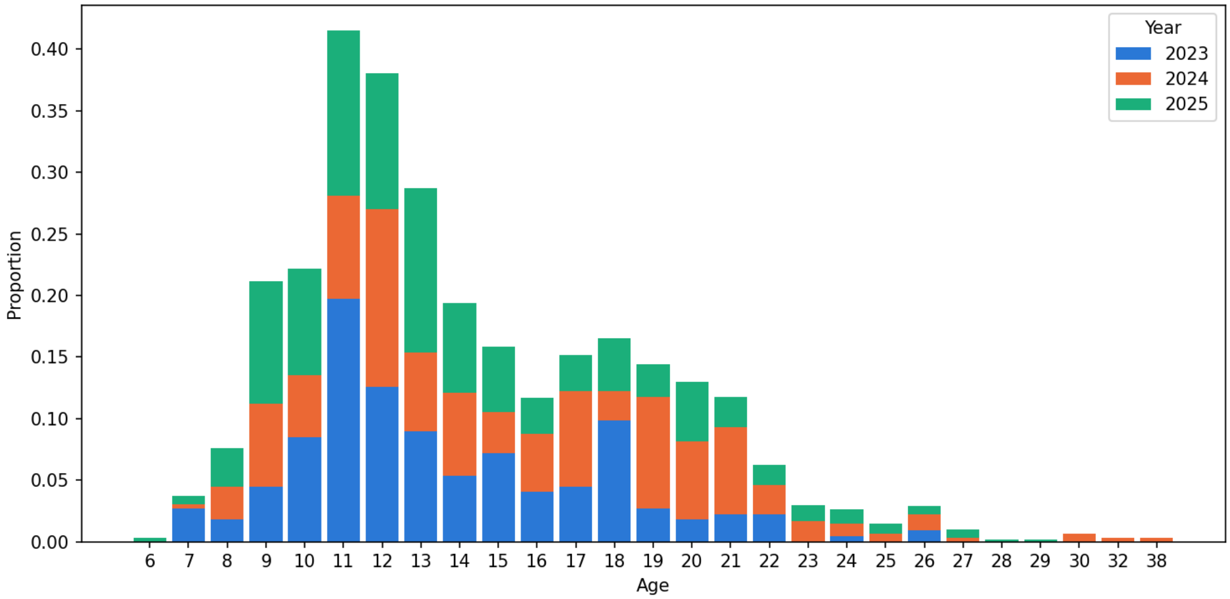


Figure 11. Stacked bar chart showing proportions of age (years) of mature (G2) female Pacific halibut collected for fecundity estimation in 2023, 2024, and 2025.

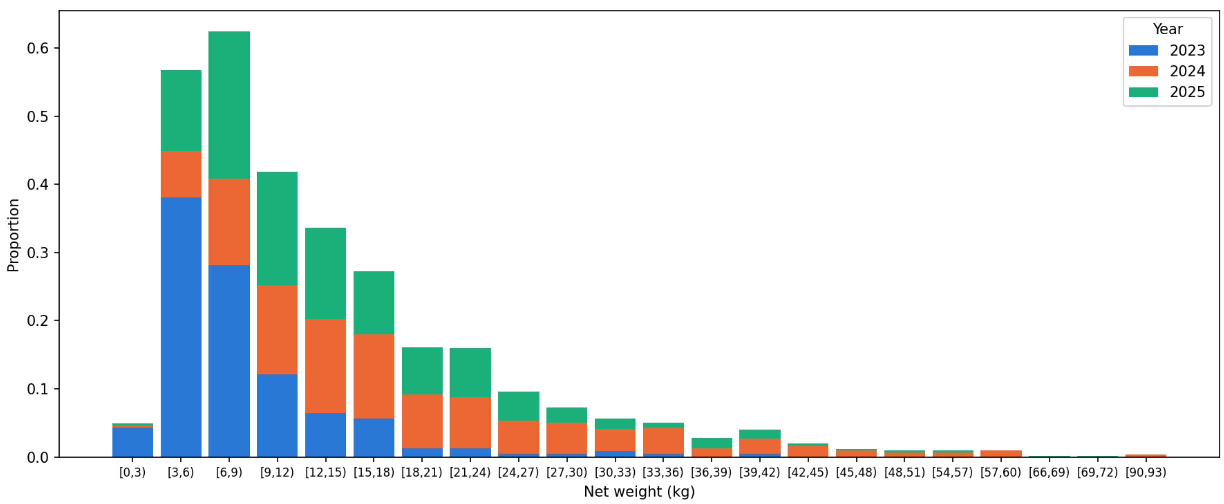


Figure 12. Stacked bar chart showing proportions of net weight (kg) of mature (G2) female Pacific halibut collected for fecundity estimation in 2023, 2024, and 2025.

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 13A) 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 13B,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), capturing approximately 80 hours of underwater footage combined, enabling us to better quantify shuttle performance and retention rates (Figure 13D). Approximately 73 hours (11/15 paired sets) of the footage has been reviewed in detail, and 5,463 hook status observations have been recorded across all four cameras.

Preliminary results from video footage suggest that the shuttle device had high retention rates of Pacific halibut when compared to other frequently encountered species (Table 6). In addition, preliminary results on catch rate comparisons between protected and unprotected skates did not show clear differences, likely due to high variability among catch rates within treatments. Overall, the shuttle device demonstrated good retention capacity (up to 835 kg/1,800 lb) in the trials, with capacity for higher weights. Incidentally, rare footage of Orcas around the groundline at depth was captured.

Table 6. 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 11 of 15 sets with video footage analyzed to date.

Common Name	Encountered	Excluded	Entered and Escaped	Entered and Passed Through	Retained
Pacific halibut	**121**	**1 (0.8%)**	**0**	**9 (7.5%)**	**112 (93.3%)**
Sablefish	186	2 (1.1%)	54 (29.4%)	34 (18.5%)	96 (52.2%)
Pacific cod	124	3 (2.4%)	13 (10.7%)	6 (5.0%)	102 (84.3%)
Rockfish	19	7 (43.8%)	2 (16.7%)	1 (8.3%)	9 (75.0%)
Skate	18	3 (16.7%)	0	2 (13.3%)	13 (86.7%)

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

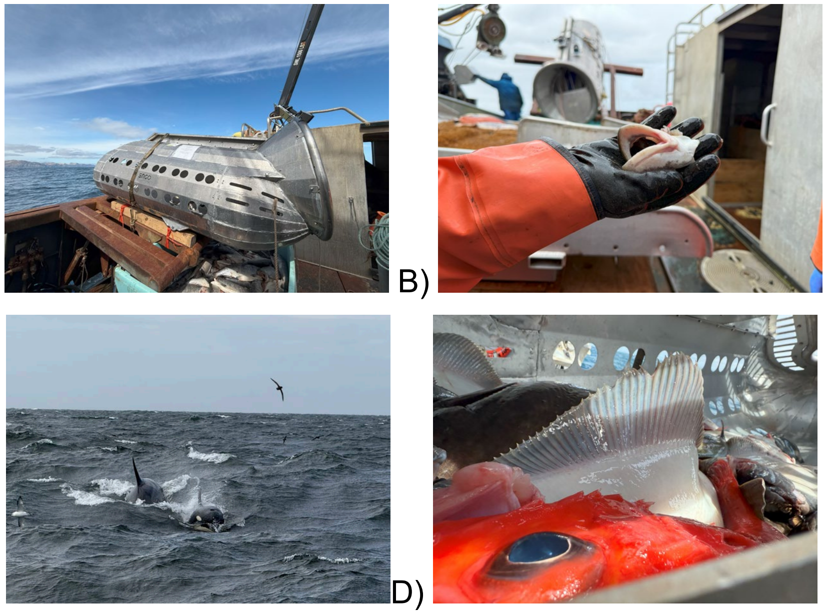
A) B) C) D)


Figure 13. 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-SRB029-05 which provides a response to Requests and Recommendations from SRB028, and a report on current biological research activities contemplated within the IPHC's five-year Program of Integrated Research and Monitoring (2022-26).

REFERENCES

Akalin, A., Kormaksson, M., Li, S., Garrett-Bakelman, F.E., Figueroa, M.E., Melnick, A., and Mason, C.E. 2012. methylKit: a comprehensive R package for the analysis of genome-wide DNA methylation profiles. Genome Biology 13:R87.

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., and Planas, J.V. 2026. fst-gl: Efficient and performance-oriented estimation of F_{ST} from genotype likelihoods. Bioinformatics. In Review.

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., and 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

R Core Team. 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

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., and 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	**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)	$60,374	Stock structure	December 2024-January 2027
Total awarded ($)					**$60,374**		

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

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 18 AUGUST 2026)

PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with a response to recommendations and requests made during SRB028 (IPHC-2026-SRB028-R) and an update on the development of the 2026 stock assessment.

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.

The final 2026 assessment will be produced for the IPHC's 102nd Session of the IPHC Interim Meeting (IM102, 1 December 2026) and the 103rd Session of the IPHC Annual Meeting (AM103, 25–28 January 2027) meetings. Updated data sources, including the results of the 2026 Fishery-Independent Setline Survey (FISS), logbook and biological data from the 2026 commercial fishery, and sex-ratio information from the 2025 commercial landings-at-age will be included for the final 2026 analysis.

Following the 2026 stock assessment development reported for SRB028 (IPHC-2026-SRB028-07), this document summarizes progress made on outstanding recommendations from SRB028, other development for 2026 as well as a brief prospectus on important upcoming research that may affect the update in 2027, the full stock assessment planned for 2028, and related analyses.

SRB REQUESTS AND RECOMMENDATIONS

The SRB made one request specific to the stock assessment during SRB028:

1) SRB028-Req.04 (para. 21):

   *"**NOTING** the progress presented in IPHC-2026-SRB028-07 on assembling a list of state space modelling platforms and their associated features, the SRB **REQUESTED** an update at SRB029 on progress to develop initial models, including approaches to mimic essential features of the Pacific halibut assessment (e.g. sex specific modelling) using other means (e.g. the spatial area features in multi-WHAM)."*

Based on the comparison provided for SRB028 of existing state-space model platforms that are used for production stock assessment (Table 1 in IPHC-2026-SRB028-07), we settled on WHAM (Stock and Miller 2021), SPoRC (Cheng et al. 2026) and CEATTLE (Adams et al. 2022) as top contending platforms from which to begin development for Pacific halibut. The CEATTLE platform currently includes more major features needed for Pacific halibut than the others, but none of them includes all the features currently employed in Stock Synthesis (Methot and Wetzel 2013).

As a simple starting point a CEATTLE model input file was developed with the following specifications:

- two (2) fleets (one survey and one fishery),
- uses ages 1-20 for both the data inputs and the modelled population dynamics,
- spans the period 1992-2025,
- fixes natural mortality for female Pacific halibut at the value used in the coastwide short stock assessment model (0.15) and fixes natural mortality for male Pacific halibut at the estimate from the coastwide short model (0.13),
- employs simple time-invariant logistic selectivity with a single offset between males and females for both fleets,
- starts the modelled period with a fully estimated initial age structure and offset to account for pre-modelled period fishing mortality, and
- treats recruitment as a random effect around a log- time-series mean, with estimated log-standard deviation.

For comparison, the current coastwide short model (the simplest of the four used in the stock assessment ensemble; described in IPHC-2025-SRB026-07) includes six fleets (directed commercial, commercial discards, recreational, non-directed commercial, subsistence and the IPHC's Fishery Independent Setline (longline) Survey; FISS). That model includes population dynamics from ages 0-30 and allows for variable plus and minus groups by fleet and year for the observed age composition data. That model estimates male natural mortality and employs time-varying selectivity for both the fishery and survey fleets as well as domed selectivity for the directed discards, the non-directed commercial and the recreational fleets. That model also estimates a non-equilibrium initial age structure and recruitment deviations around a S-R function with one estimated parameter (log-R0) and one fixed parameter (steepness of 0.75) and a variance constrained by a tuned sigma (Methot and Taylor 2011).

The current CEATTLE model is still very preliminary, with only a small subset of the model features and parameter combinations explored so far. Further work will add features to more closely resemble the coastwide short model and explore the estimability of additional parameters (e.g., time-varying selectivity, natural mortality, etc.). However, based on initial exploration there are a number of features that will not be able to be replicated without adding to the CEATTLE code. These include the following.

- More complex options for offsetting male and female selectivity including a different asymptote for males.
- Assigning ageing error matrices by year, instead of only by fleet which requires separating fleets to deal with the transition between surface ages (fishery <2001; FISS <1998,1999-2001) and break-and-bake ages.
- Separating the age-range for the observations from the age-range over which to calculate the population dynamics. In Stock Synthesis, the dynamics were extended to age 30 in order to capture the critically important growth occurring at the older age classes (particularly for the calculation of reference points where fishing does not truncate the age structure). Data have been aggregated using ‘tail compression’ which allows for the proportions at age to be aggregated at the youngest and oldest ages until they reach a threshold (the smallest observation considered potentially meaningful in the data; often 0.001). This avoids having a multinomial (or other composition likelihood) that includes a large number of structural zeroes (ages that are not ever selected at any point in the time series). This also allows for different ‘plus groups’ by data source. For halibut this approach has been used to aggregate surface ages to age 20 where the bias is much less influential than for older ages, while still extending the observed age distributions to age 25 for break-and-bake ages to provide unbiased information on natural mortality and the relative selectivity of the oldest fish in the population.
- Relatedly, the choice to use age 20 for the population dynamics also truncates the population maturity vector such that no modelled age reaches 100% maturity.

The CEATTLE model has the ability to ‘mirror’ selectivity and catchability among fleets, so additional fleets can be added to address the ageing method change as well as separate the fishing mortality and demographics of the various fishing fleets. The available suite of reference points is still yet to be explored.

Although considerable development is still needed before the results of this model are potentially useful for management, the treatment of recruitment variability appears promising. Despite the fact that sigma R is estimated on a different scale for age-1 than for age-0, the range of estimated deviations appears similar and the variability may actually be propagated better in CEATTLE due to the random-effects estimation of sigma R, especially toward the end of the time-series (Figure 1) as the signal in the data on incoming year classes disappears (the youngest fish in the survey are around age-5 and in the fishery a couple of years later due to the minimum size limit).

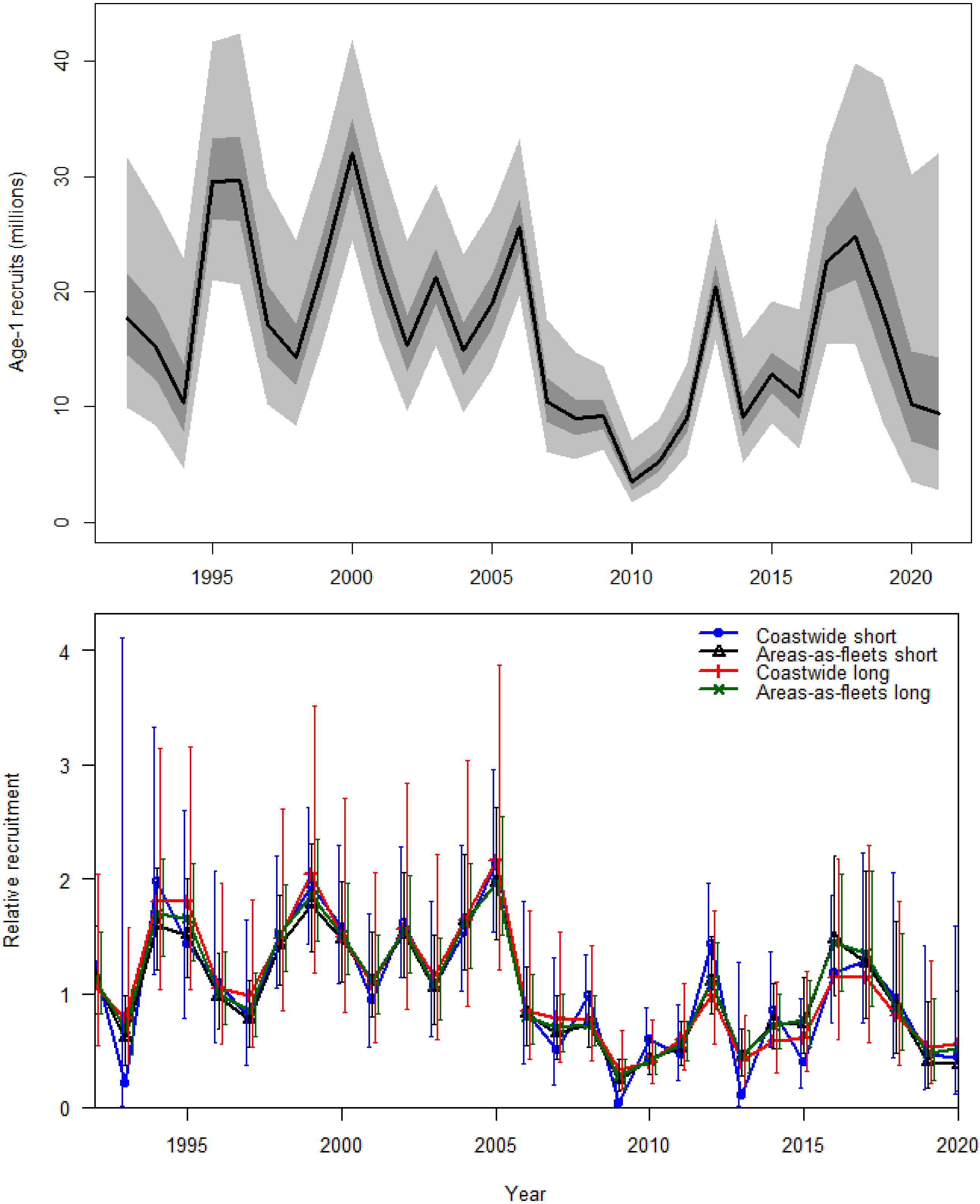


Figure 1. Estimated recruitments from the exploratory CEATTLE model (top panel) and the four models comprising the 2025 stock assessment model ensemble. Note that recruitments in the CEATTLE model occur at age-1 and so are offset one year from those in the Stock Synthesis models where recruitment occurs at age-0.

Next steps for the exploratory CEATTLE model will include bringing the configuration into as close alignment with the current coastwide short model as is possible and then comparing incremental changes in a step-wise manner to explore how a model that could potentially be used for management performs. Such a model could ultimately replace the coastwide short model in the current ensemble, be added to the ensemble (with or without sharing weighting with the current coastwide short model) or become the basis for an alternative ensemble including other state-space model configurations.

Further testing in preparation for the full stock assessment in 2028 will include a similar approach to development of models implemented in the WHAM and SPoRC platforms such that the detailed suite of features and effect of those features on management quantities can be compared across the three.

DASHBOARD DEVELOPMENT

Based on the 2025 stock assessment results presented at AM102, a stock status dashboard was developed. This page is intended to provide the salient results from the annual data overview and stock assessment summary in an accessible and intuitive manner. Secretariat staff will continue to develop and refine the content to provide easy interactive access to current stock status and assessment information.

ADDITIONAL STOCK ASSESSMENT DEVELOPMENT FOR 2026

Per standard procedures for final stock assessment preparation, the following data sources that will be included in the final 2026 stock assessment include:

1) New modelled trend information from the 2026 FISS for all IPHC Regulatory Areas.
2) Age, length, individual weight, and average weight-at-age estimates from the 2026 FISS.
3) Directed commercial fishery logbook trend information from 2026 (and any earlier logs that were not available for the 2025 assessment) for all IPHC Regulatory Areas.
4) Directed commercial fishery biological sampling from 2026 (age, length, individual weight, and average weight-at-age) from all IPHC Regulatory Areas.
5) Biological information (lengths and/or ages) from non-directed discards (all IPHC Regulatory Areas) and the recreational fishery (IPHC Regulatory Area 3A only) from 2025. The availability of these data routinely lags one year.
6) Updated mortality estimates from all sources for 2025 (where preliminary values were used) and estimates for all sources in 2026.

No preliminary data was available from 2026 in time for this document; however, preliminary raw catch rates from the 2026 FISS suggest mixed trends among IPHC Regulatory Areas with overall levels similar to 2025. Actual trends and interpretation of those trends for the coastwide stock, biological regions and individual IPHC Regulatory Areas will depend heavily on the results of the space-time modelling, including accounting for differences in the design from 2025, the age distribution of the catch and accounting for hook competition, especially where appreciable numbers of non-target species (e.g. dogfish) were encountered.

PROSPECTUS OF FUTURE ASSESSMENT MODEL AND DATA CHANGES

The development of the IPHC's research priorities is directly tied to the needs of the stock assessment and harvest strategy policy analyses, such that the IPHC's research projects will provide timely information about key biological and ecosystem processes that can then be incorporated directly into analyses supporting the management of Pacific halibut. Research priorities for the Pacific halibut stock assessment are delineated into three broad categories: data collection and processing, technical development of models and modelling approaches, and biological inputs. The highest priority items in each of these categories are highlighted in the Integrated Research and Monitoring Plan and are the primary focus of ongoing efforts. A longer list of research items can be found in the 2025 full stock assessment (IPHC-2025-SRB026-07).

Data collection and processing

This section represents projects relating specifically to existing and new data sources that could benefit the Pacific halibut stock assessment:

- Continued collection of sex-ratio from the directed commercial landings

  The ability to effectively estimate the effects of fishing, natural mortality, and other leading stock assessment parameters currently depends on the relatively short time-series of commercial fishery sex-ratio-at-age (2017-2024, with 2025 pending for inclusion in this year's stock assessment). Estimates have been consistent, and so no abrupt changes are expected, but future stock assessments will benefit from the information informing relative selectivity of males and females in the directed commercial fishery, and therefore the scale of the estimated spawning biomass, and the level of fishing intensity as measured by SPR.

- Whale depredation and tools to reduce it

  The magnitude of marine mammal depredation is unknown with no clear avenue to estimate it reliably. Unaccounted for mortality manifests as apparent low productivity in stock assessment results and therefore a biased estimate of the stock's ability to support fishery yield. If marine mammal depredation can be eliminated or at least reduced and/or estimated more precisely, mortality will be better accounted for, and our estimates of reference points will be improved. This research is unlikely to have large and immediate effects on stock assessment results but could substantially improve our understanding of stock dynamics in the long term.

