INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC–2024–SRB025–00
Last Update: 28 August 2024

25th Session of the IPHC Scientific Review Board (SRB025) – *Compendium of meeting documents*

24-26 September 2024, Seattle, WA, USA

Commissioners

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

Executive Director

David T. Wilson, Ph.D.

DISTRIBUTION: IPHC WEBSITE
LAST UPDATE: 28 August 2024

BIBLIOGRAPHIC ENTRY
IPHC 2024. 25th Session of the IPHC Scientific Review Board (SRB025) - Compendium of meeting documents. Int. Pac. Halibut Comm.

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://iphc.int/

PROVISIONAL: AGENDA & SCHEDULE FOR THE 25th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB025)

Date: 24-26 September 2024
Location: Seattle, WA, USA, & Remote Meeting
Venue: IPHC HQ & Adobe Connect
Time: 09:00-17:00 (24-25th), 09:00-11:00 (26th) PDT
Chairperson: Dr Sean Cox (Simon Fraser University)
Vice-Chairperson: Nil

1. OPENING OF THE SESSION

2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

3. IPHC PROCESS

3.1. SRB annual workflow (D. Wilson)
3.2. Update on the actions arising from the 24th Session of the SRB (SRB024) (D. Wilson)
3.3. Outcomes of the 100th Session of the IPHC Annual Meeting (AM100) (D. Wilson)
3.4. Observer updates (e.g. Science Advisors)

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

4.1. RESEARCH

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

4.2. MONITORING

4.2.1. Fishery-dependent data
4.2.2. Fishery-independent data
- IPHC Fishery-Independent Setline Survey (FISS)
  - 2024 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. MANAGEMENT SUPPORTING INFORMATION

6. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 25th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB025)

SCHEDULE FOR THE 25th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB025)

Tuesday, 24 September 2024		
Time	**Agenda item**	**Lead**
09:00-09:15	1. OPENING OF THE SESSION 2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION	S. Cox & D. Wilson
09:15-10:00	3. IPHC PROCESS 3.1 SRB annual workflow (D. Wilson) 3.2 Update on the actions arising from the 24th Session of the SRB (SRB024) 3.3 Outcomes of the 100th Session of the IPHC Annual Meeting (AM100) 3.4 Observer updates (e.g. Science Advisors)	D. Wilson
10:00-10:15	4. INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED RESEARCH AND MONITORING (2022-26)	D. Wilson
10:15-12:30	4.1 RESEARCH 4.1.1 Pacific halibut stock assessment 4.1.2 Management strategy evaluation	I. Stewart A. Hicks
12:30-13:30	Lunch	
13:30-16:00	4.1 Cont. (or off mic collaborative discussions (SRB-Secretariat)	
16:00-17:00	SRB drafting session	SRB members
19:00-21:30	SRB Dinner (Location TBA)	

Wednesday, 25 September 2024		
Time	**Agenda item**	**Lead**
09:00-09:30	Review of Day 1 and discussion of SRB Recommendations from Day 1	Chairperson
09:30-12:30	4.1.3 Biology and ecology	J. Planas
12:30-13:30	Lunch	
13:30-16:00	4.2 MONITORING 4.2.1. Fishery-dependent data 4.2.2. Fishery-independent data • IPHC Fishery-Independent Setline Survey (FISS) ○ 2025 FISS design evaluation (R. Webster) ○ Updates to space-time modelling (R. Webster) 4.2.3. Age composition data (both fishery-dependent and fishery-independent) • Using artificial intelligence (AI) for supplementing Pacific halibut age determination from collected otoliths (B. Hutniczak)	D. Wilson R. Webster K. Ualesi B. Hutniczak
16:00-17:00	SRB drafting session	SRB members
Thursday, 26 September 2024		
Time	**Agenda item**	**Lead**
09:00-09:15	5. MANAGEMENT SUPPORTING INFORMATION	As needed
09:15-09:30	SRB drafting session (if needed)	SRB members
09:30-11:00	6. ADOPTION OF THE REPORT OF THE 25th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB025)	S. Cox

LIST OF DOCUMENTS FOR THE 25th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB025)

Document	Title	Availability
IPHC-2024-SRB025-01	Agenda & Schedule for the 24th Session of the Scientific Review Board (SRB025)	✓ 12 Jun 2024
IPHC-2024-SRB025-02	List of Documents for the 25th Session of the Scientific Review Board (SRB025)	✓ 12 Jun 2024 ✓ 23 Aug 2024
IPHC-2024-SRB025-03	Update on the actions arising from the 24th Session of the SRB (SRB024) (IPHC Secretariat)	✓ 22 Aug 2024
IPHC-2024-SRB025-04	Outcomes of the 100th Session of the IPHC Annual Meeting (AM100) (D. Wilson)	✓ 20 Aug 2024
IPHC-2024-SRB025-05	International Pacific Halibut Commission 5-Year program of integrated research and monitoring (2022-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, & B. Hutniczak)	✓ 20 Aug 2024
IPHC-2024-SRB025-06	Development of the 2024 Pacific halibut (*Hippoglossus stenolepis*) stock assessment (I. Stewart & A. Hicks)	✓ 20 Aug 2024
IPHC-2024-SRB025-07	MSE update on progress in 2024 and development of a revised Harvest Strategy Policy (A. Hicks, I. Stewart, & D. Wilson)	✓ 22 Aug 2024
IPHC-2024-SRB025-08	Report on current and future biological and ecosystem science research activities (J. Planas, C. Dykstra, A. Jasonowicz, C. Jones)	✓ 23 Aug 2024
IPHC-2024-SRB025-09	2025-29 FISS design evaluation (R. Webster, I. Stewart, K. Ualesi, T. Jack & D. Wilson)	✓ 23 Aug 2024
IPHC-2024-SRB025-10	Using artificial intelligence (AI) for supplementing Pacific halibut age determination from collected otoliths (B. Hutniczak, J. Forsberg, K. Sawyer Van Vleck, & K. Magrane)	✓ 22 Aug 2024
Information papers		
IPHC-2024-SRB025-INF01	Interim: IPHC Harvest Strategy Policy IPHC–2024–HSP (IPHC)	✓ 21 Aug 2024

UPDATE ON THE ACTIONS ARISING FROM THE 24TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB024)

PREPARED BY: IPHC SECRETARIAT (22 AUGUST 2024)

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 SRB024.

BACKGROUND

At the SRB024, the members recommended/requested a series of actions to be taken by the IPHC Secretariat, as detailed in the SRB024 meeting report (IPHC–2024–SRB024–R) available from the IPHC website, and as provided in Appendix A.

DISCUSSION

During the 25th Session of the SRB (SRB025), efforts will be made to ensure that any recommendations/requests for action are carefully constructed so that each contains the following elements:

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

RECOMMENDATIONS

That the SRB:

1) **NOTE** paper IPHC-2024-SRB025-03, which provided the SRB with an opportunity to consider the progress made during the inter-sessional period, in relation to the consolidated list of recommendations/requests arising from the previous SRB meeting (SRB024).
2) **AGREE** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB025.

APPENDICES

Appendix A: Update on actions arising from the 24th Session of the IPHC Scientific Review Board (SRB024).

APPENDIX A

Update on actions arising from the 24th Session of the IPHC Scientific Review Board (SRB024)

RECOMMENDATIONS

Action No.	Description	Update
SRB024–Rec.01 (para. 19)	***Management strategy evaluation*** The SRB **NOTED** that the MSE is designed to address the concerns expressed by both the Canadian and USA science advisors and **RECOMMENDED** that the Commission develop a timeline for adopting a MP so that realistic answers to such concerns can be provided.	***Pending*** **Update**: The Commission will consider at the upcoming meeting series
SRB024–Rec.02 (para. 20)	The SRB **RECOMMENDED** a separate meeting between the SRB and Commissioners to clarify the intended use of the MSE and possible processes for adopting a formal MP.	***Pending*** **Update**: The Commission will consider at the upcoming meeting series
SRB024–Rec.03 (para. 22)	The SRB **RECOMMENDED** that the Commission develop a more specific and quantifiable catch objective to replace Objective c) (from AM099–Rec.02) "*Optimize average coastwide TCEY*". AM099–Rec.02 (para. 76). *The Commission RECOMMENDED that for the purpose of a comprehensive and intelligible Harvest Strategy Policy (HSP), four coastwide objectives should be documented within the HSP, in priority order:* *a) Maintain the long-term coastwide female spawning stock biomass above a biomass limit reference point (B20%) at least 95% of the time.* *b) Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point (B36%) 50% or more of the time.* *c) Optimise average coastwide TCEY.* *d) Limit annual changes in the coastwide TCEY.*	***In progress*** **Update**: The MSAB began discussions at an ad hoc working group meeting and will continue discussions at MSAB020. The Commission will consider at the upcoming meeting series.

SRB024–Rec.04 (para. 23)	The SRB **RECOMMENDED** that the Commission consider revising Objective b) (from AM099–Rec.02) "*Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point (B36%) 50% or more of the time*" to utilise a lower percentile than the 50th (median) to reflect concerns associated with the implications of low CPUE for the fishery at the 36% target for relative spawning biomass. A lower percentile better captures the role of uncertainty in this performance measure.	***In progress*** **Update**: The MSAB began discussions at an ad hoc working group meeting and will continue discussions at MSAB020. The Commission will consider at the upcoming meeting series
SRB024–Rec.05 (para. 24)	**NOTING** that the Operating Model (OM) requires a distribution of harvest across the IPHC Regulatory Areas even though distribution of the TCEY is not a recommended part of the MP, the SRB **RECOMMENDED** capturing uncertainty in future TCEY distribution via the approach described in IPHC-2024-SRB024-07, where the TCEY is distributed similar to what is done annually as part of the decision table construction process in the stock assessment.	***Completed*** **Update**: The OM has been updated to capture uncertainty in the TCEY distribution. A description is provided in **IPHC-2024-SRB025-07**.
SRB024–Rec.06 (para. 25)	**RECALLING** paper IPHC-2024-SRB024-03, Appendix A, SRB023-Rec.08 (para. 27), the SRB **RECOMMENDED**: a) removing "exceptional circumstance" item c because the expected timeline of stock assessments and OM updates will automatically revise biological parameters and processes; b) removing "exceptional circumstance" item b because: i. even though the operating model is an adequate representation of the coastwide dynamics and is useful for development of a coastwide MP, additional work on the regional stock dynamics needs to be done to improve correspondence with regional observations; ii. improving estimation of regional stock dynamics is a longer-term project that the Secretariat will continue to work on with input from the SRB;	***Completed*** **Update**: This has been documented in the harvest strategy policy document and will be presented to the MSAB and Commission.

	iii. as per paragraph 21, the SRB suggests that the annual TCEY distribution should not be included in a MP.	
SRB024–Rec.07 (para. 28)	***Biology and ecology*** The SRB **RECOMMENDED** that the Secretariat examine the relationship between blood markers of stress and recapture category (recaptured vs. still at large) to determine whether blood markers may be predictive of recreational charter sector discard mortality.	***Completed*** **Update**: The IPHC Secretariat has addressed this recommendation in document **IPHC-2024-SRB025-09**.
SRB024–Rec.08 (para. 29)	The SRB **NOTED** the analysis of depensation presented in paper IPHC-2024-SRB024-07, and **RECOMMENDED**: a) fitting a depensatory stock-recruitment model to estimate the depensation parameter value; b) operating model stress tests in the MSE with and without depensation across a range of plausible fishing intensities.	***Completed*** **Update**: These analyses are presented in document **IPHC-2024-SRB025-07**.
SRB024–Rec.09 (para. 30)	The SRB **NOTED** the Secretariat's studies of Pacific halibut stock structure based on genomics are nearing completion and suggest very limited genetic differentiation among individuals across the northeast Pacific and **RECOMMENDED** that: a) the Secretariat test for stock structure using only male Pacific halibut; b) the Secretariat prepare a manuscript for submission to a peer-reviewed scientific journal; c) subject to the results from recommendation a (above), revise the 5-Year Program of Integrated Research and Monitoring to deprioritize stock structure studies as well as consideration of separate assessments of different stock components.	***Completed*** **Update**: The IPHC Secretariat has addressed this recommendation in document **IPHC-2024-SRB025-09**.
SRB024–Rec.10 (para. 31)	The SRB **NOTED** the preliminary results on the regional and coastwide maturity schedules using samples collected during the 2022 FISS and **RECOMMENDED** that the Secretariat continue similar analyses with samples from the reduced 2023 FISS to evaluate possible temporal patterns in maturity schedules.	***Completed*** **Update**: The IPHC Secretariat has addressed this recommendation in document **IPHC-2024-SRB025-09**.

SRB024–Rec.11 (para. 37)	***2025 FISS design evaluation*** The SRB **RECOMMENDED** that the FISS analysis estimate a "vessel captain station" offset or scalar to estimate the average difference in catch rates of these non-randomly selected stations from those for standard grid stations.	***In progress*** **Update**: FISS modelling is pending final QA/QC of 2024 data.
SRB024–Rec.12 (para. 39)	***Updates to space-time modelling*** The SRB **NOTED** the Secretariat's thorough evaluation of the potential benefit of using the Tweedie distribution in the space-time model and **RECOMMENDED** not incorporating this distribution into the model unless the cross-validation statistics support its use.	***Pending*** **Update**: Further Tweedie model evaluation, including cross-validation, will be undertaken following the 2024 assessment cycle and will be reported at SRB026.
SRB024–Rec.13 (para. 42)	***Age composition data (both fishery-dependent and fishery-independent)*** The SRB **RECOMMENDED** that the Secretariat investigate: a) Fitting a power function to the AI/CNN vs manual age determination to show how bias increases with age; b) Training the model with more otoliths from older age classes; c) Alternative objective functions that put more weight on correctly estimating ages of older individuals; d) The importance of different aspects of aging accuracy/bias on the stock assessment.	***Completed*** **Update**: a) to c) See paper **IPHC-2024-SRB025-10**. d) A description of the treatment of ageing bias and imprecision in the stock assessment is included in **IPHC-2024-SRB025-06**.

REQUESTS

Action No.	Description	Update
SRB024–Req.01 (para. 14)	***International Pacific Halibut Commission 5-year program of integrated research and monitoring (2022-26)*** The SRB **REQUESTED** that the IPHC 5-year Program of Integrated Research and Monitoring be revised by SRB026 to reflect changing priorities in light of major progress on biological research and ongoing monitoring challenges.	***In Progress*** **Update**: In progress for SRB026 in 2025.
SRB024–Req.02 (para. 27)	***Biology and ecology*** The SRB **NOTED** the successful proposal to Alaska Sea Grant for development of genetic-	***Completed*** **Update**: The IPHC Secretariat has addressed

	based aging methods and **REQUESTED** that the Secretariat articulate how these methods address specific priorities for the stock assessment and/or MSE or other IPHC goals.	this recommendation in document **IPHC-2024-SRB025-09**.
SRB024–Req.03 (para. 35)	***2025 FISS design evaluation*** The SRB **REQUESTED** that the Secretariat present preliminary (at SRB025) and final (at SRB026) results of MSE runs with different FISS designs to better understand the actual net cost of the survey after accounting for potential reductions in TCEY associated with the increased uncertainty from reduced FISS designs.	***In Progress*** **Update**: Preliminary results are presented in **IPHC-2024-SRB025-07**.
SRB024–Req.04 (para. 43)	***Management Supporting Information*** The SRB **REQUESTED** that the Secretariat integrate FISS design considerations into the annual MSE workplan and 5-Year Program of Integrated Research and Monitoring to better quantify the value provided by the FISS.	***In Progress*** **Update**: The MSE framework is able to continue to investigate FISS design considerations.

OUTCOMES OF THE 100TH SESSION OF THE IPHC ANNUAL MEETING (AM100)

PREPARED BY: IPHC SECRETARIAT (20 AUGUST 2024)

PURPOSE

To provide the SRB with the outcomes of the 100th Session of the IPHC Annual Meeting (AM100), relevant to the mandate of the SRB.

BACKGROUND

The agenda of the Commission's Annual Meeting (AM100) included several agenda items relevant to the SRB:

3. IPHC PROCESS
- 3.1 Update on actions arising from the 99th Session of the IPHC Annual Meeting (AM099), 2023 Special Sessions, intersessional decisions, and the 99th Session of the IPHC Interim Meeting (IM099) (D. Wilson)
- 3.2 Report of the IPHC Secretariat (2023) (D. Wilson & B. Hutniczak)
- 3.3 2nd IPHC Performance Review (PRIPHC02): Implementation of recommendations (D. Wilson)
- 3.4 Report of the 18th Session of the IPHC Management Strategy Advisory Board (MSAB018) (Co-Chairpersons)
- 3.5 Reports of the IPHC Scientific Review Board (SRB Chairperson)
- 3.6 Report of the 24th Session of the IPHC Research Advisory Board (RAB024) (RAB Chairperson and Vice-Chairperson)
- 3.7 International Pacific Halibut Commission 5-year program of Integrated Research and Monitoring (2022-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, B. Hutniczak, & R. Webster)

4. FISHERY MONITORING
- 4.1 Fishery-dependent data overview (2023) (B. Hutniczak)
- 4.2 Fishery-independent data overview (2023)
  - 4.2.1 IPHC Fishery-Independent Setline Survey (FISS) design and implementation in 2023 (K. Ualesi)

5. STOCK STATUS OF PACIFIC HALIBUT (2023)
- 5.1 Space-time modelling of survey data (R. Webster)
- 5.2 Stock Assessment: Data overview and stock assessment (2023)

6. MANAGEMENT STRATEGY EVALUATION
- 6.1 IPHC Management Strategy Evaluation: update (A. Hicks)

7. HARVEST DECISION TABLE 2024
- 7.1 Stock projections and harvest decision table 2024-2026 (I. Stewart & A. Hicks)

8. FISS DESIGN EVALUATIONS 2024-2028
- 8.1 2024-28 FISS design evaluation (R. Webster)

9. BIOLOGICAL AND ECOSYSTEM SCIENCES – PROJECT UPDATES
- 9.1 Report on Current and Future Biological and Ecosystem Science Research Activities (J. Planas)

DISCUSSION

During the course of the 100th Session of the IPHC Annual Meeting (AM100) the Commission made a number of specific recommendations and requests for action regarding the stock assessment, MSE process, and 5-year research program. Relevant sections from the report of the meeting are provided in Appendix A for the SRB's consideration.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2024-SRB025-04 which details the outcomes of the 100th Session of the IPHC Annual Meeting (AM100), relevant to the mandate of the SRB.

APPENDICES

Appendix A: Excerpts from the 100th Session of the IPHC Annual Meeting (AM100) Report (IPHC-2024-AM100-R).

APPENDIX A

Excerpt from the 100th Session of the IPHC Annual Meeting (AM100) Report

(IPHC-2024-AM100-R)

RECOMMENDATIONS

Nil

REQUESTS

Statement on Climate Change

AM100–Req.01 (para. 8) The Commission **ADOPTED** the Statement on Climate change and **REQUESTED** that the IPHC Secretariat publish the statement on the website. The Secretariat will provide annual updates to the Commission on how the Statement is being implemented.

OTHER

6.1 IPHC Management Strategy Evaluation: update

(para. 53) The Commission **AGREED** to undertake intersessional discussions on the recommendations contained within paper IPHC-2024-AM100-11, and provide further direction to the IPHC Secretariat.

8.1 2024-28 FISS design evaluation

(para. 70) The Commission **ENDORSED** the base 2024 FISS design that includes options 1-3 in Table 4 to provide data for basic trend estimation and biological data for use in the 2024 stock assessment. Specifically, this design includes two charter regions in IPHC Regulatory Area 2B, three charter regions in IPHC Regulatory Area 2C, two charter regions in IPHC Regulatory Area 3A, and one charter region in IPHC Regulatory Area 3B.

(para. 71) The Commission **AGREED** to meet in mid-February 2024 to review the tender bids received for IPHC Regulatory Area 4, and determine whether Options 4 or 9 (Table 4), or both, should proceed in 2024 (Fig. 6).

(para. 73) The Commission **AGREED** to the goal of maintaining sufficient FISS sampling to ensure a maximum annual CV of 25% in each IPHC Regulatory Area, decreasing to 15% as financial considerations allow, and including FISS biological sampling in all Biological Regions (but not necessarily all Regulatory Areas) each year.

(para. 79) The Commission **AGREED** that supplementary funding is needed to sustain the FISS moving forward and to explore options for funding, e.g. from Contracting Parties or external partners.

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

PREPARED BY: IPHC SECRETARIAT (D. WILSON, J. PLANAS, I. STEWART, A. HICKS, B. HUTNICZAK, AND R. WEBSTER; 20 AUG 2024)

PURPOSE

To provide the SRB with an annual opportunity to comment and propose amendments to the IPHC's 5-year Program of Integrated Research and Monitoring (2022-26) (the Plan). The Plan last update was on 18 December 2023.

BACKGROUND

Recalling that:

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

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

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

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

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

The 1st iteration of the Plan was formally presented to the Commission at IM097 in November 2021 (IPHC-2021-IM097-12) for general awareness of the documents ongoing development. At the 98th Session of the IPHC Annual Meeting (AM098) in January 2022, the Commission requested a number of amendments which were subsequently incorporated. At the 99th Session of the IPHC Annual Meeting (AM099) in January 2023, the Commission recommended that the Secretariat annually present potential changes to the Plan at the IPHC Interim Meeting. Recommendations from the 99th Session of the IPHC Interim Meeting (IM099) were subsequently incorporated (IPHC-2024-AM100-03). No further requests were received at the 100th Session of the IPHC Annual Meeting (AM100) in January 2024 (IPHC-2024-AM100-R).

The Plan had already been through few cycles of review and improvement with the Scientific Review Board (SRB), with amendments being suggested and incorporated accordingly. The current version will move to an annual comment and amendment process at each years' Interim and then Annual Meetings.

DISCUSSION

The SRB should note that:

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

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

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

At the 24th Session of the Scientific Review Board (SRB024) in June 2024, the SRB provided the following request:

> ***International Pacific Halibut Commission 5-year program of integrated research and monitoring (2022-26)***

> SRB024–Req.01 (para. 14) *The SRB **REQUESTED** that the IPHC 5-year Program of Integrated Research and Monitoring be revised by SRB026 to reflect changing priorities in light of major progress on biological research and ongoing monitoring challenges.*

Responding to this request, the Secretariat is working on a revision of the Plan for presentation at SRB026.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2024-SRB025-05 which provides the IPHC 5-year program of Integrated Research and Monitoring (2022-26) with potential updates.

APPENDICES

Nil

Development of the 2024 Pacific halibut (*Hippoglossus stenolepis*) stock assessment

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 20 AUGUST 2024)

PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with a response to recommendations and requests made during SRB024 (IPHC-2024-SRB024-R) and to provide the Commission with an update on progress toward the 2024 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 2022 (IPHC-2023-SA01), following updates in 2020 and 2021. The 2023 stock assessment updated the 2022 analysis and all data sources where new information was available but made no structural changes to the methods. Development and supporting analyses arising from the 2023 assessment were reviewed by the IPHC's SRB in June (SRB022; IPHC-2023-SRB022-08, IPHC-2023-SRB022-R) and September 2023 (SRB023; IPHC-2023-SRB023-06, IPHC-2023-SRB023-R).

A summary of the 2023 stock assessment results (IPHC-2024-AM100-10) as well as stock projections and the harvest decision table for 2024 (IPHC-2024-AM100-12) were provided for the IPHC's 100th Annual Meeting (AM100). In addition, the input data files are archived each year on the stock assessment page of the IPHC's website, along with the full assessment (IPHC-2024-SA-01) and data overview (IPHC-2024-SA-02) documents. All previous stock assessments dating back to 1978 are also available at that location.

In June 2024, the Secretariat produced a summary of stock assessment development to date (IPHC-2024-SRB024-08). That preliminary development included extending the time-series and updating to the newest version of the Stock Synthesis software, neither of which affected the model results. Development also included an improvement on the parameterization of selectivity, allow for uncertainty in the random-walk process to be propagated into forward projects; this had very small effects on model projections.

This document includes a response to requests made during SRB023 and SRB024, including the results of FISS design simulation experiments, and an overview of topics planned for exploration in the 2025 full stock assessment. The final 2024 analysis will be an updated stock assessment, consistent with the schedule for conducting a full assessment and review approximately every three (3) years. Standard data sources and model configurations are expected to remain unchanged.

SRB REQUESTS AND RECOMMENDATIONS

The SRB made the following assessment recommendations and requests during SRB023 and SRB024:

1) SRB023–Rec.19 (para. 59):

   *"The SRB **RECOMMENDED** that the Secretariat continue exploring ways of estimating the impacts of different FISS designs and efficiency decisions on stock assessment outputs and*

fishery performance objectives. The end goal should be to provide a decision support tool that can frame decisions about FISS design in terms of costs and benefits in comparable currencies."

2) SRB023–Req.07 (para. 60):

   *The SRB **REQUESTED** that the Commission NOTE that some longer-term (2025 and beyond) implications of reduced FISS designs are predictable and potentially consequential. For instance, higher FISS CVs will generally result in higher inter-annual variation in TCEY under the current decision-making process. This would occur for two reasons: (1) biomass estimates and projections from the assessment model will have greater uncertainty and therefore greater variability in outputs and (2) ad hoc management adjustments to the interim harvest policy recommendations would be more frequent and/or more variable for greater input uncertainty. The SRB therefore REQUESTED the following analyses for SRB024:*

   a) Assessment of reduced FISS designs (2025-2027) via simulation tests of assessment model outputs (e.g. probability of decline, estimated stock abundance and status, TCEY) under alternative revenue-neutral FISS designs using the existing stock assessment ensemble;

   b) Mitigation options of reduced FISS designs (short-term and long-term) via MSE simulations of management procedures that deliberately aim to reduce inter-annual variability in TCEY via multi-year TCEYs and (possibly) fixed stock distribution schemes;

   c) Components (a,b) above would be integrated since (a) will need to inform simulations in (b)."

3) SRB024 (para. 42):

   *The SRB **RECOMMENDED** that the Secretariat investigate:*

   a) Fitting a power function to the AI/CNN vs manual age determination to show how bias increases with age;

   b) Training the model with more otoliths from older age classes;

   c) Alternative objective functions that put more weight on correctly estimating ages of older individuals;

   d) The importance of different aspects of aging accuracy/bias on the stock assessment.

Recommendations 1 &2 – Simulation testing FISS designs

Results of a stock assessment simulation 'self test' along with a proposal for FISS design simulation experiments were presented during SRB024. Following that basic test of the stock assessment ensemble performance, simulation experiments were developed to compare the effects of three potential FISS designs implemented over the period 2025-2027 on the stock assessment and management results:

1) A 'base block design' including good spatial coverage (at least one charter region in all Biological Regions and all IPHC Regulatory Areas each year), low CVs and very low potential for multi-year bias due to sampling all survey stations on a frequent basis.
2) A 'core design' including sampling in those areas with the highest biomass at a reduced sampling cost. This design will produce larger CVs than the block design and will have a

high likelihood of biased trends and age compositions due to low abundance and/or high-cost areas going unsampled for multiple consecutive years.

3) A ‘reduced core design’ that provides sampling only in areas that are close to or above revenue positive thresholds. This design will produce larger CVs than the core design and will have a very high likelihood of introducing biased trends and age compositions due to the extremely restricted geographic coverage.

For each of these designs, the annual index variance was calculated for 2025 through 2027 (see IPHC-2024-SRB024-06). Projections using the space-time model naturally propagate the variance associated with reduced FISS designs; however, because the reduced designs do not represent a random draw from all 1,890 survey stations there is the potential for bias in addition to reduced precision. The degree of potential bias is unknown and will depend on how the design interacts with localized trends and patterns in cohort structure, movement rates, and other factors known to vary interannually. Based a summary of previous changes in different areas of the stock, the Secretariat used +/- 15% bias in the FISS index over 3 years as a basis for investigating short-term stock assessment performance.

The current stock assessment can be used to simulate new data, given an assumed trend and precision for all data sources. This is achieved via the internal semi-parametric bootstrap used in the ‘self-test’ presented at SRB023. This same approach was applied for the FISS design simulations:

1) Using the 2024 bridging stock assessment models, extend the time-series to 2028 assuming constant harvest levels at the projected 2024 mortality for each fishery sector.
2) Fit ‘true’ models to FISS projections that include no trend, a linear 15% positive trend over the next three years (i.e. the FISS index at the end of the period is 15% larger than that observed in 2024; as the actual estimate for 2024 is not yet available it was assumed that the 2024 index was identical to 2023), and a linear 15% negative trend over the next three years using the CVs projected for the base block design. Assume all other data sources (fishery CPUE and age composition information) are sampled at the observed rates from 2023.
3) Using the ‘true’ models, bootstrap all of the data (FISS and fishery) in 2025-2028, to create 100 replicate ‘true’ data sets for each of the three trends.

When evaluating alternative or restricted survey designs it is common to consider only the index of abundance (e.g., Anderson et al. 2024); however, the age composition information is also critically important to estimating year-class strengths which can lead to very different management outcomes for the same or similar index trends. The bootstrapping approach described above naturally produces age composition information along with trend information, that can be either biased or unbiased depending on how it is used.

Based on the simulated data sets from the ‘true’ states, three experiments were conducted (Table 1). Each experiment compared a stock assessment ensemble (all four models) using unbiased trend information (the base block design) to a stock assessment using data representing the two reduced designs. This analysis therefore produced 9 ensembles, crossing the three designs with three trends. These three experiments were: compare core and reduced core designs with no trend (unbiased) to the base block design (also unbiased) to explore the effects of increased CVs and compare biased core and reduced core designs to an unbiased base block design given true FISS trends of +15% and -15%. For models fitting to data based on the restricted designs (core and reduced core), the sample sizes for the age composition data were reduced in proportion to the geographic extent of the sampling (e.g., a reduced core design will include smaller sample sizes than the other two designs and the areas-as-fleets models will have missing data from some biological regions). Fishery CPUE and age composition data were simulated as unbiased in all cases.

Table 1. Design matrix for simulations of FISS design effects on the stock assessment.

‘True’ FISS trend	Estimation models	Inference
No trend	*Unbiased*: No FISS trend, base block design *Unbiased*: No trend, core design *Unbiased* No trend, reduced core design	Effect of increased CV due to reduced designs
+15% over 3 years	*Unbiased*: +15% FISS trend, base block design *Biased*: No trend, core design *Biased*: No trend, reduced core design	Effect of failing to identify an increasing trend
-15% over 3 years	*Unbiased*: -15% FISS trend, base block design *Biased*: No trend, core design *Biased*: No trend, reduced core	Effect of failing to identify a decreasing trend

This approach provides inference on how a reduced FISS might affect the overall results of the stock assessment ensemble. Specifically: How does a reduced but unbiased FISS affect the results? How will management information be affected if we fail to detect an increasing trend? How will management information be affected if we fail to detect a decreasing trend? For each of these questions we compared key management inputs between the ensemble using the base block design and those that are either less precise and/or biased. Because they are central to management decision-making we compared the estimated spawning biomass, the estimated fishing intensity (SPR), and the estimated risk of stock decline at the end of the three-year period.

Overall, there was not a large bias in the estimated spawning biomass for any of the three experiments. The core and reduced core designs, when unbiased, resulted in only a -1% and -2% bias in spawning biomass between 2025 and the beginning of 2028. When the true trend was increasing but the FISS designs were biased (no trend), both ensembles underestimated the true spawning biomass by either -2% (core design) or -3% (reduced core design) at the end of the projection period. When the true trend was decreasing but the FISS designs were biased (no trend), both ensembles overestimated the true spawning biomass by either 3% (core design) or 2% (reduced core design) at the end of the projection period. This relatively small effect size for imprecise and biased FISS indices and age composition data makes sense for several reasons: most of the recruitments that will mature into the spawning biomass over the next few years are already informed by data through 2023, all fishery data was simulated to be unbiased and therefore stabilizes the model results, and reduced FISS designs produce less informative data than a full design, thus influencing the model fit less. This might seem to lead to the counterintuitive conclusion that when conducting a reduced survey that is potentially biased it seems better to have it be *less* informative. However, this is incorrect as the more reduced the survey design becomes the more likely it is that the results are biased.

Estimated fishing intensity (using SPR) in 2027 also did not show a large response when FISS designs were imprecise and/or biased. Fishing intensity remained unbiased for both the core and reduced core designs without bias. When the true FISS tend was increasing (true SPR=47%), but the FISS designs were biased, both the core and reduced core designs underestimated the SPR (overestimated the fishing intensity) by 1%. Conversely, when the true FISS trend was decreasing (true SPR=44%) but the FISS designs were biased, both the core and reduced core designs overestimated the SPR (underestimated the fishing intensity) by 1%. To put this degree of bias in SPR in context, in recent year's decision tables if the Commission wanted to increase the SPR by 1% (at or near the status quo harvest level) a reduction of 1.0-1.5 million pounds of TCEY would have been required. Given an average price of $6 USD per pound in the commercial fishery, this equates to approximately $7.5 million USD that would need to be temporarily forgone to ensure that the management decision was precautionary for a bias of up to 15% in the FISS index.

The third metric that was compared was the probability of spawning biomass decline at the end of the 3-year period from 2027 to the beginning of 2028. As for SPR, there was no bias created in the estimated probability of spawning biomass decline due to more uncertain but unbiased FISS designs. When the true FISS trend was increasing (a 40% chance of stock decline), but we fail to detect this change due to either biased FISS design, we overestimate the probability of stock decline by 6%. When the true FISS trend was decreasing (a 65% chance of stock decline), and we fail to detect this change we underestimate the probability of stock decline by 9%. Comparing to recent decision tables, in order to reduce the probability of stock decline by 9% in the upcoming year, recent management decisions would have required a short-term reduction in the TCEY of approximately 4 million pounds, or $24 million USD given an average commercial fishery price of $6 USD per pound.

When all the model and data assumptions are met perfectly (as in this simulation) the effects of a reduced FISS, even when biased by up to 15%, are relatively small in the short-term. However, it is our experience that the most challenging situations in stock assessment do not arise from expected outcomes, but from either rare events that cannot be included in simulations or from cases where multiple deviations from expectations occur simultaneously. Therefore, we caution that the results of these FISS design simulations should be considered 'best case' outcomes, and that actual stock assessment ensemble results and management performance may be worse under real conditions.

This simulation experiment does not quantify the value of stakeholder perception and confidence in the FISS. Across years including a range of FISS designs, from very large (e.g., 1,558 stations in 2019 and 1,489 stations in 2018) to very small (951 stations in 2020 and 544 stations in 2023), it has become very clear that the entire decision-making process relies heavily on the perception of whether the FISS was comprehensive and sufficient to capture coastwide and regional trends. Even large survey designs have often required repeated comparisons with commercial fishery catch rates and age composition information as well as the specific experiences of harvesters in each of the IPHC Regulatory Areas before a reasonable level of confidence was achieved. Where entire IPHC Regulatory Areas, or entire Biological Regions have gone unsampled, the lack of direct information has affected management allocation decisions and led to stakeholder proposals to freeze mortality limits at or below the previous year's level (Appendix II in IPHC-AM100-INF01-Rev_5). We recognize that stakeholder perception cannot be easily quantified without a specific social science analysis; however, it is nonetheless critically important to the Pacific halibut management process. We suggest that the long-term goal should be to create a sustainable survey design that meets quantitative objectives (both in the annual process and the full MSE), but also satisfies stakeholder needs and represents a point of stability in the management process rather than a point of concern.

Recommendations 3 – Ageing accuracy and precision

Age reading for Pacific halibut otoliths has used two methods over the history of the Commission: counting the rings on whole otoliths (surface reading) and counting the rings along the edge of an otolith that has been broken in half and baked to enhance the contrast in color between the dark and light bands on the structure (break-and-bake reading). Until 2002, all ages were estimated based on surface reading; in that year the primary method transitioned to break-and-bake ageing. During both periods an extensive quality control program (~5-10% per year) resulted in multiple reads (either by the same individual but blind to the first read, or by different individuals), and also comparisons between surface and break-and-bake age estimates of the same otoliths. In addition, most of the 1998 FISS ages were read a second time using break-and-bake ageing.