Technical development

There are a variety of technical explorations and improvements that could benefit the stock assessment models and the ensemble framework. Larger changes (such as entirely new data sets) naturally fit into full assessment analyses; however, incremental changes may be possible during updated assessments when and if new information or methods become available. Technical research priorities include:

- Maintaining consistency and coordination between MSE, and stock assessment data, modelling and methodology

  Every cycle of stock assessment and MSE conditioning includes an exchange of information between the two platforms, both to ensure consistency as well as to benefit from the results learned through each analysis. Most recently, the analysis and treatment of weight-at-age has benefitted from extensive exploration during the conditioning of the MSE operating model.

- Estimation of natural mortality (*M*)

  Of the four models currently included in the stock assessment, only one, the coastwide short model, relies on a fixed value (0.15 for females) for natural mortality. This model is highly sensitive to the choice of fixed value (Figure 1), which is somewhat lower than the other three model estimates. This value could be updated, through direct estimation in the model, development of an alternative model structure capable of estimating it, or via indirect analyses outside the assessment. A substantially different estimate/fixed value could have a relatively large effect on our perception of the stock biomass level, and to a much lesser degree the recent trend and sustainable fishing mortality rate.

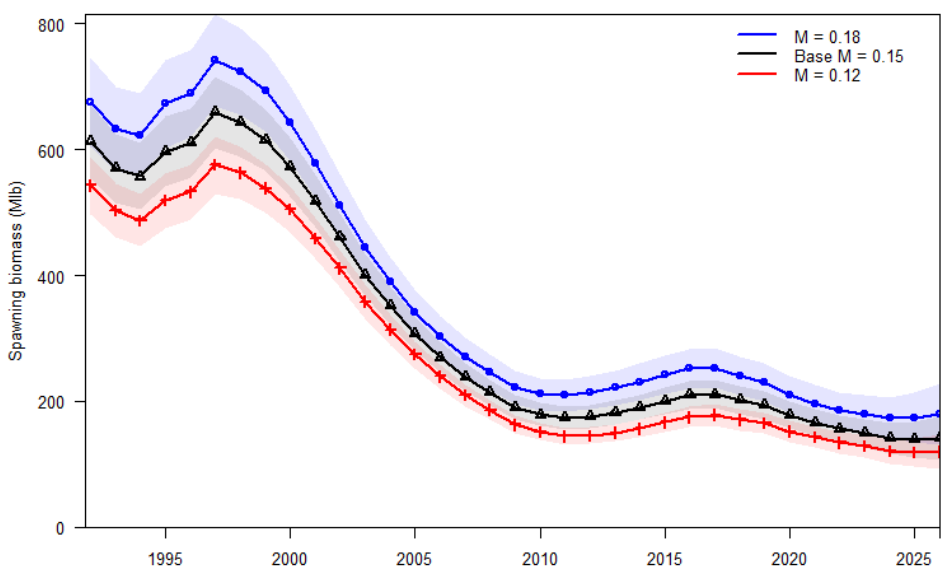


Figure 1. Sensitivity of the estimated spawning biomass from the 2025 coastwide short model to alternative fixed values of female *M*.

- Development of state-space models for Pacific halibut

  State-space models allow for more efficient statistical estimation of time-varying processes (e.g., recruitment or changes in selectivity). The SRB has identified this as a priority for the next full stock assessment planned for 2028 (initially in 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."). Adding a new model to the ensemble that may* *produce differing results could have a potentially large effect on the stock assessment output, including trends, status and reference points.*

Biological inputs

Key areas for improvement in biological understanding include:

- Updating the fecundity-weight relationship and the presence and/or rate of skip spawning

  This information has the potential to substantially revise our understanding of reproductive output from the Pacific halibut stock, particularly if an increasing relationship of egg-output to body weight and/or appreciable skip spawning are estimated to occur.

- The relative role of potential factors underlying changes in size-at-age

  Correctly delineating between the effects of environmental processes, population density, competition with other species, and the effects of fishing on growth rates is a critical step in determining reference points and sustainable harvest rates. Accurate information on the factors affecting size-at-age would better inform the harvest strategy for Pacific halibut.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2026-SRB029-06, which provides a response to requests from SRB028 and an update on stock assessment development for 2026.

b) **REQUEST** any analyses to be provided at SRB030 as part of the development of the planned 2027 update stock assessment.

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.

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. 2024. Report of the 25th session of the IPHC Scientific Review Board (SRB025). IPHC-2024-SRB025-R. 19 p.

IPHC. 2026. Report of the 28th Session of the IPHC Scientific Review Board (SRB028). Meeting held in Seattle, WA, 19-21 May 2026. IPHC-2026-SRB028-R. 16 p.

Methot, R.D., and Taylor, I.G. 2011. Adjusting for bias due to variability in estimated recruitments in fishery assessment models. Canadian Journal of Fisheries and Aquatic Sciences **68**: 1744–1760.

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

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. 2025a. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2024. IPHC-2025-SA-01. 40 p.

Stewart, I., and Hicks, A. 2025b. Development of the 2025 Pacific halibut (*Hippoglossus stenolepis*) stock assessment. IPHC-2025-SRB026-07. 124 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.

An update of the IPHC Secretariat MSE Program of Work for 2026-2028

PREPARED BY: IPHC SECRETARIAT (A. HICKS & I. STEWART; 20 AUGUST 2026)

***Outcome sought**: DISCUSS the updated MSE framework and operating model for 2026 and preliminary outcomes; provide further DIRECTION to the Secretariat for specific management procedures and scenarios to evaluate.*

PURPOSE

To provide the IPHC's Scientific Review Board with a response to recommendations and requests made during SRB028 (IPHC-2026-SRB028-R) and an update on progress of the Management Strategy Evaluation (MSE) Program of Work for 2026, including methods used for projections and preliminary results from the updated MSE framework.

1 INTRODUCTION

The International Pacific Halibut Commission (IPHC) adopted the IPHC Harvest Strategy Policy (HSP) at the 101st Session of the IPHC Interim Meeting (IM101; IPHC-2025-IM101-R, para. 25) and requested a number of items to be added to the MSE Program of Work for 2026 (IPHC-2025-IM101-R, para. 26). The Commission noted priority items for the 2026 MSE Program of 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.*

Furthermore, the SRB reviewed 2025 MSE results and the initial conditioning of the 2026 operating model (OM) at the 28th Session of the SRB (SRB028). The following requests and recommendations were made:

> **IPHC-2026-SRB028-R, para 27 (SRB028–Rec.01):** *The SRB **NOTED** that a single control rule based on relative biomass is unlikely to reach the ramp (descending limb) where reduction in F are triggered. Therefore, the SRB **RECOMMENDED** investigating HCRs based on absolute biomass.*

IPHC-2026-SRB028-R, para 23 (SRB028–Req.05): *The SRB **REQUESTED** that the Secretariat investigate, via the MSE, control rules based on changes to the risk of overfishing (often referred to as p*, see Shertzer et al. 2008).*

IPHC-2026-SRB028-R, para 25 (SRB028–Req.06): ***RECALLING** that at SRB026, the SRB made the following recommendation,*

> *IPHC-2025-SRB026-R, SRB026–Rec.07 (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."*

*and **NOTING** the update provided by the Secretariat at SRB028, the SRB **REQUESTED** an analysis of projecting recruitment via projections in environmental drivers (Pacific Decadal Oscillation) in addition to autocorrelated recruitment, which tends to rapidly revert to the mean.*

This paper presents an update on progress for the Commission's high priority topics and the SRB028 recommendations and requests. Each section below represents a high priority topic and responses to the SRB are presented accordingly within each section.

2 CONDITION THE OPERATING MODEL AND UPDATE THE MSE FRAMEWORK

The MSE framework consists of the operating model (OM) conditioned to past observations and estimates, the operating model projecting forward in time, the variability associated with the historical conditioning and the future projections, the integration of the management procedure (MP), and the process for running simulations. The OM was conditioned to recent observations and the 2025 stock assessment, the process to project future variability in weight-at-age and recruitment was revised, and the code to run simulations made more efficient.

The MSE operating model (OM) consists of four individual models based on the four models in the stock assessment ensemble, which includes new updates made during the full stock assessment in 2025. The models in the stock assessment ensemble are an areas-as-fleets (AAF) long time-series model (longAAF), an AAF using a short time-series starting in 1992 (shortAAF), a coastwide (CW) long time-series model (longCW), and a CW short time-series model (shortCW). Recent updates to the stock assessment that were incorporated into the MSE OM included updating the time-series information for the Pacific Decadal Oscillation, re-tuned recruitment variability, and an updated maturity ogive to reflect the recent histology-based estimates produced by the IPHC's Biological and Ecosystem Sciences Branch.

Each individual model in the MSE OM begins in 1952 to avoid technical challenges associated with highly uncertain but low spawning biomass and population dynamics bottlenecks in the 1920s and 1930s. This later start date, however, still captures important historical changes in the Pacific halibut stock. The parameters and assumptions from each stock assessment model were used to initialize the associated individual regional MSE model while unfished equilibrium recruitment, movement, and recruitment distribution parameters were estimated during the conditioning process to best fit the estimated spawning biomass from the associated assessment model, the stock distribution estimated from the FISS, and the age compositions estimated from the FISS. Variability was added by sampling from the multivariate normal distribution of parameters to produce 125 individual trajectories for each of the four models. The MSE OM integrates over these four models to include parameter and structural uncertainty. Details of the conditioning are provided in IPHC-2026-SRB028-08 Rev_1.

The median integrated spawning biomass for the 2026 MSE OM along with 5th and 95th percentiles are shown in Figure 1. The estimated spawning biomass from the ensemble stock assessment, shown in blue for comparison, is similar when comparing the medians but has less variability for most of the time-series. The MSE OM is designed to represent additional uncertainties to ensure that the best performing management procedures (MPs) are robust to many sources of uncertainty.

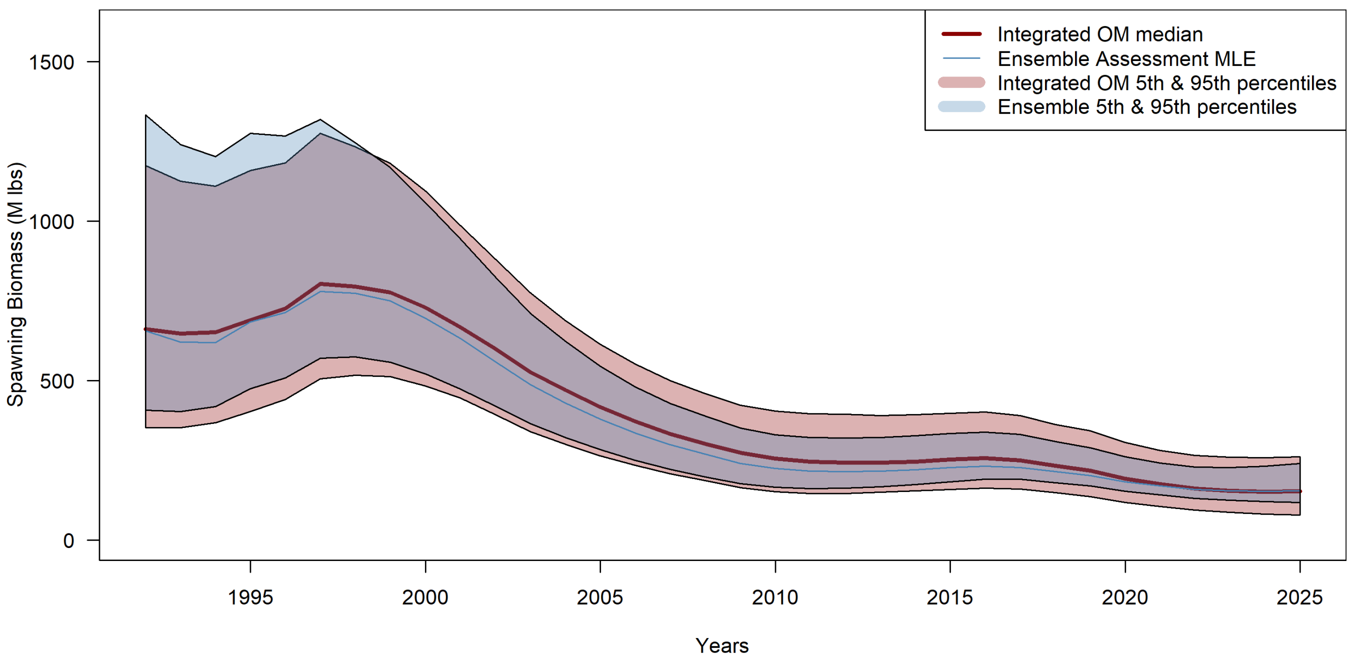


Figure 1. Integrated conditioned spawning biomass for the MSE Operating Model in 2026. The red line shows the median and the red polygon encompasses the 5th and 95th percentiles of the 500 simulated trajectories integrated over the four individual models. The blue line and polygon show the median and 5th and 95th percentiles from the stock assessment ensemble for comparison.

2.1 Projections with the MSE framework

An additional component of conditioning the OM is to simulate variability into the future. Each individual trajectory characterizes parameter and structural uncertainty in the OM, and variability is also simulated for future weight-at-age, recruitment, and fishery selectivity. Along with fishing mortality, weight-at-age and recruitment are the biggest factors influencing the biomass of the stock in the past and the future.

2.1.1 Weight-at-age projections

A new analysis of weight-at-age was conducted that provided insight into some of the factors influencing weight-at-age. Using modern random effects models (Cheng et al. 2023) year, age, and cohort effects were examined. The models incorporating cohort effects did not perform well because estimates of mean weight-at-age for older fish were often much greater than expected and additional work by the Secretariat is needed for their development. However, simply including year and age effects, as described by Xu et al. (2019), can serve as a proxy for cohort specific differences in weight-at-age (Figure 2). Additional research to specifically incorporate cohort effects will continue as time allows.

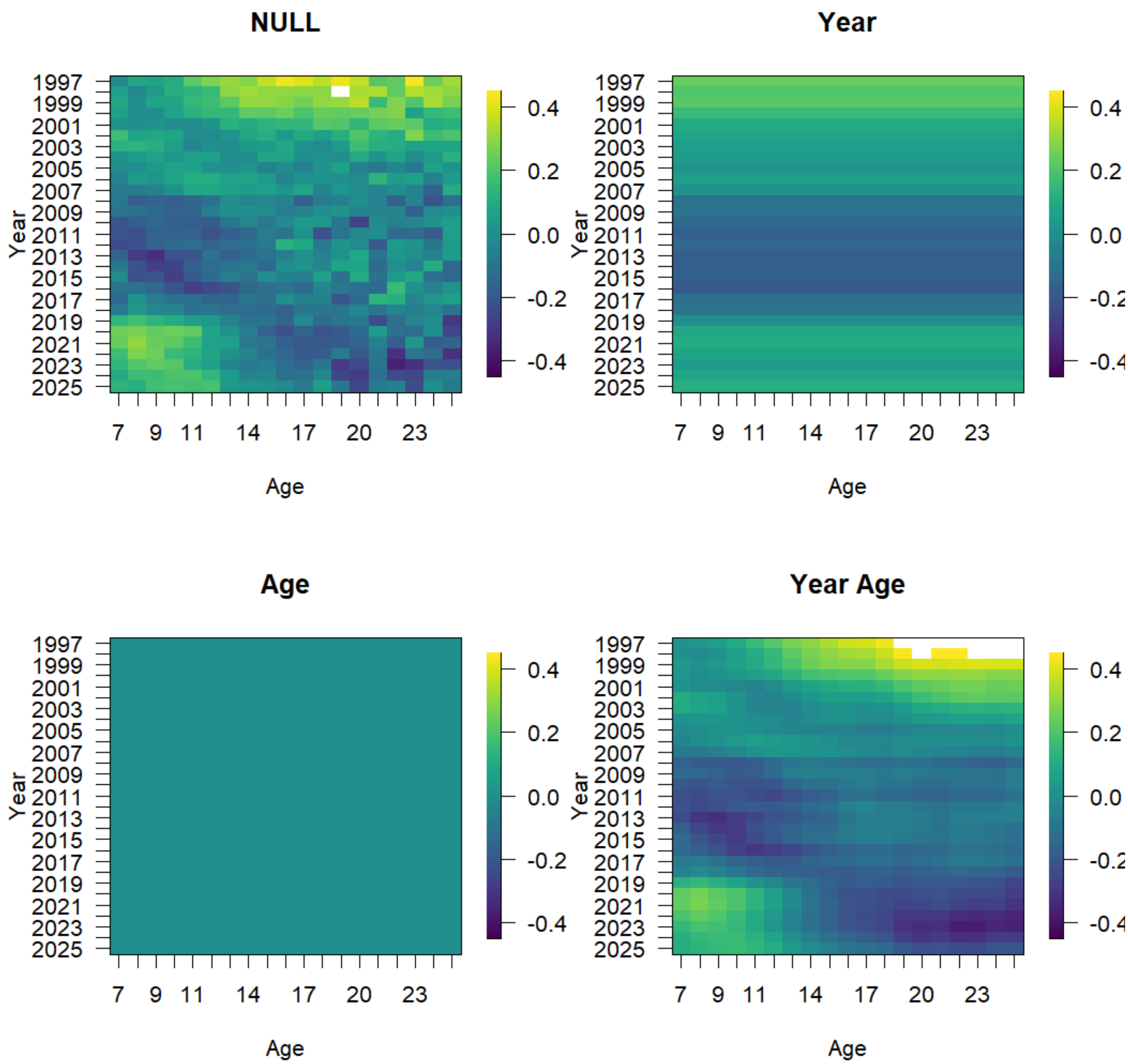


Figure 2. Models with estimated year and age effects for coastwide female Pacific halibut weight-at-age showing deviations from an overall mean weight at each age. The NULL model estimates a deviation for each year/age combination as a random effect. Blue colours indicate low weight-at-age and yellow colours indicate high weight-at-age. White regions are outside of the range indicated by the scale. Consistent coloration along a diagonal suggests that a cohort experienced similar low or high weight-at-age across its lifetime.

The model used to predict weight-at-age is a state-space model written in RTMB (Kristensen et al. 2016) and estimates a global mean weight-at-age (μ_a) and year and age deviations ($\varepsilon_{a,y}$) from those global means in the process model.

$$W_{a,y} = e^{\ln(\mu_a)+\varepsilon_{a,y}}$$

where *a* is age, *y* is year, and $\varepsilon_{a,y}$ is a matrix of age and year deviations simulated as a two-dimensional (2D) AR(1) process:

$$\boldsymbol{\varepsilon} \sim MVN(0, \sigma_\varepsilon^2 \boldsymbol{\Sigma})$$

The correlation matrix ($\boldsymbol{\Sigma}$) is equal to the Kronecker product ($\otimes$) of the two correlation matrices representing among-age and among-year AR(1) processes:

$$\boldsymbol{\Sigma} = \boldsymbol{R}_{a,a'} \otimes \boldsymbol{R}_{y,y'}$$
$$[\boldsymbol{R_a}]_{a,a'} = \rho_a^{|a-a'|}$$
$$[\boldsymbol{R_y}]_{y,y'} = \rho_y^{|y-y'|}$$

Therefore, $\boldsymbol{\Sigma}$ is a matrix of dimensions $n_y n_a \times n_y n_a$ where each element of the $n_y \times n_y$ block matrix is an $n_a \times n_a$ age matrix scaled by the corresponding year correlation. The inverse of the correlation matrices ($\boldsymbol{R}^{-1}$) is defined as a tridiagonal matrix, thus the precision matrix ($\boldsymbol{\Sigma^{-1}}$) is a sparse matrix. RTMB leverages these assumptions to create a fast and efficient random effects model. The marginal process variance of every year-age combination is σ_ε^2 because the AR(1) components are stationary with unit marginal variance.

$$Var(\varepsilon_{a,y}) = \sigma_\varepsilon^2$$

However, the variability of $W_{a,y}$ increases with age because $\varepsilon_{a,y}$ is lognormal.

A parametric process, such as the von Bertalanffy growth equation, was tested but was not used because the weight-at-age for older Pacific halibut is highly variable and nearly linear across all ages modelled (i.e. did not show a strong asymptote, as shown in Figure 3). Other formulations to force monotonically increasing weight-at-age were also tested but also showed poor convergence behaviour, sensitivity to starting values, and large departures from some observed median weight-at-age calculated across years. Therefore, the overall log mean weight-at-age was estimated freely for each age class.

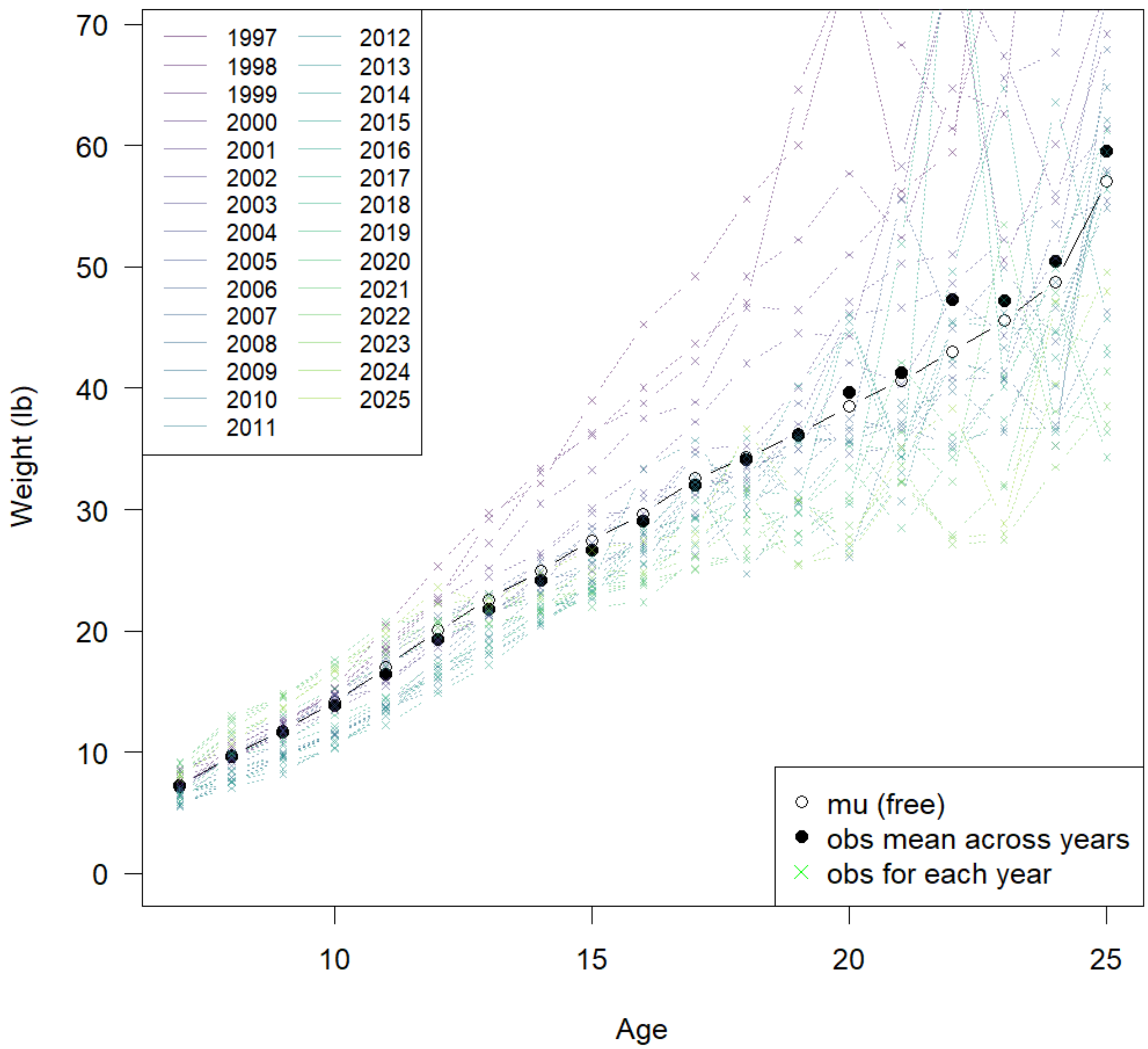


Figure 3. Observed female weight-at-age from coastwide FISS samples for each year from 1997–2025 (x's and dotted lines) with the observed mean across all years (black points). Estimated mean weight-at-age from which year and age effects apply are shown as open circles.

The observation model relates the observed mean weight-at-age to the unobserved mean weight-at-age from the process model.

$$\widehat{W}_{a,y} = W_{a,y} + e^{\tau_{a,y}}$$

$$\tau_{a,y} \sim N(0, \sigma^2_{\tau,a,y})$$

Parameters estimated included the log of the overall mean weight-at-age, the correlation for age, the correlation for year, and the variance of $\varepsilon_{a,y}$ (Table 1). Initial tests determined that also estimating the observation variance ($\sigma^2_{\tau,a,y}$) was not feasible, even if assuming it was constant across years, thus was determined from bootstrapping individual observations for each age and year and calculating the variance of the mean weight-at-age for each year.

Table 1. Estimated parameters and transformations used for the weight-at-age models.

Estimated Parameter	Model Transformation
$\ln(\mu_a)$	$\mu_a = e^{\ln(\mu_a)}$
$\ln(\sigma_\varepsilon^2)$	$\sigma_\varepsilon^2 = e^{\ln(\sigma_\varepsilon^2)}$
θ_a	$\rho_a = \text{logit}^{-1}(\theta_a) = \frac{1}{1+e^{-\theta_a}}$
θ_y	$\rho_y = \text{logit}^{-1}(\theta_y) = \frac{1}{1+e^{-\theta_y}}$

Seven (7) different models were fit to observations from the IPHC Fishery-Independent Setline Survey for the years 1997–2025 because that was a complete and consistent dataset that included individual observations from which to calculate observation error. Observations less than 7 years old were limited due to selectivity of the gear and observations older than 25 were sparse, therefore only ages 7 through 25 were used. Likelihoods and AIC from the seven (7) different model specifications, incorporating age, year, and cohort effects, were determined for model selection. As noted previously, the models with cohort effects, using a different estimation routine, did not perform well due to unexpectedly high estimated mean weight-at-age for older fish, thus were rejected due to uncertainty in producing consistent and reasonable results for forward projections. The AIC for each of four models incorporating year and/or age effects and using all sex-specific data coastwide or sex-specific data only within one of the four Biological Regions was always lowest for the model with both year and age effects (Table 2).

Year and age were important effects to predict weight-at-age, which suggests that fish in the same cohort experience a similar trajectory of weight-at-age being below or above average over their lifetime, with some variability (Figure 2). The NULL model (no year or age effects but estimating deviations for each year/age combination as a random effect) shows patterns in low and high weight-at-age, which are diagonal indicating that a deviation from average weight-at-age is apparent when the cohort is young and has not experienced much fishing pressure, and tends to remain through the life of a cohort. The NULL model is useful to understand these patterns, but is not useful to project weight-at-age into the future, which is the goal for the MSE. Year-effects alone showed changes in weight-at-age over time, but could not explain these cohort specific deviations. Age-effects alone explained very little variation in weight-at-age because the majority of the variation across age is explained by the estimated mean weight-at-age parameters. However, estimating year- and age-effects together was able to explain much of the cohort patterns apparent in the NULL model. It is uncertain if a cohort-effect may improve model.

The estimated relationships in the random effects model were used to simulate weight-at-age in the future with variability, which was the goal of this analysis for the MSE. The following objectives were used to tune the projections: 1) simulate weight-at-age covering the entire range of observed weight-at-age from 1950 to 2025, 2) mimic slow changes in weight-at-age over decadal time-scales, 3) implement a slow increase in weight-at-age from current conditions, 4) have the median of the simulated weight-at-age 70 years in the future be approaching the median observed weight-at-age from 1950 to 2025, and 5) simulate mean weight for ages 1 to 30. To achieve these objectives, the estimated parameters for the mean weight-at-age, the process error, and the correlation across years were adjusted because the analysis was based on the years 1997 to 2025 which showed a reduced range of weight-at-age relative to the longer time-series (for which individual observations are not available). Future analyses could be improved by incorporating all the data, which would require stitching summarized datasets together and determining observation error for all years. For most historical years, individual observations are not available, which will make determining the appropriate level of observation error to use challenging.

Table 2. AIC for sex-specific models with different combinations of year and age effects using coastwide data and region-specific data. The NULL model estimates a deviation for each year/age combination as independent random effects. The lowest AIC is shown in italics.

Model	**Coastwide**		**Region 2**		**Region 3**		**Region 4**		**Region 4B**	
	F	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**
No year or age (NULL)	-177	-464	-398	-528	128	-345	-38	-211	-169	-421
Year	842	-749	-150	-794	1179	-979	4	-750	54	-810
Age	5051	6003	1020	649	3661	3449	1788	1962	913	1294
Year & Age	*-1133*	*-1795*	*-958*	*-1200*	*-556*	*-1510*	*-719*	*-1157*	*-351*	*-1118*

Projections for one-hundred (100) years were completed for each sex/region/fleet combination. First, the medians of the mean weight-at-age for ages 1 to 30 were determined using observations from all years (1950–2025) and stitched together from multiple data sources (as used in the stock assessment). The medians were then lightly smoothed across ages to reduce the variability in the median weight-at-age seen at older age classes due to the paucity of observations. The median was used to provide a central point of the extended time-series to project deviations from and avoid influence from unbalanced low and high periods. Sigma was increased using a multiplier to allow coverage over the range of historical observed weight-at-age. The year correlation parameter was increased to 0.98 to produce a slow increase, decadal oscillations, and a median that approaches the central point after approximately 70 years of projections. The first deviation to begin the process was calculated from the difference between the 2025 and 2024 observed weights-at-age (in natural log scale). The minimum and maximum projected weight-at-age was bounded by 5% beyond the minimum and at the maximum observed weight-at-age observed over the entire time-series. The same seed for the standard normal deviations was used so that each fleet and sex showed consistent increases and decreases across time, but at different magnitudes.

Tuning these parameters was done ad hoc after looking at summaries of the trajectories for different fleets and sexes. The objectives were challenging to meet for all ages and fleets, and projections tended to show a smaller median weight-at-age than observed values over the full time-series. An example for population weight-at-age for females in region 2 is shown in Figure

4. The Secretariat determined these to be reasonable, especially given the priority of the Commission to consider current conditions for managing Pacific halibut. Figure 5 shows three examples of simulated weight-at-age and how they compare to historical weight-at-age. The main objective was to capture the oscillations in weight-at-age over decadal time scales.

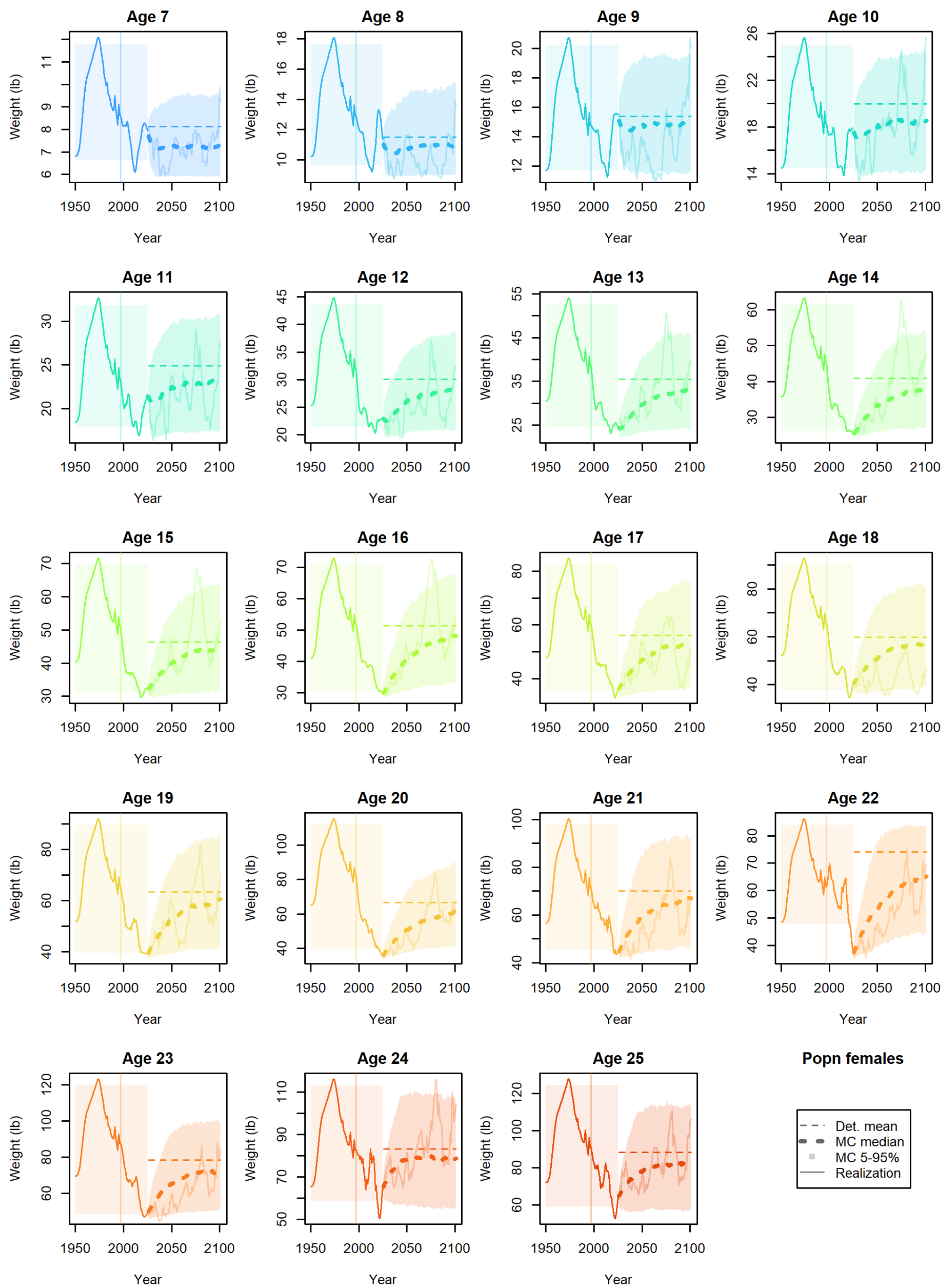


Figure 4. Historical mean weight-at-age with a shaded region between the 5th and 95th percentiles calculated across the years 1950–2025, and the median projected weight-at-age with a shaded region between the 5th and 95th percentiles calculated for each projected year (2026–2125) using 1000 simulations. The thin dashed line is the median of the historical period. One example projection realization is shown as a light line in the projection period.

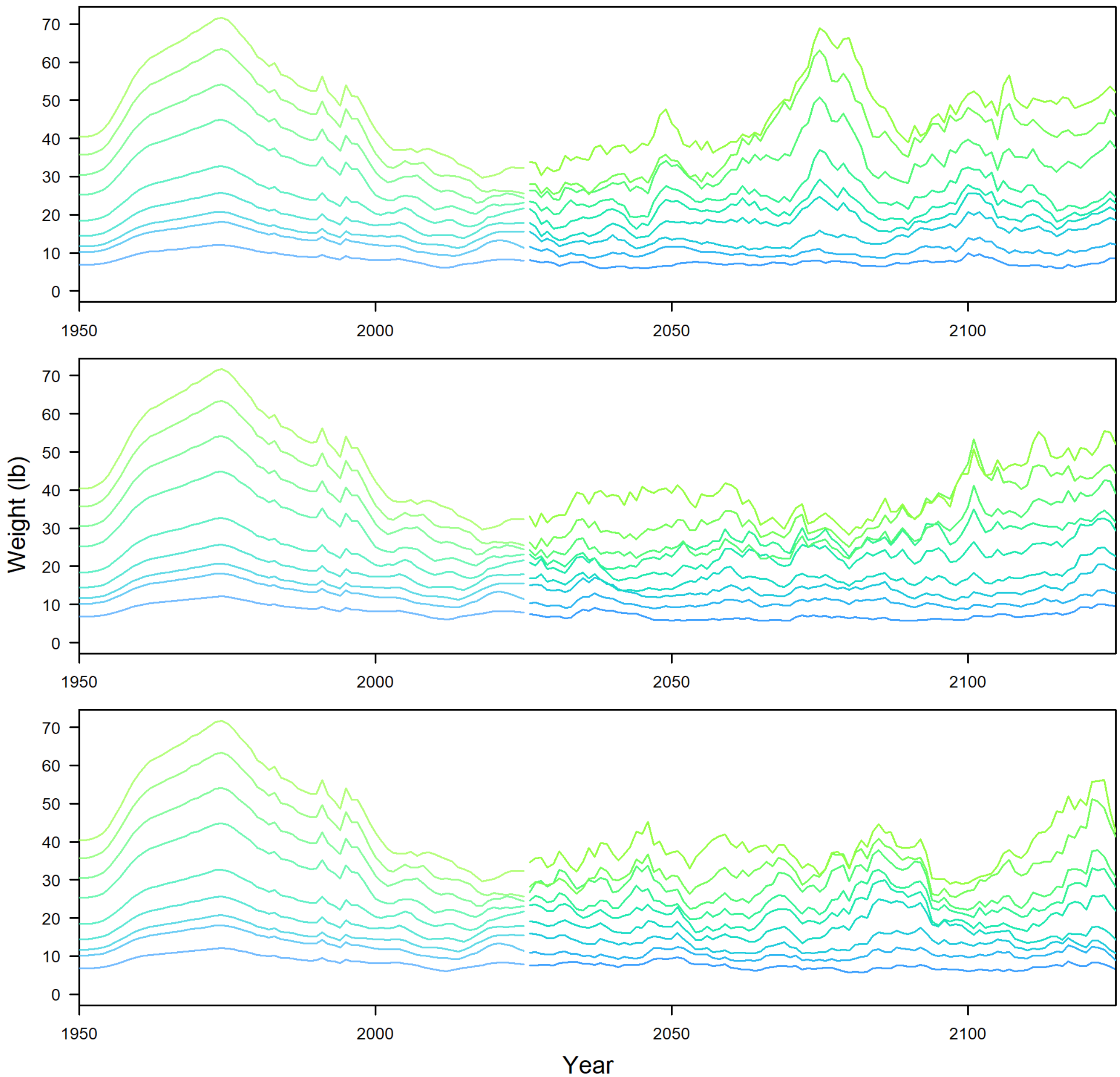


Figure 5. Historical weight-at-age and three examples of simulated weight-at-age for female Pacific halibut in Region 2 for ages 7 to 15 using a random effects model with year and age effects. The break in the time-series between 2025 and 2026 represents the transition from estimated to simulated trends.

2.1.2 Recruitment projections

Recruitment was simulated into the future with annual random deviations representing a departure from average recruitment determined from the stock-recruit relationship. Average recruitment is dependent on the PDO regime, where high average recruitment occurred in high PDO regimes, and low average recruitment occurred in low PDO regimes. The difference in average recruitment between the two regimes was determined from the stock assessment models where high average recruitment was about 1.5 times greater than low average recruitment.

The PDO regime was simulated as high or low with a typical period of 10-20 years before switching to the opposite regime. This was done by modelling a probability of switching to the opposite regime which increases, following a logistic curve, as the length of the current regime (i.e. run) increases.

$$P(\text{switch}) = \frac{1 - y_{\text{int}}}{1 + e^{-k(\text{run} - y_{\text{mid}})}} + y_{\text{int}}$$

where y_{int} is the probability when the length of the run is zero, k controls the steepness of the curve, and y_{mid} is the run length at which the probability of switching is halfway between y_{int} and 1. The values for y_{int}, y_{mid}, and k were 0, 0.2, and 20, respectively, resulting in the curve shown in Figure 6. The proportion positive, determined from 125 simulated trajectories, begins at 0 in 2026 because monthly PDO values have been negative in 2026, and increases from 0.5 in 2027 to nearly 1 in 2030 because the probabilities of switching from the current negative regime to positive in 2027, 2028, and 2029 are fixed at 0.5, 0.7, and 0.8, respectively, to encourage a more gradual switch to a positive PDO in the near-term (Figure 7). Without this constraint, following the 28 year period of low PDO values there would be a very rapid projection of switching regimes, leading to an immediate disconnect with current conditions. Years beyond 2029 show a decline in the proportion of positive PDOs that oscillates around 0.5 and dampens quickly.

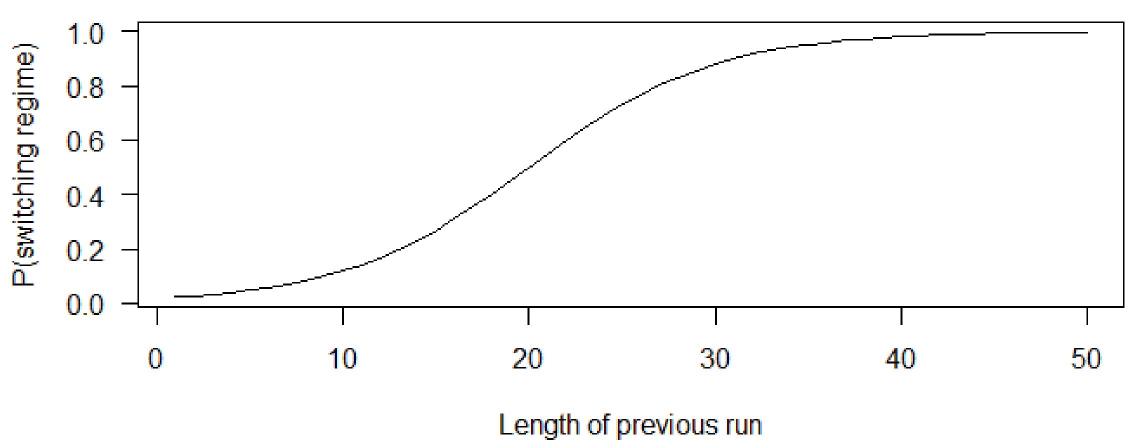


Figure 6. Modelled probability of switching the PDO regime based on the length of the current PDO regime in the simulations.

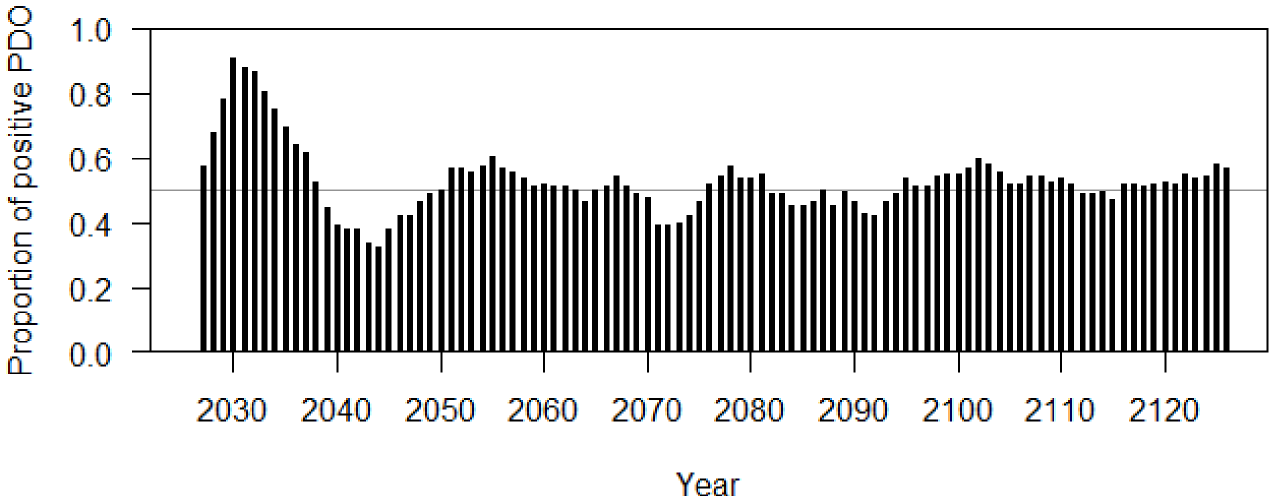


Figure 7. The proportion of simulated positive PDO values by year over 125 realizations. The year 2026 is set to zero because Monthly PDO values in 2026 has been negative. The PDO values for 2027, 2028, and 2029 have specified probabilities of being positive equal to 0.5, 0.7, and 0.8, respectively. Other years use the length of the previous run (**Figure 6)** to determine the probability of switching.

This semi-Markovian approach to simulating the PDO into the future was used because the goal was not to predict the specific future PDO transitions, but to integrate over runs of negative and positive PDO in the projections. In response to **SRB028-Req.06**, the Secretariat implemented the above method with ad hoc fixed probabilities in the first four years of the simulations to slowly move out of the current negative PDO regime. There was a small amount of evidence of autocorrelated recruitment from previous investigations, which had minor effects on the MSE results. However, instead of autocorrelated recruitment, the new MSE simulations implement this slower transition to a positive PDO regime to reflect the recent period of low mean recruitment. These will affect short-term and medium-term performance metrics from the MSE simulations, while long-term performance metrics will equally integrate over low and high regimes.