Break-and-bake aging has been shown to be unbiased using bomb radiocarbon validation (Piner and Wischnioski 2004) and also found to be very precise relative to the ageing of many groundfish species (Clark 2004). Re-aging of samples from each decade from the 1920s to the 1990s has shown that surface aging, although biased for older ages (Figure 1), has remained quite consistent over the full 100-year time series (Clark and Hare 2006; Forsberg and Stewart 2015). The imprecision in break-and-bake ages and the relative bias in surface ages were simultaneously estimated using software that accounts for the joint probability of two (or more) ageing methods based on double- and triple-reads of the same otoliths conducted as part of the IPHC's quality control protocols (Punt et al. 2008). The stock assessment treats ageing error by first calculating the underlying numbers at age in the modelled population, then multiplying these numbers by the age-imprecision key (Figure 2) before comparing the 'expected' numbers at age for each ageing method to the observed data (Methot and Wetzel 2013). The current model treats surface ages and break-and-bake ages separately, using only break-and-bake ages for those years in which that type of data are available. Further, to reduce the potential impact of estimates of the bias in surface ages, the stock assessment uses a 'plus group' (accumulating all ages at or above that age) of age-20 for this source of age composition data. For break-and-bake age compositions a plus group of age 25 is used. These plus groups describe only the aggregation of the data and expected values; the population dynamics in the assessment models include all ages to a plus group of 30 years.

For future use of Artificial Intelligence (AI) based ages (IPHC-2024-SRB025-10) it would be possible to estimate both bias and imprecision through comparisons with break-and-bake ages. Ideally, all ages from a particular year and source (e.g., FISS, commercial fishery, recreational fishery, …) would be aged using the same method, such that it would be possible to model a single age composition. Duplicate age compositions for the same year and source are also possible but would reduce the effective sample size of each and require careful partitioning such that both compositions were random with regard to the overall sampling frame. Specifically, it would not be possible to include a single age composition where otoliths were read by multiple methods without defining that approach as a new 'method; itself and creating an associated bias and imprecision estimate through comparison with break-and-bake ages. There is no limit on the number of age reading methods that can be included in the stock assessment; however re-training the AI algorithm and estimating a unique imprecision matrix for each year would add technical overhead to the already compressed stock assessment process.

There is no threshold for imprecision that would make AI-based ages usable vs. unusable in the stock assessment. Instead, the degree of precision and the choice of which age to use as the plus group (especially if there is high imprecision and/or bias in older ages from the AI method) will dictate the information content of the data. Using a lower plus group will tend to reduce the information on mortality rates but aggregating the right-hand side of the catch curve. Greater imprecision will make it more difficult to detect and track strong cohorts moving through the population. When a suitable data set has been developed, it may be helpful fit stock assessment models with age compositions from the same sources and year but different methods to directly evaluate how the models respond.

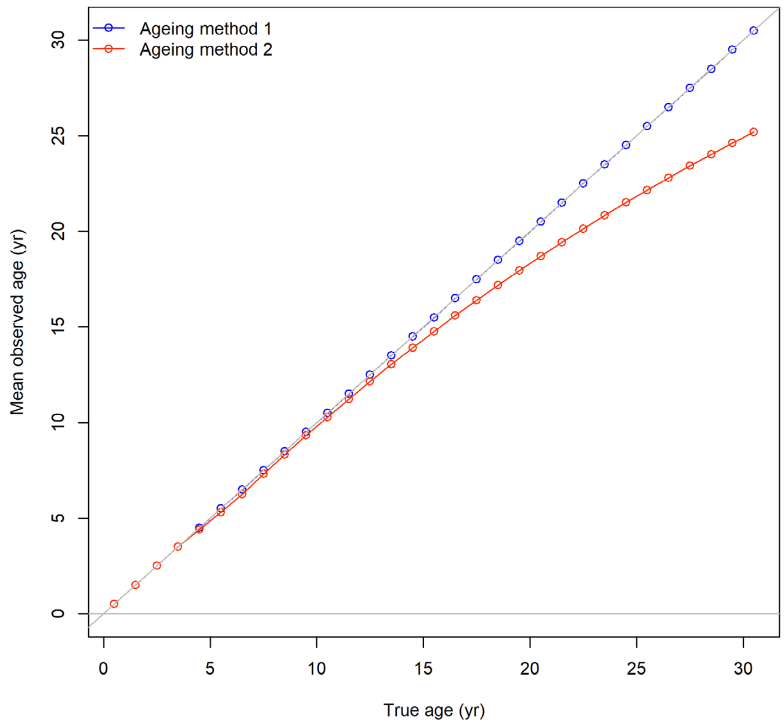


Figure 1. Relative bias estimated for break-and-bake ageing (method 1) and surface ageing (method 2) used in the stock assessment.

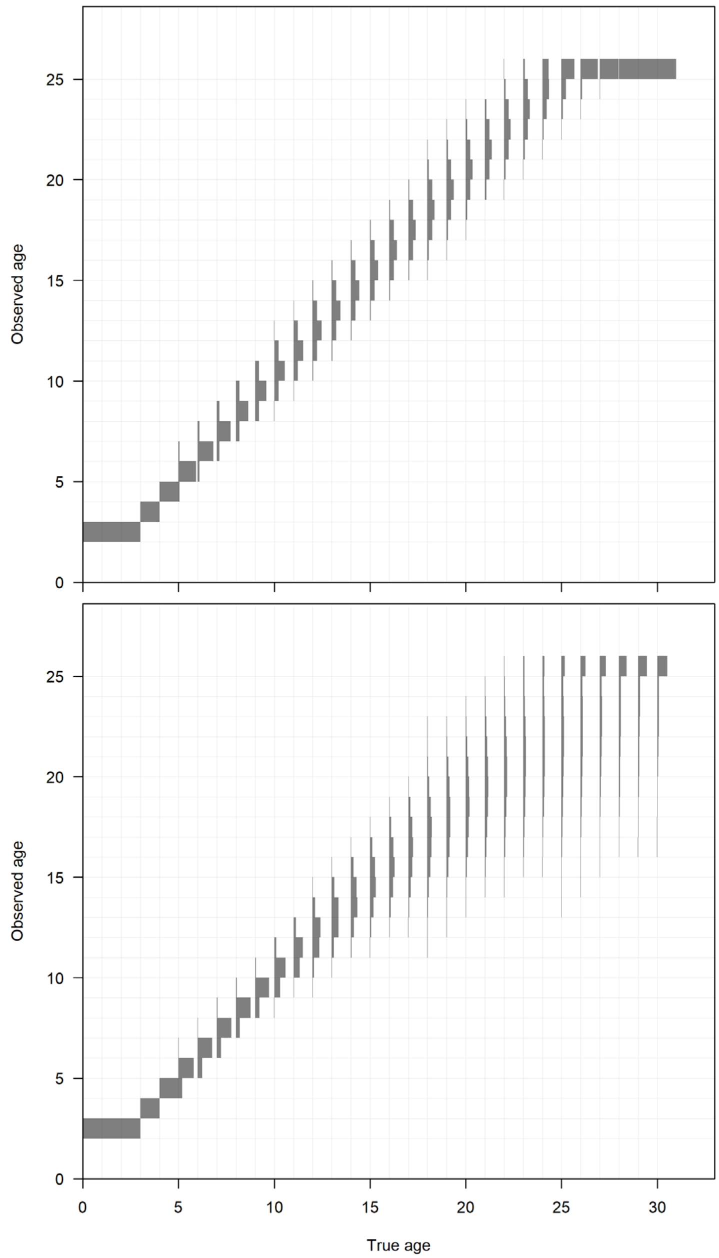


Figure 2. Relative bias and imprecision estimated for break-and-bake ageing (upper panel) and surface ageing (lower panel) used in the stock assessment.

PLANNED DEVELOPMENT IN 2025

The 2025 stock assessment is planned as a full assessment, where all aspects of data processing, model structure and ensemble construction may be revisited. Each recent full stock assessment has included new approaches to data processing and modelling methods, with major changes represented by the addition of commercial sex-ratio information in the 2019 stock assessment (IPHC-2020-SA01) and the estimation of natural mortality in the 2022 stock assessment (IPHC-2023-SA01). For 2025 several development avenues are currently planned:

Maturity and skip-spawning: Histological maturity estimates from 2022-2024 should be available for the 2025 stock assessment. Decisions will need to be made about how to include the multiple years of data (e.g., average them or treat as a time series) and whether to revise the historical maturity time-series or replace recent values with the new results. This ongoing research has the potential to have a large impact on stock assessment results, particularly if evidence of frequent skip-spawning, age/size dependent fecundity, or trends in reproductive output that depend on the environmental conditions are identified. All of these relationships affect estimates of spawning biomass or total reproductive output as well as reference points, thus specifically affecting the potential fishery yield at low stock sizes.

Treatment of the PDO: There is a revised and extended time series for the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) available that includes data from 1854, where the currently used time-series is much shorter. However, the two series are standardized anomalies from the average value over different periods, thus leading slightly different regimes. A comparison of these environmental series, and how they affect stock assessment recruitment estimates and consideration of whether the PDO is still likely to be a useful covariate to recruitment given change in the underlying relationships between environmental variables (e.g., Litzow et al. 2020) is planned for 2025.

Data weighting: As part of the 2022 stock assessment a bootstrapping procedure (Stewart and Hamel 2014) was included in all age data processing to provide an objective starting point for the weighting of the compositional data (Francis 2011). A recent publication has suggested and extension to that method which includes age-reading imprecision in the calculation of effective sample size (Hulson and Williams 2024). This approach will be added to the existing bootstrapping procedure for 2025. Other developments in weighting of compositional data include: a new formulation of the multinomial-Dirichlet distribution that has linear scaling which more closely resembles the multinomial, and an improved calculation of residuals (One-Step-Ahead or OSA residuals) for diagnosing the model fit that do not rely on standard Pearson residuals, which are statistically invalid for composition data that inherently includes a correlation among bins and are therefore not independent and identically distributed (Thygesen et al. 2017; Trijoulet et al. 2023). Exploration of these methods is planned to be included in the overall evaluation of model fit and data weighting.

Natural mortality estimation: In the 2022 stock assessment three of the four individual models in the ensemble estimated natural mortality for both female and male Pacific halibut. The short coastwide model estimated the value for males, but relied on a fixed value for females as there was no clear minima in the likelihood surface for that parameter over a reasonable range of values. Further investigation of natural mortality in that model, including potential confounding with commercial fishery sex ratio, data weighting, and other structural choices is planned.

Other analyses: There may be other improvements to data processing or model configurations that arise during the full assessment and for which the change in model results will be evaluated and documented.

The 2025 full stock assessment will be initially reviewed during SRB026 providing the opportunity for the SRB to make recommendations and for those recommendations to be explored prior to final review at SRB027. The development of the stock assessment is closely tied to Commission decisions leading to a formal Management Procedure (MP). Importantly, the assessment must be targeted to the specific needs of the Commission – a stronger reliance on the MSE output might allow for development of more complex stock assessment approaches and a change in the stock assessment schedule (e.g., from annual to biennial or triennial) would also have major impacts on assessment development goals. For this reason, final decisions about the specific topics and potential degree of change in the 2025 stock assessment will be made after the IPHC's AM101 in January 2025.

OTHER TOPICS

Assessment development during 2024 is occurring in parallel with the ongoing histological maturity study (IPHC-2024-SRB025-08). Although not yet available at the time this document was produced, a sensitivity analysis including the updated maturity schedule for Pacific halibut in the stock assessment models may be available for SRB025. It is anticipated that any major revisions to the stock assessment or to the management results inferred from it will be included in the full assessment planned for 2025. Any preliminary updates on 2024 data will also be provided if available in time for SRB025.

ADDITIONAL STOCK ASSESSMENT DEVELOPMENT FOR 2024

Per standard procedures for an update stock assessment, the secretariat will include routine minor updates and improvements to each of the models and data sets as needed. Standard data sources that will be included in the final 2024 stock assessment include:

1) New modelled trend information from the 2024 FISS for all IPHC Regulatory Areas. Increased variance and the potential for bias is a concern for IPHC Regulatory Areas 2A, 4A, and 4B due to the reduced design. Further, low spatial coverage in 4CDE, 3B and 3A also has the potential to create bias for those and for stock distribution estimates for all IPHC Regulatory Areas.
2) Age, length, individual weight, and average weight-at-age estimates from the 2024 FISS. These data may also contain bias due to the low spatial coverage in the 2024 FISS design.
3) Directed commercial fishery logbook trend information from 2024 (and any earlier logs that were not available for the 2023 assessment) for all IPHC Regulatory Areas.
4) Directed commercial fishery biological sampling from 2024 (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 2023. The availability of these data routinely lags one year.
6) Updated mortality estimates from all sources for 2023 (where preliminary values were used) and estimates for all sources in 2024.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2024-SRB025-06 which provides a response to requests from SRB023 and SRB024, and an update on model development for 2024.

b) **REQUEST** any modifications to the 2024 stock assessment.

c) **REQUEST** any analyses to be provided at SRB026 as part of the development of the full 2025 stock assessment.

REFERENCES

Anderson, S.C., English, P.A., Gale, K.S.P., Haggarty, D.R., Robb, C.K., Rubidge, E.M., Thompson, P.L., and Kotwicki, S. 2024. Impacts on population indices if scientific surveys are excluded from marine protected areas. ICES Journal of Marine Science. doi:10.1093/icesjms/fsae009.

Clark, W.G. 2004. Nonparametric estimates of age misclassification from paired readings. Canadian Journal of Fisheries and Aquatic Sciences **61**: 1881-1889.

Clark, W.G., and Hare, S.R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. International Pacific Halibut Commission Scientific Report No. 83, Seattle, Washington. 104 p.

Forsberg, J.E., and Stewart, I.J. 2015. Re-ageing of archived otoliths from the 1920s to the 1990s. IPHC Report of Assessment and Research Activities 2014. p. 405-428.

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

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. 2022. Report of the 21st session of the IPHC Scientific review board (SRB021). IPHC-2022-SRB021-R.

IPHC. 2024. Stakeholder comments on IPHC Fishery Regulations or published regulatory proposals. IPHC-2024-AM100-INF01 Rev_5. 21 p.

Litzow, M.A., Hunsicker, M.E., Bond, N.A., Burke, B.J., Cunningham, C.J., Gosselin, J.L., Norton, E.L., Ward, E.J., and Zador, S.G. 2020. The changing physical and ecological meanings of North Pacific Ocean climate indices. Proceedings of the National Academy of Sciences of the United States of America **117**(14): 7665-7671. doi:10.1073/pnas.1921266117.

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.

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**(0): 86-99. doi:http://dx.doi.org/10.1016/j.fishres.2012.10.012.

Piner, K.R., and Wischnioski, S.G. 2004. Pacific halibut chronology of bomb radiocarbon in otoliths from 1944 to 1981 and a validation of ageing methods. Journal of Fish Biology **64**: 1060-1071.

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

Stewart, I., and Hicks, A. 2020. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2019. IPHC-2020-SA-01. 32 p.

Stewart, I., and Hicks, A. 2023. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2022. IPHC-2023-SA-01. 37 p.

Stewart, I., and Webster, R. 2023. Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses. IPHC-2023-SA-02. 59 p.

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

Stewart, I., and Hicks, A. 2024b. Development of the 2024 Pacific halibut (*Hippoglossus stenolepis*) stock assessment. IPHC-2024-SRB024-08. 12 p.

Stewart, I., Hicks, A., Webster, R., and Wilson, D. 2023. Summary of the data, stock assessment, and harvest decision table for Pacific halibut (*Hippoglossus stenolepis*) at the end of 2022. IPHC-2023-AM099-11. 21 p.

Stewart, I.J., and Hamel, O.S. 2014. Bootstrapping of sample sizes for length- or age-composition data used in stock assessments. Canadian Journal of Fisheries and Aquatic Sciences **71**(4): 581-588. doi:10.1139/cjfas-2013-0289.

Thygesen, U.H., Albertsen, C.M., Berg, C.W., Kristensen, K., and Nielsen, A. 2017. Validation of ecological state space models using the Laplace approximation. Environmental and Ecological Statistics **24**(2): 317-339. doi:10.1007/s10651-017-0372-4.

Trijoulet, V., Albertsen, C.M., Kristensen, K., Legault, C.M., Miller, T.J., and Nielsen, A. 2023. Model validation for compositional data in stock assessment models: Calculating residuals with correct properties. Fisheries Research **257**. doi:10.1016/j.fishres.2022.106487.

Webster, R., Stewart, I., Ualesi, K., and Wilson, D. 2024. 2025-27 FISS design evaluation. IPHC-2024-SRB024-06. 24 p.

MSE update on progress in 2024 and development of a revised Harvest Strategy Policy

PREPARED BY: IPHC SECRETARIAT (A. HICKS, I. STEWART, & D. WILSON; 22 AUGUST 2024)

PURPOSE

To provide the Scientific Review Board (SRB) with an update on Management Strategy Evaluation (MSE) progress in 2024 and work supporting the development of the IPHC Harvest Strategy Policy (HSP).

1 INTRODUCTION

A 2024 MSE workplan was provided by the Commission through intersession decisions ID003 to ID007 (IPHC Circular 2024-015). This included investigating a new objective, evaluating management procedures (MPs), defining exceptional circumstances, drafting a harvest strategy policy, and investigating different FISS design scenarios. Many of these tasks were developed from past SRB recommendations, including recommendations related to MSE work made at the 24th session of the SRB (IPHC-2024-SRB024-R).

This document reports progress on these recommendations and how they support the development of a harvest strategy policy.

2 HARVEST STRATEGY POLICY

A Harvest Strategy Policy (HSP) provides a framework for applying a science-based approach to setting harvest levels. At the IPHC, this could be specific to the TCEY for each IPHC Regulatory Area throughout the Convention Area, or it could apply to coastwide decisions, leaving specific allocation among areas and sectors to the decision-making process. Currently, the IPHC has not formally adopted a harvest strategy policy but has set harvest levels under an SPR-based framework with elements adopted at multiple Annual Meetings of the IPHC since 2017.

The MSE work and guidance from the MSAB and SRB have been a very important part of developing the HSP. To move towards formally adopting a HSP at the IPHC in the near term, the SRB recommended separating the coastwide TCEY management procedure (MP) from the distribution procedure.

> **IPHC-2023-SRB023-R, para. 30:** *The SRB **RECOMMENDED** that the Commission consider revising the harvest policy to (i) determine coastwide TCEY via a formal management procedure and (ii) negotiate distribution independently (e.g. during annual meetings). Such separated processes are used in other jurisdictions (e.g. most tuna RFMOs, Mid Atlantic Fishery Management Council, AK Sablefish, etc.).*

The coastwide TCEY determined from the MP in the harvest strategy would be an input into the allocation decision-making process.

Therefore, the IPHC HSP can be divided into two components: management procedure and decision-making (Figure 1). The management procedure is an agreed upon method to determine the coastwide TCEY that best meets all conservation and fishery objectives. The MP must be reproducible and include elements such as how to collect data, how often to conduct a stock assessment, and the fishing intensity (i.e. SPR). A harvest strategy extends the MP to encompass objectives and other procedures such as exceptional circumstances. The harvest strategy policy further includes decision-making, where management may deviate from the outputs of the MP to account for other objectives not considered in the harvest strategy. This may be to modify the coastwide TCEY and/or the distribution of the TCEY to account for economic factors or other current conditions. At the IPHC, the policy component occurs at the Annual Meeting of the IPHC where stakeholder input is considered along with scientific information to determine the coastwide mortality limit and allocations to each IPHC Regulatory Area.

The MSE work presented here supports the continued development of the harvest strategy policy.

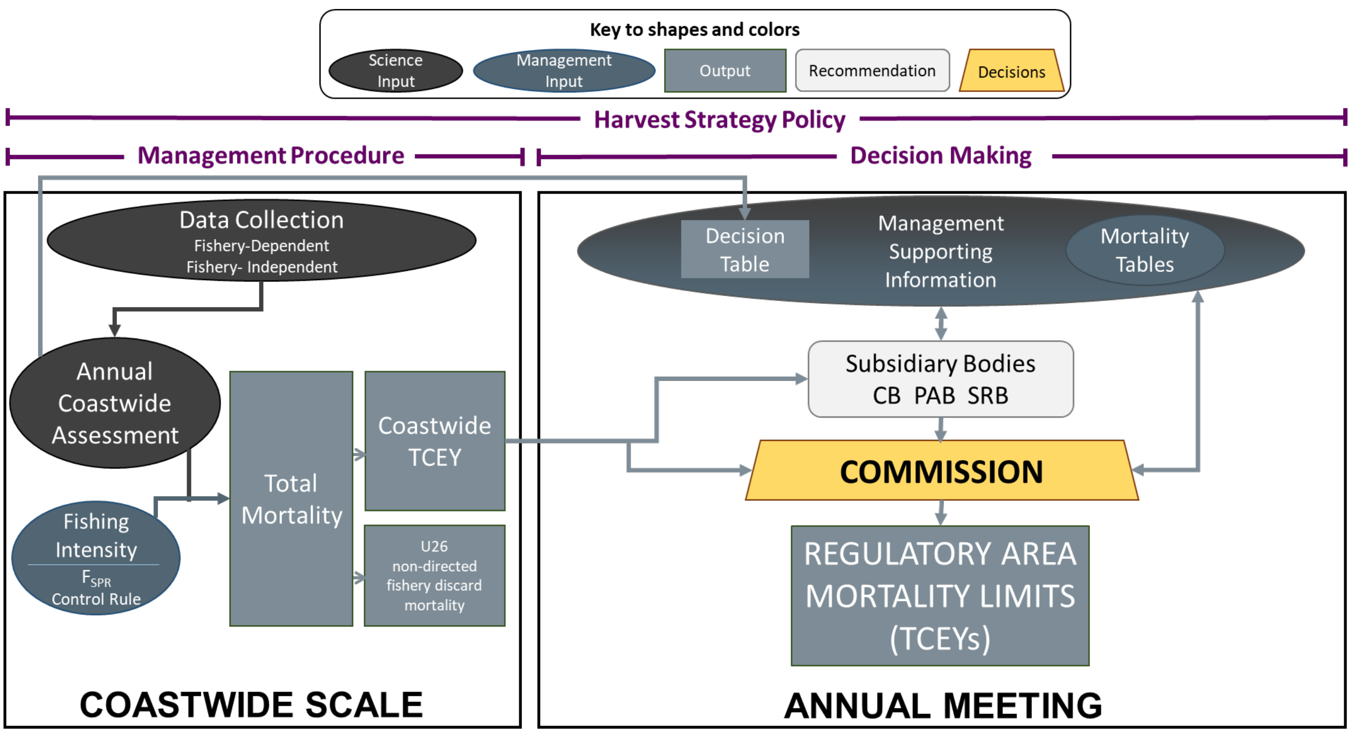


Figure 1. Illustration of the interim harvest strategy policy for the IPHC showing the determination of the coastwide TCEY (the management procedure at the coastwide scale) and the policy component that mainly occurs at the Annual Meeting.

2.1 Exceptional Circumstances

An exceptional circumstance is an event that is beyond the expected range of the MSE. Exceptional circumstances, which trigger specific actions to be taken if one is met, define a process for deviating from an adopted harvest strategy (de Moor, Butterworth, and Johnston 2022). It is important to ensure that the adopted harvest strategy is retained unless there are clear indications that the MSE may not be accurate. The IPHC interim harvest strategy policy (Figure 1) has a decision-making step after the MP, thus the Commission may deviate from an adopted MP as part of the harvest strategy policy. This decision-making variability is included in the MSE simulations.

The IPHC Secretariat, with the assistance of the SRB and MSAB, has defined exceptional circumstances and the response that would be initiated, as well as potential triggers in a management procedure that would result in a stock assessment being done (if time allows) in a year that would normally not have one scheduled (e.g. in multi-year MPs). Triggers for an exceptional circumstance have been updated following further discussions with the SRB.

> **IPHC-2024-SRB024-R, para 25**. ***RECALLING*** *paper IPHC-2024-SRB024-03, Appendix A, SRB023-Rec.08 (para. 27), the SRB* ***RECOMMENDED****:*
>
> > *a) removing “exceptional circumstance” item c because the expected timeline of stock assessments and OM updates will automatically revise biological parameters and processes;*
> >
> > *b) removing “exceptional circumstance” item b because:*
> >
> > > *• even though the operating model is an adequate representation of the coastwide dynamics and is useful for development of a coastwide MP, additional work on the regional stock dynamics needs to be done to improve correspondence with regional observations;*
> > >
> > > *• improving estimation of regional stock dynamics is a longer-term project that the Secretariat will continue to work on with input from the SRB;*
> > >
> > > *• as per paragraph 21, the SRB suggests that the annual TCEY distribution should not be included in a MP.*

Therefore, one trigger, using coastwide WPUE or NPUE, for an exceptional circumstance has been defined.

> *The coastwide all-sizes FISS WPUE or NPUE from the space-time model falls above the 97.5th percentile or below the 2.5th percentile of the simulated FISS index for two or more consecutive years.*

The following actions may take place if an exceptional circumstance is declared.

> *a) A review of the MSE simulations to determine if the OM can be improved and MPs should be reevaluated.*
>
> *b) If a multi-year MP was implemented and an exceptional circumstance occurred in a year without a stock assessment, a stock assessment would be completed as soon as possible along with the re-examination of the MSE.*

c) Consult with the SRB and MSAB to identify why the exceptional circumstance occurred, what can be done to resolve it, and determine a set of MPs to evaluate with an updated OM.

d) Further consult with the SRB and MSAB after simulations are complete to identify whether a new MP is appropriate.

The MSAB was also interested in developing exceptional circumstances using fishery-dependent data.

IPHC-2024-MSAB019-R, para. 53: *The MSAB **NOTED** that the FISS is conducted to measure the population and that it may not be an accurate depiction of the fishery, and that fishery-dependent data may provide insights into fishery concerns that the FISS may not capture.*

IPHC-2024-MSAB019-R, para. 54: *The MSAB **REQUESTED** that the SRB and Secretariat work together to consider different ways to incorporate fishery-dependent data into an exceptional circumstance.*

The MSE simulations predict many types of fishery-dependent data (e.g. WPUE, age-compositions) which may be used to develop additional exceptional circumstances. It will be important to delineate between changes in fishery dependant data that should fall within the scope of the MSE predictions and those that may be caused by management actions not reflective of Pacific halibut stock dynamics (e.g. change in catch rates due to avoidance/targeting of other species). The response in these two cases may be different. Further consideration of exceptional circumstances incorporating fishery-dependent data will continue.

3 Goals and Objectives

The Commission defined four priority coastwide objectives and associated performance metrics for evaluating MSE simulations.

IPHC-2023-AM099-R, para. 76. *The Commission **RECOMMENDED** that for the purpose of a comprehensive and intelligible Harvest Strategy Policy (HSP), four coastwide objectives should be documented within the HSP, in priority order:*

a) Maintain the long-term coastwide female spawning stock biomass above a biomass limit reference point (B20%) at least 95% of the time.

b) Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point (B36%) 50% or more of the time.

c) Optimise average coastwide TCEY.

d) Limit annual changes in the coastwide TCEY.

IPHC-2023-AM099-R, para. 77. *The Commission **AGREED** that the performance metrics associated with the objectives in Paragraph 76 are:*

a) P(RSB): Probability that the long-term Relative Spawning Biomass (RSB) is less than the Relative Spawning Biomass Limit, failing if the value is greater than 0.05.

b) P(RSB<36%): Probability that the long-term RSB is less than the Relative Spawning Biomass Reference Point, failing if the value is greater than 0.50.

c) Median TCEY: the median of the short-term average TCEY over a ten-year period, where the short-term is 4-14 years in the future.

d) Median AAV TCEY: the average annual variability of the short-term TCEY determined as the average difference in the TCEY over a ten-year period.

These priority objectives and performance metrics come from a larger list of objectives which includes objectives specific to Biological Regions and IPHC Regulatory Areas (Appendix A).

In 2024, the SRB recommended reconsidering two of these objectives.

IPHC-2024-SRB024-R, para 22. *The SRB* ***RECOMMENDED*** *that the Commission develop a more specific and quantifiable catch objective to replace Objective c) (from AM099–Rec.02) "Optimize average coastwide TCEY".*

IPHC-2024-SRB024-R, para 23. *The SRB* ***RECOMMENDED*** *that the Commission consider revising Objective b) (from AM099–Rec.02) "Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point (B36%) 50% or more of the time" to utilise a lower percentile than the 50th (median) to reflect concerns associated with the implications of low CPUE for the fishery at the 36% target for relative spawning biomass. A lower percentile better captures the role of uncertainty in this performance measure.*

The 4th ad-hoc meeting of the MSAB met in July to discuss objectives, which is summarized in an informational document for MSAB020 (IPHC-2024-MSAB020-INF01). Some highlights include the following, which will be discussed at MSAB020.

10. A management procedure defined as a reference fishing intensity or more conservative would provide flexibility to the Commission to reduce fishing intensity when short-terms trends are of concern.

12. The objective "optimize yield" may include reducing interannual variability in yield.

13. A new objective may be defined using absolute biomass, commercial catch-rates, or TCEY. However, commercial catch-rates may not be the best option because they are dependent on other factors. TCEY and/or a reference absolute spawning biomass based on what has been observed may be more meaningful, but all have downsides in being a holistic metric. The MSAB should explore these metrics (and possibly FISS WPUE) for use in updating the objectives.

14. Evaluating MPs based on performance of the worst conditions (e.g. low productivity regime) may result in avoiding low stock sizes under any conditions.

15. Objectives, such as avoiding low stock sizes or low catch-rates, may be met by adding elements to the MP, such as reducing fishing intensity when the SB is below a threshold.

17. There is likely a desire to remain above the absolute spawning biomass in 2023 and the tolerance could be 80 or 90%

The 4th ad-hoc meeting of the MSAB discussed the objective "optimize yield" and realized that optimizing yield may include multiple factors such as high yields and low interannual variability. Both of these concepts are important objectives and will be discussed at MSAB020.

Much of the discussion at the 4th ad-hoc meeting of the MSAB centered around understanding the underlying objectives based on recent decisions to reduce the TCEY from the reference TCEY. This is due to a contrast between the stock status being above 36% (a healthy zone) and a continually declining absolute spawning biomass.

Pacific halibut have seen large changes in average weight-at-age and high variability in recruitment, which have changed the stock dynamics considerably. Figure 2 shows the dynamic unfished spawning biomass, the current spawning biomass, and the RSB since 1993. Dynamic unfished spawning biomass is lower than the late 1990's because weight-at-age has decreased considerably, and dynamic unfished spawning biomass has decreased in recent years because of a recent period of low recruitment. The current spawning biomass trajectory (with fishing) has been stable in recent years, resulting in an increasing RSB. Therefore, the Pacific halibut stock is likely to be above the B_{lim} (20%), $B_{trigger}$ (30%), and B_{thresh} (36%) reference points.

However, the coastwide FISS O32 WPUE and coastwide commercial WPUE has been declining in recent years (Figure 3), causing concern about the absolute stock size and fishery catch-rates. The coastwide FISS index of O32 WPUE was at its lowest value observed in the time-series, declining by 3% from the previous year and coastwide commercial WPUE is also at its lowest value in the recent time-series, declining by 10% from the previous year (and likely more as additional logbook information is obtained). In contrast, the stock assessment for 2023 estimates current stock status (42%, Figure 2) above reference levels and a high probability of further decline in spawning biomass at the reference fishing intensity (SPR=43%). The reference coastwide TCEY of 48.9 Mlbs was projected to result in a greater than 70% chance that the spawning biomass in any of the next three years would be less than the spawning biomass in 2023. The long-term average RSB when fishing consistently at an SPR of 43% is estimated to be near 38%.

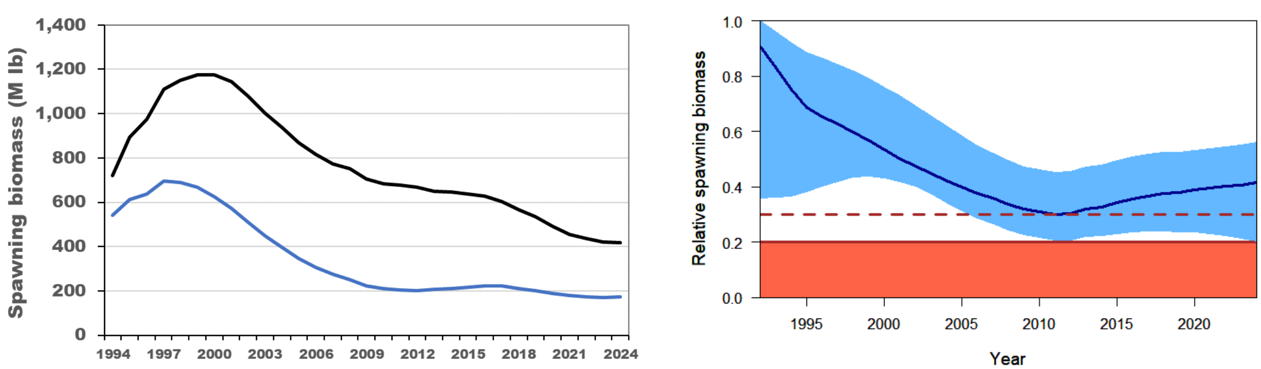


Figure 2. Dynamic unfished spawning biomass (black line) and current spawning biomass (blue line) from the 2023 stock assessment (left) and dynamic relative spawning biomass (right) with an approximate 95% credible interval in light blue and the control rule limit ($B_{20\%}$) and trigger ($B_{30\%}$) in red. Figures from IPHC-2024-SA-01.

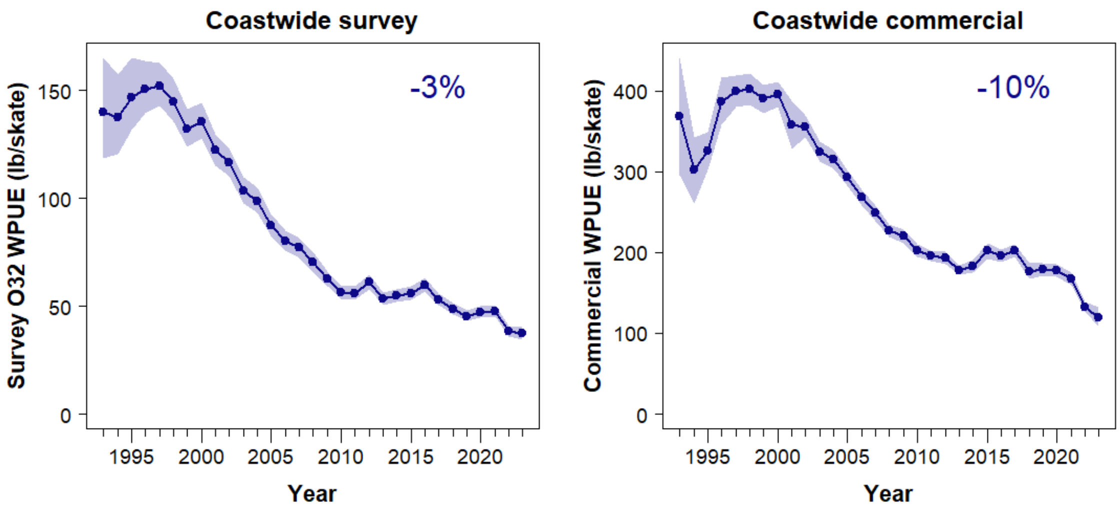


Figure 3. The coastwide FISS O32 WPUE index (left) and coastwide commercial WPUE (right) showing the percent change in the last year (from IPHC-2024-SA-02). Based on past calculations, additional logbooks collected in 2024 will likely further reduce the decline in commercial WPUE to -12%.