Additionally, relating the PDO to environmental variables and predicting regime shifts has been challenging because the PDO represents a combination of processes that span a wide area (Newman et al. 2016; Qin et al. 2023). It is possible that PDO regime shifts may be predicted from climate models (Newman et al. 2016), although the relationship of the PDO to other environmental variables seems to be changing in recent years (Litzow et al. 2020) and it is unknown if it will remain a good predictor of differences in Pacific halibut mean recruitment in the future.

2.1.3 Projection results

The parameter and structural uncertainty along with the variability in weight-at-age and recruitment results in a considerable amount of uncertainty in the spawning biomass, especially when projected 70 years into the future (Figure 8). This is consistent with the estimated dynamics and past observations of Pacific halibut, and the newly conditioned OM reflects the current understanding of the Pacific halibut stock while also incorporating an appropriate and scientifically based range of variability for the robust evaluation of MPs.

The range of projected spawning biomass is narrower when compared to the simulation results from 2025 (using the previously conditioned OM), which is mostly due to updated methods to simulate weight-at-age and average recruitment (Figure 8). At the beginning of the projections, the median spawning biomass and the median TCEY remain low, representing the persistence of low productivity in the short-term. At the end of the time-series, the median spawning biomass and median TCEY are similar to previous results, but the variability is narrower, representing the improved method to model weight-at-age where extreme high and low weight-at-age (e.g. levels that have been recently experienced) have lower chances of occurring compared to the methods used in 2025. Figure 9 shows that fixing weight-at-age at levels seen in the last five years and keeping the projected PDO in the low regime results in a similar spawning biomass and TCEY levels in short-term projections, but lower levels in the long-term compared to the simulations integrating over those factors. These results highlight the importance of evaluating results for specific weight-at-age and PDO scenarios to understand the effect these have on the outcomes (also see below).

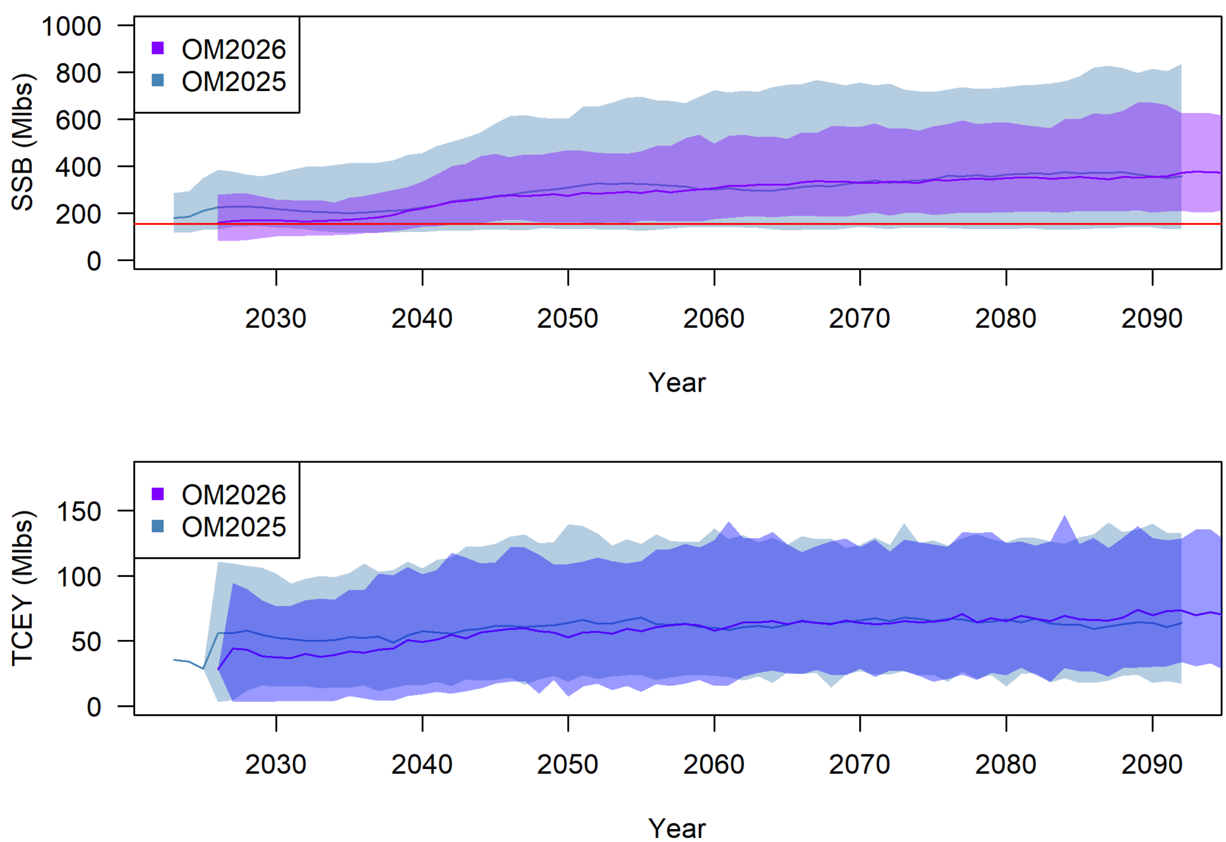


Figure 8. Projected spawning biomass (top) and the corresponding TCEY (bottom) based on harvesting at an SPR of 43%. Simulations include decision-making variability, estimation error, and observation uncertainty. Results using the updated simulation framework for 2026 are shown in purple (OM2026) and the results using the 2025 framework with the same options are shown in blue (OM2025). The red horizontal line is at a spawning biomass of 153 Mlbs to reflect the lowest estimated spawning biomass (2024) from the recent stock assessment.

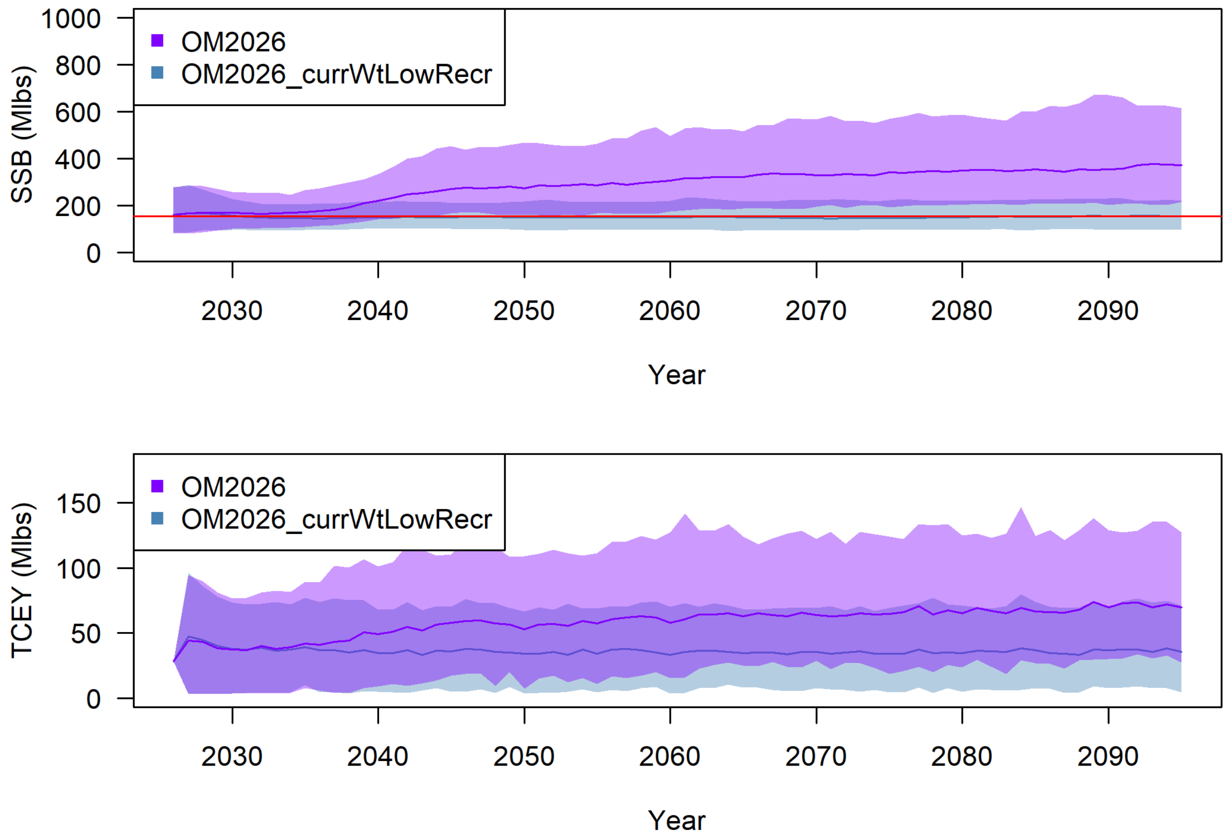


Figure 9. Projected spawning biomass (top) and the corresponding TCEY (bottom) based on harvesting at an SPR of 43%. Simulations include decision-making variability, estimation error, and observation uncertainty. Results using the updated simulation framework for 2026 are shown in purple (OM2026) and the results when fixing weight-at-age at recent levels seen in the last five years and keeping the projected PDO at low values are shown in blue (OM2026_currWtLowRecr). The red horizontal line is at a spawning biomass of 153 Mlbs to reflect the lowest estimated spawning biomass (2024) from the recent stock assessment.

3 EVALUATE A RANGE OF SPR VALUES

Simulations across a range of spawning potential ratio (SPR) values (i.e. different fishing intensities) are currently in progress to determine outcomes that can be evaluated against the Commission's objectives. Although considerable improvements to the simulation code were made to speed up the simulations, this remains a time-consuming process and the full set of results are currently not available. The MSE Explorer (https://apps.iphc.int/MSE-Explorer/) will be updated as results are available and a full report will be provided at IM102.

The Management Strategy Advisory Board (MSAB) made a number of requests related to the investigation of MPs during its recent 22nd Session of the MSAB meeting in May 2026. These included:

IPHC-2026-MSAB022-R, para. 37 (MSAB022–Req.06): *The MSAB* ***REQUESTED*** *further evaluations of the following MP elements:*

a) *fishing intensities including, but not limited to, SPRs of 40%, 43%, 46%, 49%, 52%, 55%, and 100% (no fishing), as well as no directed fishing (e.g. bycatch only);*
b) *a triennial assessment frequency with various empirical rules to determine the reference coastwide TCEY in non-assessment years.*

IPHC-2026-MSAB022-R, para. 38 (MSAB022–Req.08): *The MSAB* ***REQUESTED*** *evaluating constraints and smoothers, along with MP elements listed in para. 37, 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.*

Given preliminary results, the performance metrics associated with the Commission's priority objectives from the 2026 OM show some slight differences when compared to those determined in 2025 for an SPR of 43% (Table 3). The new results show a slightly higher probability of exceeding the 36% relative spawning biomass (RSB) threshold (0.5). The median TCEY is slightly lower and the AAV quite a bit larger. These differences are mostly due to updates in the understanding of Pacific halibut population dynamics (e.g. maturity and natural mortality) and to weight-at-age projections. Additionally, the short-term probability that the spawning biomass is less than the 2023 estimated spawning biomass is greater because the 2026 OM has a more gradual increase away from recent low productivity.

Table 3. Performance metrics from 2025 simulations (OM2025) and new simulations (OM2026) for an SPR value of 43%, comparing a scenario integrating over changes in weight-at-age and cyclical PDO and a recent (i.e. currently low) productivity scenario (i.e. current weight-at-age and negative PDO). A green colour indicates that the performance metric passes and red indicates that it does not, which applies to only the probabilistic long-term objectives.

		Integrated (low & high) Productivity			**Recent (low) Productivity**	
		OM2025	**OM2026**		**OM2025**	**OM2026**
	SPR (%)	**43**	**43**		**43**	**43**
Long-term	**P(RSB<20%)**	<0.001	<0.001		<0.001	<0.001
	P(RSB<36%)	0.195	0.263		0.462	0.629
Short-term	**Median TCEY**	52.0	42.2		41.2	36.7
	AAV	26.3%	36.2%		28.3%	36.0%
	P(SB < SB_{2023})	0.350	0.578		0.543	0.744

The performance metrics for the 2026 simulations with the newly conditioned OM and updated MSE framework show that when integrating over low and high productivity the long-term spawning biomass objectives are met with any fishing intensity from an SPR of 43% to 52%, and it is likely that higher fishing intensities would also meet these objectives (Table 4). Short-term TCEYs ranged from 35 Mlbs to 42 Mlbs. The AAV ranged from 32% to 36% and decreased most rapidly when changing from an SPR of 43% to an SPR of 46%. The probability that the short-term spawning biomass is less than the 2023 spawning biomass is not a priority objective, but it is reported for reference. This probability was greater than 0.5 for an SPR of 43% and about equal to 0.5 at an SPR of 46%.

The performance metrics showed similar patterns but different values when assuming constant low productivity (Table 4). The objective to remain at or above 36% relative spawning biomass was not met at an SPR of 43%. TCEYs were approximately 4 Mlbs less than when integrating over low and high productivity and the AAVs were similar. The probability that the short-term spawning biomass would be less than the 2023 spawning biomass was greater than 0.5 across all of the SPR values evaluated.

Table 4. Performance metrics from 2026 simulations for SPR values from 43% to 52%, comparing a scenario integrating over changes in weight-at-age and cyclical PDO (top) and a recent (i.e. currently low) productivity scenario (i.e. current weight-at-age and negative PDO; bottom). A green colour indicates that the performance metric passes and red indicates that it does not, which applies to only the probabilistic long-term objectives.

	Integrated (low & high) productivity				
	SPR (%)	**43**	**46**	**49**	**52**
Long-term	**P(RSB<20%)**	<0.001	<0.001	<0.001	<0.001
	P(RSB<36%)	0.263	0.088	0.015	0.001
Short-term	**Median TCEY**	42.2	40.2	37.5	34.8
	AAV	36.2%	33.7%	32.2%	31.9%
	P(SB < SB_{2023})	0.578	0.498	0.420	0.350

	Low (current) Productivity				
	SPR (%)	**43**	**46**	**49**	**52**
Long-term	**P(RSB<20%)**	<0.001	<0.001	<0.001	<0.001
	P(RSB<36%)	0.629	0.421	0.219	0.081
Short-term	**Median TCEY**	36.7	34.8	33.0	30.5
	AAV	36.0%	33.4%	33.2%	34.1%
	P(SB < SB_{2023})	0.744	0.666	0.610	0.544

3.1 Alternative control rules

SRB recommendation **SRB028-Rec.01** and request **SRB028-Req.05** list control rules based on absolute spawning biomass and the risk of overfishing. With the conditioning of the OM and specification of the MSE framework completed, investigation of these and other elements of management procedures will be increased in priority.

4 INVESTIGATE PRODUCTIVITY REGIMES

Pacific halibut experience variable productivity over time, which is important to capture in the MSE projections. However, it is also useful to examine simulations where productivity is fixed in the future to better understand the importance of environmental influences on important outcomes, such as mortality limits. Six scenarios defined by low, high, and current weight-at-age crossed with low or high PDO (affecting average recruitment, movement, and age-0 distribution) were simulated for comparison to the fully integrated results. The MSAB was also interested in these investigations.

> **IPHC-2026-MSAB022-R, para. 38 (MSAB022–Req.09):** *The MSAB **REQUESTED** conducting simulations assuming the following productivity regimes with a subset of the MPs from paras. 37 and 38 and all other sources of variability:*
>
> *a) low recruitment and low weight-at-age;*
> *b) low recruitment and current weight-at-age (the current perceived productivity regime);*
> *c) high recruitment and low weight-at-age.*

Three levels of weight-at-age were chosen to capture the high and low periods, but to also capture the differences in younger and older age classes during the low periods in recent years (Figure 10). The Low period (2011–2015) captures smaller young fish and larger old fish, while the Current period (2021–2025) captures larger young fish and smaller old fish, when compared to each other. The High period (1971–1975) shows average weight-at-age up to four times greater than in 2025 for the older age classes.

The productivity has a very large effect on the outcomes of the simulations with regard to spawning biomass and mortality limits. The median average long-term TCEY when integrating over all types of productivity and managing with an SPR of 43% was 70 Mlbs. If productivity was to remain as we have seen in the last five years (current weight, low PDO) the median average long-term TCEY managing with an SPR of 43% would be 36 Mlbs. The performance metrics associated with the Commission's priority objectives, including short-term fishery objectives, are less different for the low productivity scenario because the integrated results gradually increase from current conditions (Table 4). Figure 9 shows the projected spawning biomass and projected TCEY when integrating over productivity and when assuming current productivity.

It is important to note that the future is uncertain and productivity will certainly not remain constant, which is why it is integrated into the MSE simulations. Even though what was experienced in the past may not be experienced in the future, the integrated simulations provide a range of possibilities for strategic planning, and the specific scenarios ensure that the evaluation of all candidate management procedures is robust to a wide range of stock conditions.

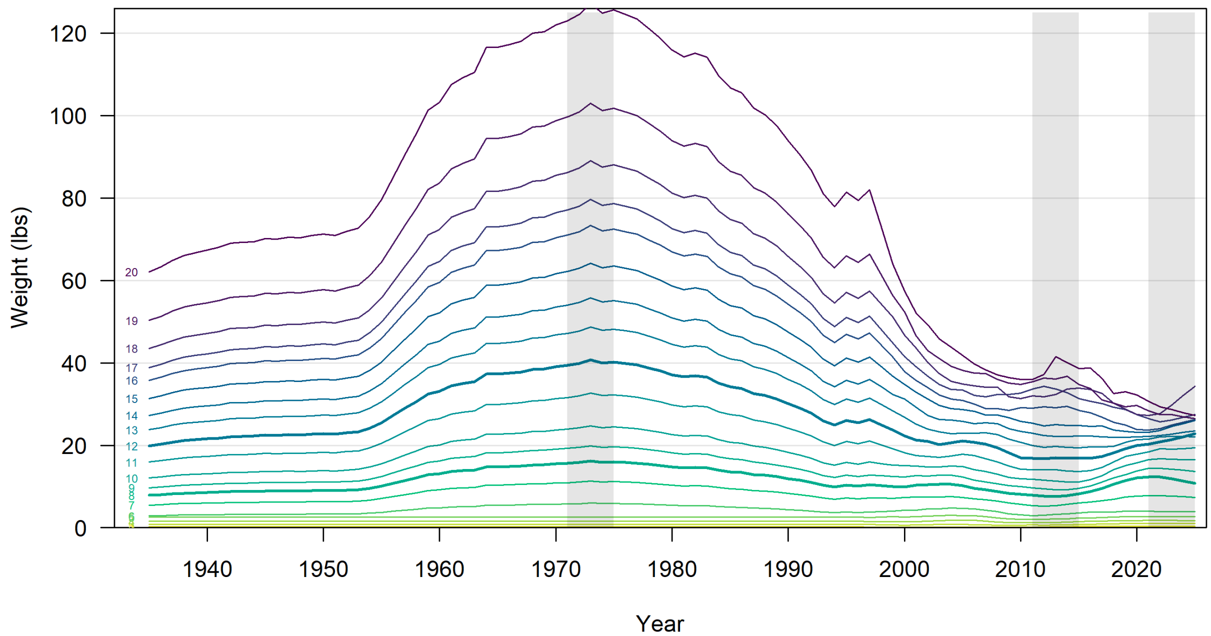


Figure 10. Average historical weight-at-age for Pacific halibut showing three different weight-at-age scenarios defined by the average over 5-year time-periods. High is from 1971–1975, Low is from 2011-2015, and Current is from 2021-2025.

5 FURTHER DEVELOP THE DEPLETED CONCEPT

The IPHC HSP describes two reference points related to spawning biomass:

- **Overfished**: the female dynamic spawning biomass level where the ecological risk to the population and the risk to the health of the fisheries is regarded as unacceptable.
- **Depleted**: the female absolute spawning biomass level below which the potential for recovery is uncertain.

The overfished level is defined as when the estimated probability that coastwide female relative spawning stock biomass is below the limit reference point (RSB20%) is greater than 50%. Depleted does not have a definition and is currently being investigated.

Overfished implies that fishing was the cause of a low biomass state, whereas a depleted condition could be caused by fishing or other factors. Both definitions are important to fisheries management because managers control fishing to avoid precariously low biomass, but the population may be at low biomass for reasons that cannot be controlled by management yet may require management action to increase the chance of recovery. The use of dynamic reference points allows for the separation of fishing effects from other effects on population size, and, a dynamic relative spawning biomass (as currently used by IPHC) is appropriate to determine if the population is overfished. An absolute spawning biomass is appropriate to determine if the population is at a low population state from which recovery could be compromised. Both concepts are shown in Figure 11 with an example level for Depleted shown, as it is not currently defined. Overfished is currently defined as 20% of unfished spawning biomass and changes over time when calculated as an absolute spawning biomass, depending on current stock conditions. Depleted is a constant absolute spawning biomass and varies in terms of relative spawning biomass.

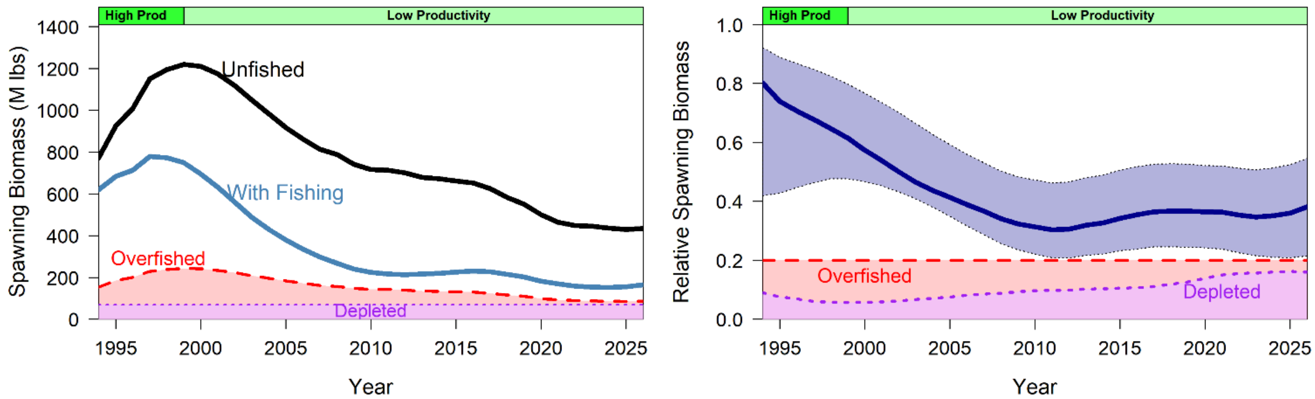


Figure 11. Estimated spawning biomass (left) if fishing had not occurred (unfished) and estimated spawning biomass from the 2025 stock assessment (with fishing). The Overfished threshold of 20% of unfished spawning biomass is shown as a dashed line and changes over time. An example "Depleted" threshold 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 mapped onto the relative spawning biomass scale is shown in purple.

Absolute spawning biomass is an appropriate measure for a depleted reference point because it directly relates to fecundity (i.e. egg production). The current understanding of Pacific halibut egg production is that it is directly related to body size. For example, a 100-pound mature female Pacific halibut produces four times more eggs than a 25-pound mature female Pacific halibut. Therefore, absolute spawning biomass is a measure of reproductive potential for the stock, and if reproductive potential approaches or drops below a critical level, management response would be warranted. Current research on fecundity by the Secretariat (IPHC-2026-SRB029-05) may suggest using reproductive output instead of spawning biomass to account for potential nonlinear reproductive potential over different sizes of Pacific halibut; it would be an easy switch to account for this but would have important effects on estimated reference points.

The Secretariat has currently identified three possible approaches to identify an appropriate absolute spawning biomass reference point for defining a depleted stock condition.

1. Use the lowest spawning biomass observed in the estimated time series from the stock assessment, which is 153 Mlbs in 2024 according to the 2025 stock assessment. The estimated spawning biomass in the 1970s may have been at similar levels seen in recent years, but recent levels are estimated to be low with much greater certainty due to data available from the IPHC's Fishery Independent Setline Survey (FISS).
2. Use a low spawning biomass level that was associated with a high recruitment event. This could be 215 Mlbs that produced the 2012 year-class, according to the 2025 stock assessment.
3. Use simulation (via the MSE framework) to determine an absolute spawning biomass reference point where the potential for recovery is uncertain based on our scientific understanding of biological and reproductive dynamics. This would involve simulating the Pacific halibut population forward at a high fishing rate for many years under a 'worst-case' scenario (e.g. low weight-at-age, low PDO) and then transition to simulating without fishing. A bifurcation point in the spawning biomass where trajectories either recover or

stabilize and those that continue to decline could indicate an appropriate depleted threshold that accounts for uncertainty.

The Secretariat will continue to work with the SRB to refine these approaches and determine an appropriate depleted reference point.

6 AI ASSISTANCE

The results in this document were prepared with AI assistance. All code and content have been reviewed and verified by A. Hicks. AI contribution: coding assistance. This disclosure is made in accordance with the IPHC's Artificial Intelligence Usage Policy.

7 RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2026-SRB029-07 which provides an update on progress for the MSE Program of Work in 2026 and preliminary results from the updated MSE framework.
b) **NOTE** that the MSE operating model (OM) has been reconditioned for 2026 using updated stock assessment inputs and improved weight-at-age and recruitment simulation methods, resulting in a more gradual increase away from current productivity and a narrower range of projected spawning biomass than the 2025 OM.
c) **NOTE** that simulations across a range of SPR values and productivity scenarios are underway and a full report is to be provided at IM102.
d) **NOTE** that productivity has a large effect on long-term projected outcomes.
e) **NOTE** that the Secretariat has identified three candidate approaches for defining an absolute spawning biomass reference point for Depleted and will continue to work with the SRB on this topic.
f) **REQUEST** any management procedures and scenarios to evaluate before IM102, including the outstanding recommendation (**SRB028-Rec.01**) and request (**SRB028-Req.05**) from SRB028.
g) **REQUEST** any analyses to be provided at SRB030.

8 REFERENCES

Cheng, M.L.H., Thorson, J.T., Ianelli, J.N., and Cunningham, C.J. 2023. Unlocking the triad of age, year, and cohort effects for stock assessment: Demonstration of a computationally efficient and reproducible framework using weight-at-age. Fisheries Research **266**. doi:10.1016/j.fishres.2023.106755.

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**: 1–21.

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.

Newman, M., Alexander, M.A., Ault, T.R., Cobb, K.M., Deser, C., Di Lorenzo, E., Mantua, N.J., Miller, A.J., Minobe, S., Nakamura, H., Schneider, N., Vimont, D.J., Phillips, A.S., Scott, J.D., and Smith, C.A. 2016. The Pacific Decadal Oscillation, Revisited. Journal of Climate **29**(12): 4399–4427. doi:10.1175/jcli-d-15-0508.1.

Qin, M., Hu, L., Qin, Z., Wan, L., Qin, L., Cao, W., Wu, S., and Du, Z. 2023. Pacific Decadal Oscillation Forecasting With Spatiotemporal Embedding Network. Geophysical Research Letters **50**(16). doi:10.1029/2023gl103170.

Xu, H., Thorson, J.T., Methot, R.D., and Taylor, I.G. 2019. A new semi-parametric method for autocorrelated age- and time-varying selectivity in age-structured assessment models. Canadian Journal of Fisheries and Aquatic Sciences **76**(2): 268–285. doi:10.1139/cjfas-2017-0446.

2027-31 FISS design evaluation and modelling updates

PREPARED BY: IPHC SECRETARIAT (R. WEBSTER, I. STEWART, K. UALESI & D. WILSON; 22 AUGUST 2026)

PART 1: 2027-31 FISS DESIGN EVALUATION

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, along with potential modular add-ons for 2027.

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, 2026).

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$4,000,000
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.

Due to the CV for IPHC Regulatory Area 2A exceeding the target range of 25% or less, the 2027 Base Block design (Figure 4) was revised from the version used to project the CVs through the addition of 20 stations off the Oregon coast. With this change, 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 result from unmonitored stock changes in regions that were unsampled for several years.

PRELIMINARY COST PROJECTIONS FOR 2027

The proposed 2027 **Base Block design** is projected to result in an operating loss of approximately **US$131,000** (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. Projected Pacific halibut average sales price for 2027 in each charter region is unchanged from our current best estimate of 2026 FISS values (based on both 2025 data and 2026 data received to date)
3. Projected Pacific halibut average landings per station remain unchanged in each charter region from 2026 FISS values (based on both 2025 data and 2026 data received to date).
4. The price of chum salmon bait remains at the average 2026 price of US$2.40/lb.

Table 3. Preliminary projected costs and revenue for the proposed 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**	3,874,000
	Byproduct sales	103,000
	Total	**3,977,000**
Expenses	**Base HQ (staff salary and wages, and benefits x 4)**	(547,000)
	Vessel contracts	(1,545,000)
	Field staff (salary and wages, and benefits)	(475,000)
	Bait	(509,000)
	Non-IPHC fish sales[@]	(432,000)
	Other expenses*	(601,000)
	Total	**(4,108,000)**
Net revenue		**($131,000)**

[@]Sales revenue from both byproduct and Pacific halibut that are paid to a third party (e.g. vessel share, ADF&G)

*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 preliminary and do not fully account for 2026 realized costs as the FISS is in progress at the time of writing. Therefore, it is important to note there is considerable uncertainty in the catch and cost projections for 2027. 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 report at that time.

MODULAR ADD-ONS

Ten potential modular add-ons to the proposed 2027 Base Block design are presented below, with the following aims:

1) Reduce the projected net loss of the FISS in 2027;
2) 'Catch up' on FISS regions that were part of the 2026 **Base Block design** but were not fished;
3) Reduce the heterogeneity in net revenue among future years by sampling in 2027 some of the more costly regions planned in future years;
4) Set the FISS station charter rate at a higher value to increase the chance of receiving bids for challenging charter regions (i.e. Adak in IPHC Regulatory Area 4B);
5) Fully clear the 'backlog' of uncertainty created by the reduced designs implemented in 2023-2026 to provide the most informative data in 2027 for the stock assessment and management decisions.

With the 2027 **Base Block design** as Option 1 in Table 4, Options 2 to 11 are as follows:

- **Options 2 and 3** add revenue-positive charter regions in IPHC Regulatory Areas 2C and 3A, respectively, to the design to further reduce the projected net loss.
- **Options 4, 5 and 6** would add charter regions from IPHC Regulatory Areas 3A and 4B that were included in the approved 2026 Base Block design but were not fished in 2026 for reasons of cost (3A) or a lack of charter bids (4B). In the case of IPHC Regulatory Area 4B, the region is split into two (2) components (west and east, 29 stations each) to allow more flexibility for those considering submitting a bid for 2027 FISS work.
- **Option 7** brings sampling in IPHC Regulatory Area 4A forward from 2028 to reduce costs in that year, which is otherwise projected to have a large net loss.
- **Options 8 and 9** bring sampling of the northern and central Bering Sea shelf edge (IPHC Regulatory Area 4CDE) forward from 2028 and 2029, respectively, potentially reducing net losses in those years. If adopted, these options would result in complete sampling of standard FISS stations in IPHC Regulatory Area 4CDE in 2027.
- **Option 10** brings forward sampling of stations in IPHC Regulatory Area 2A from 2028, reducing costs in that year, along with stations in deep and shallow waters and the Salish Sea that have not been sampled since 2018 but were not planned until after 2031.
- **Option 11** fixes the charter rate at $5,500 per station in the Adak region of IPHC Regulatory Area 4B, which would be a 28% increase over the previous highest accepted bid. It expands sampling over Options 5 and 6 (58 stations combined) to include all 118 stations in the Adak charter region.

Figure 10 presents a map of stations included in Options 2 to 11.

The United States of America has agreed to voluntarily provide US$749,000 in supplementary funding for the 2027 FISS in order to fund modular Options 4 to 9 of Table 4 as additions to the 2027 Base Block design (Figure 4).

Table 4. Modular changes to Option 1 (2027 Base Block design), including projected expenses, income, net revenue, and benefits to the IPHC. Each of modular Options 2 to 10 can be added in any combination to Option 1, with the net revenue of the resulting FISS design found by summing the revenue changes for the Base Block design and each selected option. Option 11 is an alternative to Options 5 and 6 combined.

Option	Design	Sampled IPHC Regulatory Areas (with number of FISS charter regions)	Projected expenses (US$)	Projected income (US$)	Projected net revenue	Benefit/rationale
1	Base Block	2A(3), 2B(2), 2C(2), 3A(4), 3B(2), 4B(1), 4CDE(1)	($4,108,000)	$3,977,000	($131,000)	Optimal long-term design
	Design change	**Change in sampling**	**Projected change in expenses ($US)**	**Projected change in income ($US)**	**Projected change in net revenue**	
2	Add Sitka	2C(+1)	($208,000)	$253,000	$45,000	Revenue positive: reduces overall net loss.
3	Add Gore Pt	3A(+1)	($221,000)	$238,000	$17,000	Revenue positive: reduces overall net loss.
4	Add Shelikof	3A(+1)	($245,000)	$226,000	($19,000)	3A catch-up. Last sampled 2024.
5	Add Adak West	4B(+1)	($196,000)	$103,000	($93,000)	4B catch-up. Last sampled 2021.
6	Add Adak East	4B(+1)	($196,000)	$103,000	($93,000)	4B catch-up. Last sampled 2025.
7	Add Unalaska	4A(+1)	($367,000)	$99,000	($268,000)	Reduces costs in 2028.
8	Add 4CDE North	4CDE(+1)	($168,000)	$12,000	($155,000)	Reduces costs in 2029. Last sampled 2021.
9	Add 4CDE Central	4CDE(+1)	($188,000)	$67,000	($121,000)	Potential to reduce costs in 2030. Last sampled 2022.
10	Expand 2A sampling to include all stations north of 40°N	2A(+2)	($239,000)	$89,000	($150,000)	Reduces costs in 2028. Includes deep, shallow, and Salish Sea stations not sampled since 2018.
11	Fixed Contract rate[1] for expanded Adak (alternative to Options 5-6)	4B(+2)	($937,000)	$419,000	($519,000)	Reduces probability of receiving no bids for this region (as occurred in 2023 and 2026)

[1] This option provides for a fixed 28% increase in inflation-adjusted charter costs paid to the contracting vessel over previous accepted bids.

DISCUSSION

The **Base Block design** has a preliminary projected net loss of US$131,000 for 2027 and therefore can be implemented using FISS reserves without the need for supplementary funding. It is projected that adding two revenue-positive charter regions from IPHC Regulatory Areas 2C and 3A would reduce the net loss to US$69,000. With supplementary funding, the design is able to add charter regions in IPHC Regulatory Areas 3A and 4B that were part of the approved 2026 Base Block design but were not fished this year and bring forward other revenue-negative regions to reduce projected costs in 2028 and subsequent years.

RECOMMENDATION

That the Scientific Review Board **NOTE** paper IPHC-2026-SRB029-08 (Part 1), which presents potential Base Block designs for 2027-31, including a preliminary projection of revenue and expenses for the 2027 design and potential modular add-ons to this design.

References

IPHC (2012). IPHC setline charters 1963 through 2003 IPHC-2012-TR058. 264p.

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 (2026) 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.

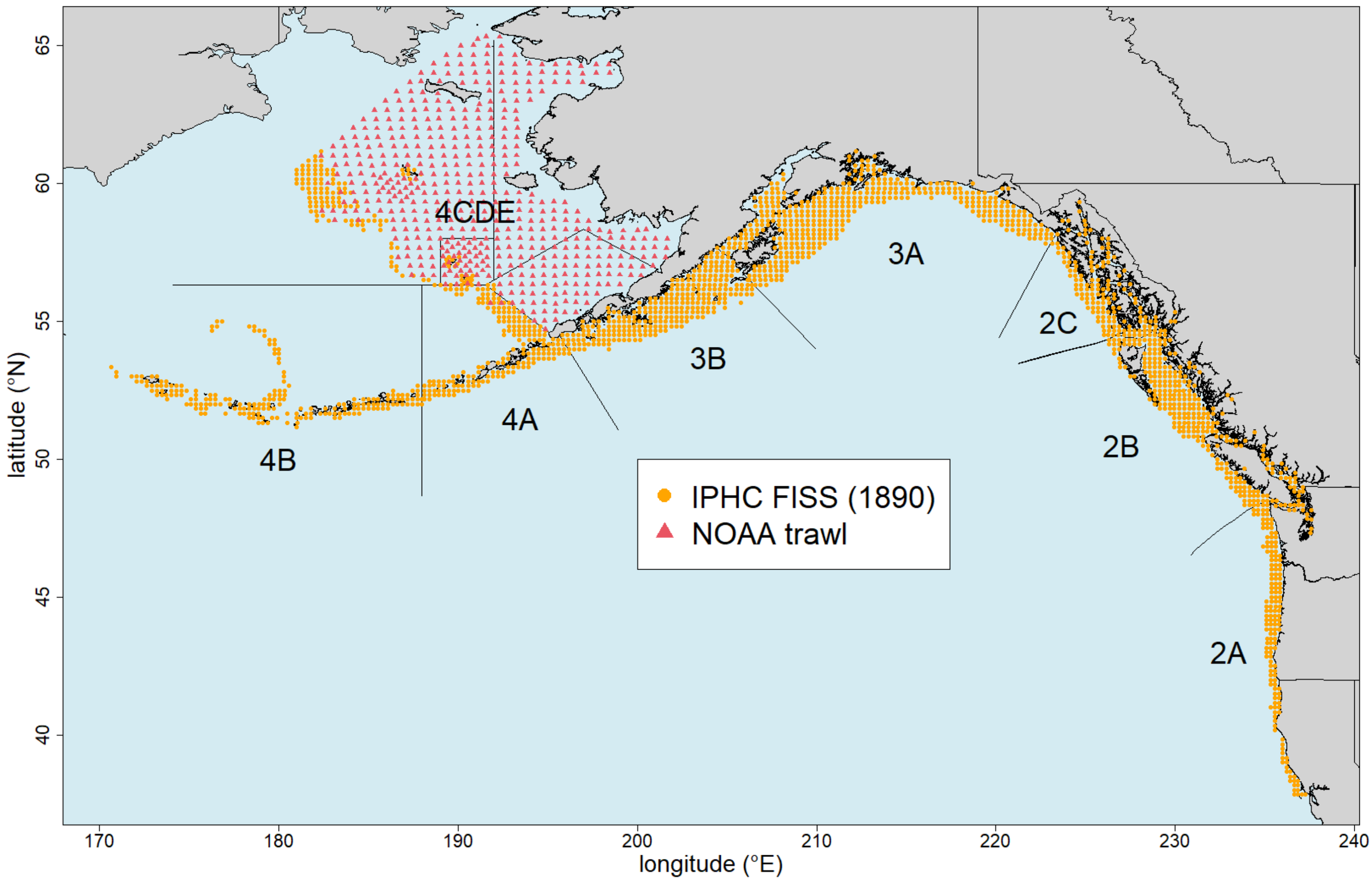


Figure 1. Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs. Red triangles represent standard locations of NOAA trawl stations used to provide complementary data for Bering Sea modelling (actual NOAA trawl design can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

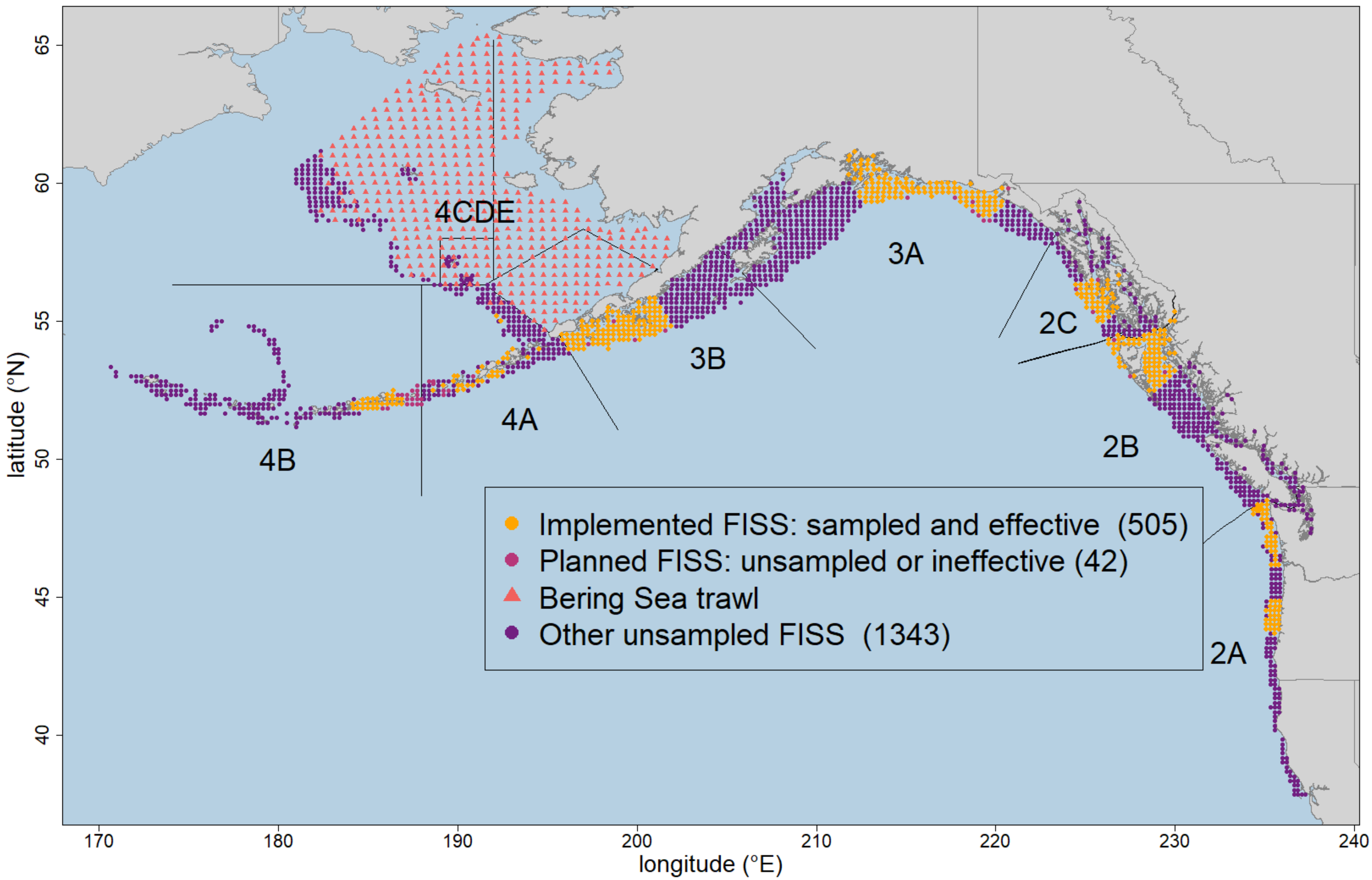


Figure 2. Map of implemented 2025 sampled FISS design showing sampled stations with data used in modelling (orange circles for FISS, red triangles for trawl), along with planned but ineffective FISS stations, FISS grid stations fished off grid as vessel captain stations and other unsampled FISS stations.