Recent Commission decisions (2023 and 2024) have set coastwide TCEYs less than the reference TCEY estimated by the stock assessment and current interim management strategy. Main concerns noted by the Commission include 1) low absolute spawning biomass, 2) low catch-rates in the commercial fishery, 3) high probability of decline in absolute spawning biomass at a fishing mortality above 39 Mlbs, and 4) a large amount of uncertainty in the projections.

The continued departure from the current interim MP and reduction in coastwide TCEY suggests that there may be an additional objective. Related to these concerns, the SRB initially made a recommendation to re-evaluate what they called the target objective (objective b), followed by the recommendation at SRB024 (IPHC-2024-SRB024-R, para 23).

> **IPHC-2023-SRB023-R, para. 25.** *The SRB* ***RECOMMENDED*** *that the Commission re-evaluate the target objective for long-term coastwide female spawning stock biomass given that estimated 2023 female spawning biomass (and associated WPUE), which was well-above the current target B36%, in part triggered harvest rate reductions from the interim harvest policy. Such ad-hoc adjustments limited the value of projections and performance measures from MSE.*

A higher threshold reference point could be achieved with a lower reference fishing intensity or an alternative control rule, such as 40:20. However, instead of updating the $B_{36\%}$ relative spawning biomass objective, it may better reflect recent Commission actions to consider an absolute spawning biomass, or catch-rate, threshold in a new objective.

Clark and Hare (2006) noted that "[t]he Commission's paramount management objective is to maintain a healthy level of spawning biomass, meaning a level above the historical minimum that last occurred in the mid-1970s." Thompson (1937) stated the following:

> *In actual practice, capital is accumulated in order that interest may be secured from it, and an accumulated stock of fish may also be profitable. The most obvious gain is the greater economy of effort in obtaining a catch from a larger accumulated stock. […] It not only means less effort, but also less time at sea before the catch is landed. (William F. Thompson, International Fisheries Commission, 1937)*

An objective to maintain the absolute spawning biomass above a threshold may be a useful objective for several reasons. First, the level of spawning biomass likely correlates with catch-rates in the fishery, and a higher spawning biomass would likely result in a more efficient and economically viable fishery. Second, current priority conservation objectives use dynamic relative spawning biomass which may result in a low absolute spawning biomass with a satisfactory stock status. Third, a minimum absolute coastwide spawning biomass may be necessary to ensure successful reproduction (such a level is currently unknown for Pacific halibut). Lastly, an observed reference stock level may have concrete meaning to stakeholders. For example, the recent estimated spawning biomass may be near or below the lowest spawning biomass estimated since the mid-1970's and observed fishery catch rates were historically low in 2022 and 2023.

One way to implement this new objective is to continue the use of a limit reference point for relative spawning biomass ($SB_{20\%}$) and add a fishery biomass limit reference point for which dropping below would result in serious hardships to the fishery. The fishery biomass limit reference point could be defined using an absolute metric in units of spawning biomass, fishery CPUE, FISS WPUE, or some other estimable quantity. A fishery limit reference point differs importantly from a fishing intensity limit, where the former is a threshold used to maintain catch-rates and the latter is a threshold used to indicate the potential for overfishing. A fishery absolute spawning biomass limit may also add extra protection for the stock by further reducing the probability of breaching existing limit and threshold reference points. A new objective related to fishery performance could be phrased as:

> *Maintain the coastwide female spawning stock biomass (or FISS WPUE or fishery catch-rates) above a threshold.*

The metric, the threshold value, and the tolerance for being below that threshold are not obvious choices. Clark and Hare (2006) used the estimated spawning biomass in 1974, which subsequently produced recruitment resulting in an increase in the stock biomass. However, there is a high uncertainty in the estimates of historical absolute spawning biomass before the 1990's. Recent estimates of spawning biomass may be reasonable as they are relevant to concerns of low catch-rates, but it is unknown how and if the stock will quickly recover from this current state.

If an efficient fishery is the objective, then fishery catch-rates may be a reasonable choice for the same reasons listed above for an absolute level of spawning biomass. A subtle difference between catch-rates and spawning biomass are that catch-rates may increase or decrease due to many factors (e.g. improvements in technology, avoidance of non-target species) without a change in spawning biomass.

The discussion of objectives is on the agenda for the 20th Session of the MSAB, where recommendations for updating the objectives will be made to the Commission. The Secretariat will summarize all recommendations from the MSAB and SRB related to these objectives and present them to the Commission at the 100th Interim Meeting of the IPHC and the 101st Annual Meeting of the IPHC.

4 MANAGEMENT PROCEDURES, METHODS, AND ASSUMPTIONS

The SRB made a recommendation at SRB023, which coincides with MSAB and Commission recommendations, providing guidance on management procedures (MPs) to evaluate. The investigation of these MPs will support the development of the harvest strategy policy.

> **IPHC-2023-SRB023-R, para. 29.** *The SRB **RECOMMENDED** evaluating fishing intensity and frequency of the stock assessment elements of management procedures and FISS uncertainty scenarios using the MSE framework. MP elements related to constraints on the interannual change in the TCEY and calculation of stock distribution may be evaluated for a subset of the priority management procedures as time allows.*

4.1 MP elements

Elements of MPs that were evaluated included assessment frequency, fishing intensity, and constraints on the interannual change in the TCEY.

4.1.1 Assessment frequency and an empirical management procedure

The frequency of conducting the stock assessment is a priority element of the MP to be investigated. This includes conducting assessments annually (every year), biennially (every second year), or triennially (every third year) to determine the status of the Pacific halibut stock and the coastwide TCEY for that year. In years with no assessment, the coastwide TCEY would be determined using a simpler approach and the estimated status of the stock would not be updated.

The mortality limits in a year with a stock assessment can be determined as specified by previous defined MPs (i.e. SPR-based approach), and in years without a stock assessment, the mortality limits would need an alternative approach. There are many different empirical rules that could be applied to determine the coastwide TCEY in non-assessment years and two have been previously identified for evaluation.

a. A multi-year TCEY set constant until a stock assessment is available.
b. Update the coastwide TCEY proportionally to the change in the coastwide FISS O32 WPUE.

Other potential methods to set the TCEY in years without an assessment include, but are not limited to, the following.

c. Update the coastwide TCEY proportionally to the change in the coastwide FISS all-sizes WPUE.
d. Use projected TCEY’s from the stock assessment with the reference SPR and control rule. This method is common among other fisheries management organizations.

e. Incorporate commercial fishery catch-rates into the empirical rule.

The MSAB requested collaboration between the Secretariat and the SRB to develop empirical rule options.

> **IPHC-2024-MSAB019-R, para 40:** ***RECALLING*** *paragraph 39 item a) the MSAB* ***REQUESTED*** *the Secretariat and SRB develop empirical rule options using the following possible sources of data:*
>
> *a) A static coastwide TCEY determined from the stock assessment;*
>
> *b) FISS O32 WPUE;*
>
> *c) Incorporation of commercial and FISS age data with FISS O32 WPUE.*

Another option, currently not being considered, is to use a simple statistical model, tuned to meet the objectives, that would determine the coastwide TCEY. Stock assessments would be completed periodically to update the status of the stock and verify that the management procedure is working appropriately.

4.1.2 Constraints

One of the priority objectives (Appendix A) is to limit annual changes in the coastwide TCEY. Due to variability in many different processes (e.g. population, estimation, and decision making) the interannual variability of the TCEY from MSE simulations is typically higher than 15%. Over the past ten years (2015–2024), the interannual variability (average annual variability or AAV) in the adopted coastwide TCEY was 5.4% and the AAV of the reference coastwide TCEY was 14.5%. Across those years, the percent change in the adopted coastwide TCEY ranged from -10% to 8% and the coastwide reference TCEY ranged from -21% to 29% (Table 1). This was a period of relatively stable spawning biomass and higher variability is expected when the stock is increasing or decreasing.

Decision-making since 2015 has reduced the interannual variability in the coastwide TCEY, compared to the reference. The adopted TCEYs have a smaller range than the reference TCEYs and tend to cluster around 39 million pounds (Figure 4). The adopted TCEYs also tend to be closer to the status quo (i.e. the TCEY from the previous year) than the reference TCEYs when the reference TCEY difference from status quo was not near zero (Table 1 & Figure 4). This is akin to saying the change from one year to the next is less for the adopted TCEYs than the reference TCEYs. The spawning biomass has been relatively stable during the last ten years, and it is not known how the recent decision-making process would react to a rapidly increasing or decreasing spawning biomass. Therefore, decision-making variability was modelled as a gaussian random process in the OM with a fixed standard deviation of 7Mlbs.

This interannual variability in the coastwide reference TCEY can be reduced by adding a constraint in the MP, mimicking the recent decision-making process. The MSAB has suggested many different constraints including a 15% constraint on the change in the coastwide TCEY from one year to the next, and a slow-up/fast-down approach (TCEY increases by one-third of the increase suggested by the unconstrained MP or decreases by one-half of the decrease suggested by the unconstrained MP). The MSAB has requested further investigating constraints on the coastwide TCEY.

Table 1. Percent change in the adopted TCEY from the previous year (2015–2024) for each IPHC Regulatory Area and coastwide, and for the coastwide reference TCEY determined from the interim management procedure in place for that year.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE	Coastwide Adopted	Coastwide Reference
2015	-4.5%	3.5%	13.3%	7.9%	-0.3%	25.6%	2.7%	19.3%	8.1%	6.0%
2016	18.9%	4.2%	5.5%	-1.9%	-8.3%	-0.5%	-10.5%	-4.7%	-0.1%	2.3%
2017	16.7%	1.0%	7.6%	1.6%	16.7%	-7.7%	-2.2%	-5.7%	2.9%	7.7%
2018	-10.2%	-14.7%	-9.9%	-3.2%	-17.8%	-3.3%	-4.5%	-5.7%	-8.7%	-20.7%
2019	25.0%	-3.8%	0.0%	7.7%	-11.3%	11.5%	13.3%	10.5%	3.8%	29.0%
2020	0.0%	0.0%	-7.7%	-9.6%	7.6%	-9.8%	-9.7%	-2.5%	-5.2%	-20.3%
2021	0.0%	2.5%	-0.9%	14.8%	0.0%	17.1%	6.9%	2.1%	6.6%	22.3%
2022	0.0%	8.0%	1.9%	3.9%	25.0%	2.4%	3.6%	3.0%	5.7%	5.7%
2023	0.0%	-10.3%	-1.0%	-17.0%	-5.9%	-17.6%	-6.2%	-6.1%	-10.3%	26.0%
2024	0.0%	-4.6%	-1.0%	-6.0%	-6.0%	-6.9%	-8.1%	-3.9%	-4.6%	-5.9%

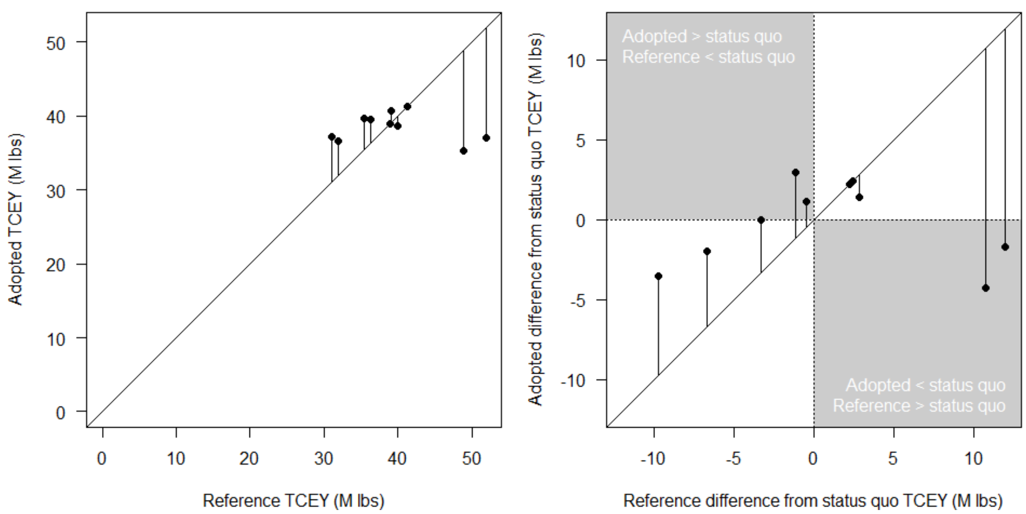


Figure 4. The adopted TCEY vs the reference TCEY (left) and the adopted difference from the status quo TCEY vs the reference difference from the status quo TCEY (right) for the last ten years (2015–2024). The 1:1 line shows when the two are equal. The grey quadrants in the right plot show when the adopted and reference TCEY differences from the status quo are opposite.

Constraints simulated in this round of MSE analyses included the following:

- A maximum 15% change in the coastwide TCEY in either direction from one year to the next.

Additional constraints will be evaluated in the future.

- A maximum 15% change in the coastwide TCEY only when the TCEY is increasing. There is no constraint when the TCEY is decreasing.

- A maximum 20% change in the coastwide TCEY in either direction from one year to the next.

4.1.3 Fishing intensity

The fishing intensity is determined by finding the fishing rate (*F*) that would result in a defined spawning potential ratio (F_{SPR}). Because the fishing rate changes depending on the stock demographics and distribution of yield across fisheries, SPR is a better indicator of fishing intensity and its effect on the stock than a single *F*. A range of SPR values between 35% and 52% (the interim reference SPR is currently 43%) were investigated.

4.1.4 Distribution of the TCEY

The distribution of the TCEY to IPHC Regulatory Areas is a necessary part of the harvest strategy, but is not a part of the management procedure currently being evaluated. Therefore, the distribution of the TCEY is a source of uncertainty in the MSE simulations. In the past, five distribution procedures spanning a range including recent Commission decisions were integrated into the simulations.

For these simulations, we implemented the approach recommended by the SRB.

> **IPHC-2024-SRB024-R, para 24**. ***NOTING*** *that the Operating Model (OM) requires a distribution of harvest across the IPHC Regulatory Areas even though distribution of the TCEY is not a recommended part of the MP, the SRB* ***RECOMMENDED*** *capturing uncertainty in future TCEY distribution via the approach described in IPHC-2024-SRB024-07, where the TCEY is distributed similar to what is done annually as part of the decision table construction process in the stock assessment.*

We used the observed distribution of the TCEY in recent years to define the simulated percentage of TCEY in each IPHC Regulatory Area. For the last six years, the TCEY in IPHC Regulatory Area 2A has been 1.65 M lbs (Table 2). Over the last twelve years, the adopted TCEY in IPHC Regulatory Area 2B has ranged from 17.1% to 20.8% of the coastwide TCEY with the three most recent years equal to 18.3% and no relationship with the coastwide TCEY (Table 3 and Figure 5). The simulated distribution of the TCEY to IPHC Regulatory Areas 2A and 2B was therefore simply 1.65 Mlbs for 2A and a randomly drawn percentage from a triangle distribution with percentages ranging from 17% to 21% for 2B with the mode of the distribution at 18.3%.

The simulated TCEY in IPHC Regulatory Areas in Alaska was distributed after the TCEY had been distributed to IPHC Regulatory Areas 2A and 2B. A year was randomly sampled, and the observed percentages in only Alaskan areas were used (Table 4).

Table 2. Adopted TCEYs (millions of pounds) for each IPHC Regulatory Area from 2013 to 2024.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
2013	1.11	7.78	5.02	17.07	5.87	2.43	1.93	4.28	45.48
2014	1.11	7.64	5.47	12.05	3.73	1.56	1.49	3.58	36.65
2015	1.06	7.91	6.2	13.00	3.72	1.96	1.53	4.27	39.63
2016	1.26	8.24	6.54	12.75	3.41	1.95	1.37	4.07	39.59
2017	1.47	8.32	7.04	12.96	3.98	1.80	1.34	3.84	40.74
2018	1.32	7.10	6.34	12.54	3.27	1.74	1.28	3.62	37.21
2019	1.65	6.83	6.34	13.5	2.90	1.94	1.45	4.00	38.61
2020	1.65	6.83	5.85	12.2	3.12	1.75	1.31	3.9	36.60
2021	1.65	7.00	5.80	14.00	3.12	2.05	1.40	3.98	39.00
2022	1.65	7.56	5.91	14.55	3.90	2.10	1.45	4.10	41.22
2023	1.65	6.78	5.85	12.08	3.67	1.73	1.36	3.85	36.97
2024	1.65	6.47	5.79	11.36	3.45	1.61	1.25	3.7	35.28

Table 3. Adopted percentage of the coastwide TCEY (millions of pounds) for each IPHC Regulatory Area from 2013 to 2024.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE
2013	2.4%	17.1%	11.0%	37.5%	12.9%	5.3%	4.2%	9.4%
2014	3.0%	20.8%	14.9%	32.9%	10.2%	4.3%	4.1%	9.8%
2015	2.7%	20.0%	15.6%	32.8%	9.4%	4.9%	3.9%	10.8%
2016	3.2%	20.8%	16.5%	32.2%	8.6%	4.9%	3.5%	10.3%
2017	3.6%	20.4%	17.3%	31.8%	9.8%	4.4%	3.3%	9.4%
2018	3.5%	19.1%	17.0%	33.7%	8.8%	4.7%	3.4%	9.7%
2019	4.3%	17.7%	16.4%	35.0%	7.5%	5.0%	3.8%	10.4%
2020	4.5%	18.7%	16.0%	33.3%	8.5%	4.8%	3.6%	10.7%
2021	4.2%	17.9%	14.9%	35.9%	8.0%	5.3%	3.6%	10.2%
2022	4.0%	18.3%	14.3%	35.3%	9.5%	5.1%	3.5%	9.9%
2023	4.5%	18.3%	15.8%	32.7%	9.9%	4.7%	3.7%	10.4%
2024	4.7%	18.3%	16.4%	32.2%	9.8%	4.6%	3.5%	10.5%

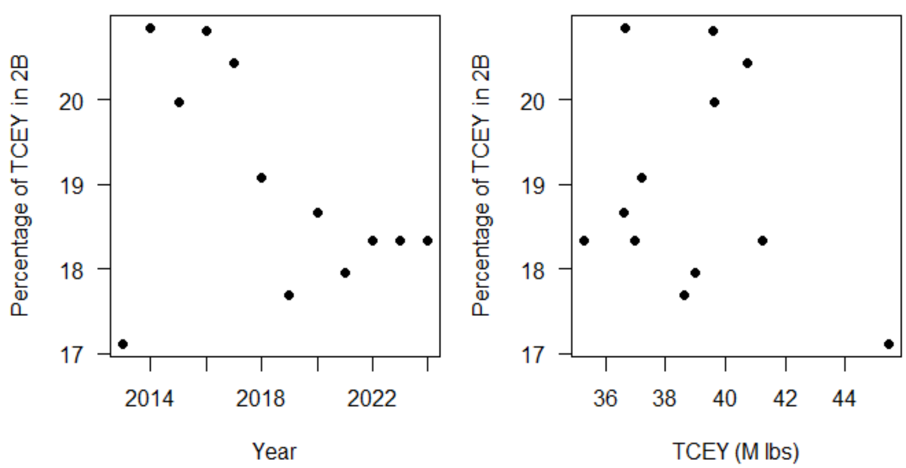


Figure 5. The percentage of the coastwide TCEY in IPHC Regulatory Area 2B plotted against year (left) and the coastwide TCEY (right).

Table 4. Percentage of the adopted TCEY for Alaskan IPHC Regulatory Areas only in each Alaskan IPHC Regulatory Area. IPHC Regulatory Areas 2A and 2B are omitted.

Year	2C	3A	3B	4A	4B	4CDE
2013	13.7%	46.6%	16.0%	6.6%	5.3%	11.7%
2014	19.6%	43.2%	13.4%	5.6%	5.3%	12.8%
2015	20.2%	42.4%	12.1%	6.4%	5.0%	13.9%
2016	21.7%	42.4%	11.3%	6.5%	4.6%	13.5%
2017	22.7%	41.9%	12.9%	5.8%	4.3%	12.4%
2018	22.0%	43.6%	11.4%	6.0%	4.4%	12.6%
2019	21.0%	44.8%	9.6%	6.4%	4.8%	13.3%
2020	20.8%	43.4%	11.1%	6.2%	4.7%	13.9%
2021	19.1%	46.1%	10.3%	6.8%	4.6%	13.1%
2022	18.5%	45.5%	12.2%	6.6%	4.5%	12.8%
2023	20.5%	42.3%	12.9%	6.1%	4.8%	13.5%
2024	21.3%	41.8%	12.7%	5.9%	4.6%	13.6%

4.2 FISS designs

An element of the management procedure that can be evaluated is the collection of data from the FISS. The FISS design was reduced from the proposed scientific designs in 2022, 2023, and 2024 to maintain revenue neutrality and future reductions may be necessary. The SRB made two recommendations to evaluate FISS designs using the MSE framework:

> **IPHC-2024-SRB024-R, para** 35. *The SRB **REQUESTED** that the Secretariat present preliminary (at SRB025) and final (at SRB026) results of MSE runs with different FISS designs to better understand the actual net cost of the survey after accounting for potential reductions in TCEY associated with the increased uncertainty from reduced FISS designs.*

> **IPHC-2024-SRB024-R, para** 43. *The SRB **REQUESTED** that the Secretariat integrate FISS design considerations into the annual MSE workplan and 5-Year Program of Integrated Research and Monitoring to better quantify the value provided by the FISS.*

There are three sources of variability and uncertainty in the simulations, all of which may be affected by the FISS design.

- **FISS uncertainty** affects the estimates of FISS WPUE and NPUE directly. This is used in the empirical rule and affects the stock assessment estimates. It may have some feedback into decision-making variability.
- **Estimation error** is from the stock assessment and is influenced by FISS uncertainty. Estimation error is also influenced by the variability in the population and fishery-dependent data.
- **Decision-making variability** is the variability resulting from decisions made by the Commission to depart from the MP. This could be affected by bias in the FISS and assessment estimates because the Commission may respond similarly based on the trends they perceive (e.g. autocorrelation in the deviations from the MP). It is possible to correlate decision-making with the FISS estimate, but this may mimic a control rule (i.e. element of the MP) and would conflate the estimation error with the decision-making

variability, possibly making performance metrics, such as the probability that the spawning biomass is less than the 2023 spawning biomass, less meaningful. FISS uncertainty is not currently modelled with an effect on decision-making variability.

The MSE framework is capable of examining FISS designs, given the necessary inputs. Projections of estimated uncertainty of FISS O32 WPUE (see document IPHC-2024-SRB024-06) and simulations investigating the outcomes of the stock assessment given different FISS design assumptions (see IPHC-2024-SRB025-06) informed the inputs to the MSE simulations. Unlike the stock assessment simulations, where specific trends in the population are investigated, the MSE simulations have emergent trends influencing uncertainty and bias.

Four FISS designs were simulated, representing increasing observation and assessment error (Table 5). A few simulations assuming no observation error were also included for comparison. The Base FISS design represents an ideal sampling approach with a random selection of stations occurring in all areas. The Base Block FISS design includes sampling in all Biological Regions and IPHC Regulatory Areas each year. It relies on a rotating selection of entire charter regions where individual charter regions are sampled every 1-5 years. The Core FISS design samples charter regions in IPHC Regulatory Areas 2B, 2C, 3A, and 3B every year and other areas are not surveyed. The Reduced Core FISS design samples a subset of higher catch-rate charter regions in areas 2B, 2C, 3A, and 3B. Bias is expected in the Core and Reduced Core FISS designs because some areas are not surveyed. It would not be expected that either of these core designs would be implemented in perpetuity without occasionally surveying other areas.

Table 5. Assumptions of observation and estimation error for four FISS designs.

FISS Design	Frequency	Coastwide WPUE CV	Coastwide WPUE Bias	Assessment Uncertainty	Assessment Bias
Base	Every year	3%	None	15%	None
Base Block	Every year	4%	None	18%	None
Core	2-4 years	6%	Increases annually up to 3%	19%	Increases annually up to 2%
Reduced Core	2-4 years	8%	Increases annually up to 4%	20%	Increases annually up to 2.5%

The Core FISS and Reduced Core FISS designs have additional details in how bias is modelled. Bias is additive depending on the trend in spawning biomass, and is halved when a survey is done on non-core areas. When the spawning biomass is large, the survey is more likely to be revenue neutral increasing the ability to survey non-core areas.

Core FISS design

- Frequency
  - When the spawning biomass is less than the spawning biomass in 2020 other areas are surveyed every 5th year and bias is reduced by one-half.
  - When the spawning biomass is greater than the spawning biomass in 2020 other areas are surveyed every 3rd year and bias is reduced by one-half.
- FISS bias
  - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas:
    - 0-5%: ±0.5% bias added to current bias. Sign chosen randomly.
    - 5-15%: annual increase of 1% bias opposite direction of trend
    - 15-30%: annual increase of 2% bias opposite direction of trend
    - >30%: annual increase of 3% bias opposite direction of trend

- Assessment bias
  - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas:
    - 0-5%: ±0.25% bias added to current bias. Sign chosen randomly.
    - 5-15%: annual increase of 0.5% bias opposite direction of trend
    - 15-30%: annual increase of 1% bias opposite direction of trend
    - >30%: annual increase of 2% bias opposite direction of trend

Reduced Core FISS design

- Frequency
  - When the spawning biomass is less than the spawning biomass in 2020 other areas are surveyed every 5th year and bias is reduced by one-half.
  - When the spawning biomass is greater than the spawning biomass in 2020 other areas are surveyed every 3rd year and bias is reduced by one-half.
- FISS bias
  - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas
    - 0-5%: ±0.5% bias added to current bias. Sign chosen randomly.
    - 5-15%: annual increase of 2% bias opposite direction of trend
    - 15-30%: annual increase of 3% bias opposite direction of trend
    - >30%: annual increase of 4% bias opposite direction of trend
- Assessment bias
  - Bias depends on recent 3-year coastwide trend and the number of years without a block design surveying non-core areas
    - 0-5%: ±0.25% bias added to current bias. Sign chosen randomly.
    - 5-15%: annual increase of 0.75% bias opposite direction of trend
    - 15-30%: annual increase of 1.5% bias opposite direction of trend
    - >30%: annual increase of 2.5% bias opposite direction of trend

The MSE analysis of FISS designs will not capture the stakeholder perception and possible lack of confidence in the FISS as a tool for management. FISS observations have been important for the stock assessment, distribution of the TCEY, general understanding of the trends in each IPHC Regulatory Area, and in negotiations of the coastwide and area-specific TCEYs.

4.3 Depensation

The Pacific halibut population has shown a high amount of variability in spawning biomass over 100 years of commercial fishing, sometimes increasing to high levels quickly after a low period. However, if a population experiences a very low number of spawners, it may have reduced reproductive success. Depensation occurs if the per-capita rate of growth decreases as the density or abundance decreases to low levels (Liermann and Hilborn 2001). In other words, it is inverse density dependence at low population sizes and is also referred to as the Allee effect (Dennis 2002).

There are many mechanisms that may result in depensation (Liermann and Hilborn 2001), such as increased adult mortality observed in Northwest Atlantic cod (*Gadus morhua*) stocks (Kuparinen and Hutchings 2014). It is not known if Pacific halibut may experience depensation, but MSE is a useful tool to examine the effects on the population and management outcomes if depensation was present. The SRB recommended examining the effects of possible depensation in the Pacific halibut stock using the MSE framework.

> **IPHC-2024-SRB024-R, para** 29. *The SRB* ***NOTED*** *the analysis of depensation presented in paper IPHC-2024-SRB024-07, and* ***RECOMMENDED****:*
>
> *a) fitting a depensatory stock-recruitment model to estimate the depensation parameter value;*
>
> *b) operating model stress tests in the MSE with and without depensation across a range of plausible fishing intensities.*

The stock-recruitment elements of the operating model were updated to allow for a depensation parameter following Liermann and Hilborn (1997).

$$R_t = \frac{\alpha S^{\delta}}{\beta^{\delta} + S_t^{\delta}}$$

where R_t is the number of recruits at time t, S_t is the spawning biomass at time t, α is the maximum number of predicted recruits (asymptote), β is the level of spawners that produces $\alpha/2$ recruits, and δ is the depensation parameter. A value greater than 1 for δ indicates depensation. The Pacific halibut stock assessment (and many other stock assessments from around the world) use the steepness parameterization (Mace and Doonan 1998) and use steepness, R_0, and B_0 to calculate the α and β parameters. The derived parameter B_0 is a function of R_0 and other life-history parameters.

$$\alpha = \frac{\left(5^{\delta} - 1\right)R_0 h}{5^{\delta}h - 1}$$

$$\beta^{\delta} = \frac{B_0^{\delta}(1 - h)}{5^{\delta}h - 1}$$

An example Beverton-Holt stock-recruit curve is shown in Figure 6 with these various parameters and concepts labeled.

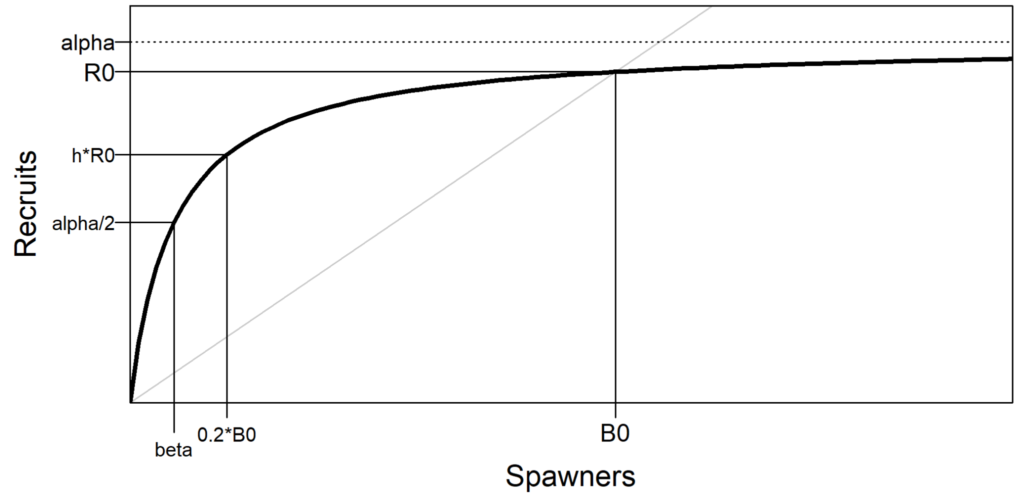


Figure 6. An example Beverton-Holt stock-recruit curve with various parameters and concepts labeled.

Environmental effects may change R_0, which changes the stock-recruit curve. For example, the Pacific halibut stock assessment assumes a steepness of 0.75 and estimates R_0 (and thus B_0) for two different environmental regimes related to periods of low or high Pacific Decadal Oscillation (PDO). Therefore, in each regime, the α and β parameters would be different resulting in different stock-recruit relationships, which should be accounted for in the calculation of recruitment. Figure 7 shows the estimated Beverton-Holt stock-recruit curves for the two regimes within the two 'long' models of the Pacific halibut stock assessment ensemble.

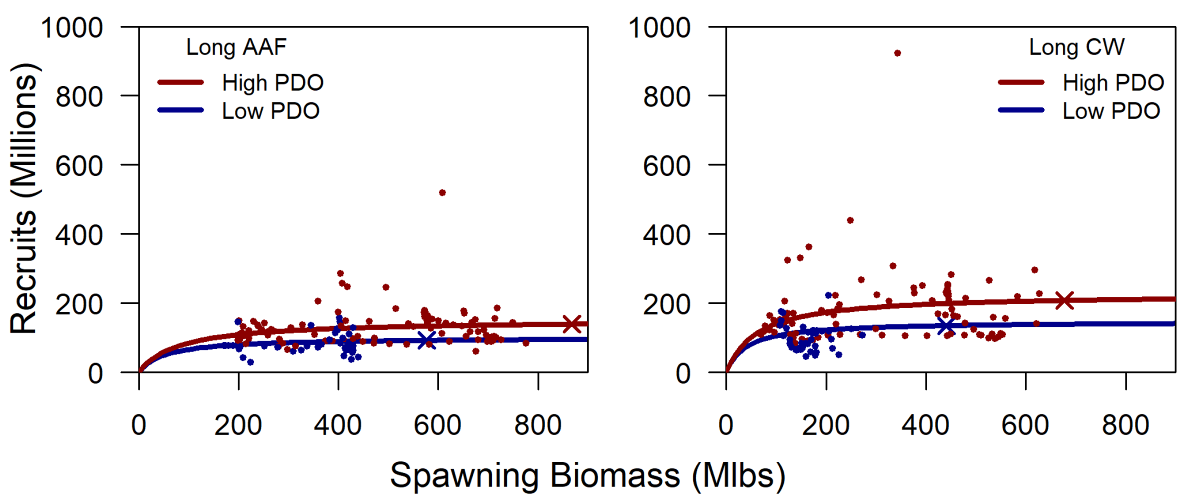


Figure 7. Beverton-Holt stock-recruit curves for two regimes as estimated in the two long models of the stock assessment ensemble. Points are estimated recruits at spawning biomass and the Xs mark the unfished equilibrium R_0 and B_0.

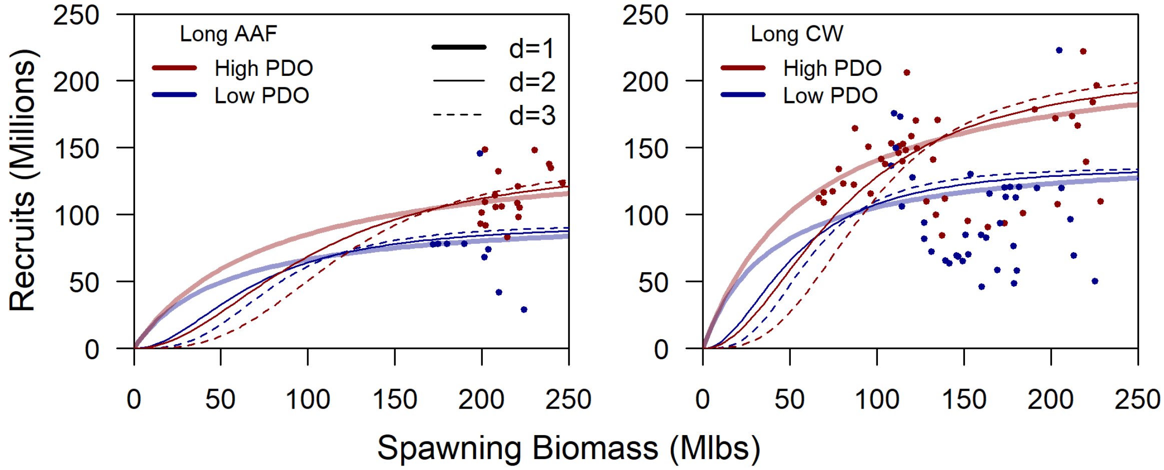


Figure 8. Beverton-Holt stock-recruit curves for the two regimes as estimated in the two long models of the stock assessment ensemble with three different values for depensation. Points are estimated recruits at spawning biomass. Axes have been truncated to focus on the change in the curve at low spawning biomass.

Using the above formulation, depensation with δ at values greater than 1 shows a steepening of the curve at low spawning biomass with a resulting increase in recruits above the curve to meet the consistent R_0.

Estimates of recruitment and estimates of spawning biomass from the two 'long' models in the 2023 stock assessment ensemble were treated as data in a Beverton-Holt stock-recruit model to estimate three parameters, including depensation. The independent and dependent 'observations' (i.e. stock assessment outputs) are both subject to uncertainty, but spawning biomass was treated as a known (i.e. independent) variable in this analysis.

For each long model (LongAAF and LongCW) three analyses were done: 1) all data were combined into a single analysis to estimate the stock-recruit parameters, 2) only recruits and spawning biomass from years with a positive PDO were used, and 3) only recruits and spawning biomass from years with a negative PDO were used. For each analysis, the set of parameters that minimized the lognormal likelihood of observed and predicted recruitment were found using 'optim' in R. A likelihood profile of the depensation parameter determined the 95% confidence interval as the values of δ that produced a likelihood that was 1.92 units away from the minimum.

From the investigation of depensation (results reported below) MSE simulations were done using two levels of depensation, three fishing intensities, and the base block FISS design (Table 6). The average recruitment changed with regime, but the α and β parameters in the stock-recruit relationship were not updated for each recruitment regime (to be consistent with the conditioned OM models). Recruitment was calculated as follows in the OM.

$$R_{s|t} \quad = \quad p_s \times f(B^{sp}_{s=1}) \times e^{(\varepsilon_t - b_t \frac{\sigma_R^2}{2})} \times e^{I_t \gamma} \tag{1}$$

where p_s is the proportion of sex s (0.50), $f(B^{sp}_{s=1})$ is the equilibrium stock-recruit relationship using α and β parameters determined from the low PDO average recruitment and the beginning of the current time-step spawning biomass (superscripts) for females, e^{ε_t} is the annual deviation in recruitment for time-step t, b_t is a bias-correction multiplier for time-step t (Methot and Taylor

2011), and $e^{I_t \gamma}$ is an overall adjustment for changes in recruitment due to regime shifts. Improvements to the stock-recruit modelling with different environmental regimes is expected in the future.

Furthermore, introducing depensation to the operating models changes the stock-recruit function and recruitment deviations without depensation would not necessarily match with recruitment deviations estimated with depensation. Models, however, were not reconditioned by incorporating depensation.

Table 6. Specifications of MSE simulations investigating depensation.

Parameter	Values
Depensation (δ)	δ = 1 or 2
SPR	35%, 43%, 52%
FISS design	Base block

The spawning biomass of Pacific halibut is currently at low values and may be at the lowest values observed historically. However, stock status remains above 30% and the spawning biomass of Pacific halibut has likely remained above levels where depensation can be detected, if present. Therefore, parameterizing depensation in the MSE simulations is largely a theoretical exercise to conduct a “stress-test” and show the potential effects if present.

4.4 Summary of MSE simulations

The Base Block FISS design was used to compare other elements of the MPs such as assessment frequency, constraints, and depensation (Table 7). Assessment frequencies of annual, biennial, and triennial were simulated with an empirical rule proportional to FISS O32 WPUE. No constraint was contrasted with a constraint on the coastwide TCEY of 15% in both directions (15% u). A depensation level of 2 was contrasted over three fishing intensities.

Table 7. MSE simulations using the Base Block FISS design and decision-making variability.

Empirical Rule		Proportional to FISS O32			NA	NA	NA
Depensation		None			None	None	δ=2
Constraint		None			15% u/d	15% u	None
Assessment		Annual	Biennial	Triennial	Annual	Annual	Annual
SPR	35						
	40						
	43						
	46						
	49						
	52						

Simulations with the Core and Reduced Core FISS designs were done with only the annual assessment frequency and four levels of fishing intensity from 43% to 52%. Simulations using the Base FISS design and simulations without estimation, observation, and decision-making variability were done only with a fishing intensity of 43%.

5 RESULTS

5.1 Evaluating MP elements

Assessment frequency, different fishing intensities (SPR), and a constraint were simulated assuming a Base Block FISS design with estimation error and decision-making variability. Performance metrics associated with the four priority objectives are shown in Table 8. The probability of being below a relative spawning biomass (RSB) of 36% was similar for each assessment frequency at the same fishing intensity, and an SPR of 40% resulted in an RSB near 36%. The short-term median TCEY was increase and the AAV decreased as the assessment frequency increased; this is opposite of the expected pattern that a greater TCEY results in a higher AAV. The AAV was lowest with the triennial assessment frequency, but was greater than 15% (a past benchmark defined by the MSAB) for all fishing intensities and assessment frequencies. For the annual and biennial assessment frequencies, the AAV was lowest (but above 22%) for a fishing intensity of 46% and increased with lower and higher fishing intensities. This may be a consequence of how decision-making variability was modelled (i.e. constant standard deviation).

Results with no observation error, no estimation error, and no decision-making variability show a slightly higher median TCEY and a much lower AAV (Table 9). Some variability remains in the interannual change in the TCEY due to the annual assessment tracking changes in the population. However, the AAV was near 12% for the biennial and triennial assessment frequencies because the TCEY is proportional to the FISS O32 WPUE which is a different demographic of the population than is tracked using SPR, and when the assessment occurred it resulted in a large correction to maintain the SPR. Using all sizes FISS WPUE may result in a reduced AAV for biennial and triennial assessment frequencies.

Table 8. Performance metrics associated with priority objectives for various fishing intensities (SPR) and an annual, biennial, or triennial assessment with an empirical rule proportional to FISS O32 WPUE used to determine the TCEY in non-assessment years. All simulations assumed the Base Block FISS design, estimation error, and decision-making variability. No constraints are applied to the interannual change in the TCEY. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

Assessment Frequency			**Annual**		
SPR	**40**	**43**	**46**	**49**	**52**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.4534	0.2466	0.0896	0.0144	0.0012
Median TCEY	64.26	60.11	56.08	52.03	47.87
AAV	25.3%	24.2%	23.5%	23.5%	23.7%
Assessment Frequency			**Biennial**		
SPR	**40**	**43**	**46**	**49**	**52**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.4638	0.2912	0.1294	0.0400	0.0066
Median TCEY	64.96	60.38	56.28	52.27	48.17
AAV	23.3%	22.6%	22.5%	22.8%	23.5%
Assessment Frequency			**Triennial**		
SPR	**40**	**43**	**46**	**49**	**52**

P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.4624	0.2634	0.1198	0.0362	0.0036
Median TCEY	64.93	61.00	56.66	52.53	48.63
AAV	18.0%	17.2%	16.7%	16.2%	15.9%

Table 9. Performance metrics associated with priority objectives for an SPR of 43% and an annual, biennial, or triennial assessment with an empirical rule proportional to FISS O32 WPUE used to determine the TCEY in non-assessment years. All simulations assumed **no observation error**, **no estimation error**, and **no decision-making variability**. No constraints are applied to the interannual change in the TCEY. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

Assessment Frequency	Annual	Biennial	Triennial
P(RSB<20%)	<0.002	<0.002	<0.002
P(RSB<36%)	0.2438	0.2534	0.2652
Median TCEY	60.34	61.08	61.69
AAV	6.2%	11.5%	12.0%

Including a constraint of 15% when the TCEY goes up or down in the MP reduced the AAV, but the AAV remained above 15% with decision-making variability (Table 10). With a constraint, the median TCEY was less, resulting in a smaller probability of the RSB being less than 36%. The 15% constraint resulted in a lower potential range of TCEYs with the 5th percentile of the TCEY as low as 14.7 M lbs (Figure 9).

Table 10. Performance metrics associated with priority objectives for an SPR of 43%, an annual assessment with and without a 15% constraint on the change in the TCEY, and with and without decision-making variability. All simulations assumed the Base Block FISS design. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

Decision-making variability	No	No	Yes	Yes
Constraint	**None**	**15%**	**None**	**15%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2420	0.0564	0.2466	0.0506
Median TCEY	59.92	52.30	60.11	49.51
AAV	20.8%	14.5%	24.2%	16.6%

Overall, the range of SPR values investigated and the three assessment frequencies met the conservation objective and the objective to remain above an RSB of 36% at least 50% of the time. The TCEY increased with higher fishing intensity and was slightly higher with a longer interval between assessments. The interannual variability in the TCEY was greater than 15% but lowest with a triennial assessment frequency. AAV decreased with decreasing fishing intensity when the assessment frequency was every third year.

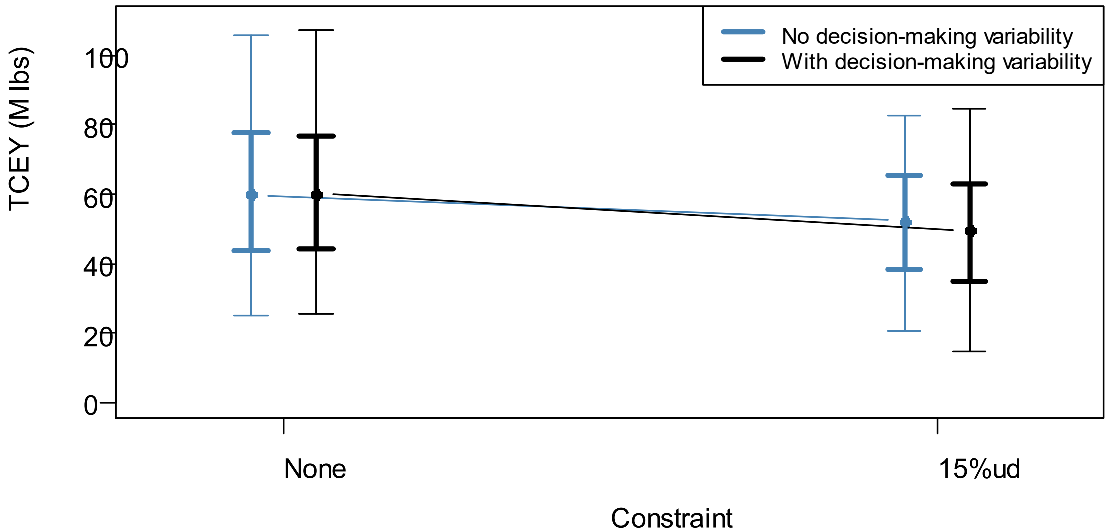


Figure 9. The TCEY (M lbs) for simulations with and without a constraint (15% maximum change up or down) and with and without decision-making variability. All simulations assumed the Base Block FISS design, an annual assessment, and an SPR of 43%. Light whiskers show the 5-95% interval, dark whiskers the 25-75% interval and the dot the median.

5.2 FISS Designs

The three FISS designs were compared across multiple fishing intensities, but with the annual assessment frequency only. Decision-making variability was present in all simulations.

The conservation objective of remaining above an RSB of 20% was met for all fishing intensities and FISS designs (Table 11). The probability that the RSB was less than 36% decreased with the reduced FISS designs, indicating that the population size was slightly larger when the non-core areas were not sampled. This occurred because the median TCEY was less when using the Core FISS design compared to the Base Block FISS design, and was less again when using the Reduced Core FISS design compared to the Core FISS design. The AAV increased with the Core and Reduced Core FISS designs (Figure 10).

With an SPR of 43%, the median TCEY declined by 450,000 lbs moving to the Core FISS design from the Base Block FISS design, and another 450,000 lbs moving to the Reduced Core FISS design. At $6.00/lb, a 450,000 lb drop in the TCEY would equate to a $2.7 million reduction in economic value. A similar drop occurred for an SPR of 52%. This metric includes the long-term, multi-year result where a reduction in the TCEY may provide fish for future years to spawn or be caught at a larger size. This may be why this value is less than the value determined from the stock assessment simulation results reported in document IPHC-2024-SRB025-06. As also discussed in document IPHC-2024-SRB025-06, there is a non-economic value to the FISS in that it is used for decision-making, comparisons, and to have a better understanding of the population trends.

Table 11. Performance metrics associated with priority objectives for various fishing intensities (SPR) and different FISS designs. All simulations assumed an annual assessment and decision-making variability. No constraints were applied to the interannual change in the TCEY. Relative spawning biomass (RSB) performance metrics are long-term and yield based performance metrics (TCEY and AAV) are short-term metrics.

FISS design	**Base Block**			
SPR	**43%**	**46%**	**49%**	**52%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2466	0.0896	0.0144	0.0012
Median TCEY	60.11	56.08	52.03	47.87
AAV	24.2%	23.5%	23.5%	23.7%
FISS design	**Core**			
SPR	**43%**	**46%**	**49%**	**52%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2308	0.0856	0.0164	0.0010
Median TCEY	59.66	55.30	51.23	47.32
AAV	24.9%	24.0%	24.0%	24.4%
FISS design	**Reduced Core**			
SPR	**43%**	**46%**	**49%**	**52%**
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.2256	0.0860	0.0180	0.0012
Median TCEY	59.21	55.10	50.88	47.07
AAV	26.4%	25.5%	25.0%	25.3%

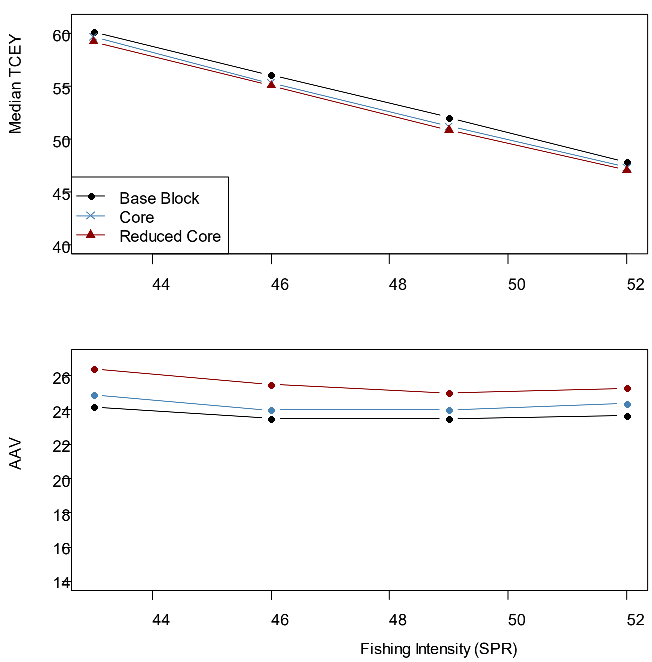


Figure 10. Median TCEY (top) and AAV (bottom) for different fishing intensities (SPR) and FISS designs.

5.3 Depensation Stress Test

The results of estimating the amount of depensation for Pacific halibut are presented first. This is followed by an evaluation of the simulations without depensation and with a depensation level of 2.

5.3.1 Estimates of depensation in the Pacific halibut population

The long areas-as-fleets model (AAF), with all years, showed a nearly linear increase in the number of recruits with increasing spawning biomass (Figure 11). The range of spawning biomass was from 172 Mlbs to 776 Mlbs. The point estimate for depensation was 0.35 and the confidence interval ranged from 0.22 to 1.75 (Table 12). The observations associated with a positive PDO showed depensation with an estimated point value of 4.49 and a 95% confidence interval from 1.35 to 20.85 (Table 12 & Figure 12). Observations associated with a positive PDO showed little difference in likelihood across a wide range of values of δ (Table 12 & Figure 12).

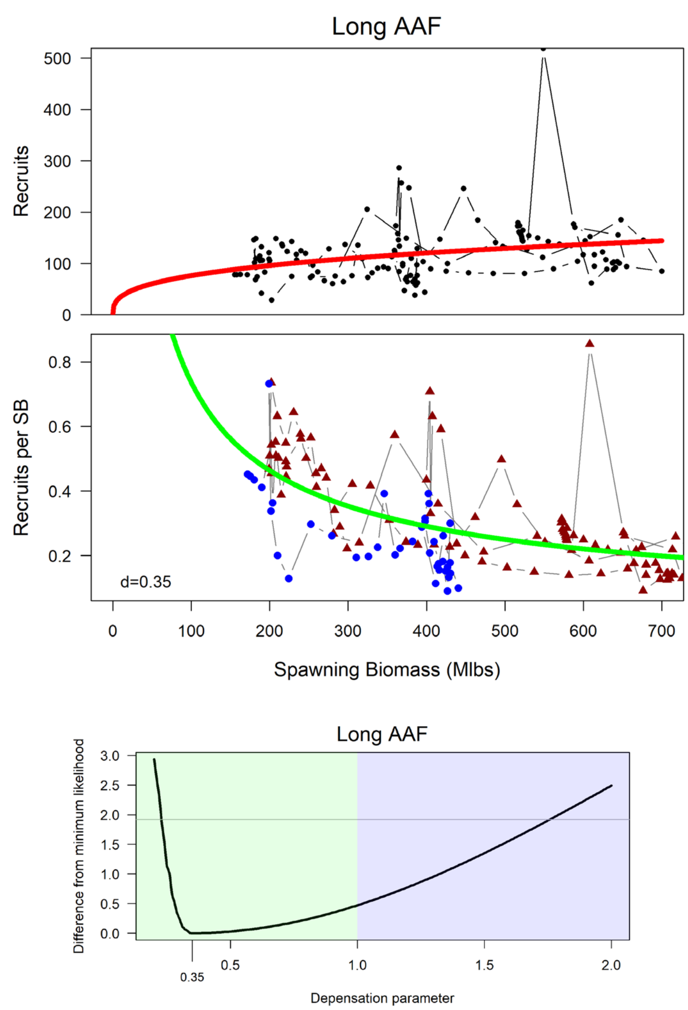


Figure 11. Fitted stock-recruit curve with a depensation parameter when using all observations from the LongAAF model (top plots). The likelihood profile for the depensation parameter with the 95% significance level shown as a dotted horizontal line (bottom plot).

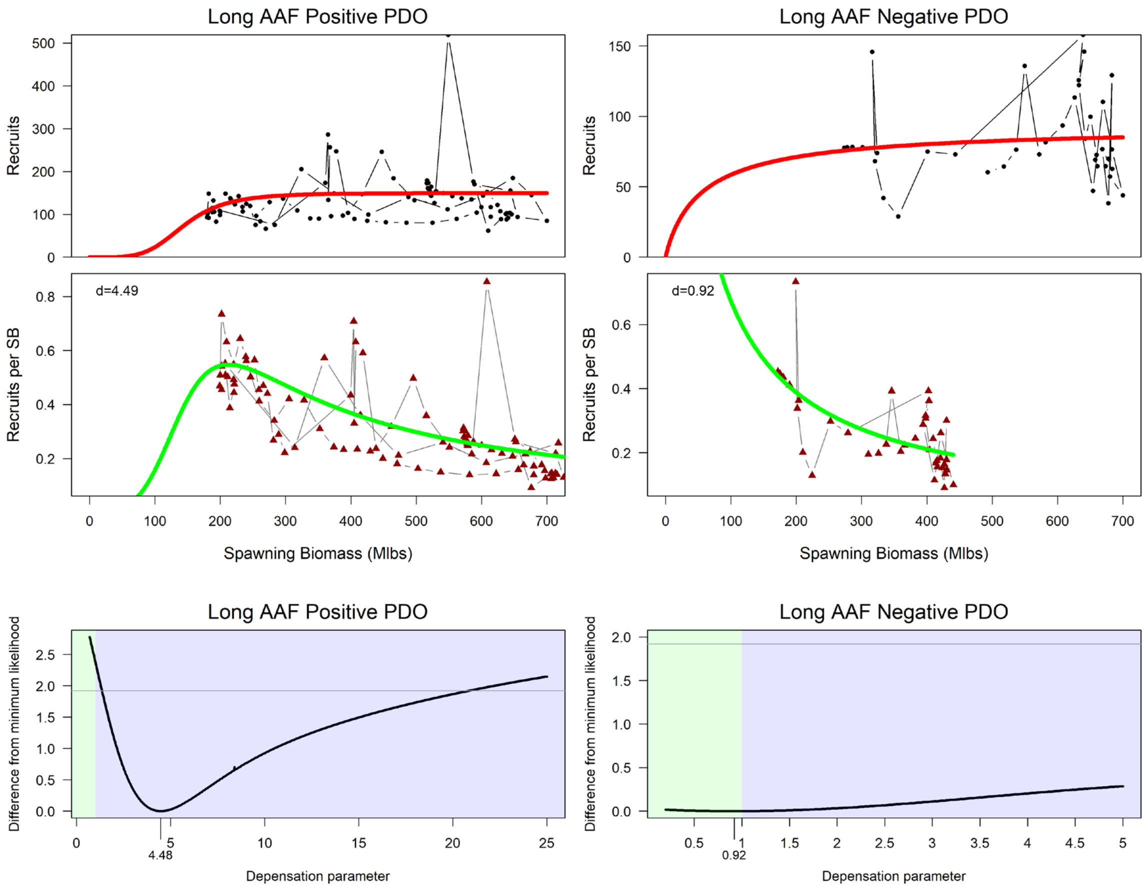


Figure 12. Fitted stock-recruit curve with a depensation parameter when using the high PDO observations (left) or negative PDO (right) observations from the longAAF model (top plots). The likelihood profile for the depensation parameter for the same PDO regimes with the 95% significance level shown as a dotted horizontal line (bottom plots).

Results from the long coastwide model (LongCW) also showed a low estimate of the δ parameter (0.36) when using all of the data (Table 12). However, unlike the longAAF results, the confidence interval for the longCW model with all data did not span 1.0 (Figure 13). Observations from the positive PDO showed potential depensation with a 95% confidence interval for δ ranging from 0.7 to 9.43 (Figure 14). When using only observations associated with the negative PDO, the β parameter was estimated at a negative value. This is not theoretically impossible, and implies less decline in recruits with spawning biomass. However, given this formulation of the Beverton-Holt stock recruit function, a negative β causes NA values when raising it to a non-integer value, and changes the sign when raising it to an even integer value, resulting in a sawtooth pattern in the likelihood profile (see Figure 14). Assuming that δ can only be odd integer values shows a high amount of depensation. This occurs to fit the steep decline in recruitment as low spawning biomass declines (which may be more indicative of a Ricker shaped stock-recruit curve). Regardless, there are few observations at low spawning biomass from a negative PDO phase to inform a stock-recruit-curve, especially with depensation.

Table 12. Estimated depensation parameter for the LongAAF and LongCW model observations combined or separated by PDO regime. The lower and upper 95% confidence interval determined from the likelihood profile is also shown (An NA indicates that the confidence limit could not be determined over the range tested).

Model	Data	Depensation (δ)	Lower	Upper
Long AAF	All	0.35	0.22	1.75
	Positive PDO	4.49	1.35	20.85
	Negative PDO	0.92	NA	NA
Long CW	All	0.36	0.24	0.81
	Positive PDO	2.9	0.70	9.43
	Negative PDO	13	5	29

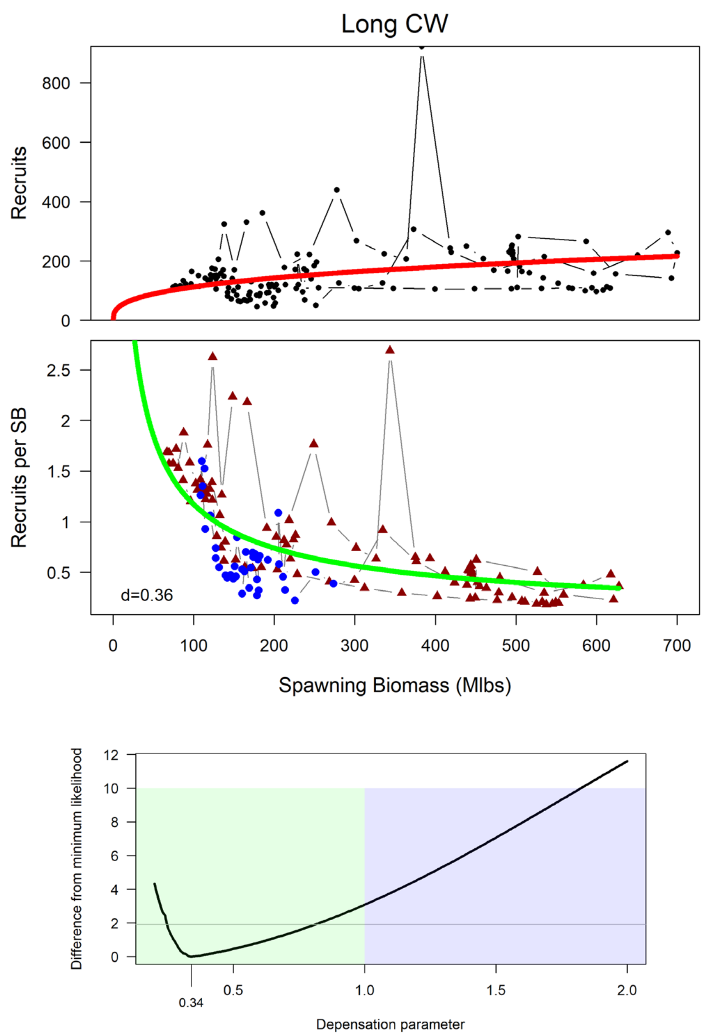


Figure 13. Fitted stock-recruit curve with a depensation parameter when using all observations from the Long CW model (top plots). The likelihood profile for the depensation parameter with the 95% significance level shown as a dotted horizontal line (bottom plot).

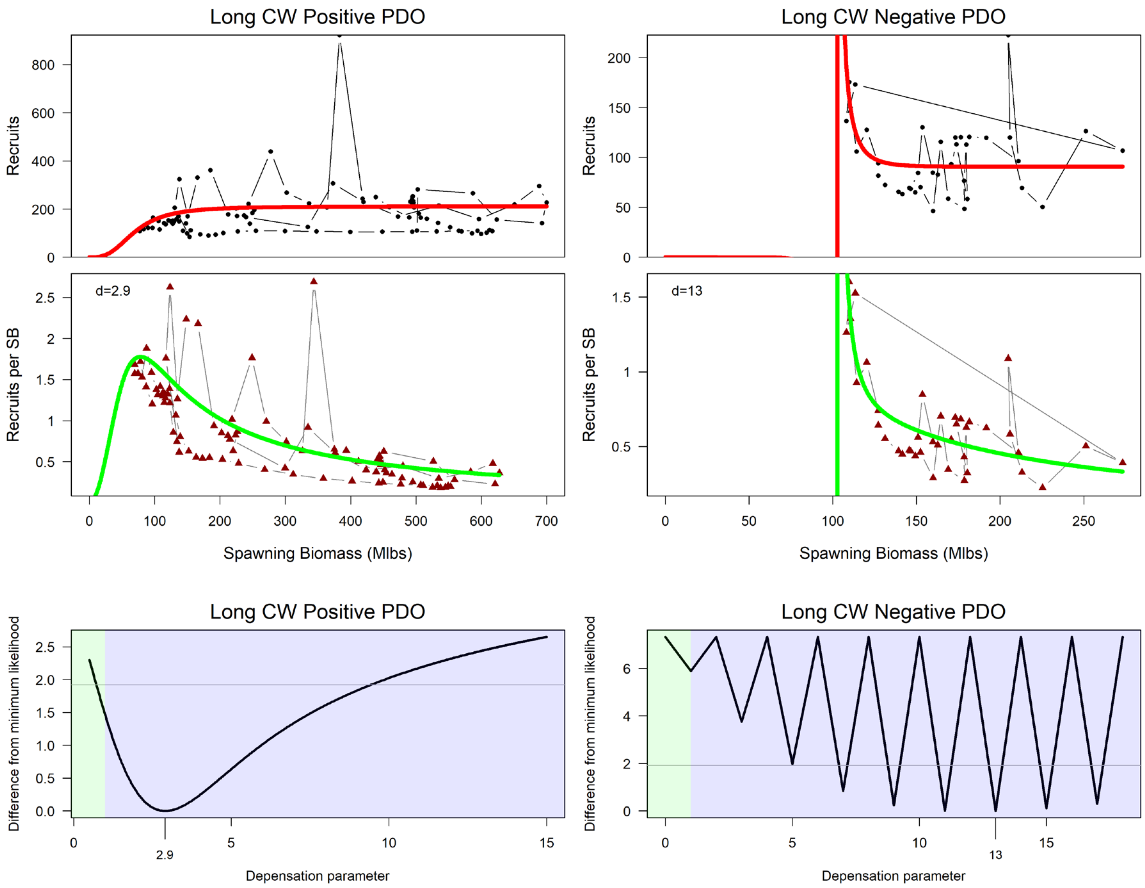


Figure 14. Fitted stock-recruit curve with a depensation parameter when using the high PDO observations (left) or negative PDO (right) observations from the Long CW model (top plots). The likelihood profile for the depensation parameter for the same PDO regimes with the 95% significance level shown as a dotted horizontal line (bottom plots).

From these results, there is not a clear indication of depensation over the observed range of spawning biomass and the value of δ is highly uncertain. Analyzing only recruits from high PDO years showed potential depensation, but was uncertain. Low PDO years had fewer observations, especially at low spawning biomass. The uncertainty in the estimate of depensation is due to variable recruitment and the lack of observations at low spawning biomass.

The purpose of this analysis was to determine a reasonable level of depensation for a stress test using the MSE framework. Given no clear indication of depensation, a value of δ = 2 was chosen. Other values may be reasonable but were not tested at this time. Applying depensation only in a specific environmental regime is also possible but was not attempted here because the OM does not change the stock-recruit function in separate environmental regimes, but simply multiplies recruitment by a factor for the high PDO regime. Future improvements to the OM are expected where tested management outcomes with depensation on specific environmental regimes would be appropriate.

5.3.2 MSE simulations with depensation

Including depensation in the OM (δ = 2) resulted in an undetectable difference in long-term performance metrics for all fishing intensities investigated (SPR = 35%, 43%, and 52%). There are two explanations for no effect due to depensation. First, a control rule reduces the fishing intensity when RSB is less than 30%, and sets directed fishery mortality to zero when below 20%. This results in a realized fishing intensity that may be lower than implied by the input SPR, especially at an SPR of 35% (the long-term median realized SPR was 36% with an input SPR of 35%). Second, this control rule reduces the chance that the spawning biomass falls to a low enough level where depensation becomes a concern.

Depensation	δ=1			δ=2		
SPR	35%	43%	52%	35%	43%	52%
P(RSB<20%)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
P(RSB<36%)	0.7106	0.2466	0.0012	0.7102	0.2462	0.0012
Median TCEY	71.78	66.55	57.81	71.78	66.55	57.81

This does not conclude that depensation does not occur for Pacific halibut. Depensation may exist, especially below spawning biomass levels lower than have been observed. However, if it does exist, the use of a 30:20 control rule and recent levels of fishing intensity seem to avoid these low spawning biomass levels where depensation would have an effect.

6 Conclusions

Three concepts were evaluated using the MSE: assessment frequency along with harvest control rule elements, FISS designs, and depensation. These simulations show that reducing the fishing intensity (i.e. higher SPR) would achieve a higher spawning biomass, lower interannual variability in the TCEY, and move towards a potential new objective of avoiding low absolute spawning biomass. However, yield would be reduced, on average. Biennial and triennial assessments may improve yield and would lower the interannual variability in the TCEY. This would also allow more time to improve assessment and MSE methods, but at the cost of not providing detailed annual information such as stock status. Reducing the FISS to the core areas, and occasionally surveying non-core areas would reduce yield and increase uncertainty and interannual variability in the TCEY. Finally, depensation is likely not a concern for the Pacific halibut stock, given likely management decisions in the future.

This work supports the development of the harvest strategy policy. Next steps include obtaining support from the SRB to use these results to update the current draft harvest strategy policy (IPHC-2024-SRB025-INF01), work with the MSAB to recommend updated objectives and endorse the MSE simulation results, and then present this work to the Commission along with an updated harvest strategy policy for their endorsement.

RECOMMENDATION/S

That the SRB:

1) **NOTE** paper IPHC-2024-SRB025-07 presenting recent MSE work including exceptional circumstances, goals and objectives, evaluating assessment frequency, a constraint and fishing intensity, investigating the effects of reduced FISS designs, and simulating a scenario with depensation.
2) **RECOMMEND** any additional exceptional circumstances using fishery-dependent data.
3) **RECOMMEND** adding a measurable objective related to absolute spawning biomass under the general objective 2.1 "maintain spawning biomass at or above a level that optimizes fishing activities" to be included in the priority Commission objectives after, or in place of, the current biomass threshold objective.
4) **RECOMMEND** further analyses to support the development of the harvest strategy policy.
5) **REQUEST** any further analyses to be provided to the Commission or at SRB026.

REFERENCES

Clark, William G., and S.R. Hare. 2006. *Assessment and management of Pacific halibut: data, methods, and policy.* International Pacific Halibut Commission. https://www.iphc.int/uploads/pdf/sr/IPHC-2006-SR083.pdf.

de Moor, C. L., D. Butterworth, and S. Johnston. 2022. "Learning from three decades of Management Strategy Evaluation in South Africa." *ICES Journal of Marine Science* 79: 1843-1852.

Dennis, Brian. 2002. "Allee effects in stochastic populations." *Oikos* 96: 389-401. https://doi.org/https://doi.org/10.1034/j.1600-0706.2002.960301.x.

Kuparinen, Anna, and Jeffrey A. Hutchings. 2014. "Increased natural mortality at low abundance can generate an Allee effect in a marine fish." *R. Soc. open sci.* 1: 140075. https://doi.org/http://dx.doi.org/10.1098/rsos.140075.

Liermann, Martin, and Ray Hilborn. 2001. "Depensation: evidence, models and implications." *Fish and Fisheries* 2: 33-58. https://doi.org/ https://doi.org/10.1046/j.1467-2979.2001.00029.x.

Mace, P.M., and Doonan, I.J. 1988. A generalised bioeconomic simulation model for fish population dynamics. N.Z. Fish. Assess. Res. Doc. 88/4.

Thompson, W. F. 1937. *Theory of the effect of fishing on the stock of halibut.* https://www.iphc.int/uploads/pdf/sr/IPHC-1937-SR012.pdf.

APPENDICES

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

Appendix A
Primary objectives used by the Commission for the MSE

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

General Objective	Measurable Objective	Measurable Outcome	Time-frame	Tolerance	Performance Metric
1.1. Keep female spawning biomass above a limit to avoid critical stock sizes and conserve spatial population structure	Maintain the long-term coastwide female spawning stock biomass above a biomass limit reference point ($B_{20\%}$) at least 95% of the time	*B* < Spawning Biomass Limit (B_{Lim}) B_{Lim}=20% unfished spawning biomass	Long-term	0.05	$P(B < B_{Lim})$ PASS/FAIL Fail if greater than 0.05
	Maintain a defined minimum proportion of female spawning biomass in each Biological Region	$p_{SB,2} > 5\%$ $p_{SB,3} > 33\%$ $p_{SB,4} > 10\%$ $p_{SB,4B} > 2\%$	Long-term	0.05	$P\left(p_{SB,R} < p_{SB,R,min}\right)$
2.1 Maintain spawning biomass at or above a level that optimizes fishing activities	Maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point ($B_{36\%}$) 50% or more of the time	*B*<Spawning Biomass Reference (B_{Thresh}) B_{Thresh}=$B_{36\%}$ unfished spawning biomass	Long-term	0.50	$P(B < B_{Thresh})$ Fail if greater than 0.5
2.2. Provide Directed Fishing Yield	Optimize average coastwide TCEY	Median coastwide TCEY	Short-term		*Median* $\overline{TCEY}$
	Optimize TCEY among Regulatory Areas	Median $TCEY_A$	Short-term		*Median* $\overline{TCEY_A}$
	Optimize the percentage of the coastwide TCEY among Regulatory Areas	Median $\%TCEY_A$	Short-term		*Median* $\overline{\left(\frac{TCEY_A}{TCEY}\right)}$
	Maintain a minimum TCEY for each Regulatory Area	Minimum $TCEY_A$	Short-term		*Median Min(TCEY)*
	Maintain a percentage of the coastwide TCEY for each Regulatory Area	Minimum $\%TCEY_A$	Short-term		*Median Min(%TCEY)*
2.3. Limit Variability in Mortality Limits	Limit annual changes in the coastwide TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Median coastwide Average Annual Variability (AAV)	Short-term		*Median AAV*
	Limit annual changes in the Regulatory Area TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Average AAV by Regulatory Area (AAV_A)	Short-term		*Median* AAV_A

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

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

Report on Current and Future Biological and Ecosystem Science Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, C. DYKSTRA, A. JASONOWICZ, C. JONES, 23 AUGUST 2024)

PURPOSE

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

BACKGROUND

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

1) Migration and Population Dynamics. Studies are aimed at improving current knowledge of Pacific halibut migration and population dynamics throughout all life stages in order to achieve a complete understanding of stock structure and distribution across the entire distribution range of Pacific halibut in the North Pacific Ocean and the biotic and abiotic factors that influence it.
2) Reproduction. Studies are aimed at providing information on the sex ratio of the commercial catch and to improve current estimates of maturity and fecundity.
3) Growth. Studies are aimed at describing the role of factors responsible for the observed changes in size-at-age and at evaluating growth and physiological condition in Pacific halibut.
4) Mortality and Survival Assessment. Studies are aimed at providing updated estimates of discard mortality rates in the guided recreational fisheries and at evaluating methods for reducing mortality of Pacific halibut.
5) Fishing Technology. Studies are aimed at developing methods that involve modifications of fishing gear with the purpose of reducing Pacific halibut mortality due to depredation and bycatch.