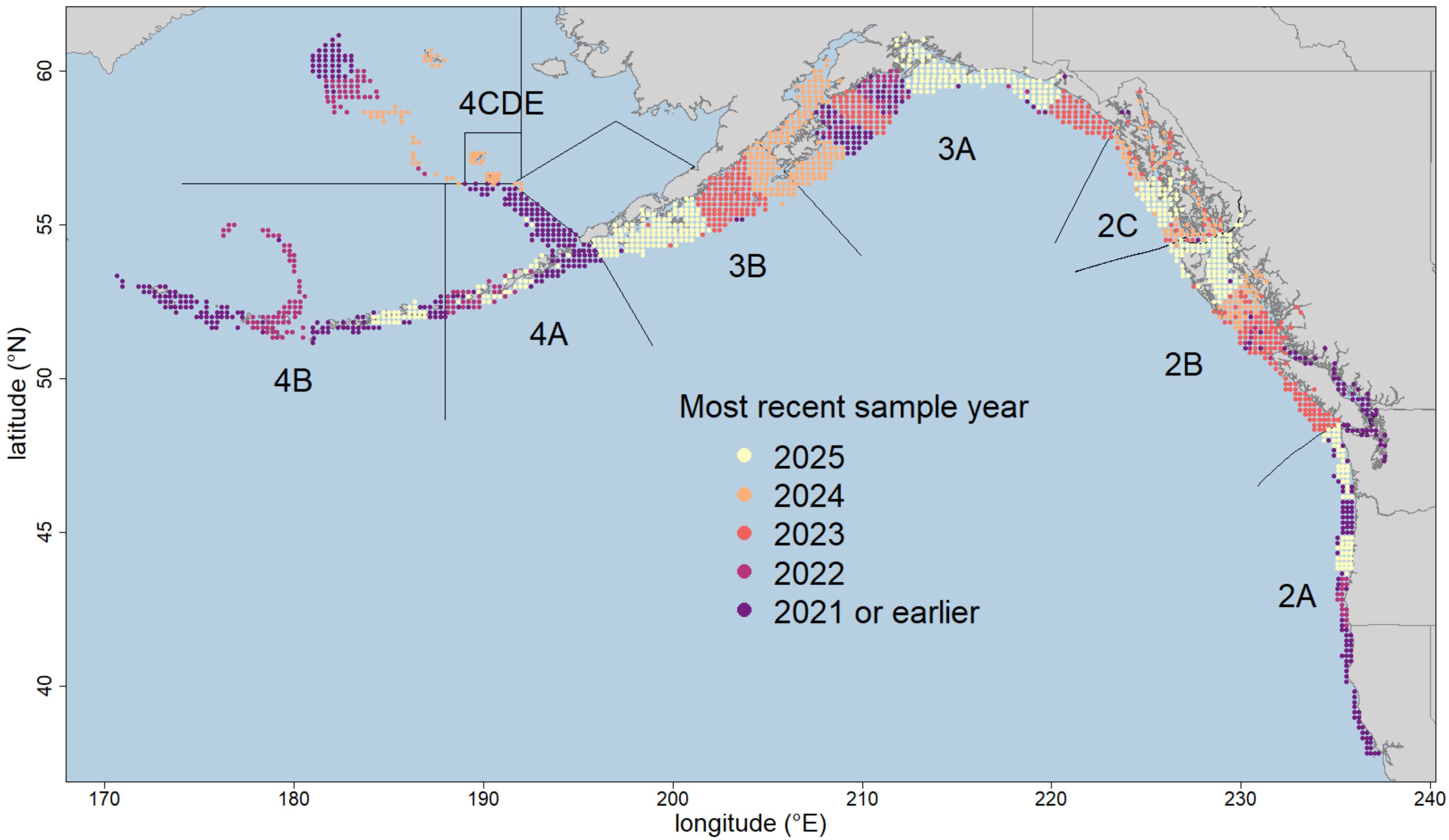


Figure 3. Map showing the most year that each station on the full FISS grid was successfully sampled.

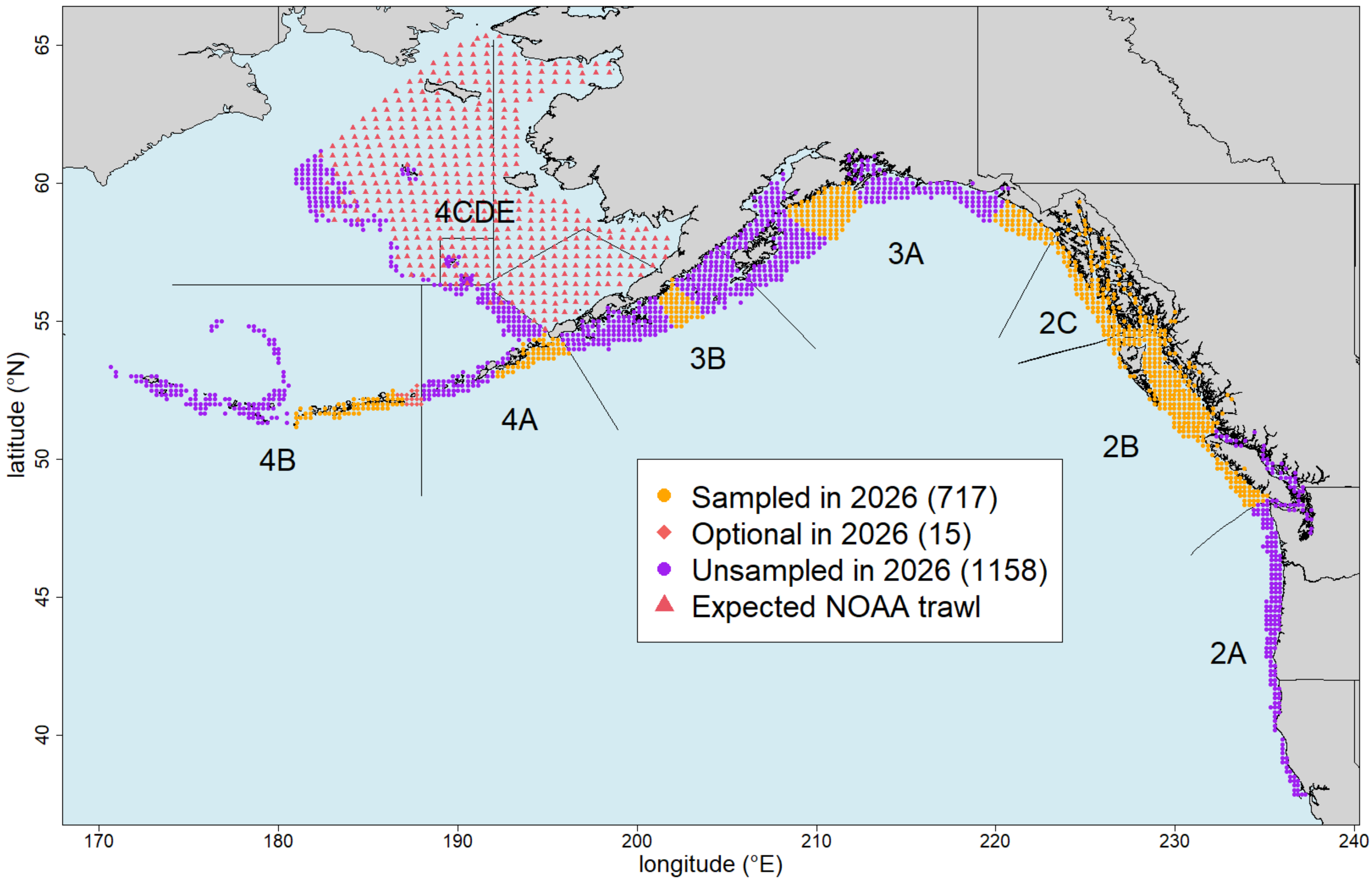


Figure 4. Adopted 2026 FISS design, with planned FISS stations shown as orange circles.

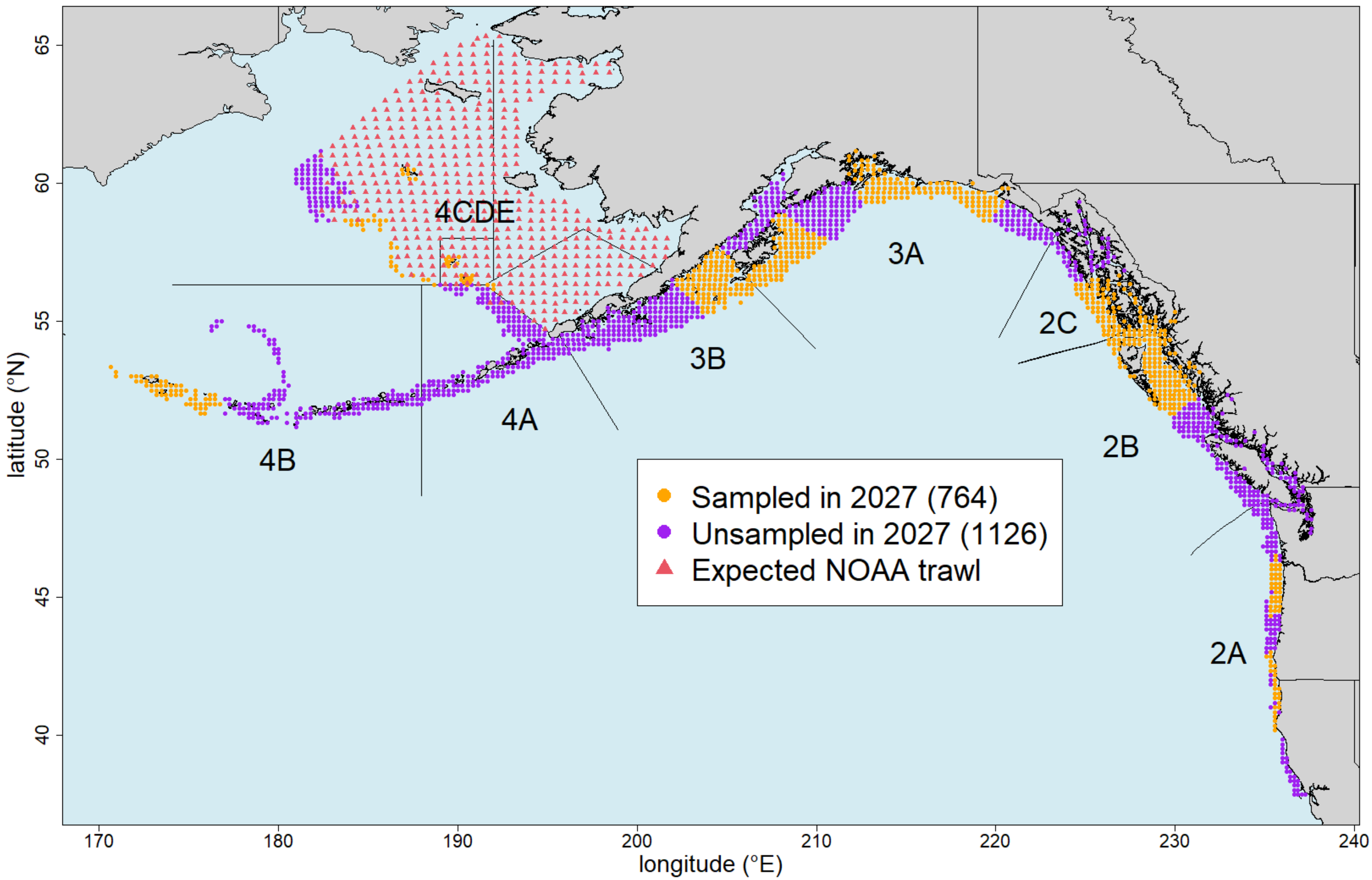


Figure 5. Base Block design for 2027 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

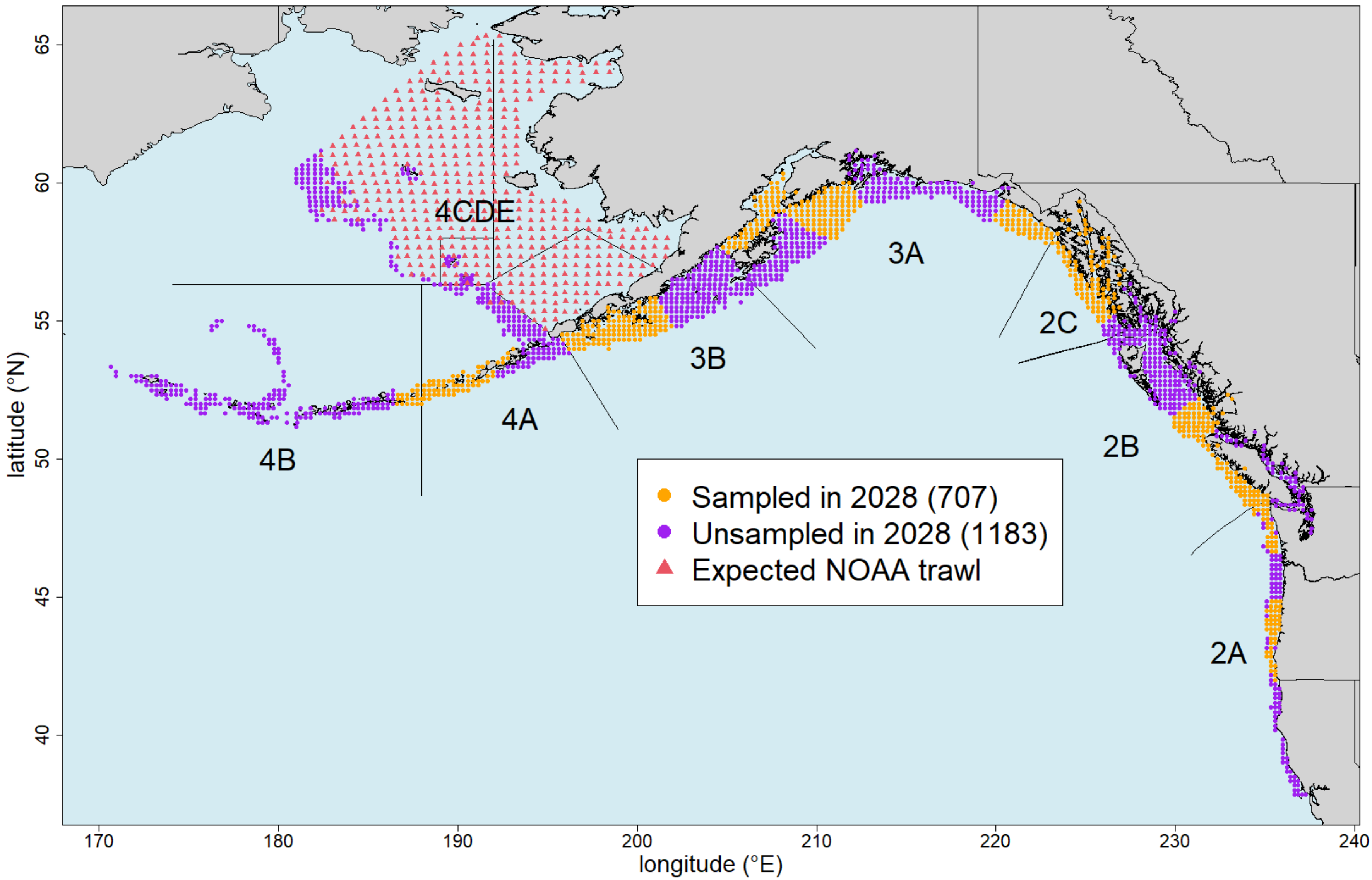


Figure 6. Base Block design for 2028 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

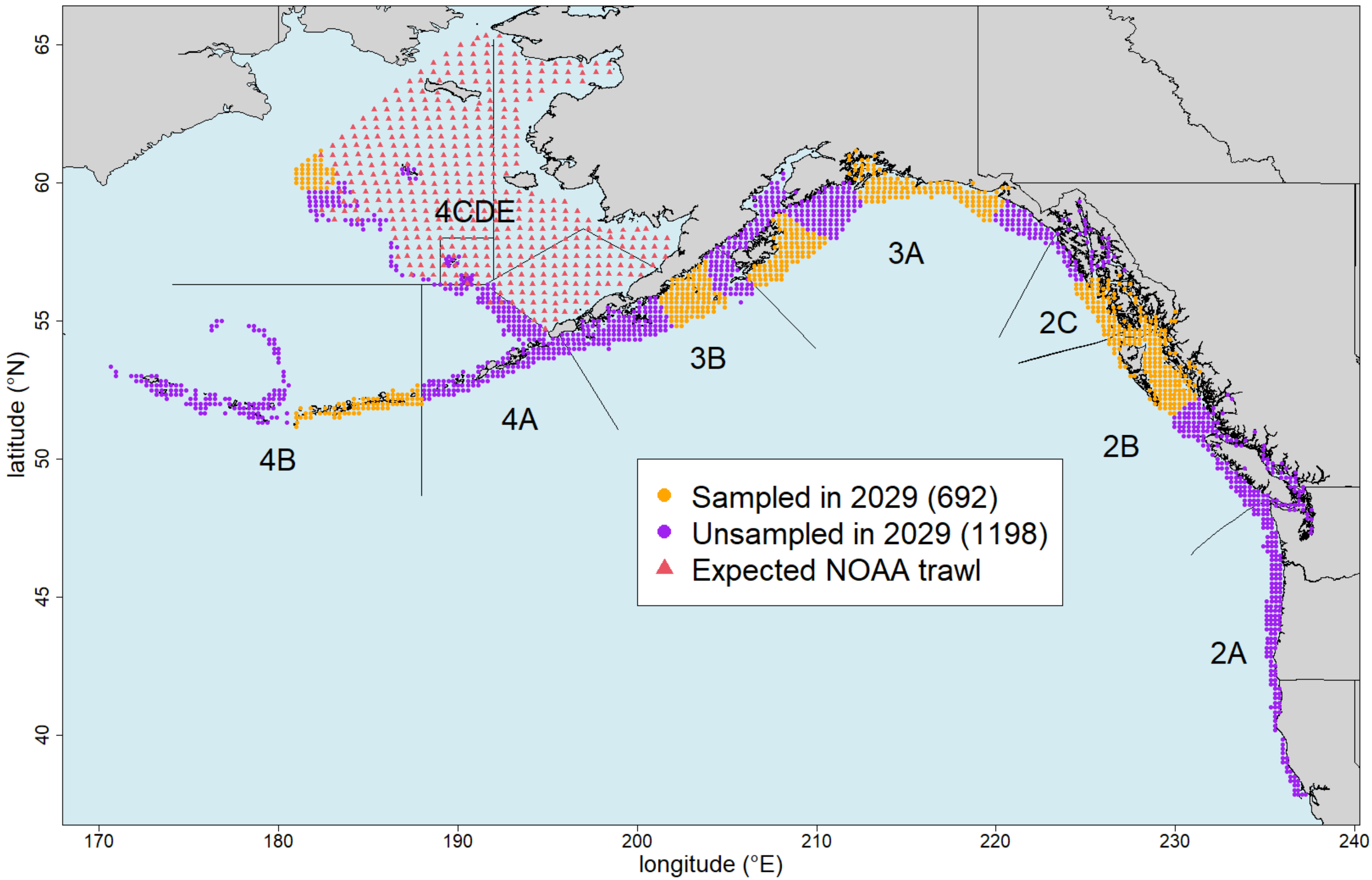


Figure 7. Base Block design for 2029 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

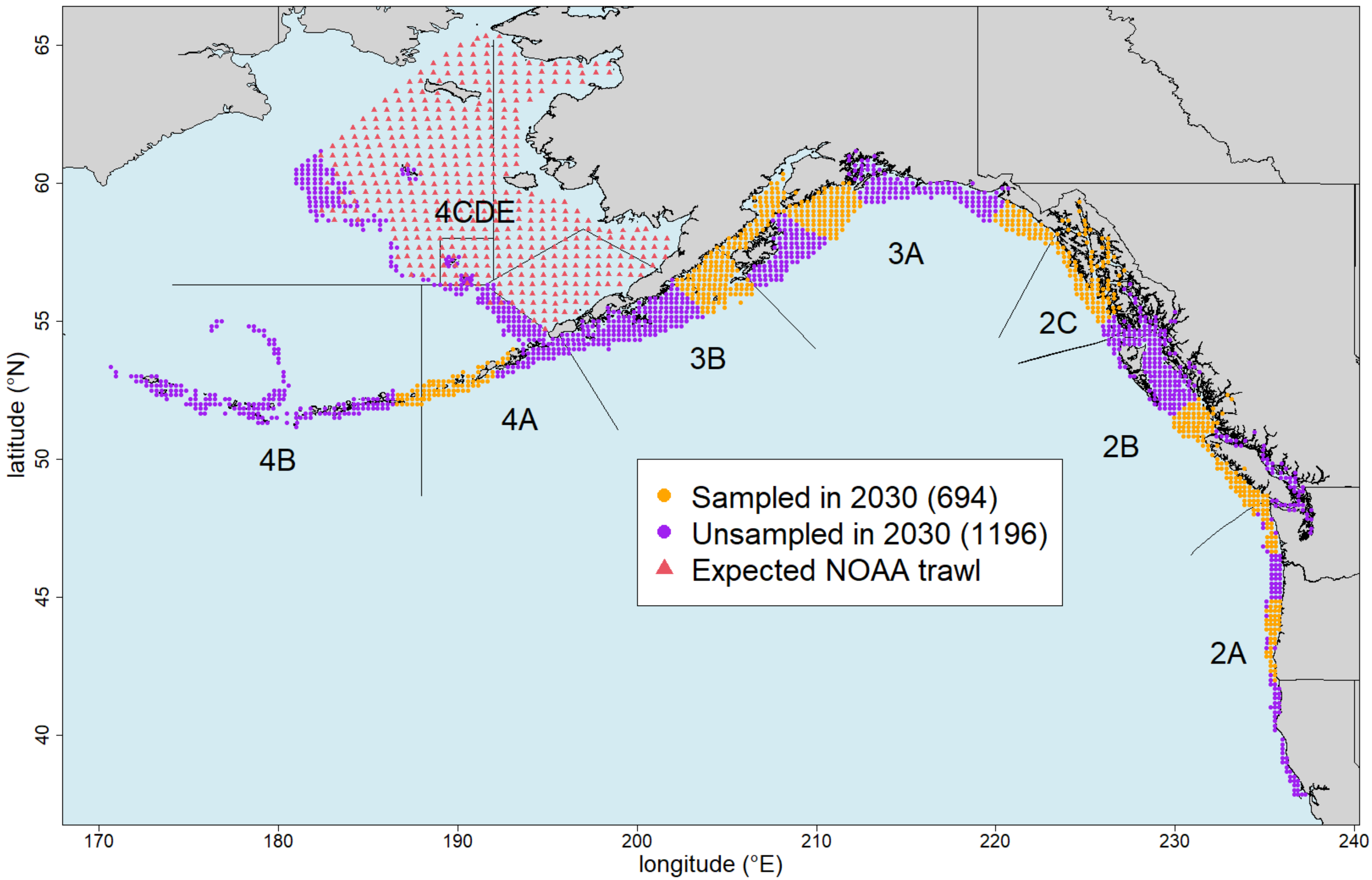


Figure 8. Base Block design for 2030 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