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

SRB RECOMMENDATIONS AND REQUESTS

The SRB issued several recommendations and requests in their report of SRB024 (IPHC-2024-SRB024-R) in relation to presentation IPHC-2024-SRB024-09:

SRB024–Rec.07 (para. 28) The SRB ***RECOMMENDED*** *that the Secretariat examine the relationship between blood markers of stress and recapture category (recaptured vs. still at large) to determine whether blood markers may be predictive of recreational charter sector discard mortality.*

Comparison of the levels of blood markers of stress (glucose, lactate, and cortisol) measured in Pacific halibut prior to release between fish recaptured vs. fish still at large, showed that they were not predictive of survivability (see Figure 14, this report).

SRB024–Rec.08 (para. 29) The SRB ***NOTED*** *the analysis of depensation presented in paper IPHC-2024-SRB024-07, and* ***RECOMMENDED****:*

a) *fitting a depensatory stock-recruitment model to estimate the depensation parameter value;*

b) *operating model stress tests in the MSE with and without depensation across a range of plausible fishing intensities.*

The IPHC Secretariat is currently studying this recommendation in the context of the goals and objectives of the 5Y-PRIM 2022-2026.

SRB024–Rec.09 (para. 30) The SRB ***NOTED*** *the Secretariat's studies of Pacific halibut stock structure based on genomics are nearing completion and suggest very limited genetic differentiation among individuals across the northeast Pacific and* ***RECOMMENDED*** *that:*

a) *the Secretariat test for stock structure using only male Pacific halibut;*

b) *the Secretariat prepare a manuscript for submission to a peer-reviewed scientific journal;*

c) *subject to the results from recommendation a (above), revise the 5-Year Program of Integrated Research and Monitoring to deprioritize stock structure studies as well as consideration of separate assessments of different stock components.*

The IPHC Secretariat has conducted additional analyses to evaluate stock structure using male Pacific halibut and was not able to detect discrete genetic groups of Pacific halibut using only males (Figure 1C, this report). The IPHC Secretariat intends to submit a manuscript for publication in a peer-reviewed journal and is currently directing efforts to do so.

SRB024–Rec.10 (para. 31) The SRB ***NOTED*** *the preliminary results on the regional and coastwide maturity schedules using samples collected during the 2022 FISS and* ***RECOMMENDED*** *that the Secretariat continue similar analyses with samples from the reduced 2023 FISS to evaluate possible temporal patterns in maturity schedules.*

The IPHC Secretariat is currently finalizing the histological analyses of samples collected during the reduced 2023 FISS and will present preliminary results at the SRB025 meeting.

*SRB024–Req.02 (para. 27) The SRB **NOTED** the successful proposal to Alaska Sea Grant for development of genetic-based aging methods and **REQUESTED** that the Secretariat articulate how these methods address specific priorities for the stock assessment and/or MSE or other IPHC goals.*

Age estimations are critical to our understanding of the composition of the stock for sustainable management, of historical changes in size-at-age, maturity-at-age, year class strength, mortality, etc., as well as of the response of the Pacific halibut stock to current and future climate variability. DNA methylation-based aging is a well-established alternate aging method in fish species. The potential importance of this method for Pacific halibut relies on its accuracy, high-throughput capability and the lack of reliance on terminal samples (e.g. otoliths). This method can provide age information to research projects and applications involving live Pacific halibut, including migration and discard survival studies using tags or image recognition, captive studies, etc., allowing for the first time to relate age to specific life history characteristics in live fish. Furthermore, this method could allow for estimating the age composition of Pacific halibut discarded by non-directed fisheries (e.g., trawl).

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 movement and distribution within the Convention Area

   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 and IPHC-2024-SRB024-09.

1.1.1. Methods. To explore the potential for differences in migratory behavior between males and females that could potentially lead to sex-specific patterns of population structure, additional analysis has been carried out. Following the procedure used to analyze all samples (IPHC-2024-SRB024-09), we used principal components analysis (PCA), followed by k-means clustering to examine patterns of population structure for each sex independently. First, PCAngsd (v1.2) (Meisner and Albrechtsen 2018) was used to estimate separate covariance matrices for males and females using only single nucleotide polymorphisms (SNPs) with a minor allele frequency (MAF) of at least 0.05. Eigendecomposition was performed in R (v4.2.2) (R Core Team 2022) using the eigen function. Scree plots of the first 10 eigenvalues from the PCA for each sex were plotted and Cattell's rule (Cattell 1966) was used to determine how many principal components (PCs) to retain for k-means clustering. K-means clustering was performed for each sex on the retained PCs using the kmeans function in R. To determine the optimal number of clusters (K) present in the data, we tested a range of K values (1 to 20) and used total within-cluster sum of squares (WSS) and Bayesian information criterion (BIC) to compare the K values tested and identify the best supported number of clusters.

1.1.2. Results. We retained 4.83 million SNPs and 4.78 million SNPs with a MAF ≥ 0.05 for the male and female specific PCAs respectively. Inspection of the top two PCs indicated a lack of population structure for both males and females (Figure 1). A single cluster of individuals was formed for each sex with a large degree of overlap among geographic areas (Figure 1). For both males and females, only the first three PCs were retained for k-means clustering of each dataset (Figure 2). Similar to the results obtained using the entire dataset (see IPHC-2024-SRB024-09), we observed a continual decay of total within-clusters sum of squares and BIC for both males and females as increasing values of K were tested (Figure 3). For both males and females, this is consistent with the lack of discrete genetic groups observed in Figure 1.

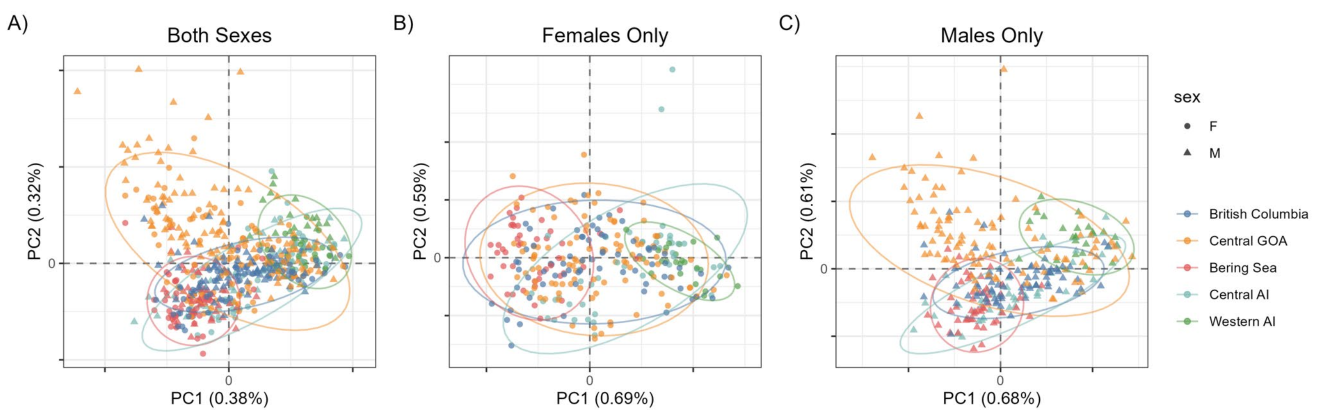


Figure 1. PCA biplots of the first two PC axes for Pacific halibut collected in IPHC Convention Waters. Both sexes were analyzed together (A, n=570), females only (B, n=281) and males only (C, n=289). PCA Samples are colored by geographic area in all panels with 95% confidence ellipses drawn for each geographic area.

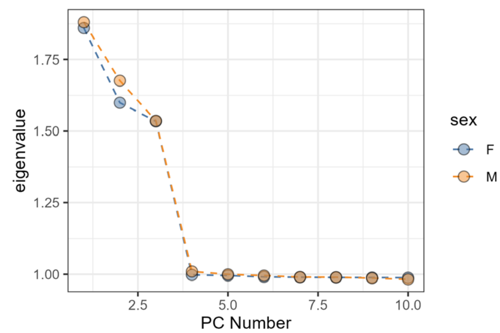


Figure 2. Scree plot of the eigenvalues for the first 10 principal components (PCs) for female (blue) and male (yellow) specific PCAs.

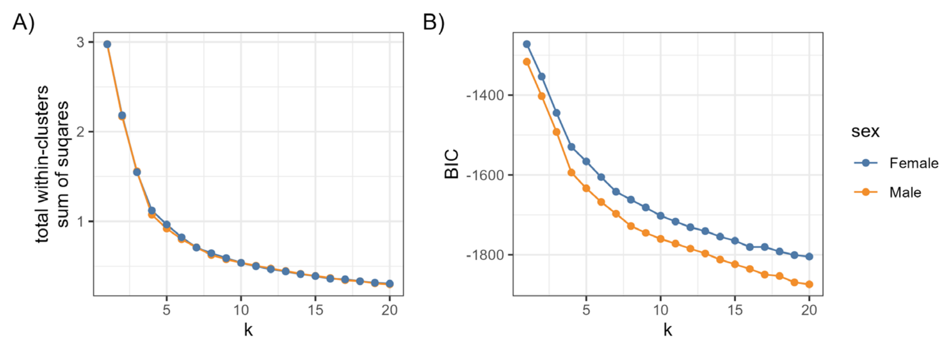


Figure 3.Total within-clusters sum of squares (A) and Bayesian information criterion (B) for each value of K tested (1-20), females are plotted in blue and males in yellow.

1.1.3. Conclusions. The lack of structure observed when males and females are analyzed independently of one another is consistent with previously reported results (see IPHC-2024-SRB024-09) that did not detect discrete genetic groups of Pacific halibut in the northeast Pacific Ocean. While the pattern observed in the male only PCA (Figure 1C) is very similar to the pattern observed when both sexes are analyzed together (Figure 1A), there are subtle differences in the patterns observed in the male only (Figure 1C) when compared to female only (Figure 1B) PCAs, specifically with respect to the males collected in the central Gulf of Alaska. Despite these subtle differences, a large amount of overlap among geographic areas exists regardless of whether each sex is analyzed independently or together, suggesting considerable geneflow among the geographic areas sampled for this study.

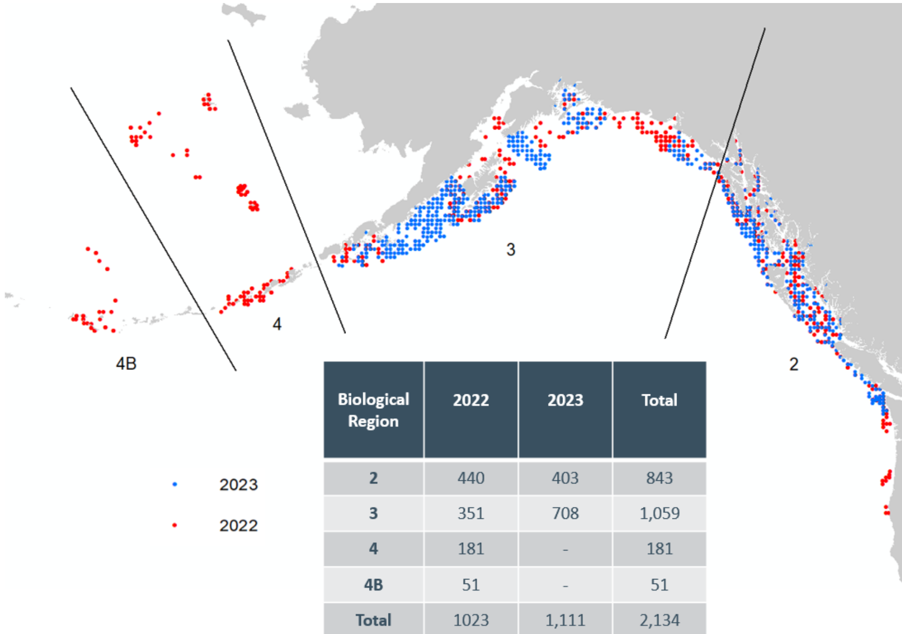
2. Reproduction.

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 2023 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. In order 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 histological-based data; and 2) fecundity estimations.

2.2.1. Update of maturity schedules based on histological-based data. The IPHC Secretariat is undertaking studies to revise maturity schedules in all four IPHC Biological Regions through histological (i.e. microscopic) characterization of maturity, as reported previously. The coastwide maturity schedule (i.e. the proportion of mature females by age) that is currently used in SA was based on visual (i.e. macroscopic) maturity classification in the field (Fishery-independent Setline Survey (FISS)). To accomplish this objective, the IPHC Secretariat has collected ovarian samples for histology during the 2022 and 2023 FISS. The 2022 FISS sampling resulted in a total of 1,023 ovarian samples collected. Due to a reduced FISS design in 2023, sampling only occurred in Biological Regions 2 and 3. A total of 1,111 ovarian samples were collected from 333 distinct FISS stations, with 403 ovarian samples from Biological Region 2 and 708 samples from Biological Region 3. A total of 2,134 ovarian samples have been collected for 2022 and 2023 (Figure 4).



Biological Region	2022	2023	Total
2	440	403	843
3	351	708	1,059
4	181	-	181
4B	51	-	51
Total	1023	1,111	2,134

Figure 4. Map of 2022 and 2023 maturity samples for histology collected on FISS. Red dots (2022) and blue dots (2023) indicate a distinct FISS station in which a sample was collected.

When examining the temporal component of sampling (by week) in 2023, sample collection took place from the end of May (week 21) to the end of August (week 35) in Biological Region 2, and beginning of June (week 22) to the middle of August (week 33) in Biological Region 3. Biological Regions 2 and 3 both had consistent collection (no gaps) across time in 2023 (Figure 5).

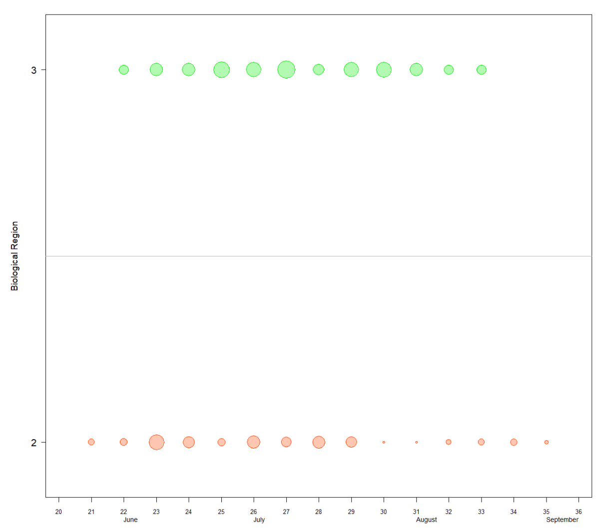


Figure 5. Timing of maturity sample collection on the 2023 FISS. The size of the bubbles indicates the number of samples collected at each bin during week of calendar year.

When examining the age and length distribution of fish collected for sampling in 2022 and 2023, the distribution of fish appeared to be right-skewed for both parameters, but more pronounced for age (Figure 6). For the samples collected in 2023, the total range of ages was from 5 to 33 years old, and the total range of lengths was from 50 to 190 cm. The largest proportion of sampled fish was from 7 to 10 years old, and from 80 to 90 cm in length. A Welch's two sample t-test was used to determine differences between age and length samples for 2022 and 2023. No significant difference was found among years for age ($t(1994.2) = -1.71$, $p = 0.09$) and length ($t(1984.4) = 1.75$, $p = 0.08$) (Figure 7).

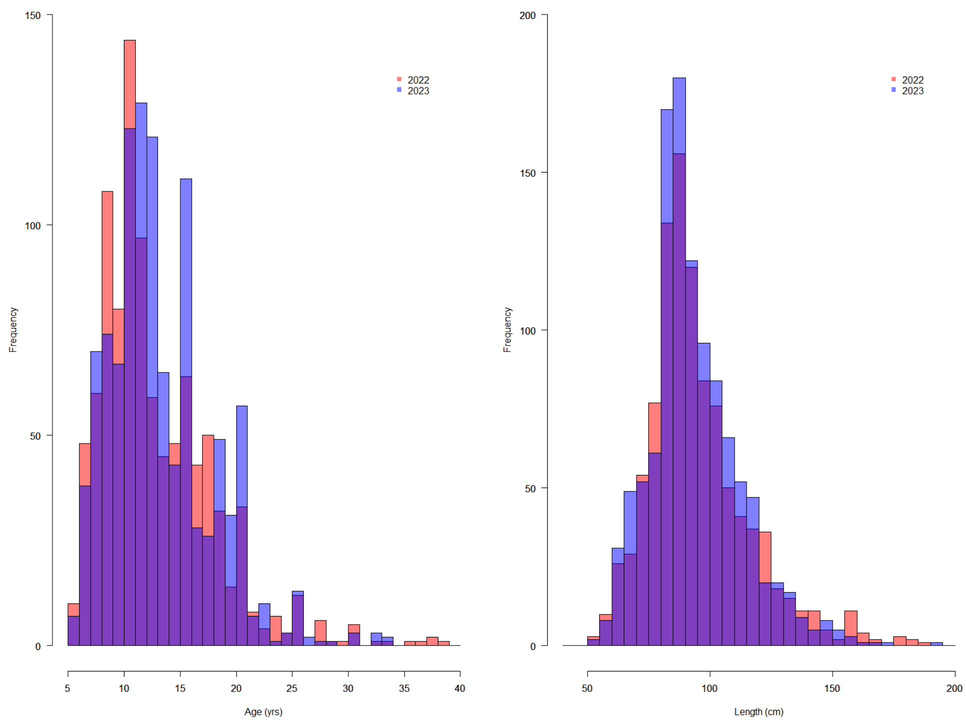


Figure 6. Histograms showing distribution of age and length of female Pacific halibut collected for maturity samples in the 2022 (red) and 2023 (blue) FISS. The purple color indicates overlap between the two years.

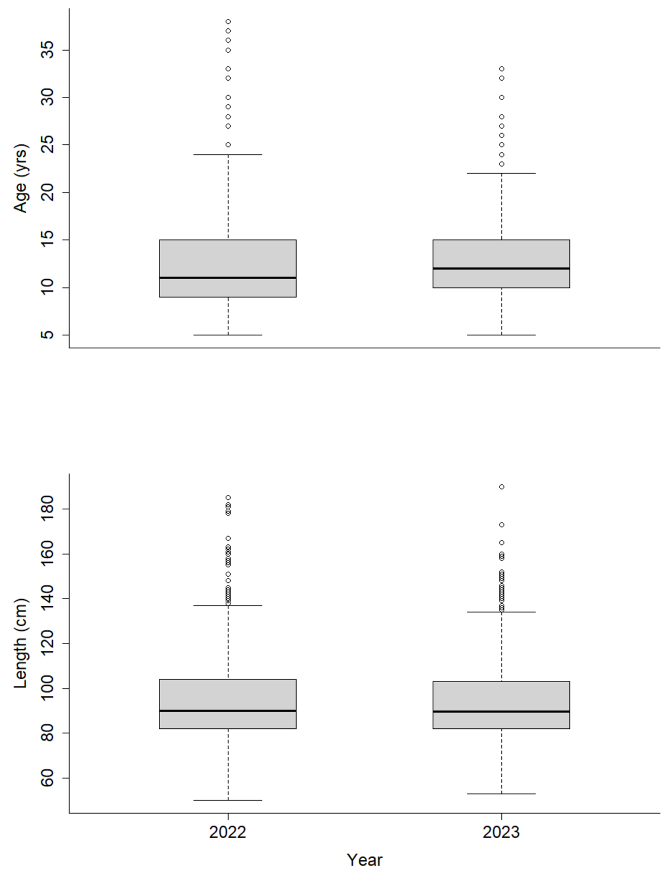


Figure 7. Boxplots showing distribution of age and length of female Pacific halibut collected for maturity samples in the 2022 (red) and 2023 (blue) FISS.

Ovarian samples from 2022 and 2023 were processed for histology and IPHC Secretariat staff finalized scoring samples for maturity using histological maturity classifications, as previously described in Fish et al. (2020, 2022). Following this maturity classification criteria, all sampled Pacific halibut females were assigned to either the mature or immature categories. Mature female Pacific halibut are deemed to have at least reached early vitellogenesis (Vtg1) for oocyte development.

Maturity ogives (i.e., the relationships between the probability of maturity determined by histological assessments and variables including IPHC Biological Region, age, and year) were estimated by fitting generalized linear models (GLM) and generalized additive models (GAM) with logit link (i.e., logistic regression). That is, if p_i is the probability that the *i*th sampled fish is mature, then the model is:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \sum_{m=1}^{M} \beta_m x_{m,i}$$

where $x_{m,i}$ is the value of the mth variable in the model for fish i (e.g., age, log(age), length, etc). The β_m are the coefficients to be estimated when fitting the model.

Alternative models were compared using the Akaike information criterion (AIC, Akaike 1973), with smaller AIC values indicating better fitting models (Table 1). The models fitted with log(age) provided a better fit, with the estimated curves better matching the steep rise in the proportion of mature females from age 6 to 8, and subsequent slower increase for older fish. For GLM, models were fitted using function glm from the stats package (R Core Team 2013) in R 4.3.2.

IPHC Secretariat first re-ran the best-fit GLM (Figure 8) and GAM (Figure 9) models using log(Age) and Region for the 2023 samples. For the GLM, Biological Region 2 is once again showing higher maturity-at-age than Biological Region 3. With more individuals classified as mature for 2023 than 2022, the rate of maturation in Biological Region 2 increased at younger ages causing the steepness of curve to also increase. Biological Region 3 showed similar trends in maturity-at-age when comparing 2022 and 2023. For the GAM, we can use the effective degrees of freedom (edf) to quantify differences of non-linearity among curves. The edf is a summary statistic of GAM and it reflects the degree of non-linearity of a curve, with an edf equal to 1 being equivalent to a linear relationship (Wood 2006). The curve of Biological Region 2 increased in non-linearity from 2022 to 2023 (Table 2). This is most likely due to the increased steepness and bend of curve near age 15 (Figure 9). The curve of Biological Region 3 showed similar trends to 2022 but has a lower edf value (Figure 9). This is due to less non-linearity from ages 8-12. The GAM models, once again, do a better job of capturing the initial rise of maturity at age 7 and also show greater uncertainty at older ages (25+) where sample sizes are small.

Incorporating both 2022 and 2023 samples, IPHC Secretariat tested multiple models for both GLM and GAM using year as a factor. GLM Model #4 showed the lowest AIC value and was used for further analysis (Table 1). The best-fit GLM showed very similar trends when compared to model outputs using 2022 and 2023 as separate model runs (Figure 10). After including year into the GLM, the model still shows a small percentage of females mature at the age of 5 and 6. Using histological methods we know this not to be true. The two models tested using year as a factor for the GAM gave equal AIC values (Table 1). IPHC Secretariat chose to use GAM Model #3 as it is more similar to the best-fit GLM model, and adding an additional smoothing function to the GAM would overcomplicate it without improving the fit. An extra year of data increased the edf (3.4) for Biological Region 2, while decreasing the edf (2.82) for Biological Region 3. With model runs being very similar in Biological Region 3 for 2022 and 2023, the GAM is doing a nice job of smoothing out the curve. Biological Regions 4 and 4B remained the same as no samples were collected there in 2023. When compared to the GLM, the GAM model is doing a better job of capturing the initial steep rise in female maturity from age 6 to 8, while also showing greater uncertainty in female maturity after age 25 due to small sample sizes (Figure 11).

GLM or GAM	Model #	Model	AIC
GLM	1	log(Age) * Region	1858.7
GLM	2	log(Age) * Region + Year	1811.7
GLM	3	log(Age) * Region + log(Age) * Year	1812
GLM	4	log(Age) * Region + Year * Region	1807
GLM	5	log(Age) * Region + log(Age) * Year + Year * Region	1808.2
GLM	6	log(Age) * Region * Year	1809.2
GAM	1	s(log(Age) * Region)	1832.4
GAM	2	s(log(Age) * Region) + s(log(Age) * Year)	1778.9
GAM	3	s(log(Age) * Region) + Region * Year	1778.9

Table 1. Generalized linear model (GLM) and generalized additive model (GAM) comparisons with lower Akaike information criterion (AIC) values indicating better fitting models.

	Model Output Year(s)		
Region	2022	2023	2022/2023
2	1.03	2.74	3.4
3	5.01	2.48	2.82
4	1.58		1.58
4B	1.1		1.1

Table 2. Effective degrees of freedom (edf) values from best-fit generalized additive model (GAM) outputs.

IPHC Secretariat continues to collect ovarian samples in the 2024 FISS. Targets for 2024 were to collect 400 samples in Biological Regions 2 and 3, and 552 in Biological Region 4. These samples will allow us to further investigate both spatial and temporal differences in histological-based female Pacific halibut maturity.

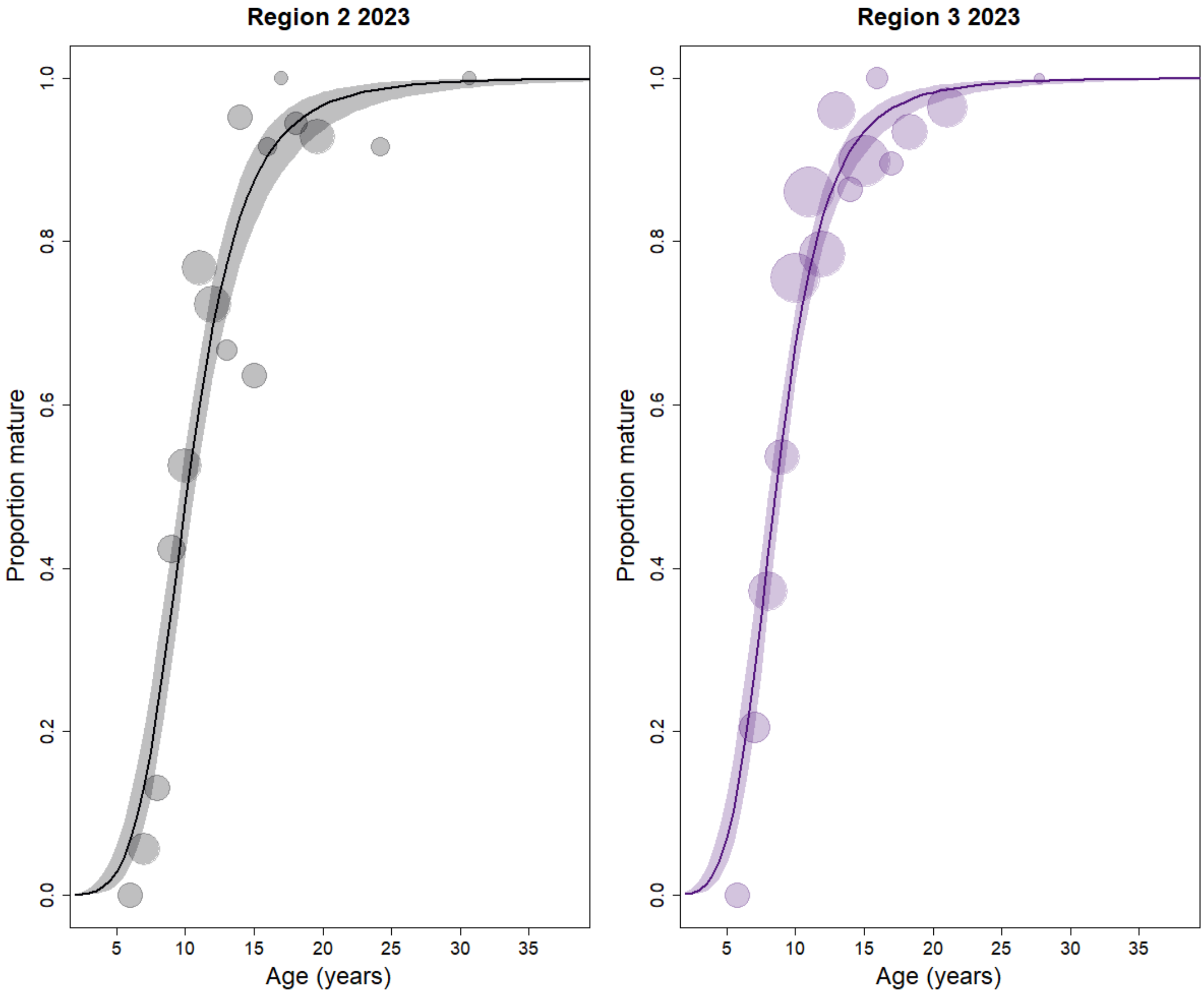


Figure 8. Female Pacific halibut age at maturity by IPHC Biological Region in 2023 using best-fit GLM, with color shading indicating 95% CI for each IPHC Biological Region.

.

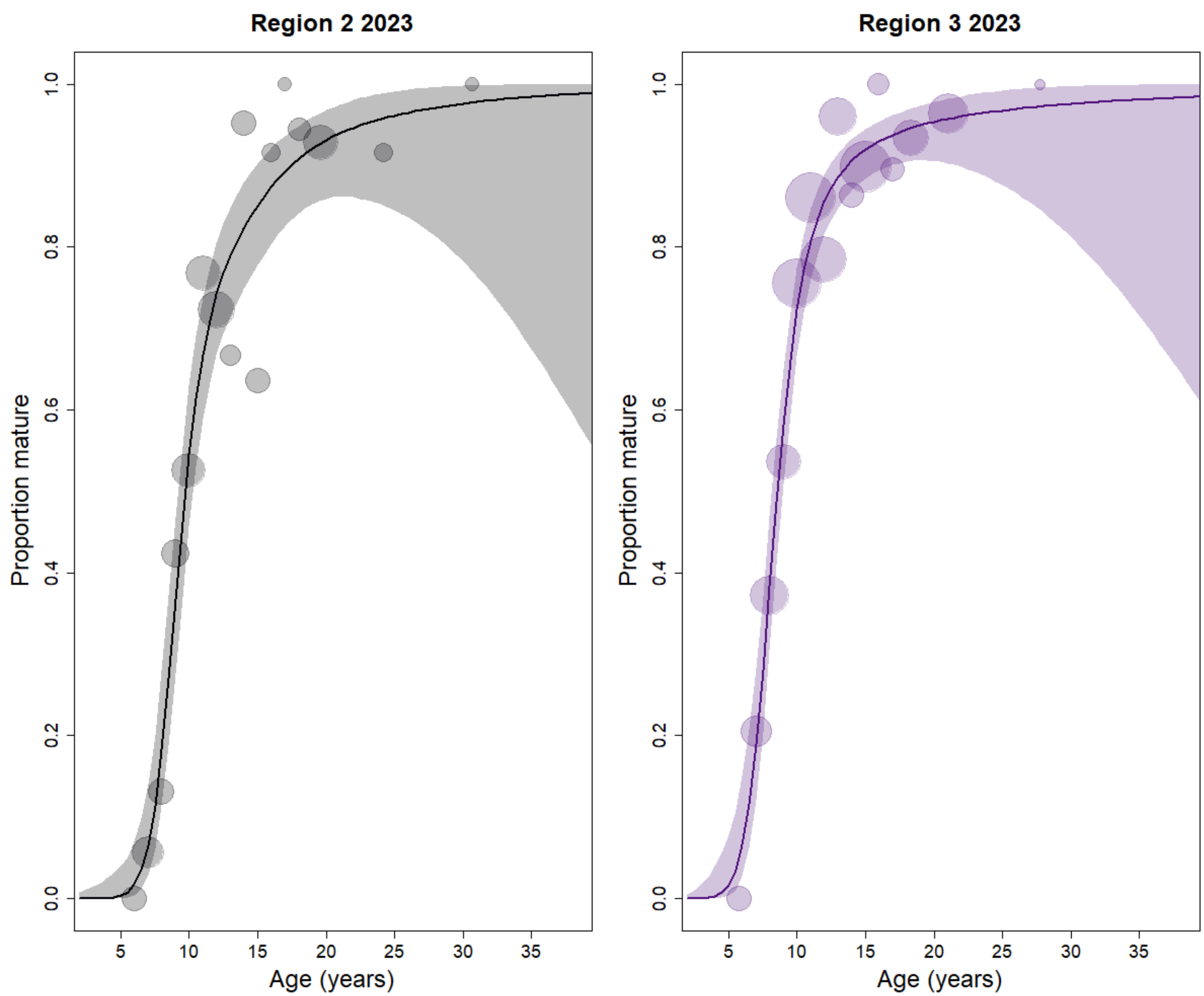


Figure 9. Female Pacific halibut length at maturity by IPHC Biological Region in 2023 using best-fit GAM, with color shading indicating 95% CI for each IPHC Biological Region.

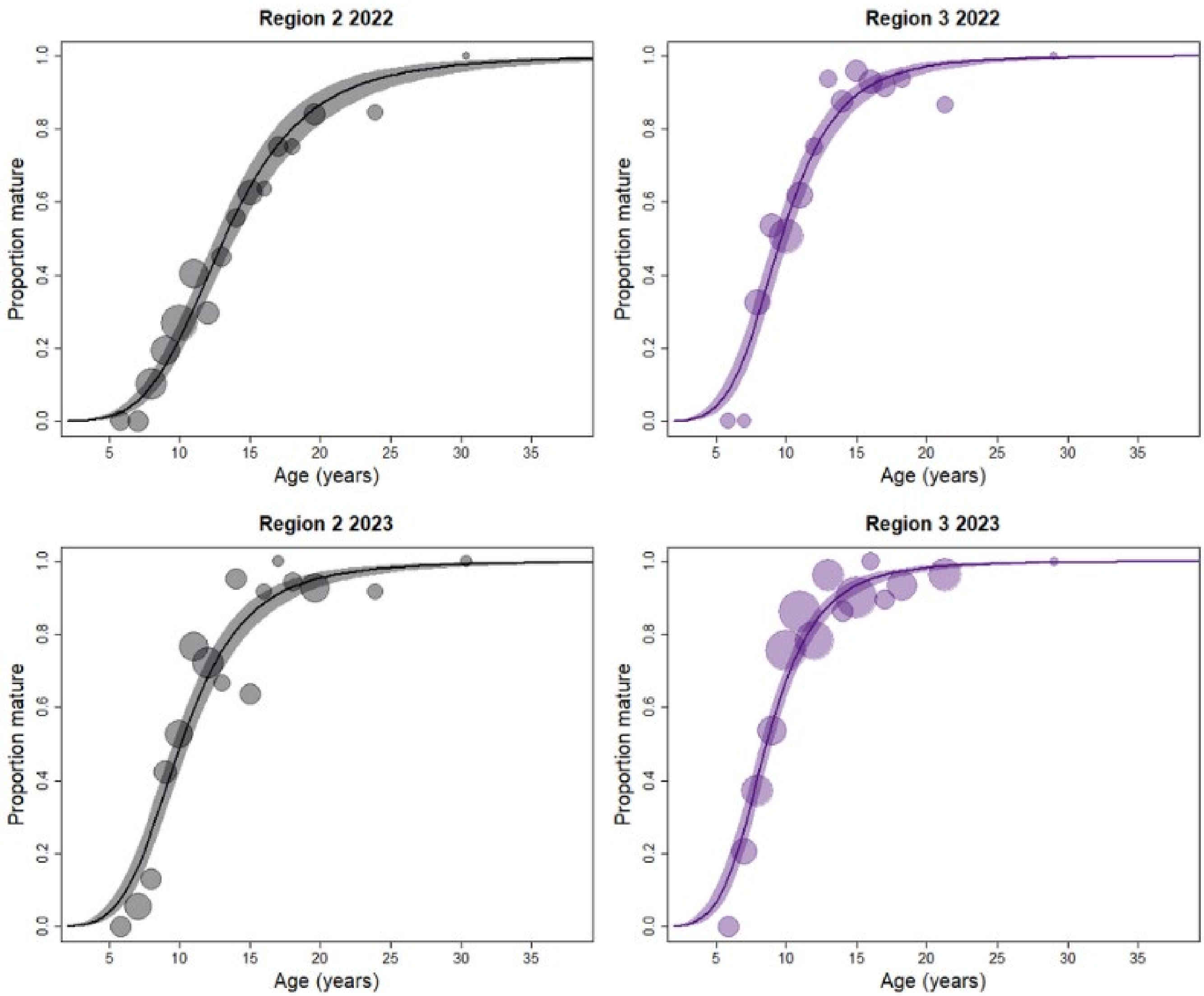


Figure 10. Female Pacific halibut age at maturity by IPHC Biological Region and year using best-fit GLM, with color shading indicating 95% CI for each IPHC Biological Region.

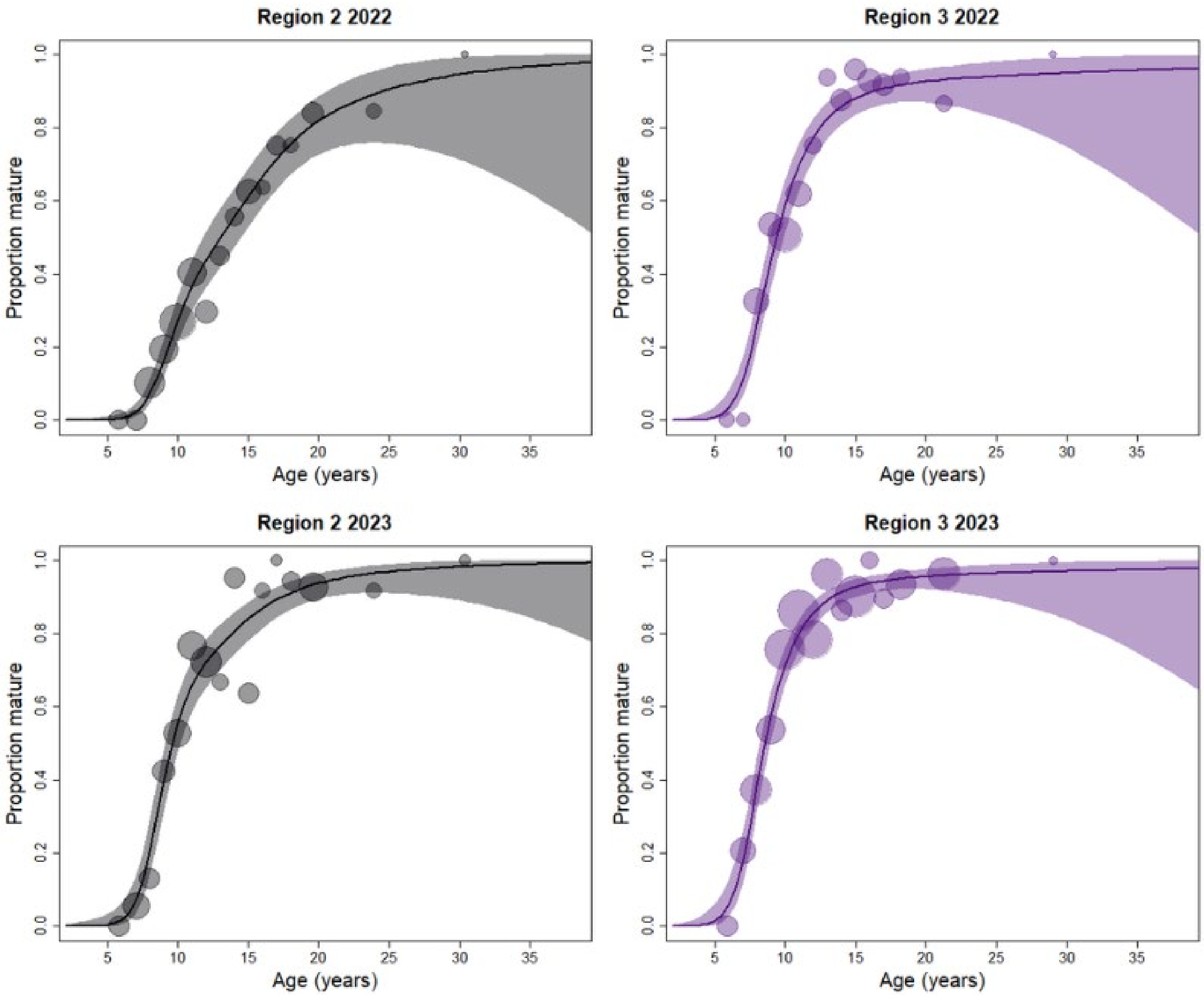


Figure 11. Female Pacific halibut age at maturity by IPHC Biological Region and year using best-fit GAM, with color shading indicating 95% CI for each IPHC Biological Region.

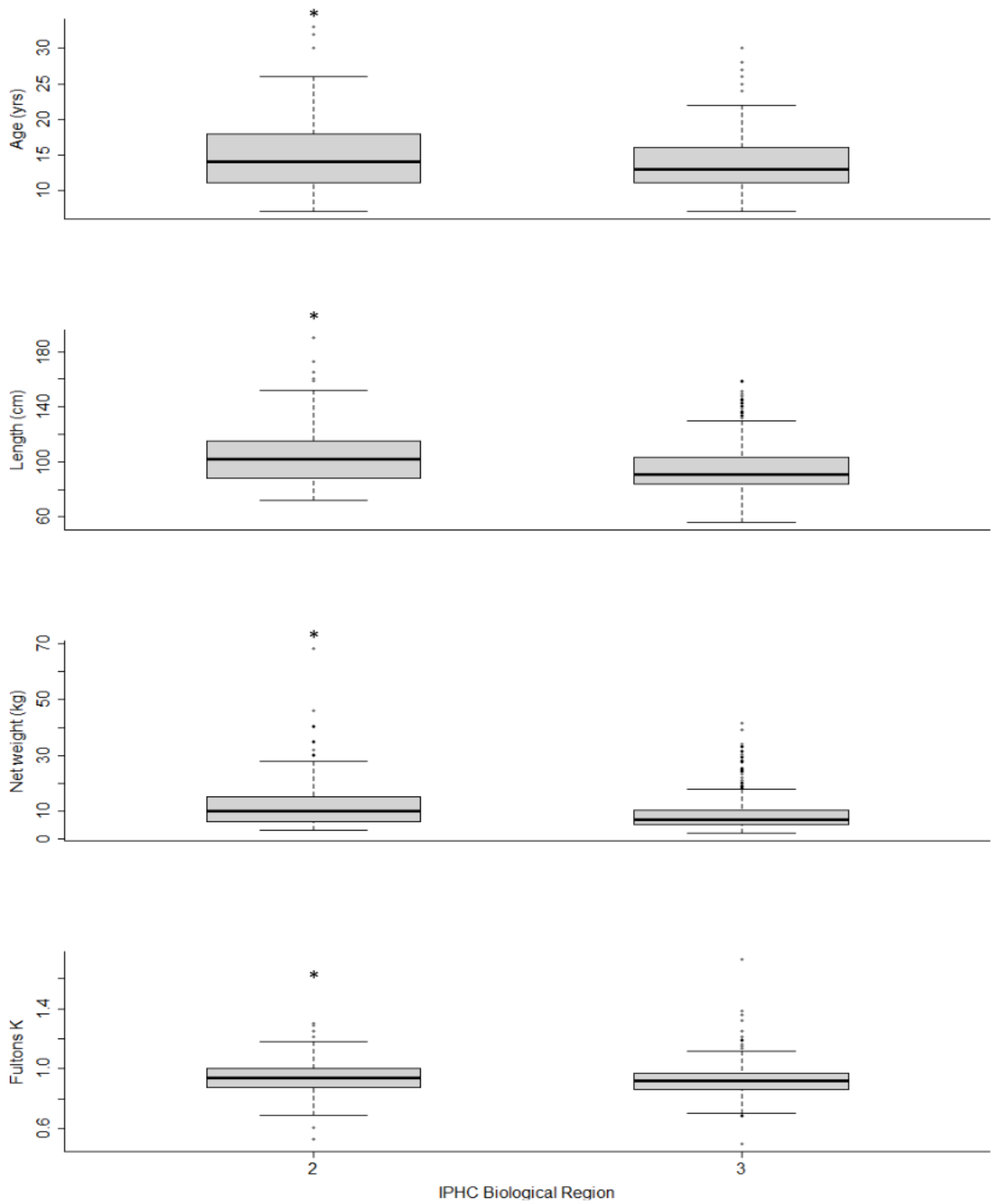


Figure 12. Comparison of age, length, net weight, and Fulton's condition factor (K) for mature individuals by IPHC Biological Region in 2023. Star symbol (*) indicates statistically significant differences among regions.

To further examine potential differences in maturity ogives among Biological Regions 2 and 3 in 2023, we compared mature individuals using a Welch two sample t-test with region as the independent variable and age, length, net weight and condition factor (Fulton's K) as dependent variables (Figure 12). Fulton's K formula was based off Froese (2006) as

$$K = (W/L^3) * 100$$

where W is the net weight in grams and L is the fork length of the fish sampled. Only mature individuals were used due to their importance in driving the observed differences in maturity ogives among Biological Regions. There was a statistically significant difference between Biological Regions 2 and 3 for age ($t(383.9) = 3.35$, $p < 0.001$), length ($t(413.9) = 6.29$, $p < 0.001$), net weight ($t(353.6) = 5.46$, $p < 0.001$), and Fulton's K ($t(441) = 2.22$, $p = 0.03$). The 2023 data continues the trend observed in 2022 showing that females are maturing at an older age and size in Biological Region 2 when compared to Biological Region 3.

Histological ovarian development across the summer months in 2023 showed very similar patterns to 2022 (Figure 13). Females in Biological Region 2 showed a clear increase in the proportion of mature individuals from May (50%) until August (80%), with females advancing from Vtg1 to Vtg3 during this period (Figure 13). In contrast, the proportion of mature females in Biological Region 3 was already high in May (>75%) and stayed elevated through August, with mature females rapidly advancing through and nearing completion of vitellogenesis by that time. With two years (2022 and 2023) of ovarian samples, the temporal analysis of ovarian development in mature females is consistent across Biological Regions and years, and also provides useful insights into the existence of differences related to the timing of ovarian development in mature females throughout Convention waters.

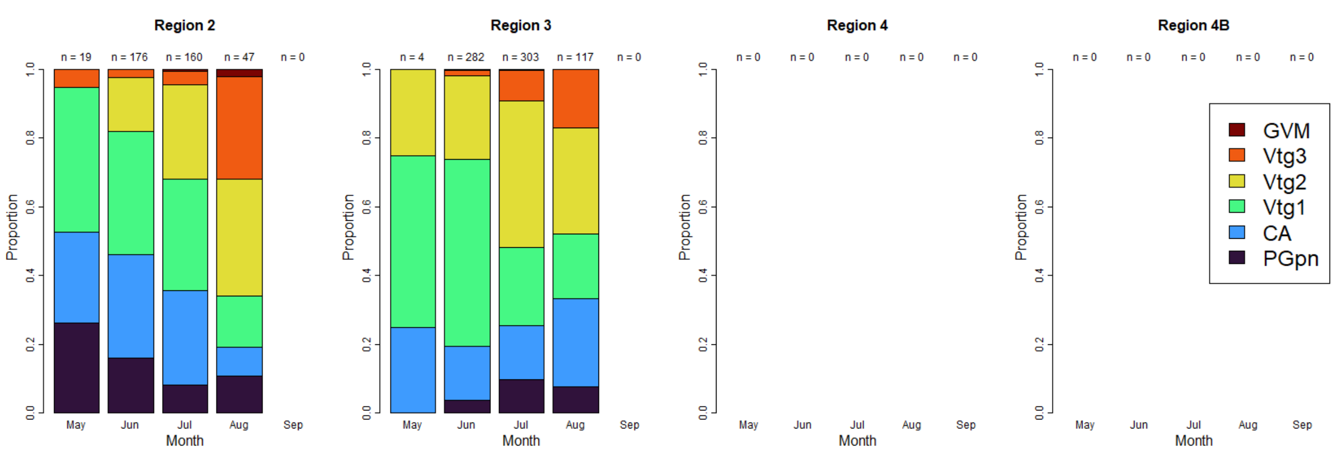


Figure 13. Reproductive development of female Pacific halibut by month sampled and IPHC Biological Region in 2023. Number of samples (n) collected by month shown at the top of each stacked bar

2.2.2. Fecundity estimations. The IPHC Secretariat has initiated studies that are aimed at improving our understanding of Pacific halibut fecundity. This 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 stock assessment and management reference points. Fecundity determinations will be conducted using the auto-diametric method (Thorsen and Kjesbu 2001; Witthames et al., 2009). 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 fecundity estimations were collected during the 2023 and 2024 FISS. In 2023, sampling was conducted in IPHC Biological Region 3, with a total of 456 fecundity samples collected. In 2024, sampling was conducted in IPHC Biological Regions 2 and 4. 149 fecundity samples were collected in Biological Region 2 and 359 samples collected in Biological Region 4, for a total of 508 fecundity samples in 2024. Using histology, as described in 2.2.1, only samples deemed mature will be processed for fecundity estimations.

3. Growth.

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

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

No updates to report.

4. 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, represent important sources of mortality that can result in significant reductions in exploitable yield in the directed fishery. Given that the incidental mortality from the commercial Pacific halibut fisheries and bycatch fisheries is included as part of the total removals that are accounted for in stock assessment, changes in the estimates of incidental mortality will influence the output of the stock assessment and, consequently, the catch levels of the directed fishery. Research activities conducted in this Research Area aim at providing information on discard mortality rates and producing guidelines for reducing discard mortality in Pacific halibut in the longline and recreational fisheries. The relevance of research outcomes from these activities for stock assessment (SA) resides in their ability to improve trends in unobserved mortality in order to improve estimates of stock productivity and represent the most important inputs in fishery yield for stock assessment (Appendix II). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in fishery parametrization (Appendix III).

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

4.1. <u>Evaluation of the effects of hook release techniques on injury levels and association with the physiological condition of captured Pacific halibut and estimation of discard mortality using remote-sensing techniques in the directed longline fishery</u>. This project has been completed and the results have been published in the peer-reviewed literature (Loher et al., 2022; Dykstra et al., 2024).

4.2. <u>Estimation of discard mortality rates in the charter recreational sector</u>. Results from a similar study conducted in fish captured using guided recreational fishery practices yielded an estimated discard mortality rate of 1.35% (95% CI 0.00-3.95%) for Pacific halibut released in Excellent viability category that were captured and released from circle hooks and tagged with acceleration-logging pop-up archival transmitting tags (sPATs). This estimate is consistent with the supposition that fish discarded in the recreational fishery from circle hooks in excellent condition have a mortality rate that is arguably lower than 3.5%, as is currently used for Excellent viability fish released in the commercial fishery (Meyer, 2007). As this project has had a high rate of fishery recoveries to date (~12.2%, with 35 wire, 7 sPAT, 2 sPAT tether) we are investigating ways in which we can use these data to enhance the survivability modeling conducted with the sPAT data. Comparisons of blood stress markers measured just before release show no significant differences between levels in those fish that have been recaptured and those that are still at large (Figure 14). Final data analysis and manuscript preparation are underway.

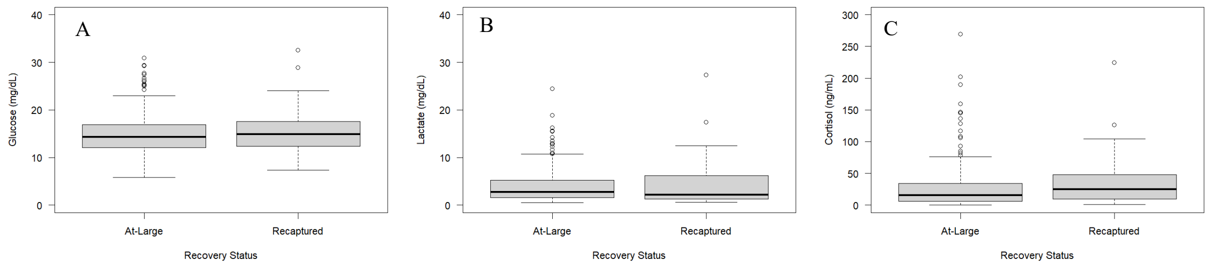


Figure 14. Blood plasma levels of stress indicators (glucose (A), lactate (B), and cortisol (C)) measured prior to release using typical charter sector gear and practices in tagged fish still at-large and in recaptured fish.

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 is 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 objectives of this study are 1) to work with fishermen and gear manufacturers, via direct communication and through an international workshop, to identify effective methods for protecting hook-captured flatfish from depredation; and 2) to develop and pilot test 2 simple, low-cost catch-protection designs that can be deployed effectively using current longline fishing techniques and on vessels currently operating in the Northeast Pacific Ocean.

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

During the second phase of the project, the IPHC Secretariat worked with catch protection device manufacturers for the design of two different types of devices for field testing: one based on a modification of Sago Solutions SA's catch protection device (i.e., shuttle) and one based on a modification of a slinky pot (i.e., shroud) deployed on branch line gear. Pilot testing was designed to investigate (1) the logistics of setting, fishing, and hauling of the two pilot catch protection designs, and (2) the basic performance of the gear on catch rates and fish size compared to non-protected gear. Field work was conducted off Newport, OR, aboard the R/V Pacific Surveyor (56' length) in late May 2023. The results obtained showed that the shuttle had good performance and similar catch entrapment and catch sizes as the control, while the shroud did not produce enough catch for a proper evaluation and would need considerable more development and testing to be commercially viable. Specific results and discussion were provided at the SRB024 meeting: IPHC-2024-SRB024-09.

In a third phase of this project, the IPHC Secretariat has recently received another grant from the Bycatch Reduction Engineering Program-NOAA entitled "Full scale testing of devices to minimize whale depredation in longline fisheries" (NA23NMF4720414; Appendix IV) to refine effective methods for protecting longline captured fish from depredation, and to complete replicates in the presence of toothed whales in known depredation hotspots to demonstrate the efficacy and safety of the gear. Challenges securing a vessel to conduct this project in 2024 has resulted in a delay of the field component until the Spring or Summer of 2025.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2024-SRB025-08 which provides a response to Recommendations and Requests from SRB024, and a report on current biological research activities contemplated within the IPHC's five-year Program of Integrated Research and Monitoring (2022-26).

REFERENCES

Akaike, H. 1973. Maximum likelihood identification of Gaussian autoregressive moving average models. Biometrika, 60(2), 255-265.

Cattell, R.B. 1966. The Scree Test For The Number Of Factors. Multivariate Behavioral Research 1(2): 245--276. doi:10.1207/s15327906mbr0102_10.

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

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

Fish, T., Wolf, N., Smeltz, T.S., Harris, B.P., Planas, J.V. 2022. Reproductive biology of female Pacific halibut (Hippoglossus stenolepis) in the Gulf of Alaska. Frontiers in Marine Science. 9: 801759. doi: https://doi.org/10.3389/fmars.2022.801759.

Froese, R. 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology, 22(4), 241-253.

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

Meisner, J., and Albrechtsen, A. 2018. Inferring Population Structure and Admixture Proportions in Low-Depth NGS Data. Genetics 210(2): 719--731. doi:10.1534/genetics.118.301336.

Meyer, S. 2007. Halibut discard mortality in recreational fisheries in IPHC Areas 2C and 3A [online]. Discussion paper presented to the North Pacific Fishery Management Council, September 2007. Alaska Department of Fish and Game. Available from: https://www.npfmc.org/wp-content/PDFdocuments/halibut/HalibutDiscards907.pdf.

R CoreTeam. 2022. R: A language and environment for statistical computing (v4.2.2).

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.

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. J. Sea Res. 46: 295-308.

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

Wood, S. 2006. Generalized additive models: an introduction with R. Chapman and Hall/CRC, New York, New York, USA

APPENDIX I

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

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

APPENDIX II

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

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

APPENDIX III

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

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

APPENDIX IV

Summary of current external research grants

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**Bycatch Reduction Engineering Program - NOAA**	Full scale testing of devices to minimize whale depredation in longline fisheries (NA23NMF4720414)	IPHC	NOAA Fisheries - Alaska Fisheries Science Center (Seattle)	$199,870	Mortality estimations due to whale depredation	November 2023 – April 2026
2	**Alaska Sea Grant (pending award)**	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)	$60,374	Stock structure	December 2024-December 2026
Total awarded ($)					**$260,244**		

2025-29 FISS design evaluation

PREPARED BY: IPHC SECRETARIAT (R. WEBSTER, I. STEWART, K. UALESI, T. JACK & D. WILSON; 23 AUGUST 2024)

PURPOSE

To provide the Scientific Review Board with the opportunity to comment on potential FISS design alternatives for 2025-29 in order to inform Commission decision making regarding the FISS. A revised preliminary cost evaluation of the 2025 designs is included.

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.

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 was a modification of a design developed and implemented in the 1960s, and involved 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 NOAA-Fisheries 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 within 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. 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, resulting in the sampling of the entire FISS design of 1890 stations in the shortest time logistically possible. 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 annual station selection process began in 2019 for the 2020 FISS and continues with the current review of design proposals for 2025-29. 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, 2020-24

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 actual sampling occurring only in the core areas. The 2021-22 FISS sampling proceeded largely as designed, although with planned stations in western IPHC Regulatory 4B in 2022 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 (see below). The 2023 FISS design (Figure 2) had more limited spatial coverage, with almost no FISS 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 was carried out in northern IPHC Regulatory 2A, while planned stations around the IPHC Regulatory Area 4A/4B boundary were not sampled due to a lack of charter bids.

The adopted 2024 FISS design (IPHC-2024-AM100-R) includes high sampling rates in IPHC Regulatory Areas 2B and 2C, a small number of charter regions in IPHC Regulatory Areas 3A and 3B, and sampling of the southern shelf edge and Bering Sea islands in IPHC Regulatory Area 4CDE (Figure 3). This design is expected to provide larger variance estimates and a relatively high risk of bias in unsampled areas but represents the maximum coverage that could be achieved given the revenue available due to projected low catch rates, increased costs and low prices. In order to further reduce costs and improve revenue, several efficiencies were introduced into the 2024 design:

- No oceanographic monitoring;
- NOAA Fisheries trawl surveys were not staffed by the IPHC;

- Allow for "vessel captain stations" in IPHC Regulatory Areas 2B and 2C: vessel captains can choose to fish up to one third of their sets at a location that is optimal in terms of catch rates or revenue;
- Use of less expensive pink salmon baits on 50% of sets.

Space-time modelling

In 2016, a space-time modelling approach was introduced to estimate time series of weight and numbers-per-unit-effort (WPUE and NPUE), and to estimate the stock distribution of Pacific halibut among IPHC Regulatory Areas. This represented an improvement over the largely empirical approach used previously, as it made use of additional information within the survey data regarding the degree of spatial and temporal correlation in Pacific halibut density, along with information from covariates such as depth (see Webster 2016, 2017). It also allowed a more complete of accounting of uncertainty; for example, prior to the use of space-time modelling, uncertainty due to unsurveyed regions in each year was ignored in the estimation. Prior to the application of the space-time modelling, these unsampled regions were either extrapolated using independently estimated scalar calibrations (if fished at least once), or catch-rates at unsampled stations were assumed to be equal to the mean for the entire Regulatory Area. The IPHC's Scientific Review Board (SRB) has provided supportive reviews of the space-time modelling approach (e.g. IPHC-2018-SRB013-R), and the methods have been published in a peer-review journal (Webster et al. 2020). Similar geostatistical models are now routinely used to standardize fishery-independent trawl surveys for groundfish on the West Coast of the U.S.A. and in Alaskan waters (e.g. Thorson et al. 2015 and Thorson 2019). The IPHC space-time models are fitted through the R-INLA package in the R software (R Core Team, 2024).

FISS DESIGN OBJECTIVES (Table 1) – Current Commission decision

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 the IPHC's management procedure. 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: *Long-term revenue neutrality.*

The FISS is intended to have long-term revenue neutrality, and therefore any implemented design must consider both logistical and cost considerations.

Tertiary objective: *Minimize 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 IPHC policies.

Table 1. Prioritization of 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	Long term revenue neutrality	Logistics and cost: operational feasibility and cost/revenue neutrality
Tertiary	Minimize removals and assist others where feasible on a cost-recovery basis.	Removals: minimize 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 completion of the FISS expansions in 2019, a review process has been developed 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 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 Commissioners 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);
- 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 November Interim Meeting;
    - Ad-hoc modifications to the design for the current year (due to unforeseen issues arising) remain possible as late as the Annual Meeting of the Commission;
    - The endorsed design for current year is then modified (if necessary) by the Secretariat to account for any additional tertiary objectives or revised evaluation of secondary objectives prior (i.e. updated cost estimates) 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).

Note that while the review process examines designs for the next three to five years, revisions to designs for the second and third years are expected during subsequent review periods as additional data are collected. Fourth- and fifth-year designs are provided for general comparison only as all inputs are expected to change prior to implementation this far in the future. Having design proposals available for multiple years ahead 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 2025-29

At IM099, Secretariat staff presented options for 2024 and subsequent years based on rotational block designs (IPHC-2023-IM099-13 Rev_1, Part 2). For these designs, the random selection of FISS stations in design proposals for 2020-24 for IPHC Regulatory Areas 2B, 2C, 3A and 3B were replaced with sampling complete FISS charter regions in each area, with sampled regions rotated over a two to three year period depending on area. This type of design was first proposed in 2019 (IPHC-2019-IM095-07 Rev_1, Figure 4) to complement the similar subarea design proposed and adopted for areas at the ends of the stock (2A, 4A and 4B).

Block designs are potentially more efficient from an operational perspective than a randomized design, as they involve less running time between stations, possibly leading to cost reductions on a per station basis. By rotating among charter regions over years there is no potential for persistent bias in FISS indices from this design approach.

The block designs shown in Figures 4 to 8 for 2025-29 (called the **Base Block design**) were presented to Commissioners at IM099 as potential designs for 2024-28, although the Base Block design was not considered for adoption for 2024 due to high projected cost. These block designs ensure 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 designs also include some sampling in all IPHC Biological Regions in each year, ensuring that data from across the spatial range of Pacific halibut are available to the stock assessment and for stock distribution estimation. We note that paragraph 72 of the AM100 report (IPHC-2024-AM100-R) states:

> *The Commission NOTED that the use of the base block design (Figures 7 to 11 of paper IPHC-2024-AM100-13) will be the focus of future planning and annual FISS proposals from the Secretariat.*

Under recent catch rates and FISS net revenues, implementation of the Base Block design had been projected to result in a substantial operating loss and would therefore require supplementary funding. For this reason, we compare the Base Block design to two alternative block designs that would achieve lower net costs through reductions in spatial coverage:

- **Core Block design** (Figures 9 to 13): Maintain the same rotating block coverage in the core IPHC Regulatory as the Base Block design but remove sampling outside of the core areas.

- **Reduced Core design** (Figure 14): Sample only the FISS charter regions in the core areas that are planned for 2024 as these are likely to result in relatively low net losses for the FISS overall. (While the more profitable charter regions will vary over time, this design is intended to be representative of similar low-coverage designs.)

Using samples generated from the fitted 2023 space-time models as simulated data for 2024-27, we projected the coefficient of variation (CV, a relative measure of precision) for mean O32 WPUE for each year of the design by IPHC Regulatory Area and Biological Region. As CVs are generally greater in the terminal year of the time series and that year is 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 values for 2026 were found by fitting the model to the data for 1993-2026 (with simulated data used for 2024-26).

Table 2. Projected coefficients of variation (CVs, %) for mean O32 WPUE by FISS design, terminal year of time series, and IPHC Regulatory Area or Biological Region.

Regulatory	**Base Block**			**Core Block**			**Reduced Core**		
Area	2025	2026	2027	2025	2026	2027	2025	2026	2027
2A	17	22	23	29	29	31	29	31	34
2B	8	10	7	8	10	7	9	9	9
2C	6	6	6	6	6	6	5	5	5
3A	9	7	7	9	7	7	11	13	15
3B	13	12	15	13	12	15	19	21	26
4A	19	13	20	26	29	33	28	31	33
4B	15	20	18	35	39	44	35	39	44
4CDE	8	8	8	8	9	9	8	9	9
Biological Region									
Region 2	5	6	5	5	6	5	5	5	6
Region 3	7	7	8	7	7	8	10	12	14
Region 4	8	7	9	11	12	14	11	14	15
Region 4B	15	20	18	35	39	44	35	39	44
Coastwide	4	4	4	5	5	6	6	7	8

With uncertainty in future designs, it is expected that by 2027 implemented designs will vary significantly from those in the three sets of block designs presented in this document. Nevertheless, to compare potential levels of uncertainty five years from now under designs with similar sampling coverage, we also projected CVs for IPHC Regulatory Areas 2A, 3B and 4B for 2029. For IPHC Regulatory Area 2A, 2029 CVs of 34 and 38% are projected for the Core Block and Reduced Core designs, while for IPHC Regulatory Area 4B, a CV of 51% is projected for both designs. In contrast, the Base Block design would lead to CVs of 21% and 14% for 2A and 4B respectively in 2029. For IPHC Regulatory Area 3B, which receives some sampling under all three designs, a 14% CV is projected for both Base Block and Core Block designs in 2029, while the Reduced Core design is expected to result in a CV of 30%.

Base Block design: Projected terminal year CVs for the Base Block design for 2025-27 are all 25% or less for all IPHC Regulatory Areas. In the core areas (2B, 2C, 3A and 3B), CVs are at 15% or less (Table 2). All Biological Region CVs except Region 4B are below 10% while the coastwide CV is projected to be 4% in all years. The Base Block design is therefore projected to maintain precise estimates of indices of Pacific halibut density and abundance across the range of the stock, and to provide a strong basis for estimating trends, demographics, and the distribution of the stock. At the same time, the rotating nature of the sampled blocks means that almost all FISS stations are sampled within a 5-year period (2-3 years within the core areas) resulting in low risk of missing important stock trends and therefore a low risk of large bias in estimates of trend and stock distribution. The consistent nature of the sampling design means that CVs will be maintained at comparable values beyond 2027.

For context, the 'global average' research survey CVs has been estimated to be approximately ~20%; however, this value includes estimated observation and process error (based on lack of fit in the stock assessments), and so is larger than the survey-only observation CVs projected in this report (Francis et al. 2003). In NOAA Fisheries trawl survey results in the Bering Sea (roughly analogous to one Biological Region for Pacific halibut), commercially important species showed a range of average annual model-based CVs, including: Pacific cod (5%), Walleye pollock (7%), Northern rock sole (6%), and yellowfin sole (5%) over 1982-2019 (DeFilippo et al. 2023). These values are comparable to the projected 5-9% CVs for IPHC Biological Regions that would be expected from the base block design (with the exception of Biological Region 4B), but lower than corresponding values for the Core Block and Reduced Core designs.

Core Block design: With sampling maintained in the core areas, projected CVs for IPHC Regulatory Areas 2B, 2C, 3A and 3B remain at 15% or less with this design (Table 2). However, the absence of sampling outside of the core leads to CVs for 2A, 4A and 4B increasing quickly with time, which carries over to increasing CVs for Biological Regions 4 and 4B. Expected data from the NOAA trawl survey in IPHC Regulatory Area 4CDE continues to result in CVs below 10% for that area. With a large proportion of the stock unsampled for 2025-27 with this design, the risk of bias also increases in unsampled areas and regions, as well as coastwide. Beyond 2027, CVs will continue to increase outside of the core areas. The risk of substantial bias in non-core areas compromises the information on demographics in Biological Regions 4 and 4B and estimates of stock distribution for all IPHC Regulatory Areas.

Reduced Core design: In this design, only IPHC Regulatory Area 2B and 2C receive spatially extensive sampling, which maintains CVs below 10% for these areas (Table 2). With relatively low proportions of IPHC Regulatory Areas 3A and 3B sampled, CVs increase to 15% and 26% respectively as uncertainty grows in the unsampled parts of these areas. Regional and coastwide CVs also increase outside of Region 2. Bias risk is very high under this design, as a very large proportion of the stock is not monitored during the 2025-27 period. Outside of IPHC Regulatory Areas 2B and 2C, CVs are expected to continue increasing beyond 2027. The risk of substantial bias in all but Biological Region 2 compromises the information on demographics in other Regions and estimates of stock distribution for all IPHC Regulatory Areas.

Table 3 gives preliminary net revenue projections for all three designs for 2025. Projections include the following assumptions:

1. Designs are optimized for numbers of skates, with 4, 6 or 8 skate-sets used, depending on projected catch rates and bait costs.
2. 2025 Pacific halibut price and catch rates decline by 5% per year from those used to develop the 2024 design.
3. Chum and pink salmon bait each continue to be used on approximately 50% of the stations and prices remain similar to those for 2024.

Costs for each design are given with and without oceanographic monitoring undertaken using the IPHC's Seacat water column profilers.

Cost estimates in this report are largely based on information from the 2023 FISS and outcomes of the 2024 charter bidding process, and it is important to note there is high uncertainty in the any catch and cost projections for 2025 this far in advance. Final cost and accounting information will be available at the end of the 2024 fiscal year and will be used to refine these preliminary projections at that time.

Table 3. Comparison of preliminary projected net revenue for the 2025 Base Block, Core Block and Reduced Core designs.

Design	With Seacat	Without Seacat
Base Block	−$2,539,000	−$2,399,000
Core Block	−$1,741,000	−$1,641,000
Reduced Core	−$1,344,000	−$1,264,000

At SRB024, the Scientific Review Board noted the importance of also considering the costs to the fisheries of potential decision-making errors due to reductions in the FISS design. From IPHC-SRB024-R (para. 34):

*"The SRB **NOTED** that the alternative FISS designs generate specific operating costs but also provide different economic impacts in mitigating risk of losses and instability in TCEY due to errors in decision-making and that such value is not reflected in standard presentations of alternative FISS design costs."*

The Secretariat is proceeding with simulations of the effects of reduced FISS designs on the annual stock assessment and on the performance management procedures via the MSE.

DISCUSSION

At AM100 (IPHC-2024-AM100-13), IPHC Secretariat recommended that the Commission endorse block designs for all future planning as a viable alternative to the randomised sampling in use for the core of stock from 2020-23. Block designs increase efficiency by reducing vessel travel time among stations. Sampling effort should not be lower than the levels presented in the Base Block design in Figures 4 to 6.

The Base Block design has a projected net loss of -$2,399,000 without oceanographic monitoring and therefore will rely on supplementary funding for implementation. Depending on updated cost and revenue estimates from the 2024 FISS, the level of available supplementary funding, and Commission priorities during Interim and Annual Meeting decision making process, we can anticipate the adopted FISS design for 2025 to differ in spatial scope from the design presented in Figure 4.

Like the adopted 2024 FISS design, the Core Block and Reduced Core designs will result in less information available for the annual stock assessment and management supporting calculations such as stock distribution than in years prior to 2024. The increased uncertainty in the index of abundance is likely to cause the assessment model to rely more heavily on the commercial fishery catch-per-unit-effort index. Given current spatial variability and uncertainty in the magnitude of younger year classes (2012 and younger), the limited biological information from the core of the stock distribution (Biological Region 3) makes it unclear whether the stock assessment will detect a major change in year class abundance, either up or down. Some of this information may come from Commercial fishery sampling; however, due to the minimum size limit there is a longer lag between recruitments occurring in the population and their identification in the fishery data than is the case for the FISS. Although the basic stock assessment methods can remain unchanged, a greater portion of the actual uncertainty in stock trend and demographics will not be able to be quantified due to missing FISS data from a large fraction of the Pacific halibut stock's geographic range. The implications for the assessment would be of increasing concern if Core Block or Reduced Core designs were implemented beyond 2025 due to increasing uncertainty and risk of bias in stock trend estimates and the unrepresentativeness of the biological samples. Further, as was evident at AM100, reduced FISS designs that do not fully inform stock distribution with annual sampling in all IPHC Regulatory areas lead to reduced stakeholder confidence in the FISS results and in the aggregate scientific information from the stock assessment. This may have a strong effect on the perception of risk and on decision making by the Commission if reduced survey designs continue to be consecutively implemented.