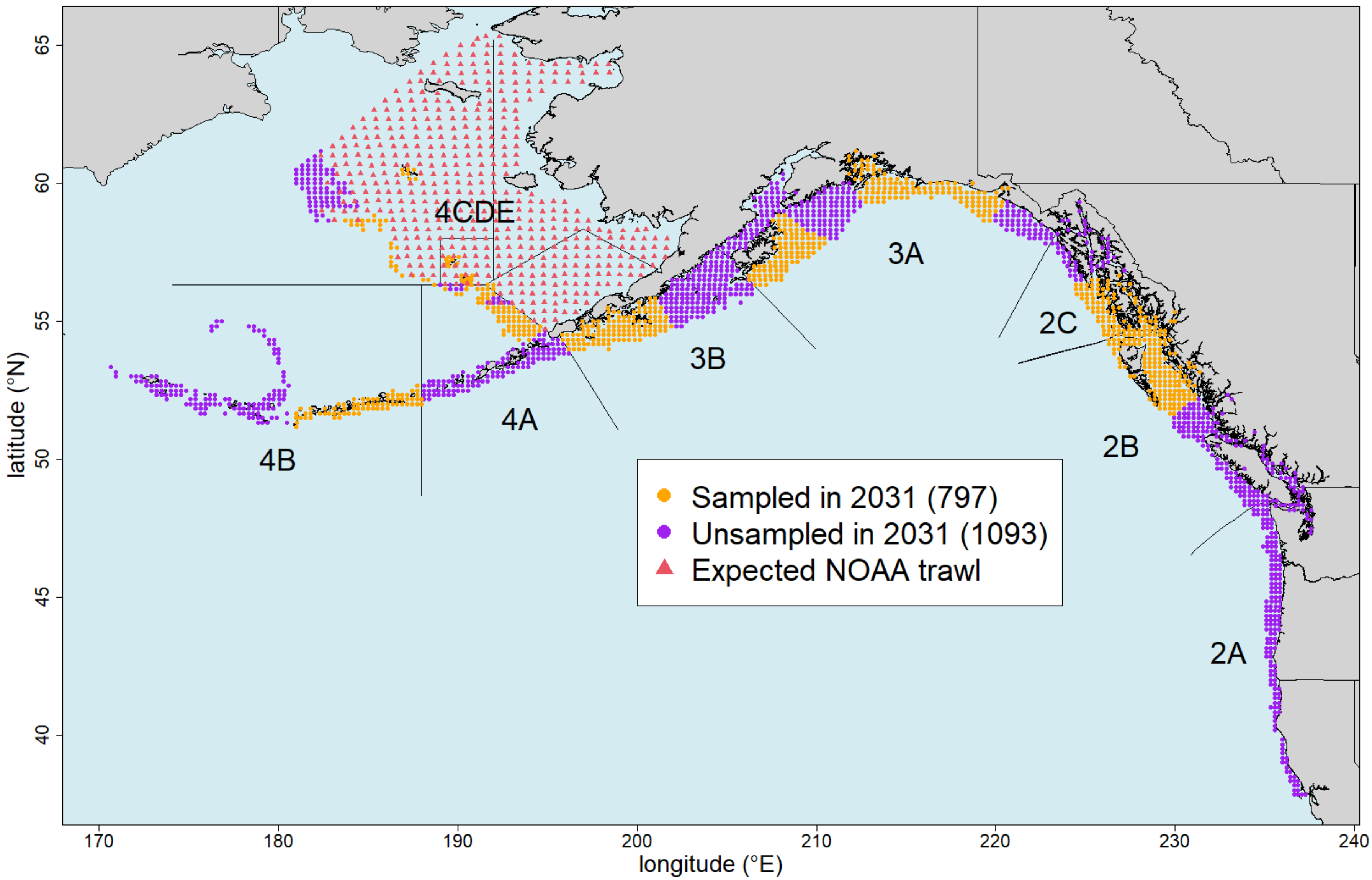


Figure 9. Base Block design for 2031 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

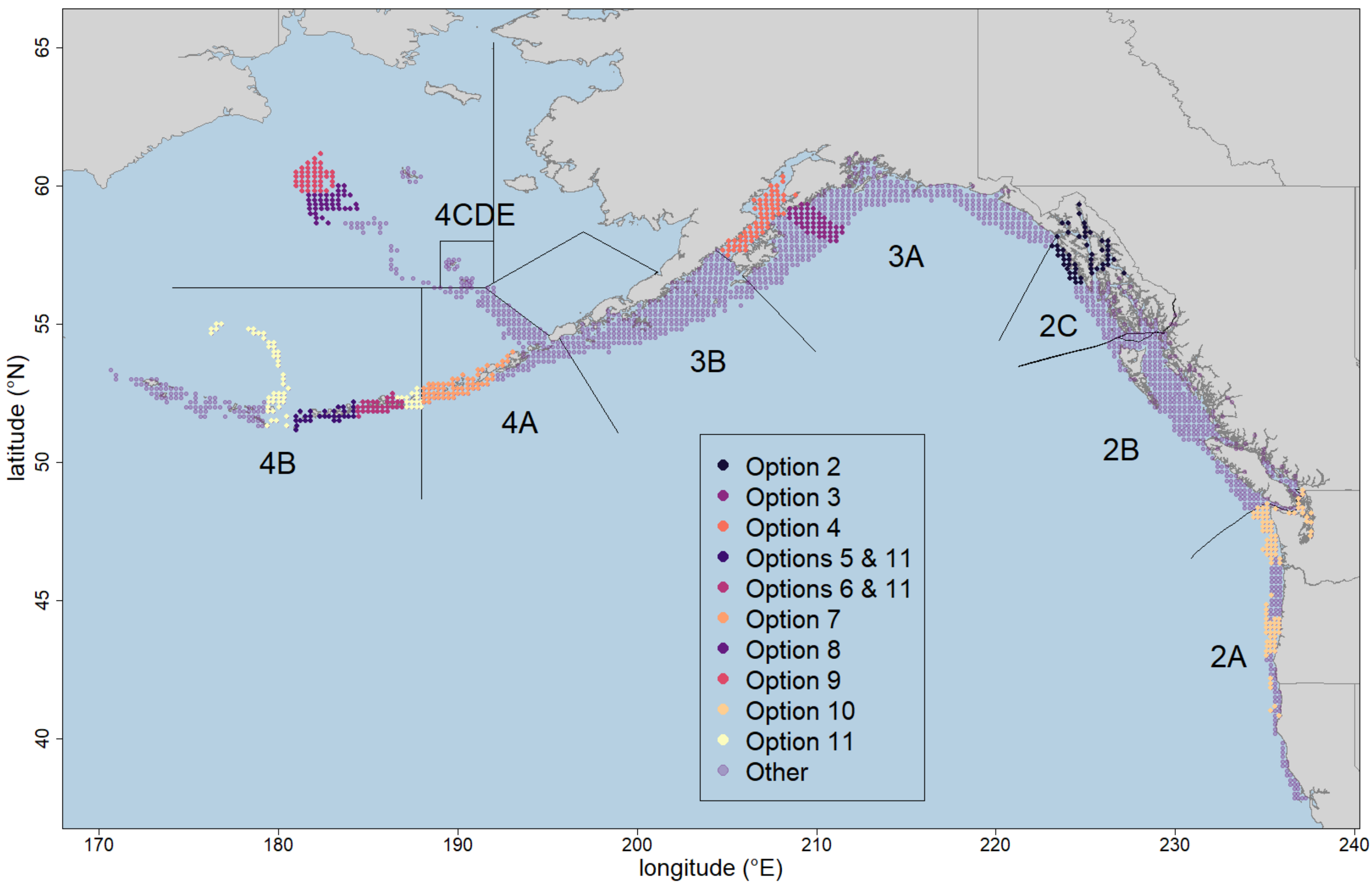


Figure 10. IPHC FISS modular Options 2 to 11 (Table 4) for 2027.

PART 2: MODELLING UPDATES

PURPOSE

To update the SRB on recent work on coastwide modelling of Pacific halibut survey data, with particular application to maturity data (histological and visual) collected on the IPHC's fishery-independent setline survey from 2002-24.

BACKGROUND

At SRB027, we presented some preliminary results from fitting coastwide models to IPHC maturity data (Webster et al. 2025, Part 2, and accompanying presentation). This is part of a broader effort to simplify the space-time modelling of FISS data, which since its first application in 2016, has relied on modelling data at the level of IPHC Regulatory Area. Background material from SRB027 is included as Appendix A in this report.

Currently, generalized additive models (GAMs) are used to estimate the relationship between maturity probability and age by IPHC biological region. The GAM models allow flexibility from a strict logistic model (i.e., linear on the logit scale) but require the assumption of independent observations. At SRB027 (Webster et al. 2025), we discussed results of fitting several spatial models of differing complexity for modelling the relationship of maturity probability and age, including:

- Logistic models, with fixed effects for intercept and slope that vary by IPHC Biological Region, with spatially-dependent errors
- Logistic models with spatially-varying intercept and slope (i.e., slope and intercept are spatially-dependent random effects)
- Versions of the models above with added "GAM-like" flexibility through a random walk term in the age relationships.

These models were fitted to the 2022-24 histological assessment data, which provided model output that was broadly consistent with GAM modelling results (Planas et al. 2025) that showed lower A50 values in Biological Region 3 (Gulf of Alaska) than in adjacent Biological Regions 4 (eastern Aleutians and Bering Sea) and 2 (Southeast Alaska, British Columbia and the West Coast).

The preliminary modelling was based on only three years of data from a sampling design with partial and inconsistent spatial coverage across the three years. For this reason, those models used combined data across years and did not account for temporal dependence. The IPHC has visual assessments of maturity data for Pacific halibut from 2002, including for the individual sampled fish with histological data from 2022-24. Combining the histological and visual data into a single model allows us to:

- Estimate a calibration between visual and histological maturity curves using the paired data from 2022-24
- Model the entire 2002-24 time series of maturity curves, including modelling of both spatial and temporal correlation in model parameters
- Predict histology-based maturity curves across space and time

As with the shorter 2022-24 time series modelled previously, coastwide maturity curves can be calculated by predicting maturity probability at age for each survey station, and computing weighted averages at age using station-level mean NPUE values from the space-time modelling of catch-rate data as weights. Ongoing work includes exploring other options for flexibility in maturity relationships and computing cross-validation metrics for model comparisons.

Modelling results are currently being processed for inclusion in the presentation of this material at SRB029.

RECOMMENDATION

That the Scientific Review Board **NOTE** paper IPHC-2026-SRB029-08 (Part 2), which provides an update on recent work on coastwide modelling of Pacific halibut survey data, using histological maturity data as a test case.

References

Bakka, H., Vanhatalo, J., Illian, J. B., Simpson, D., and Rue, H. (2019). Non-stationary Gaussian models with physical barriers. Spatial Statistics 29: 268-288. https://doi.org/10.1016/j.spasta.2019.01.002

Lindgren, F., and Rue, H. (2015). Bayesian spatial modelling with R-INLA. J. Stat. Softw. 63: 1–27. https://doi.org/10.18637/jss.v063.i19

Planas, J., Dykstra, C., Jasonowicz, A., and Jones, C. (2025). Report on Current and Future Biological and Ecosystem Science Research Activities. IPHC-2025-SRB026-06. 27 p.

Webster, R., Steward, I., Ualesi, K. and Wilson, D. (2025). 2026-28 FISS design evaluation and modelling updates. IPHC-2024-SRB027-09. 31 p.

Appendix A: Background to coastwide modelling of IPHC survey data

At present, the IPHC models Pacific halibut survey data by fitting a spatio-temporal model (Webster et al. 2020) to data from each individual IPHC Regulatory Area, and aggregates model output to produce estimate for larger geographical units (Biological Regions, coastwide waters). The advantages of this approach versus a single coastwide model include:

- Smaller modelling regions allow for finer meshes (see below) without leading to prohibitively long runtimes
- Faster model runtimes due to both smaller datasets and smaller modelling regions
- Easily allows model parameters to differ among areas

The main drawbacks of splitting modelling into smaller components are (1) that there may be discontinuities at area boundaries due to differences in model parameter values between adjacent areas, and (2) samples drawn from posterior predictive distributions (used to create time series of variables of interest) will not be spatially correlated across boundaries as each area's samples are drawn independently from each other. These drawbacks have been relatively minor for the catch rate (weight and numbers per unit effort, WPUE and NPUE) data modelled to date, with no obvious discontinuities appearing on maps of model predictions (see the maps at the IPHC Space-time Explorer), and the range parameter for spatial models being small relative to the size of each area. The latter means spatial correlation declines relatively steeply with increasing distance and independence between samples on either side of an area boundary has little impact on estimates of standard deviations or coefficients of variation for estimates based on combining areas (i.e., to form Biological Region or coastwide estimates).

Recent improvements in the runtime of the spatio-temporal models (fitted via the R package, R-INLA, www.r-inla.org) have made it more likely that fitting models to coastwide data sets will not result in prohibitive computation time. While fitting coastwide models for Pacific halibut WPUE and NPUE data may now be feasible, coastwide models have utility beyond estimating time series of indices of density and abundance. The FISS also collects biological data on individual Pacific halibut, some of which has been collected over a shorter timeframe than the modern 33-year FISS, and in some instances, spatial coverage may be less spatially consistent. This is also true of oceanographic monitoring data, which sometimes has gaps in coverage due to loss or failure of the water column profiler units or recent reductions in FISS coverage. In such cases, modelling on a coastwide basis should lead to more powerful inference than restricting models to data subsets based on IPHC Regulatory Areas or a similar geographical unit.

The IPHC has collected histological data on Pacific halibut maturity on the FISS since 2022 (see Planas et al, 2025, for details). Maturity is assessed on individual female Pacific halibut, and each fish has an approximate capture location given by the midpoint of the location of the FISS set on which it was captured. Previous modelling of the relationship of maturity probability and age has used statistical methods that assume each fish is sampled independently, which ignores the likelihood of spatial correlation in the probability of maturity and the fact that fish are sampled in clusters on each set. Spatial (or spatio-temporal) modelling can account for this lack of independence.

Coastwide mesh and barrier models

The INLA approximation uses a set of basis functions defined on a triangulated mesh covering the region of interest (Lindgren and Rue 2015). IPHC data imply that Pacific halibut do not inhabit depths greater than 732 m (400 fathoms) at non-negligible densities during the summer survey period, and therefore our starting point for a modelling region is all USA and Canadian waters within 0 to 732 m from northern California to the southern Chukchi Sea. To provide an additional buffer at the region's outer edge, we extended the region a depth of 800 fathoms and further into Russian waters in the Bering Sea to account for the fact that this is not a hard boundary and that there is some correlation between values in sampled US waters and those in adjacent unsampled Russian waters. Other offsets were made to the mesh boundaries to smooth the edge and avoid narrow inlets within which R-INLA's mesh creation function would have to include many vertices and thereby increase the dimensionality of the modelling problem. The smoothing and offsetting can remove or reduce the size of islands and peninsulas, and we therefore selected values that preserved such features as much as possible to ensure that nonexistent pathways were not created in the mesh space. The coarseness of the mesh itself was defined so that the number of vertices allowed comprehensive spatial coverage without being so numerous that the model processing would become prohibitively slow. Another consideration in approximating the coastline with the triangulated mesh was ensuring that sample locations (survey stations) did not end up falling on "land". This was particularly challenging in the narrow inlets of IPHC Regulatory Areas 2B and 2C, and ultimately the selected mesh required the exclusion of a single FISS station: alternative refinements of the mesh definition led to the exclusion of more stations located on "land".

In addition to the mesh defined within IPHC habitat, the functions in R-INLA were used to define the land and deeper waters as barriers, which when used with a non-stationary barrier model (Bakka et. al, 2019) ensure that the model's correlation structure cuts off pathways through land, including large islands and peninsulas, along with areas of deeper water that Pacific halibut do not inhabit. Barrier models achieve this without additional computational cost by defining the range parameter (the distance at which the correlation between two points is small, i.e., ≈0.1) on land to be a small fraction of the value on water. The coastwide mesh for IPHC survey data, including barriers shaded in yellow, is presented in Figure 11.

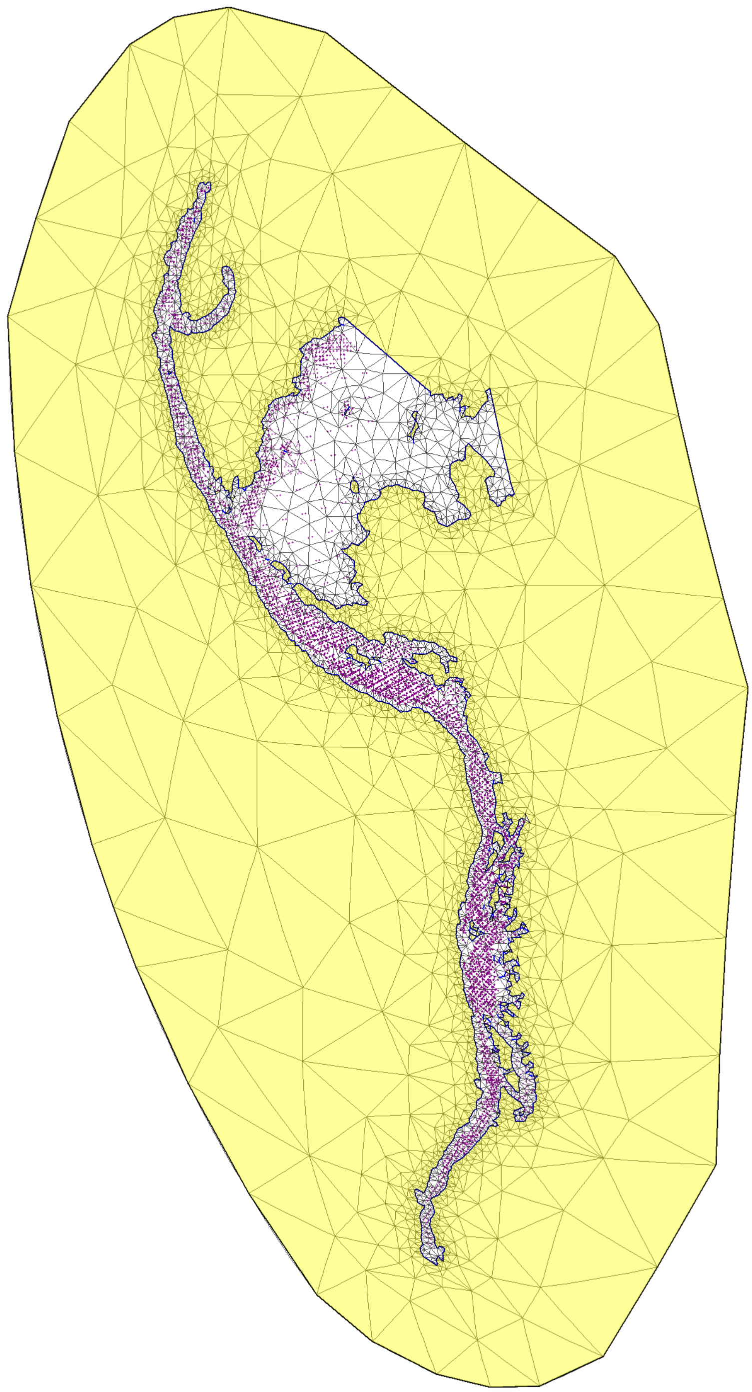


Figure 11. Triangulated mesh used in spatio-temporal modelling of histological maturity data. Barriers are shown with yellow shading**.**

References

Bakka, H., Vanhatalo, J., Illian, J. B., Simpson, D., and Rue, H. (2019). Non-stationary Gaussian models with physical barriers. Spatial Statistics 29: 268-288. https://doi.org/10.1016/j.spasta.2019.01.002

Lindgren, F., and Rue, H. (2015). Bayesian spatial modelling with R-INLA. J. Stat. Softw. 63: 1–27. https://doi.org/10.18637/jss.v063.i19

Planas, J., Dykstra, C., Jasonowicz, A., and Jones, C. (2025). Report on Current and Future Biological and Ecosystem Science Research Activities. IPHC-2025-SRB026-06. 27 p.

IPHC-2026-SRB029-INF01

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

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.***

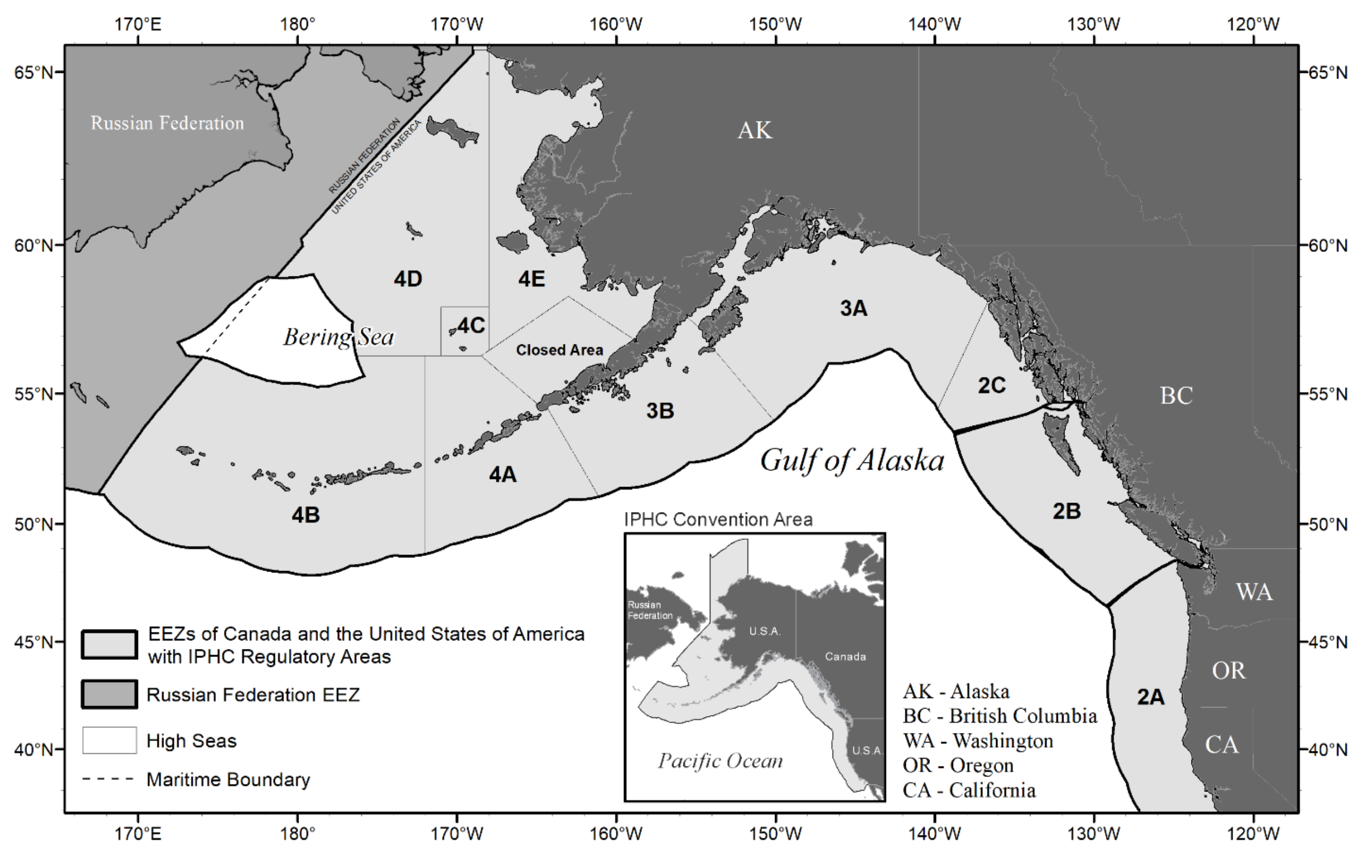


Figure 1. Map of the IPHC Convention Area (map insert) and IPHC Regulatory Areas.