RECOMMENDATION

That the Scientific Review Board:

1) **NOTE** paper IPHC-2024-SRB025-09 that presents potential FISS design options for 2025-29 and preliminary cost evaluations of potential 2025 designs. Secretariat staff request that the SRB provide scientific guidance to the Commission regarding the design options to assist Commission decision making for the FISS in 2025 and subsequent years.

References

DeFilippo, L., Kotwicki, S., Barnett, L., Richar, J., Litzow, M.A., Stockhausen, W.T., and Palof, K. 2023. Evaluating the impacts of reduced sampling density in a systematic fisheries-independent survey design. Frontiers in Marine Science **10**. doi:10.3389/fmars.2023.1219283.

Francis, R.I.C.C., Hurst, R.J., and Renwick, J.A. 2003. Quantifying annual variation in catchability for commercial and research fishing. Fishery Bulletin **101**: 293-304.

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

IPHC 2018. Report of the 13th Session of the IPHC Scientific Review Board (SRB) IPHC-2018-SRB013-R. 17 p.

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

IPHC 2024. Report of the 24th Session of the IPHC Scientific Review Board (SRB024) IPHC-2024-SRB024-R. 19p.

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

Thorson, J. T., Shelton, A. O., Ward, E. J., and Skaug, H. J. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES Journal of Marine Science 72(5): 1297-1310. doi:10.1093/icesjms/fsu243.

Thorson, J. T. 2019. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. Fisheries Research 210: 143-161. doi:10.1016/j.fishres.2018.10.013.

Webster, R. A. 2016. Space-time modelling of setline survey data using INLA. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2015: 552-568.

Webster, R. A. 2017. Results of space-time modelling of survey WPUE and NPUE data. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2016: 241-257.

Webster, R. 2019. Space-time modelling of IPHC Fishery-Independent Setline Survey (FISS) data. IPHC-2019-IM095-07 Rev_1. 19 p.

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. and Wilson, D. (2023). 2024, and 2025-28 FISS Design Evaluation. IPHC-2023-IM099-13 Rev_1. 30 p.

Webster, R., Stewart, I., Ualesi, K. and Wilson, D. (2024). 2024, and 2025-28 FISS Design Evaluation. IPHC-2024-AM100-13. 19 p.

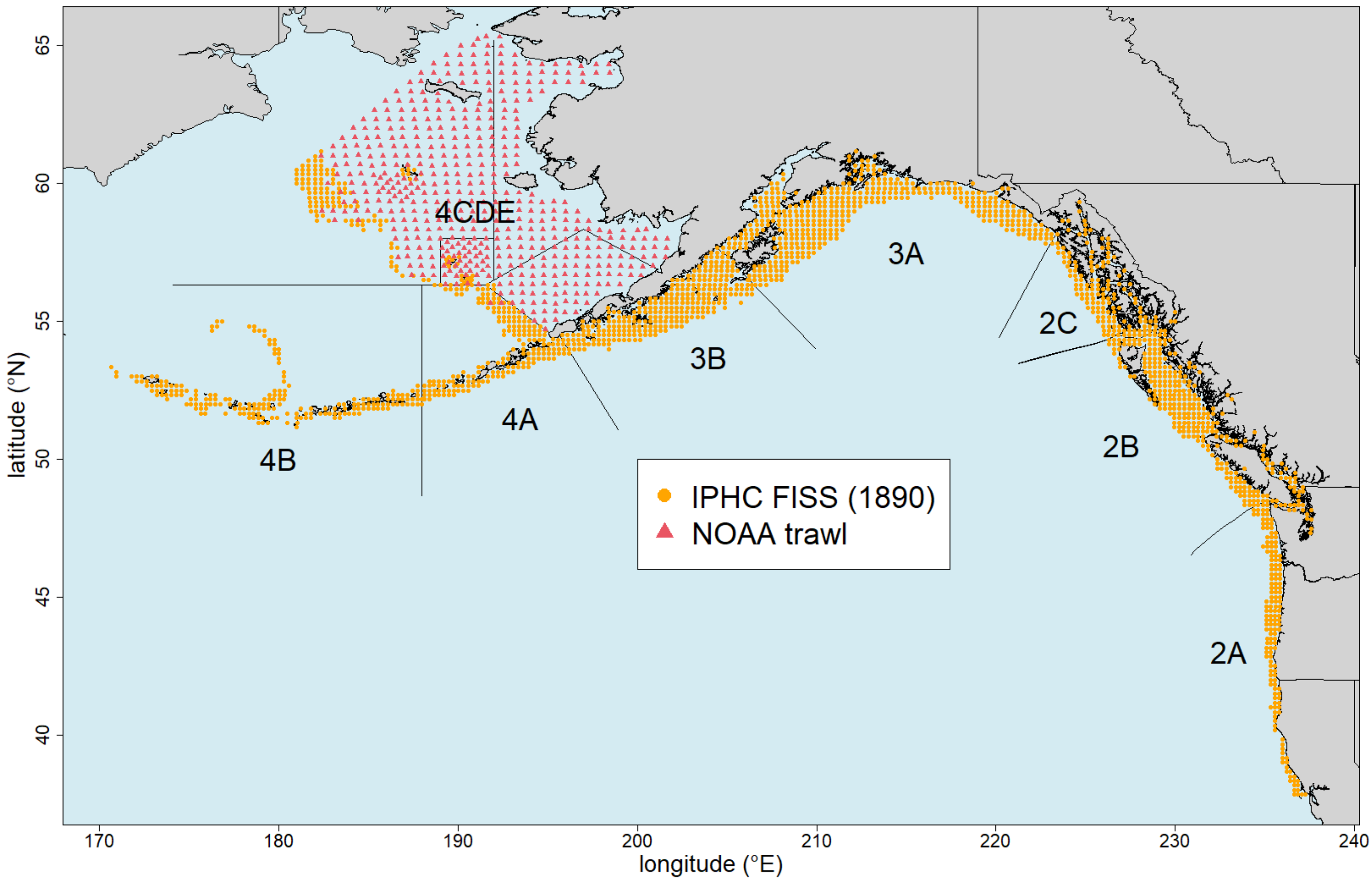


Figure 1. Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs. Red triangles represent the locations NOAA trawl stations used to provide complementary data for Bering Sea modelling (not all are sampled each year).

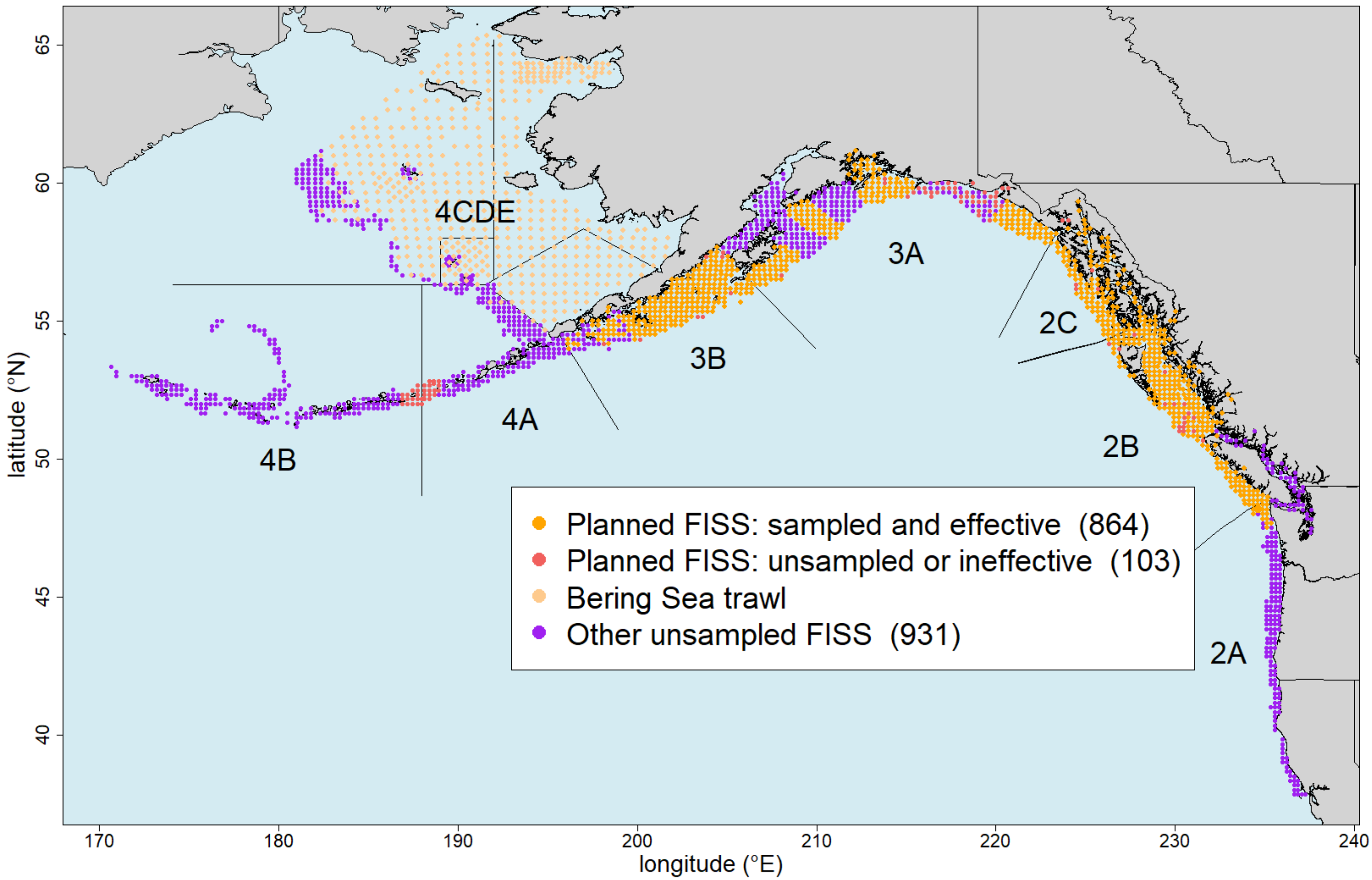


Figure 2. Implemented 2023 FISS design, with successfully fished (effective) stations shown in orange circles.

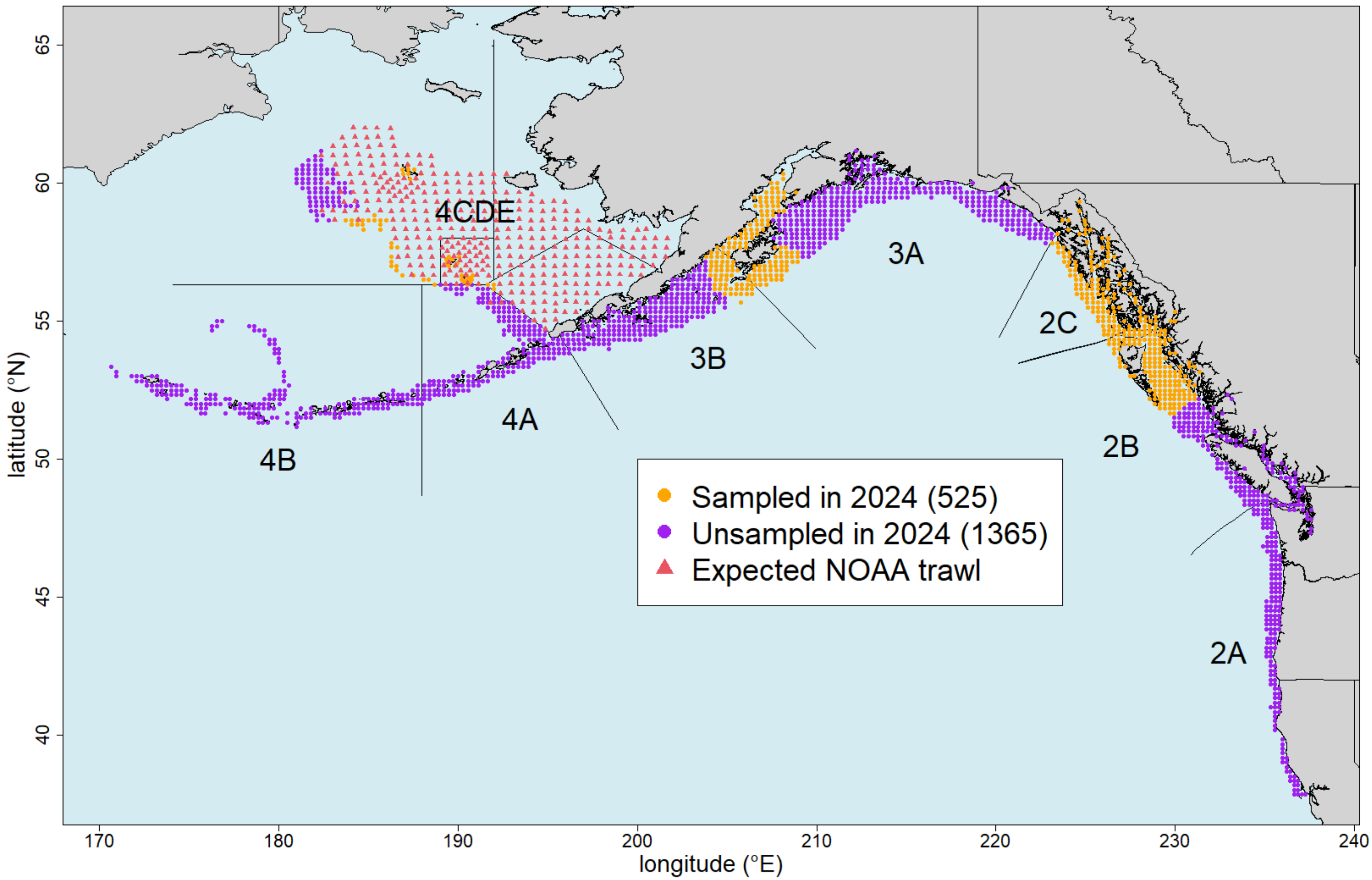


Figure 3. Adopted 2024 FISS design, with planned FISS stations shown as orange circles and expected NOAA trawl stations as red triangles.

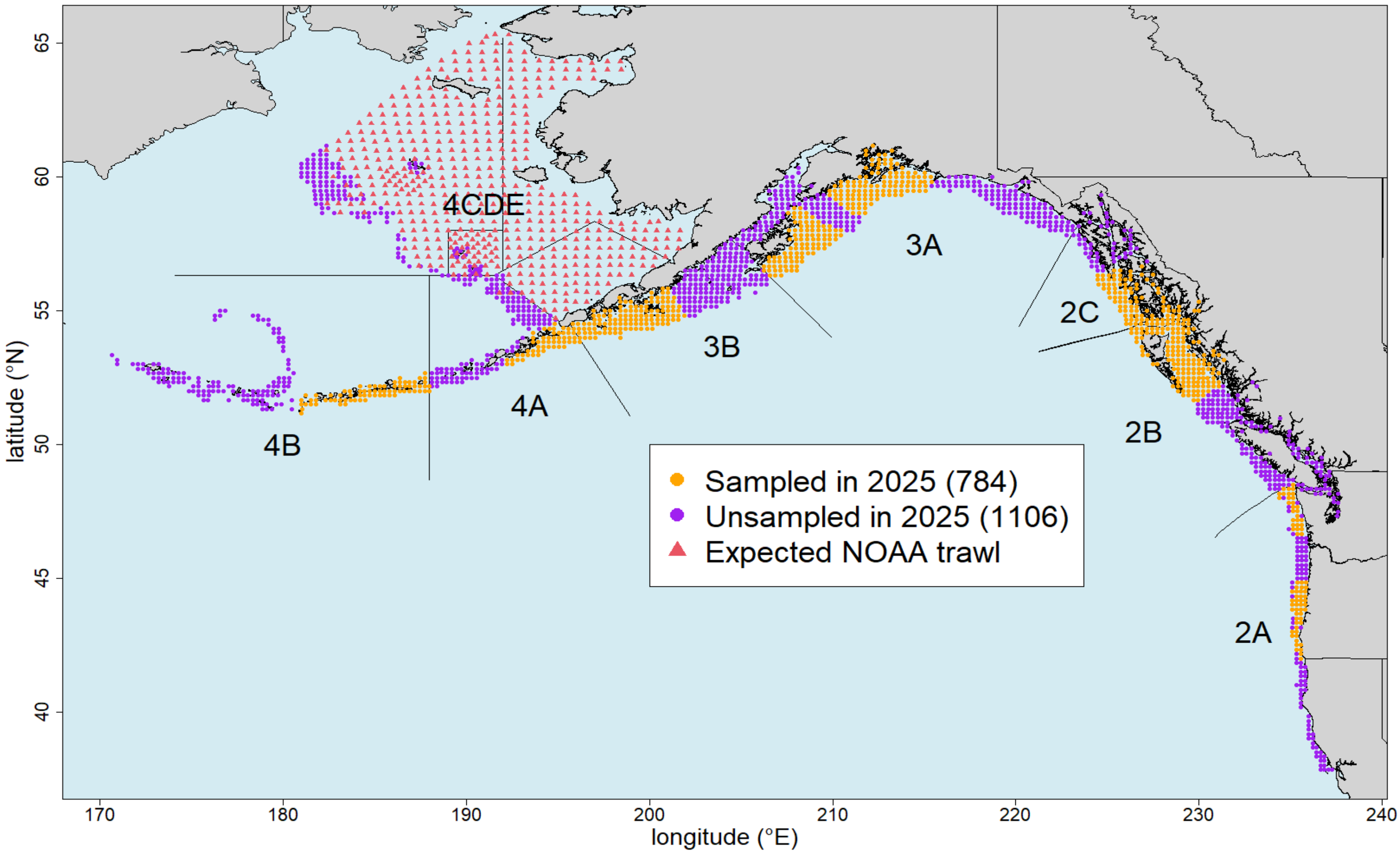


Figure 4. Base Block design for 2025 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

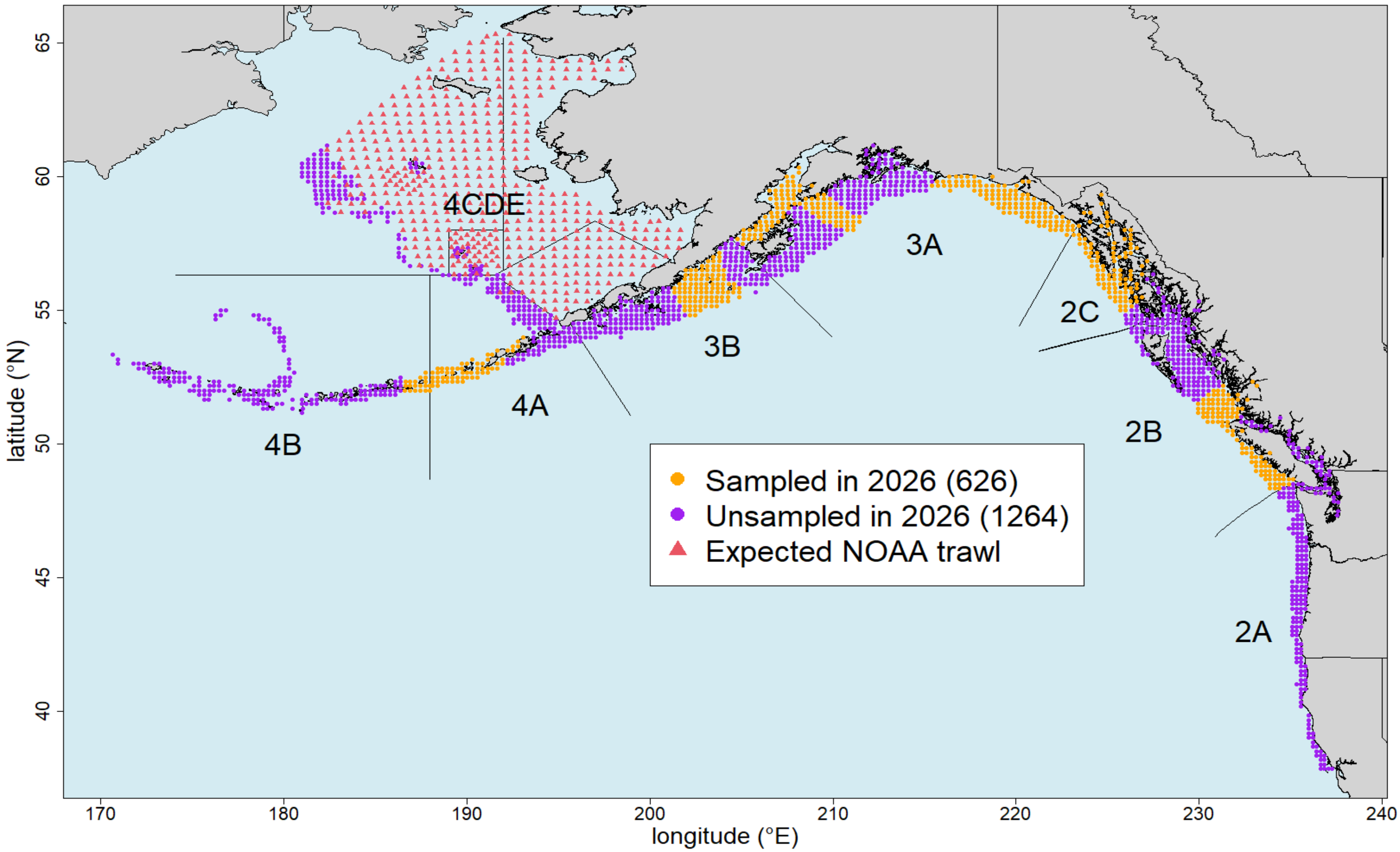


Figure 5. Base Block design for 2026 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

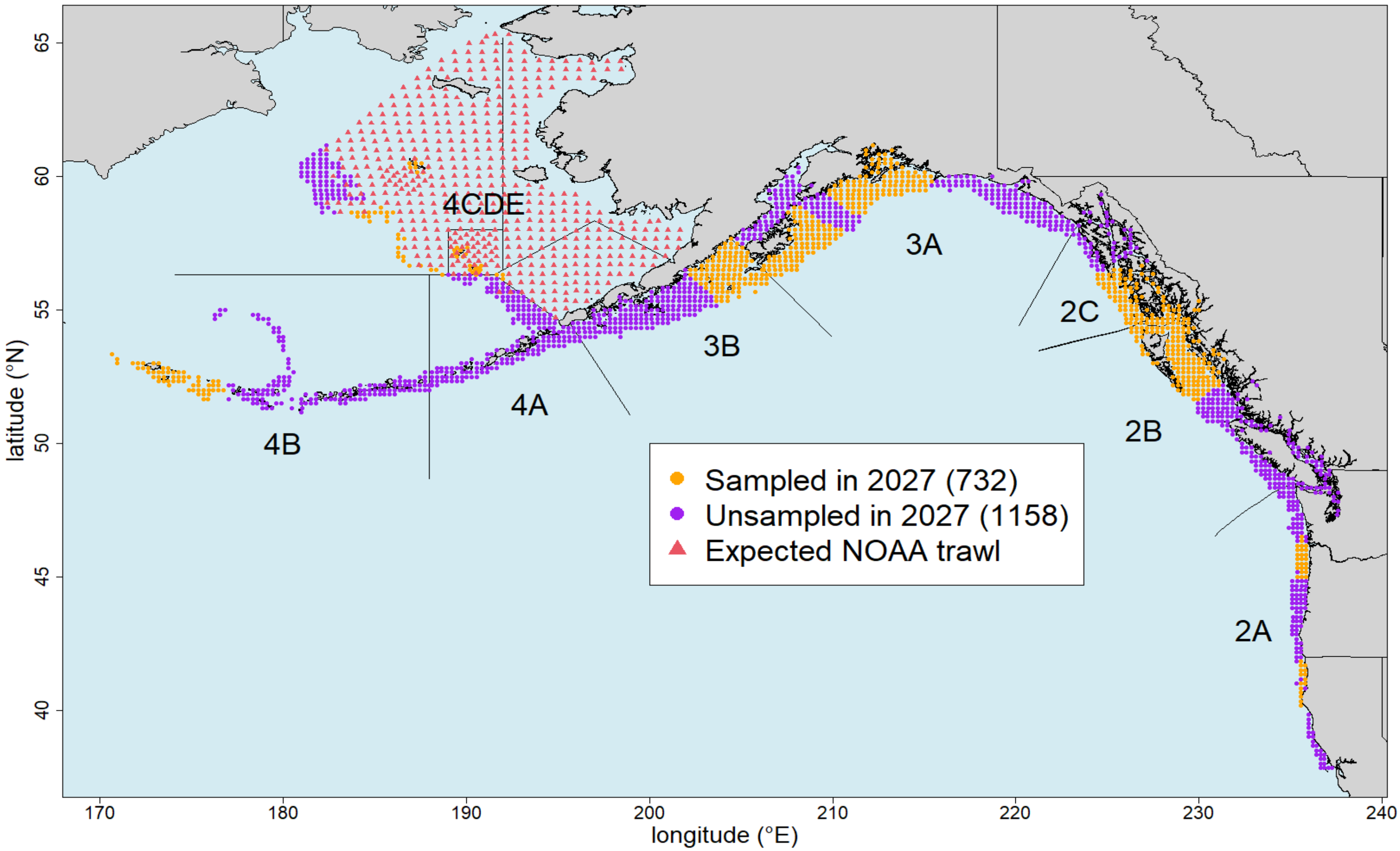


Figure 6. Base Block design for 2027 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

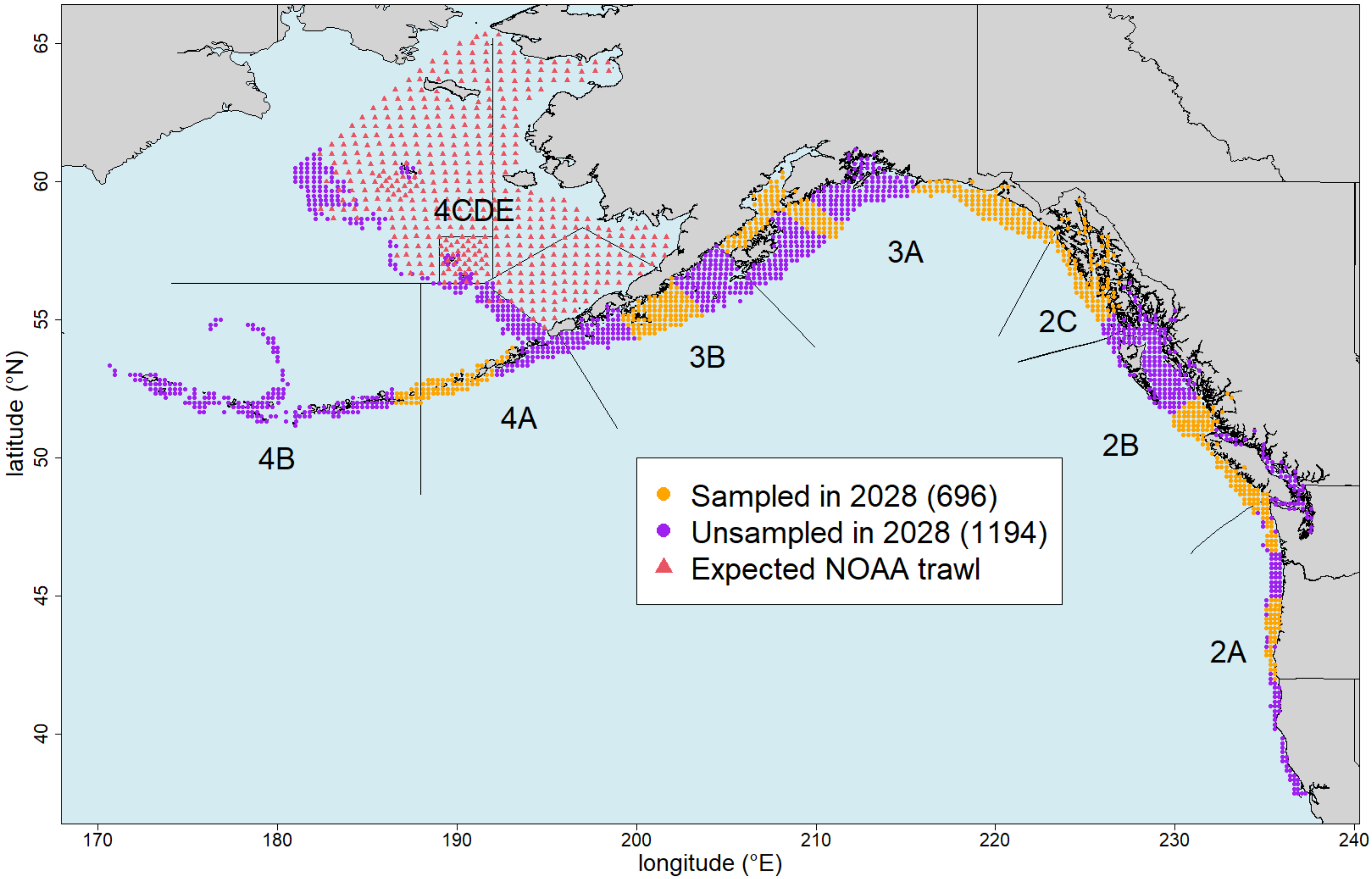


Figure 7. Base Block design for 2028 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

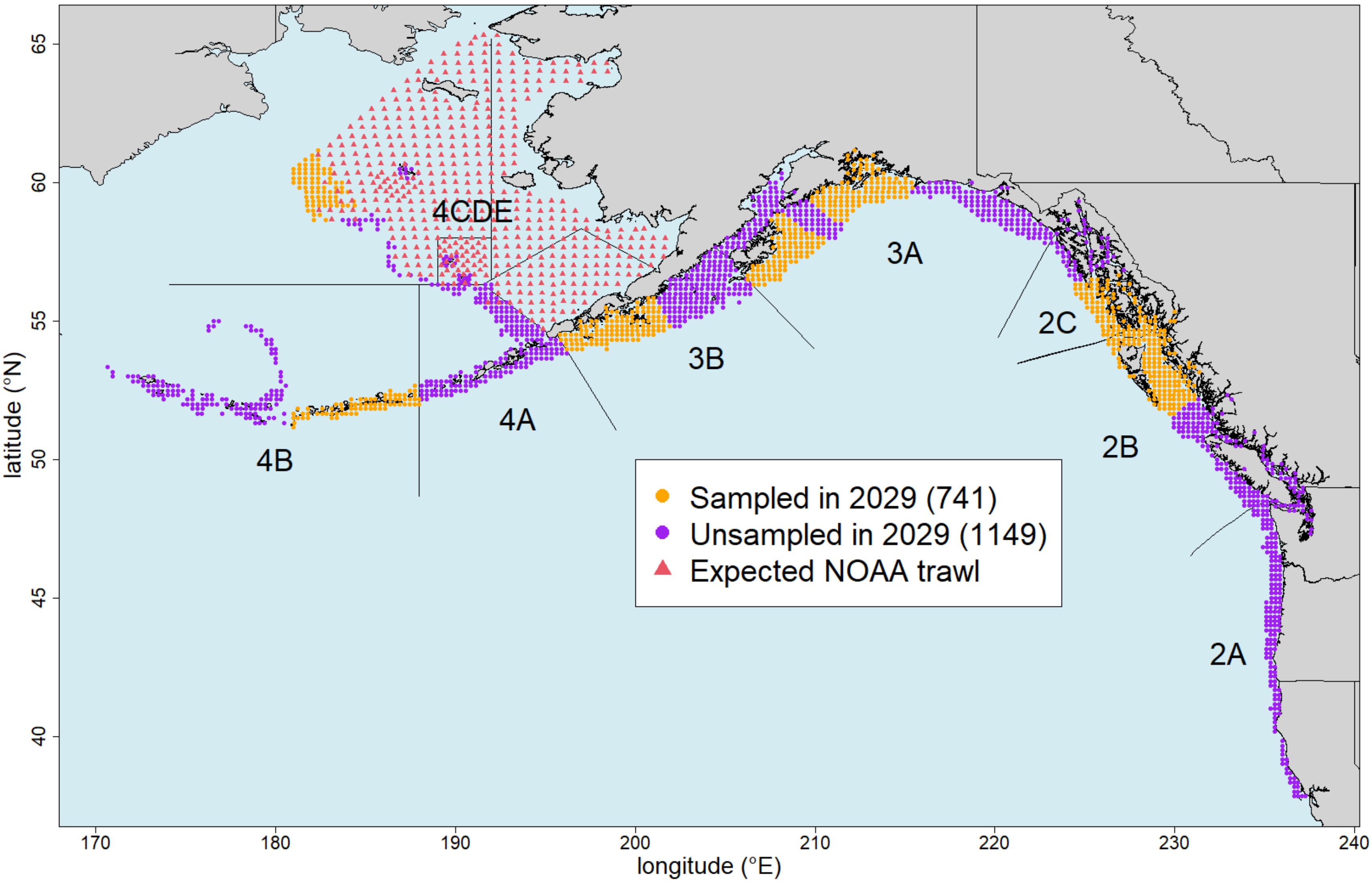


Figure 8. Base Block design for 2029 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

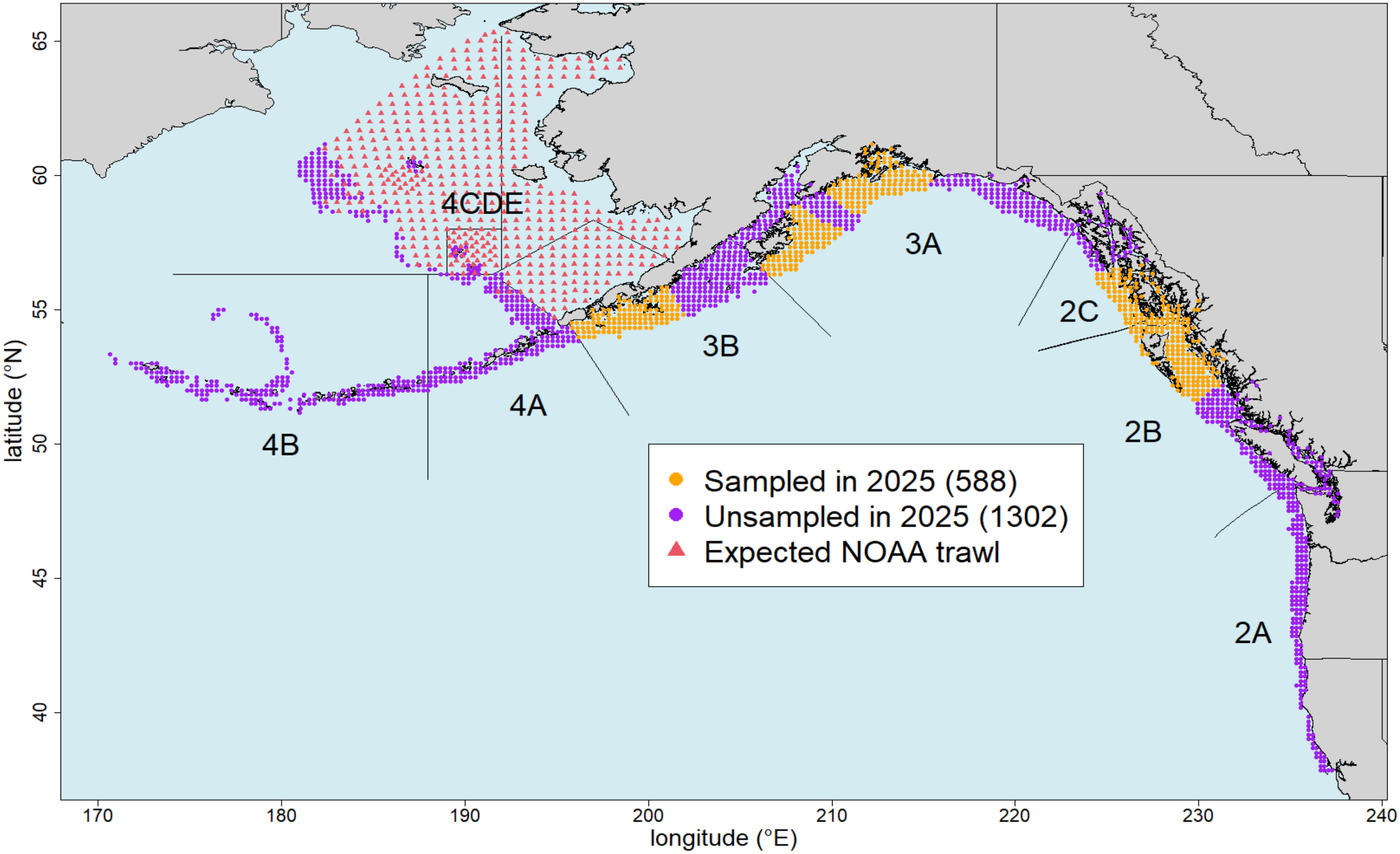


Figure 9. Core Block design for 2025 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