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.

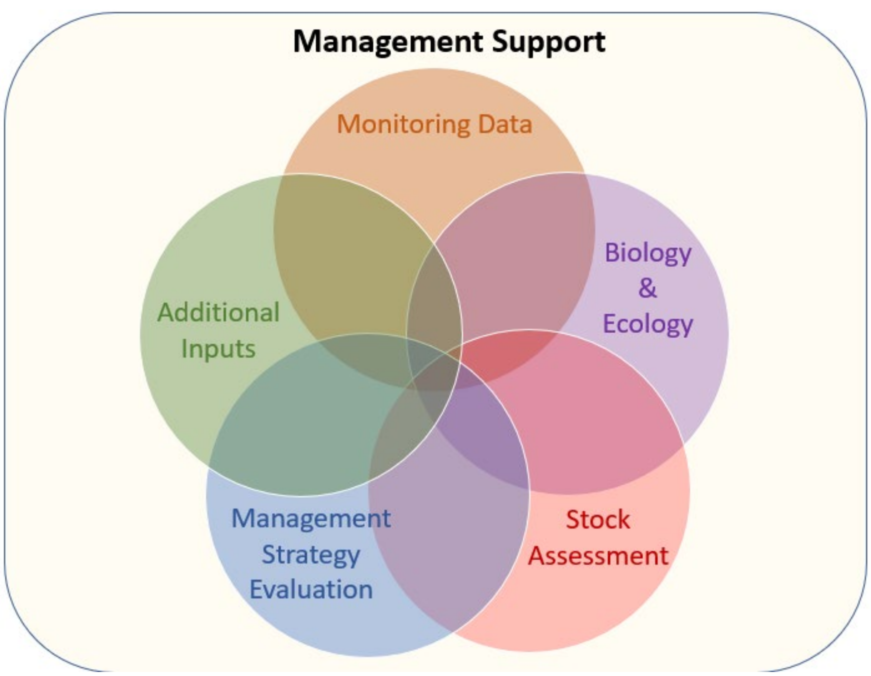


Figure 2. Core areas of the IPHC's Integrated Research and Monitoring Plan (IRMP) provide management support.

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.

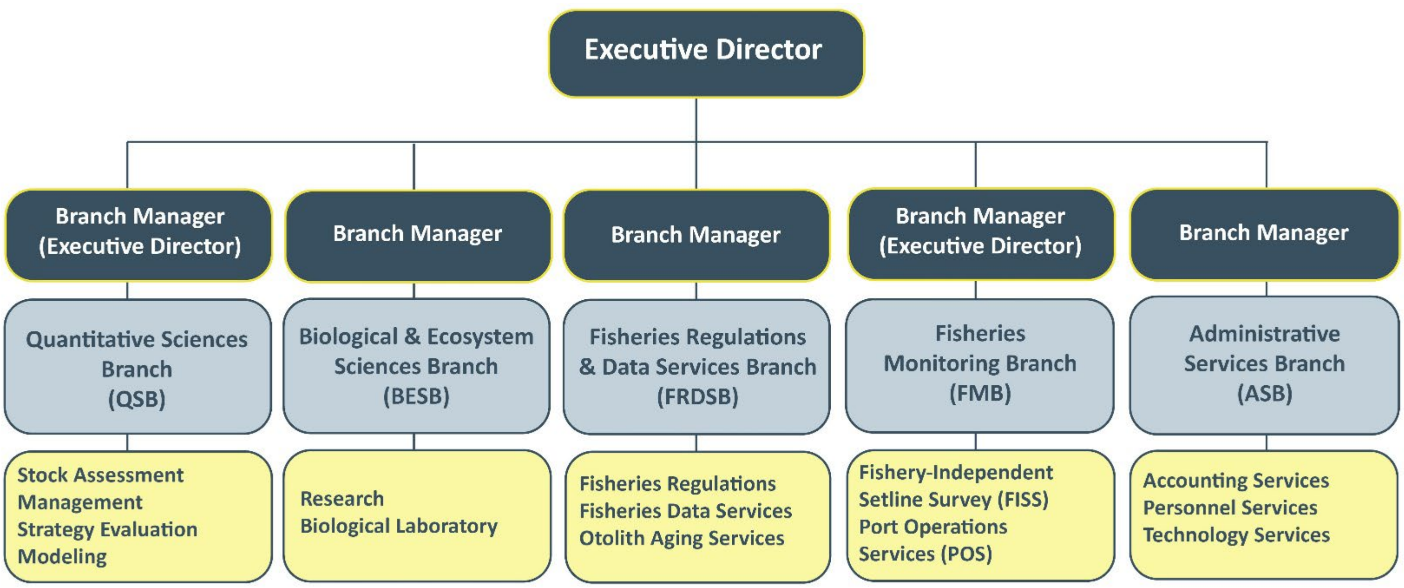


Figure 3. IPHC Secretariat organisation chart (2025).

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.

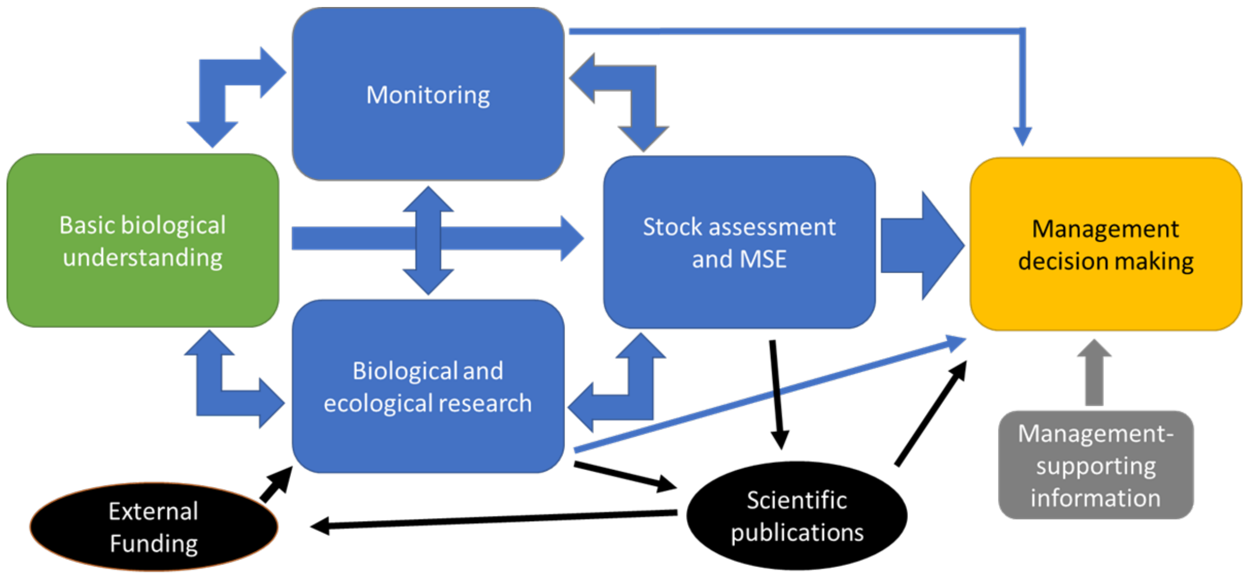


Figure 4. Flow of information from basic biological understanding of the Pacific halibut resource, through IPHC research components (monitoring, biological and ecological research, stock assessment, and MSE) to management decision-making. Management-supporting information (grey) constitutes a range of 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.

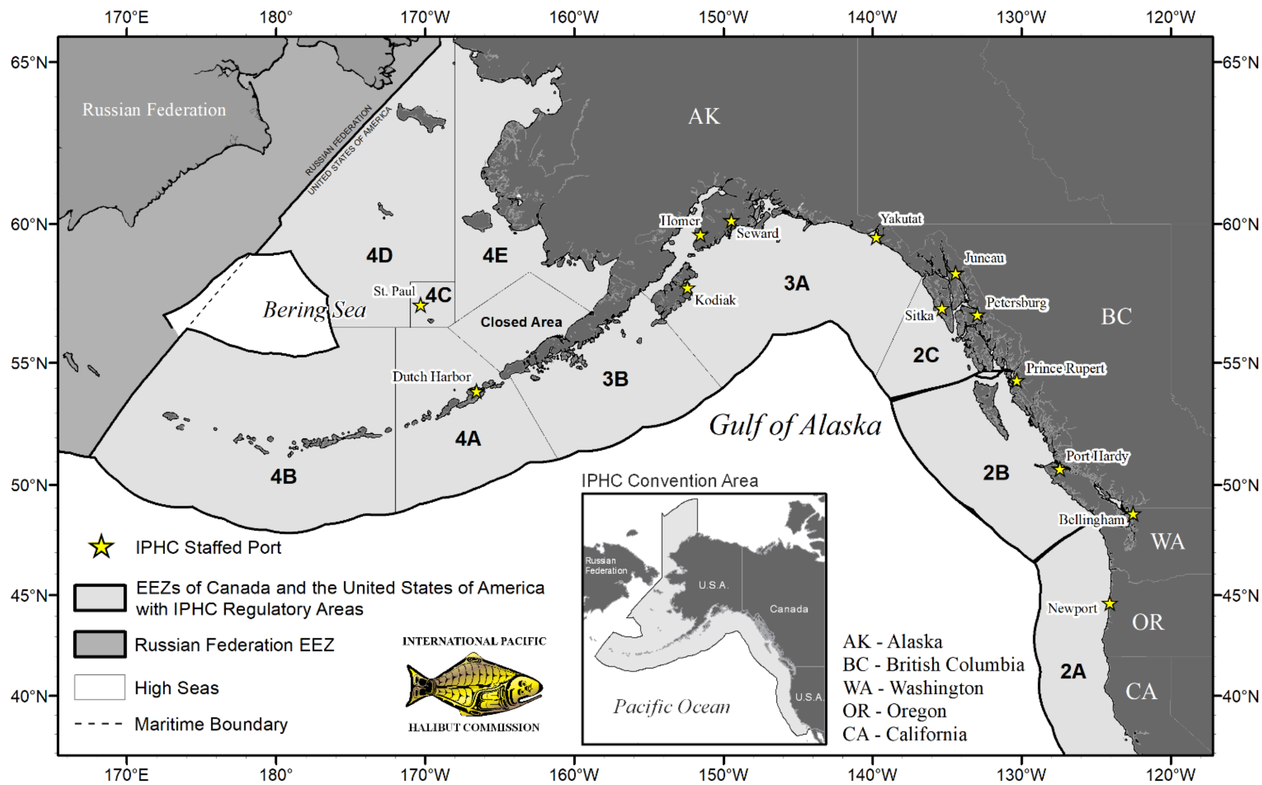


Figure 5. Ports where the IPHC has sampled directed commercial landings throughout the fishing period in recent years (note: ports sampled may change from year to year for operational reasons).

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).

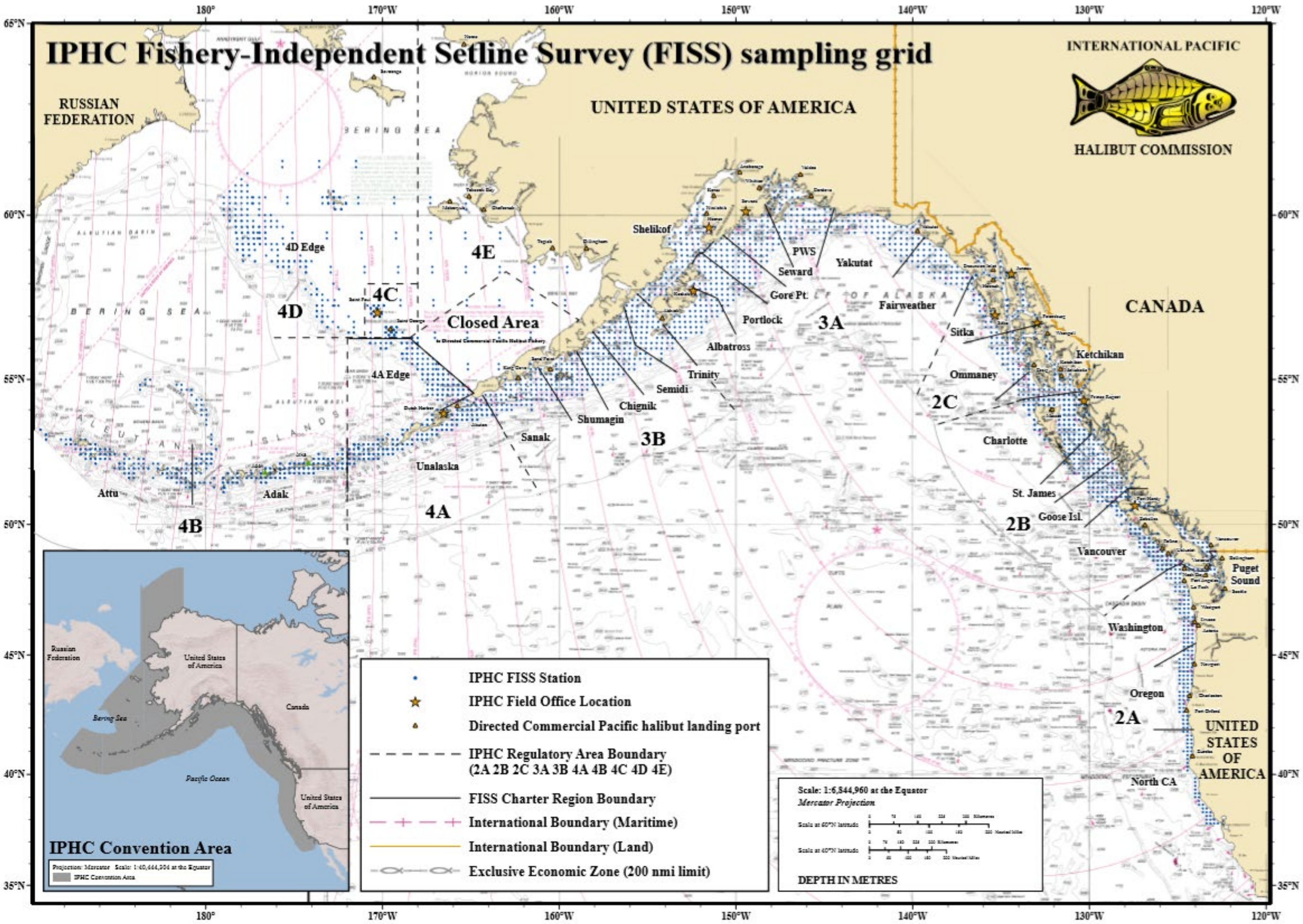


Figure 6. IPHC Fishery-Independent Setline Survey (FISS) with full sampling grid and charter regions.

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.

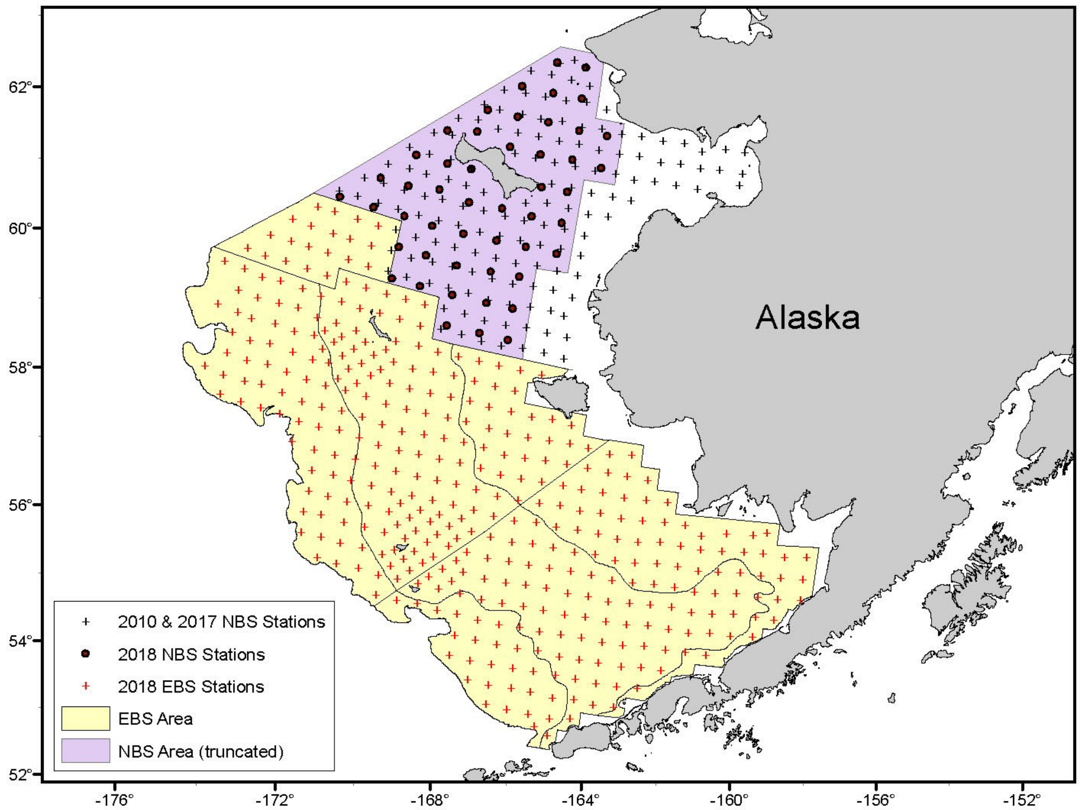


Figure 7. Representative sampling design for the NOAA Bering Sea bottom trawl survey. Black dots are stations sampled in the 2018 Northern Bering Sea trawl survey and black plus signs are stations sampled in prior Northern Bering Sea trawl surveys.

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.

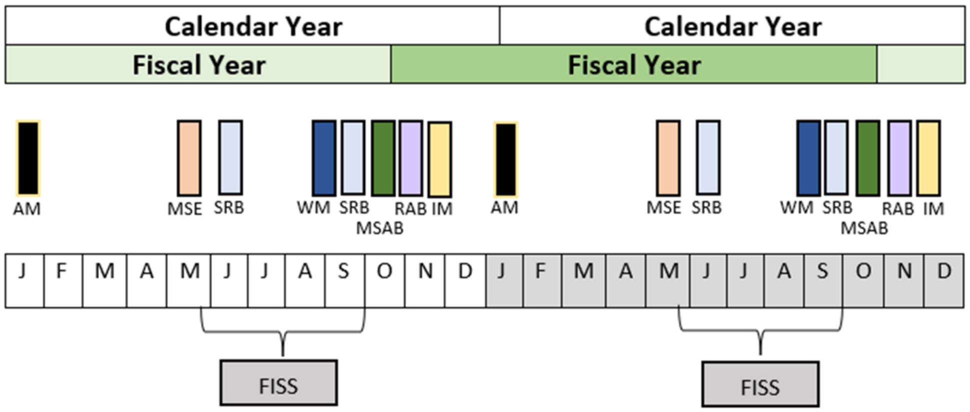


Figure 8. The typical IPHC annual meeting schedule with the calendar year and fiscal year shown. The meetings, shown in the middle row are: Annual Meeting where the Commission makes many final decisions for that year (AM), an MSE informational session (MSE), Scientific Review Board meetings (SRB), the 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. <u>Mortality estimations</u>. 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.

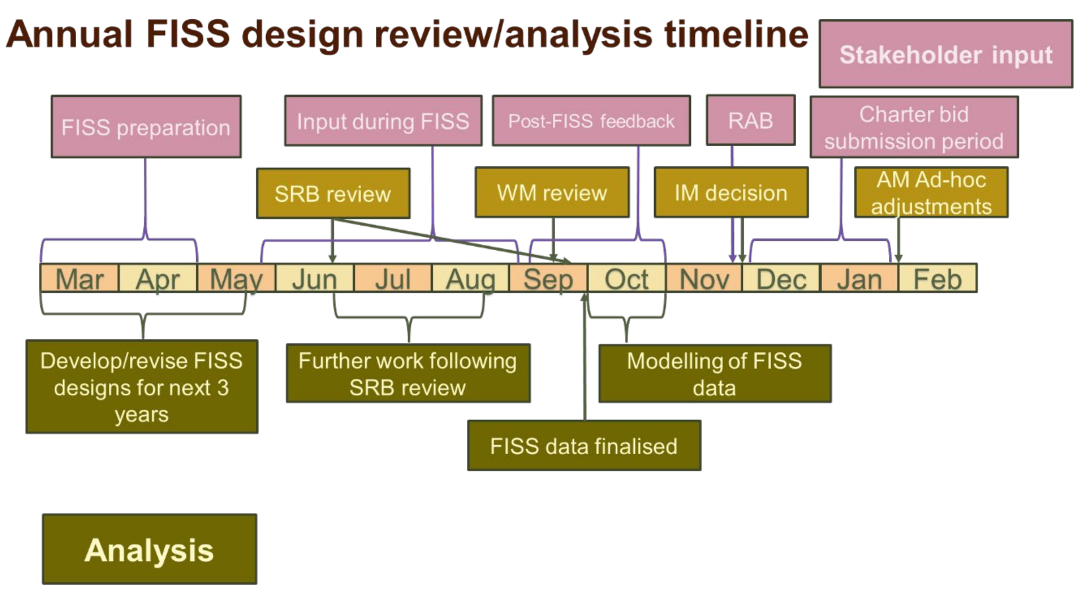


Figure 9. Timeline of annual FISS design review process.

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. Development and application of genomic approaches. Planned research outcomes: generation of genomic resources for Pacific halibut that will support genomic research.

Main results:

- 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. Population genomic studies. Planned research outcomes: delineation of population structure within Convention Waters.

Main results:

- 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