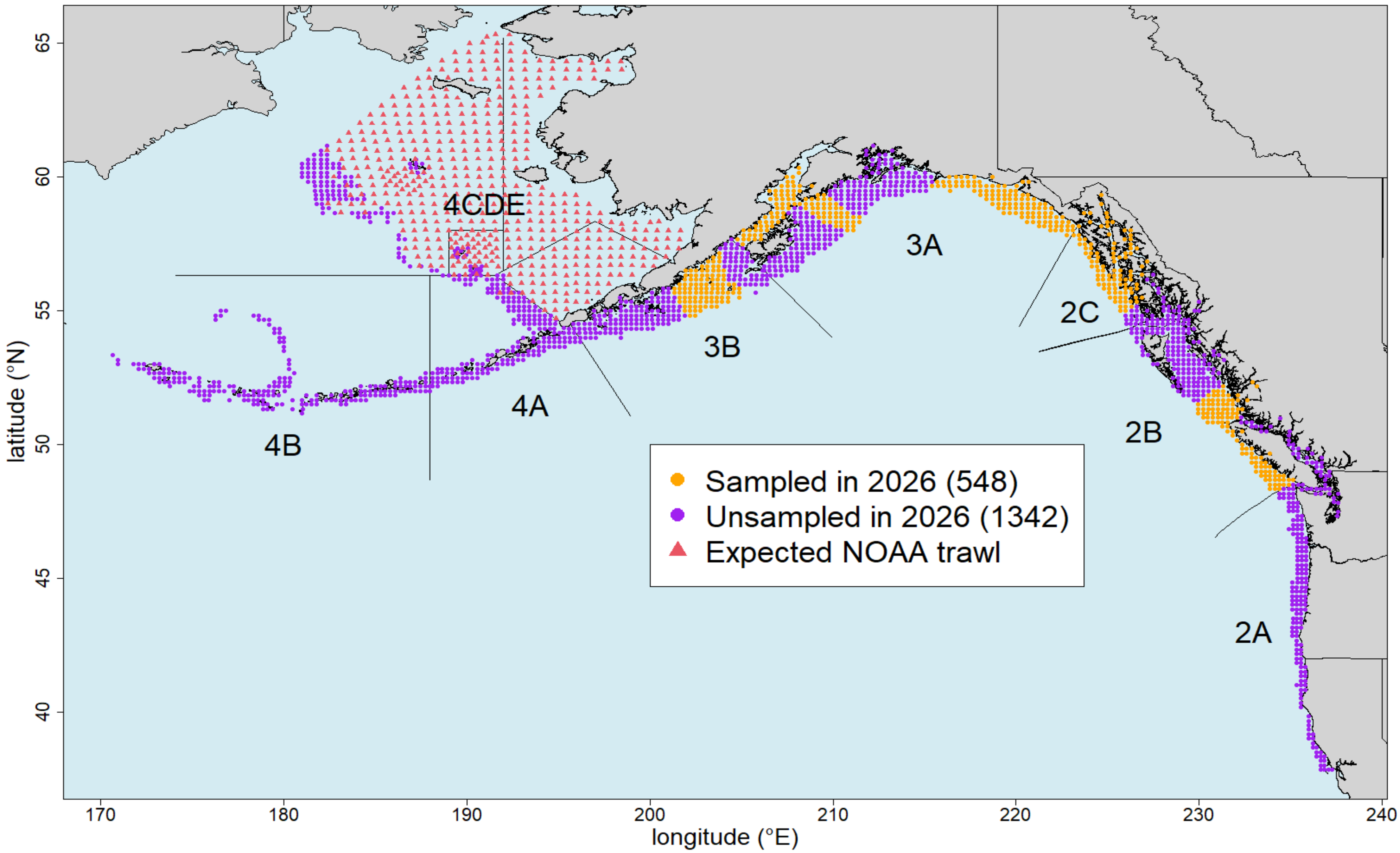


Figure 10. Core Block design for 2026 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

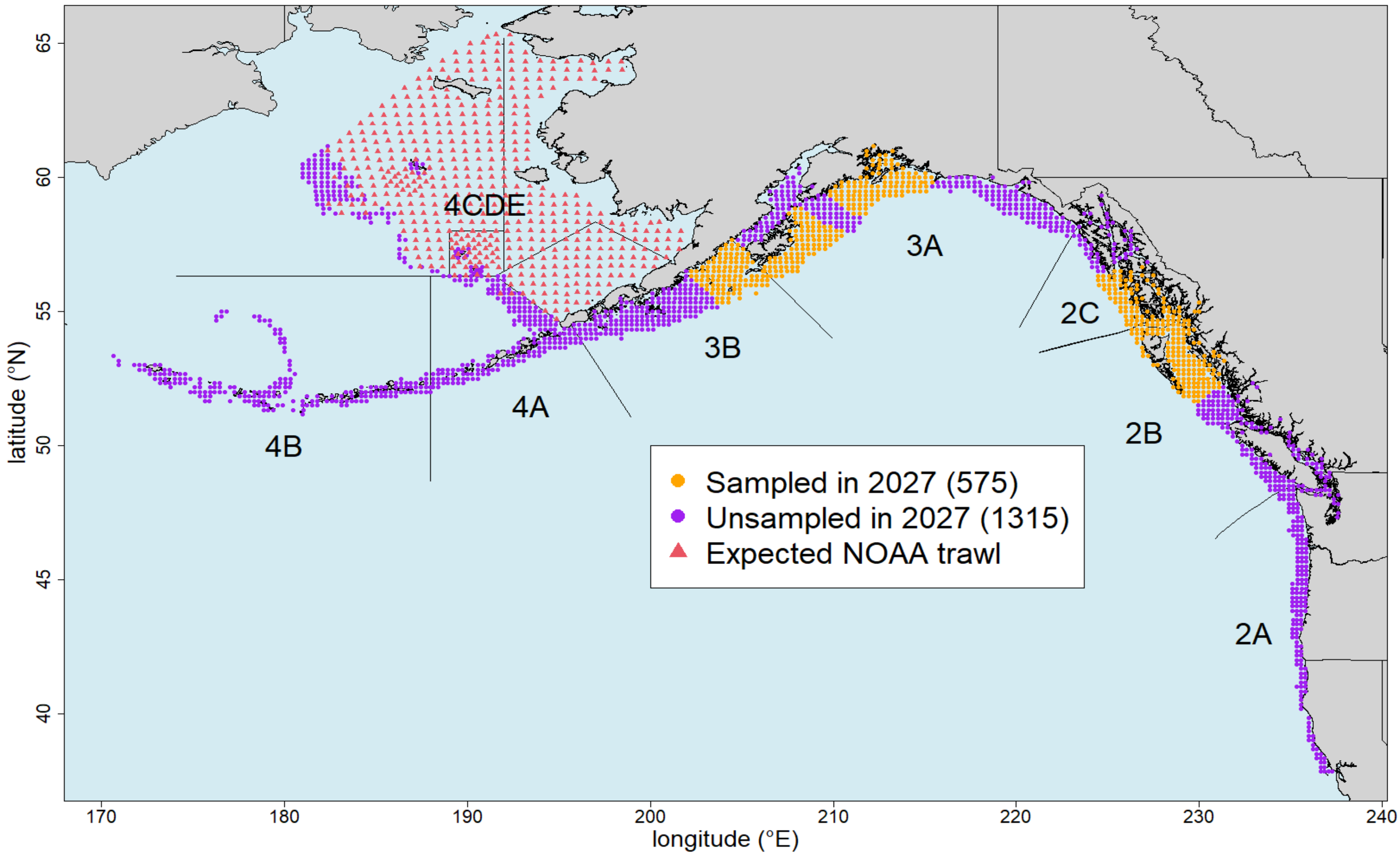


Figure 11. Core Block design for 2027 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

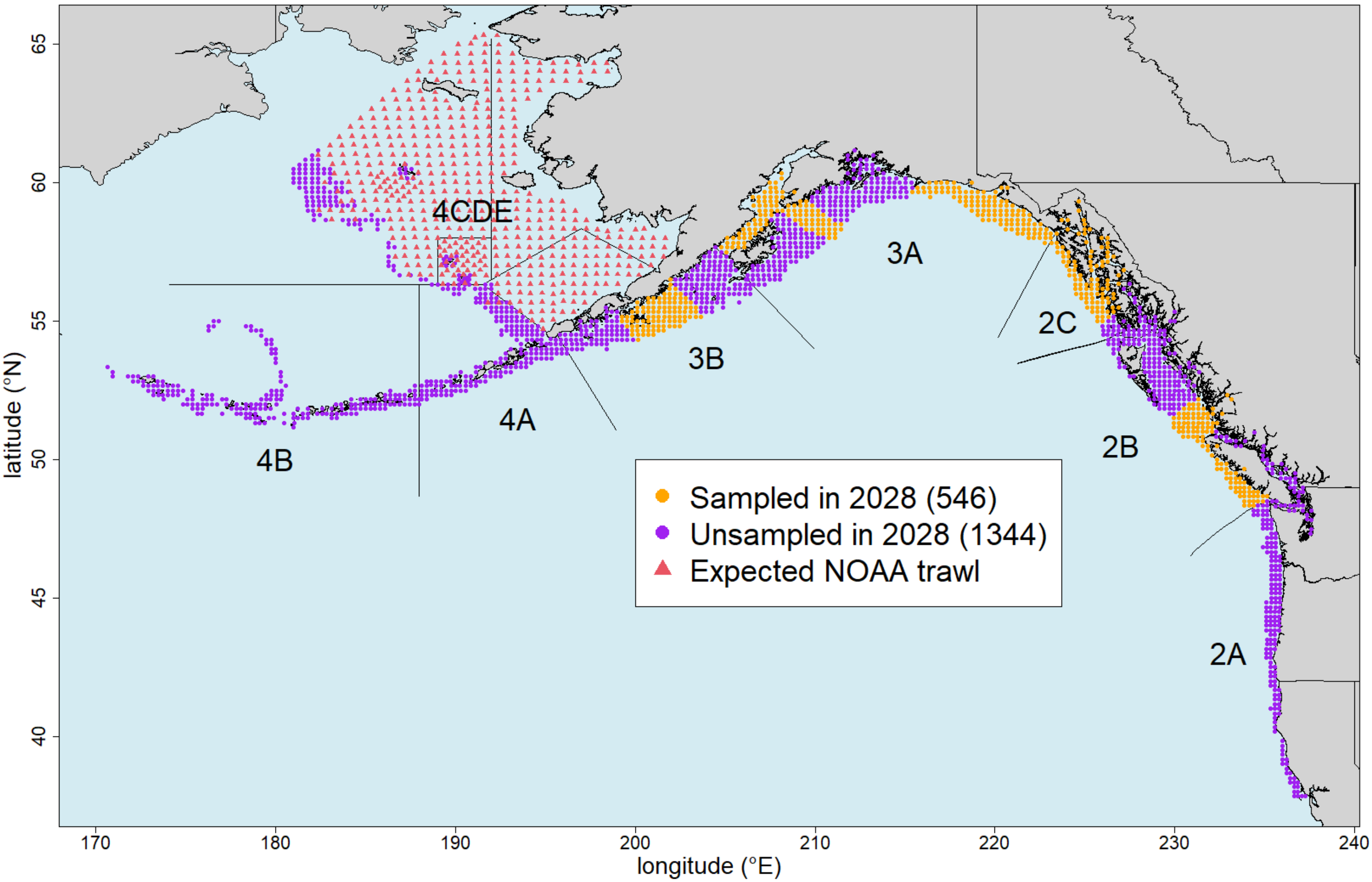


Figure 12. Core Block design for 2028 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

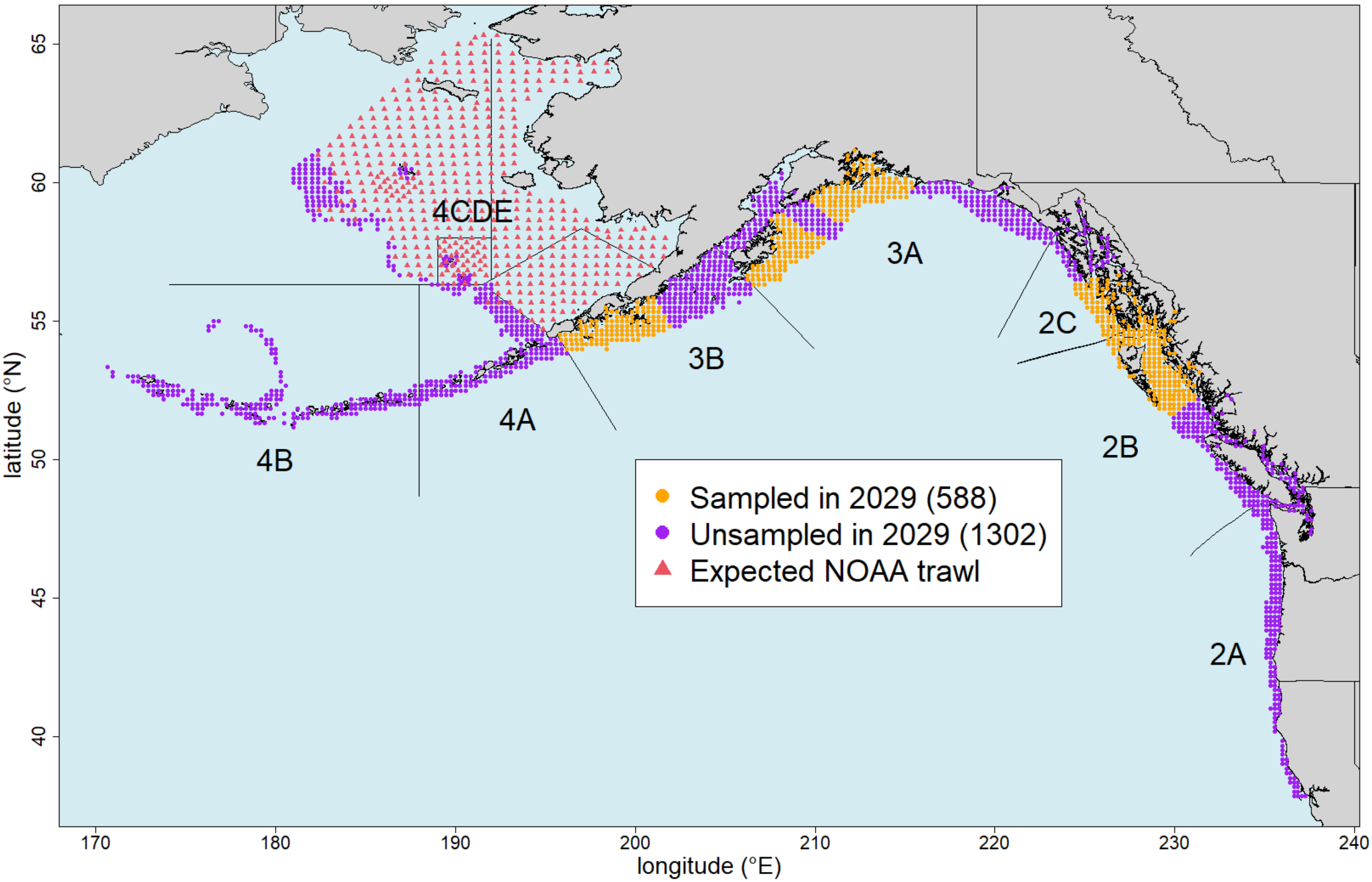


Figure 13. Core Block design for 2029 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

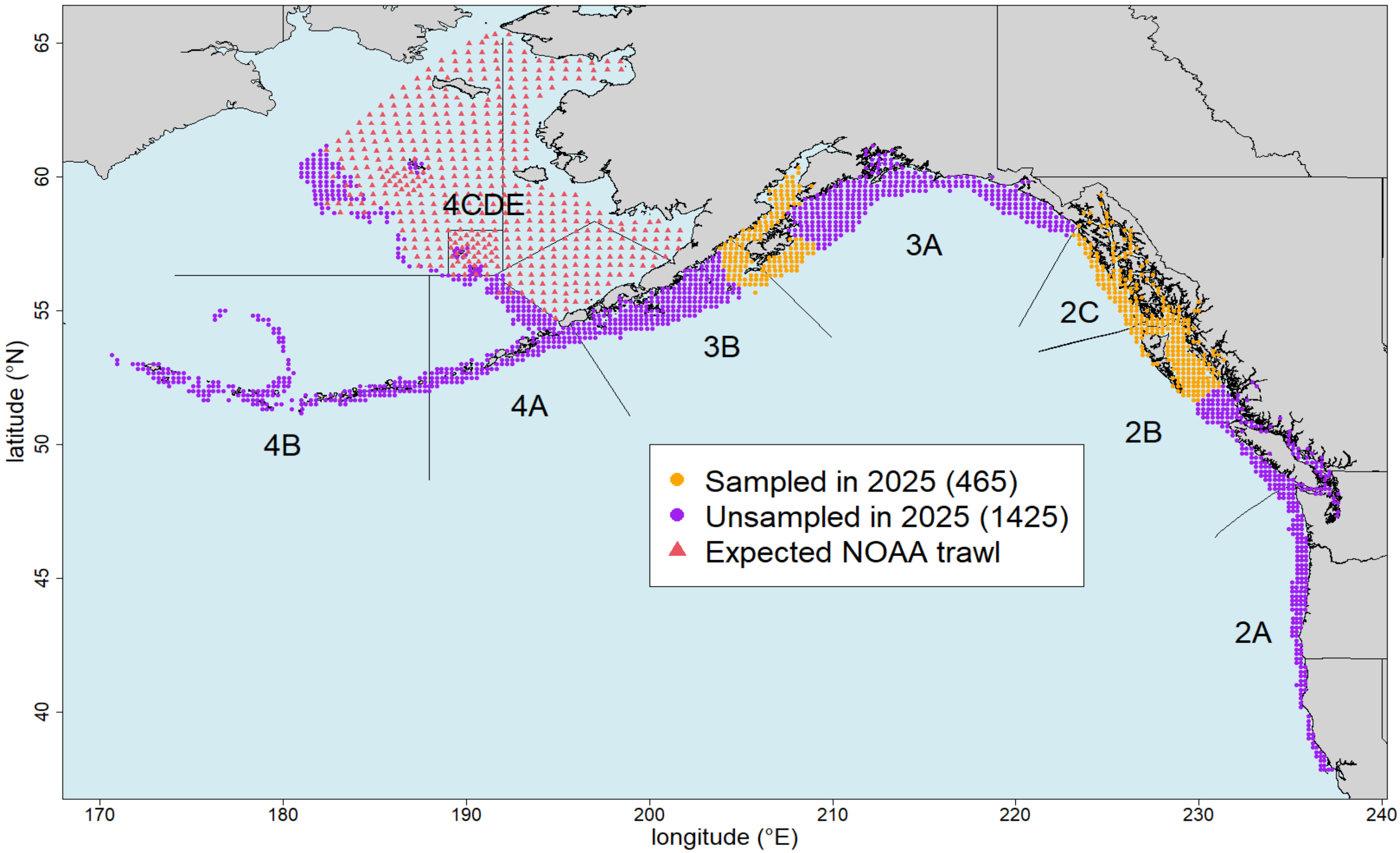


Figure 14. Reduced Core design for 2025-29 (orange circles). Design is based on fishing only the current highest revenue blocks of stations in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

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

PREPARED BY: IPHC SECRETARIAT (B. HUTNICZAK, J. FORSBERG, K. SAWYER VAN VLECK, & K. MAGRANE; 22 AUGUST 2024)

PURPOSE

This document summarizes the information available on the use of artificial intelligence (AI) for determining the age of fish from images of collected otoliths and provides an update on the exploratory work of implementing an AI-based age determination model for Pacific halibut.

The purpose of this document is twofold. First, to provide a background in support of developing a protocol for creating a database of pictures with expert-provided labels for ageing use. Second, to propose an AI-based modeling approach for supplementing current Pacific halibut ageing protocol.

BACKGROUND

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

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

This manual ageing process is expensive, time-consuming,[1] and can be subject to bias[2] as well as imprecision due to variations in age estimations between readers and within readers over

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

[2] While the count of annual rings on Pacific halibut otoliths was found to provide unbiased age estimate using validation against bomb radiocarbon isotopes (Piner & Wischniowski, 2004), an earlier oxytetracycline (OTC) mark-

time. Recent advances in imaging technologies and machine learning suggest that AI can assist in this process by automating the analysis of otolith images[3] and identifying and measuring the growth rings to determine age. AI algorithms can be trained on a large dataset of otolith images with known ages to learn the patterns and variations in growth rings. Once trained, the AI model can analyze new otolith images and predict the age of the fish based on the identified patterns in the image.

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

MODEL

The model framework (Figure 1) includes a continuous process of training the model using available labelled data (aged otoliths), querying the model to select the next sample, labeling or relabeling the selected sample, and enriching the model with newly labelled samples.

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

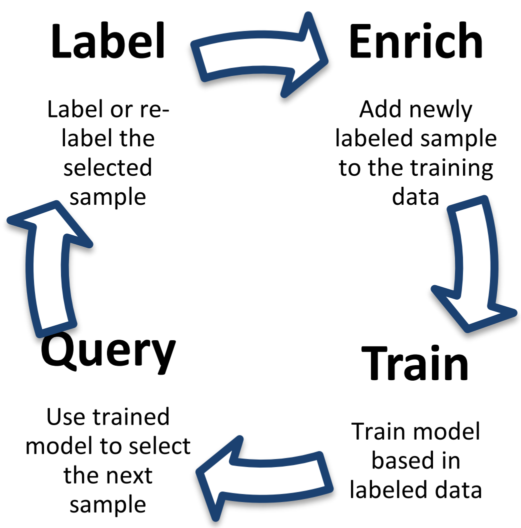


Figure 1. Model framework.

recapture study indicated biases among age readers (Blood, 2003). In the 1980s, the IPHC applied injections with the antibiotic oxytetracycline (OTC) during routine tagging operations to evaluate validity of ageing method (IPHC, 1985). Upon injection, the OTC is absorbed by the fish's bony structure, including the otoliths, and leaves a mark that is easily seen when viewed under an ultraviolet light. When an OTC-injected tagged fish is recovered, the otoliths are removed and examined under the ultraviolet light. By comparing the number of annuli laid since the OTC mark to the fish recovery, the accuracy of the age readings can be determined.

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

Modeling approach

Previous literature (see perspective piece by Malde et al., 2020) suggests adapting a pre-trained convolutional neural network (CNN) designed for image classification to estimate age using otolith images obtained via microscope camera. This type of model is trained on a large collection of images of otoliths previously aged by human readers. Moen et al. (2018) presents the first case of the use of deep learning and CNN to estimate age from images of whole otoliths of Greenland halibut (*Reinhardtius hippoglossoides*).[4]

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

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

In CNNs (LeCun et al., 1998; Simonyan & Zisserman, 2015), the layers are structured as stacks of filters, each recognizing increasingly abstract features in the data. Convolutional layers may be understood as an efficient way to transform an input image into another image, highlighting meaningful patterns, learned from data during training. The training is sequential, meaning the output of each layer is the input of the next layer, and the useful features are learned in the various layers during training. This approach is very effective for many image analysis problems, where objects are often recognized independent of their location. During network training, the performance is monitored over sequential epochs. Epochs represent the number of times that the training dataset is passed forward and backward through the network to refine model weights. Whenever the validation loss decreases, the trained model is saved, ending up with the network that corresponds to the minimum loss and highest accuracy on the validation set. The trained network is then evaluated on the testing set.

In the CNN model, prediction of age can be defined as a classification task (age as a class category) or image regression, that is a task of predicting a continuous variable from an image, in this case prediction of age as a numeric value from an otolith image. Both approaches can be tested for devising a method better suited for Pacific halibut. Considering fish age as a discrete parameter is a common approach used to identify the individual year class, i.e. grouping fish originating from the spawning activity in a given year (Moen et al., 2018), although this may be

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

less appropriate for long-living species with a larger number of age categories in the sample. The oldest Pacific halibut on record were aged at 55 years (Keith et al., 2014).

Software options

The proposed approach follows that of (Moen et al., 2018; Moore et al., 2019) who chose TensorFlow and Keras libraries to implement and train the model. TensorFlow is currently the largest and most popular library available for deep learning. Keras is a high-level API which runs on top of TensorFlow and simplifies implementation of TensorFlow models.

The approach uses a transfer-learning technique to develop a CNN for otolith age estimation. Transfer learning is the process of repurposing a machine learning model that has been pre-trained for another, related, task. Specifically, it starts with the Inception v3 model from Google, pre-trained on the ImageNet database. ImageNet database contains over 14 million (14,197,122) annotated images classified intro 1000 categories. The CNN layers are loaded with pre-trained (with ImageNet data) and publicly available weights, as opposed to using random initialization. Various training meta-parameters contribute substantially to final accuracy by using a stochastic gradient descent (SGD) optimizer and by leaving all network layers as trainable.

For the application to otolith ageing for Pacific halibut, the input layer was scaled to match the images' resolution.[5] The output layer was changed from a multi-dimensional output vector representing class probabilities to a single numeric output, effectively transforming it to a new regression layer.[6] This design follows the following pattern: Input → InceptionV3 (feature extractor) → Classifier/Regressor → Output. At this point, the neural network is trained to minimize the mean squared error (MSE) between predicted ages and human expert age estimates,[7] using the otolith images as inputs.

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

Use of auxiliary data

Precision of age predictions of otoliths using neural networks from geometric features could be potentially improved by using auxiliary data, for example, fish size or date and location of capture (Moen et al., 2018). Past IPHC work suggests a good deal of spatial variation in Pacific halibut growth ring patterns. This points to the importance of good spatial coverage in the training sample. Additionally, the project plans to explore the use of additional spatial covariates for better

[5] Resolution is the total number of pixels along an image's width and height, expressed as pixels per inch (PPI). The Inception v3 model processes images that are 299 x 299 pixels in size. The original images, which were 2548 x 2548 pixels, were resized to 400 x 400 pixels.

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

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

age prediction. Other available auxiliary data include year collected, which could be applied to account for variation between cohorts and prevalent environmental conditions throughout the aged fish life histories, and the collection dates, which provides insights into seasonal variation to the interpretation of the otolith edge.

Performance metrics

Performance of the CNN to correctly assign ages (rounded output of the regression layer) to otolith images in the test set is assessed via the root mean squared error (RMSE). Moen et al., (2018) also suggest calculating coefficient of variation (CV).[8]

For the production set, accuracy could be further refined using a mixed-method approach. A minimum number of otoliths (e.g., 10%) could be reexamined by human readers after the selection based on the model-derived confidence intervals, targeting samples where the confidence is low. The final bias relevant to products such as stock assessment could integrate the predicted age estimates derived following the re-label phase. In practice, mixed-method approach would eliminate the need for human experts to read ‘easy’ otoliths, while maintaining human-based decision control over more ‘difficult’ otoliths.[9]

Achieved accuracy

Moen et al., (2018), for Greenland halibut, achieved MSE for the left and right otoliths and pair of 3.27, 2.71 and 2.99, respectively. Age was correctly estimated for 48 out of the 164 tested otolith-pairs (29%). In addition, 63 cases (38%) were estimated to be one year off the read age. There was also a clear tendency for the system to predict a lower age for older individuals, when compared to human readers. The variance of the predictions also increased with the age of the otolith.

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

The age model for Greenland halibut by Politikos et al., (2022) gave RMSE of 1.69 years between age prediction and age reading by experts (n=8218, 26 age categories). For Greek red mullet, correct age was predicted for 69.2% individuals, with an additional 28.2% being within 1 year of error (n=5027).

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

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

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

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

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

Database

The IPHC annually ages a considerable number of otoliths (see *Appendix B* for details). Since 1925, over 1.5 million otoliths have been aged and stored for potential future use. Otoliths collected by the IPHC for ageing purposes undergo additional processing. Otoliths are sectioned (broken in half) and baked to enhance the contrast between the growth rings. These stored and previously aged otoliths serve as a valuable resource for creating a database of images for training purposes. To optimize model training, the selection of otoliths included in the model covers a broad spectrum of fish sizes, ages, sexes, and collection locations.

Before photographing, processed otoliths were placed in a monochrome tray featuring an elongated groove designed to keep the otolith upright and immersed in water. The pictures were taken with AmScope 8.5MP eyepiece cameras,[11] under consistent lighting conditions and magnification. The input database includes images of standardized size, 2548 by 2548 pixels, which are later resized to the desired resolution based on the model's specification.[12]

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

Figure 2 shows an example of a range of images used in the CNN training dataset.

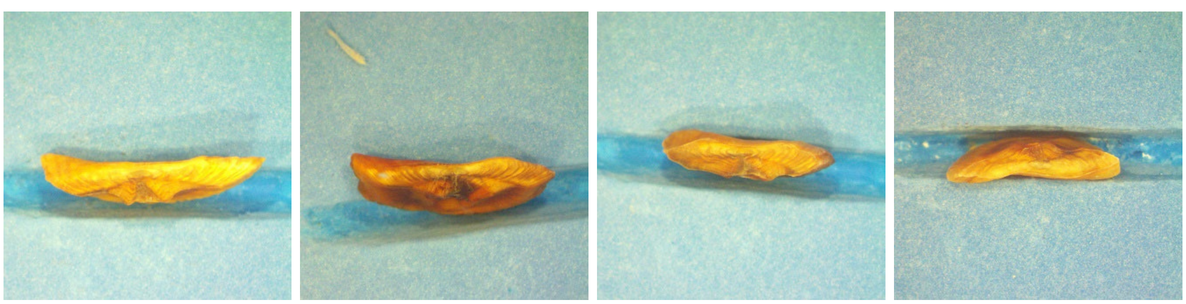


Figure 2. Examples of Pacific halibut otolith images taken for inclusion in the training set.

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

[12] Moen et al. (2018) used images 400 by 400 pixels, which required the input layer to be scaled to match the images size as Inception v3 classifies by default images with a size of 299 by 299 pixels. Ordoñez et al. (2020), using the same set of images, built a CNN with images resized to 224 by 224 pixels, the default input of the VGG-19 model. Higher resolution images offer the flexibility to adapt the model in the future to more detailed and complex image analysis tasks, potentially improving the accuracy and effectiveness of image recognition capabilities.

Note: In due course, the IPHC will create a database comprising labelled images of otoliths both pre- and post-processing and conduct a cost-benefit analysis of processing the otoliths for ageing using AI. The analysis will look at the accuracy improvement when using an image database containing images of processed (broken and baked) otoliths with enhanced contrast vs. those captured prior to processing (i.e. whole otoliths). In their research, Politikos et al. (2022) utilized digital images of otoliths that were not subject to any additional processing in the laboratory, immersed in water and placed under a stereomicroscope on a white background with transmitted light. However, it is important to note that even if results indicate that breaking and baking is not necessary for age determination using AI, a subsample chosen for the Label and Enrich phases would have to be fully processed for age determination with traditional methods by an expert reader.

Presorting otoliths

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

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

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

Image collection

The image collection is associated with labels storing:

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

[13] Crystalized otoliths have an altered composition – specifically, where the aragonite in the otolith is partially or mostly replaced by vaterite, a phenomenon known as otolith crystallization. Crystallized otoliths are not suitable for ageing.
[14] About 1% of otoliths are partly crystallized and are assigned ages. The same is true for broken otoliths that are aged (1%)
[15] IPHC is currently using genotyping for Pacific halibut sex determination.

PRELIMINARY RESULTS

The latest model run utilized 2,682 images of otoliths collected during the 2019 IPHC fishery-independent setline survey (FISS). The 2019 FISS offers a valuable starting point for image database creation, being the most recent extensive survey expected to have captured the regional differences in otoliths, providing a robust dataset for initial modeling efforts.

The images were divided into training, validation, and test datasets. The training set (1,595) was used for training purposes. The validation set (282) was used to evaluate the model during the training process, allowing for adjustments without using the test set, which was reserved for the final evaluation. The test dataset (30%, 805) was used to assess the performance of the model after training, providing an unbiased evaluation of its generalization capability to new, unseen data. Additional set of 91 images (referred to as secondary test set) was used to compare the results between different model configurations. All images were resized to 400x400 pixels. Images of broken otoliths were excluded. The number of epochs was set to 1000, with EarlyStopping applied and patience set to 100. Learning rate was set to 0.0002 and batch size to 16.

Normalized age MSE in training set was 0.000198 and 0.0015 in validation set. The model was trained for 417 epochs (i.e., 317 effective epochs with patience=100). The model achieved RMSE in the test set of 1.90, and 1.94 when applied to rounded results. Correct age was predicted for 30.3% individuals, with an additional 40.7% being within 1 year of error. Figure 3 shows accuracy adjustment over the training process, while Figure 4 compares manually-derived age with AI predicted age. Figure 5 compares age composition derived manually with model predictions.

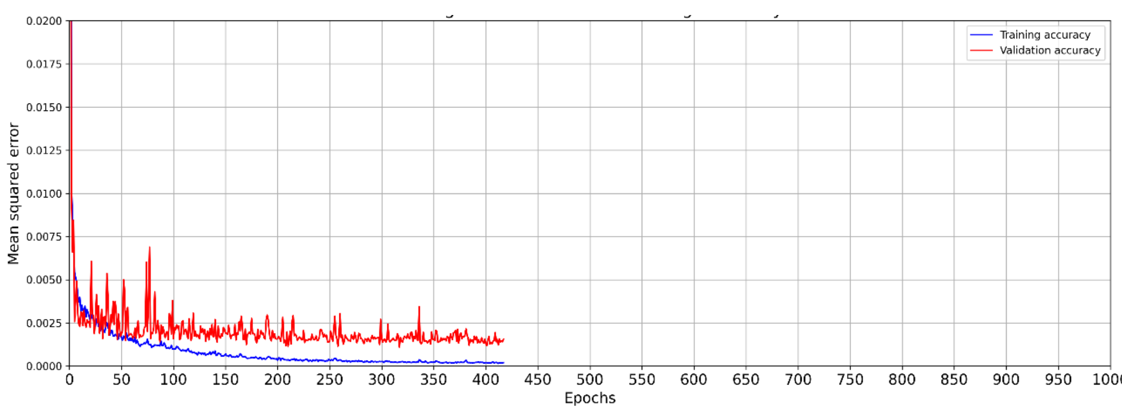


Figure 3. Age accuracy (measured as normalized age MSE) throughout the training process.

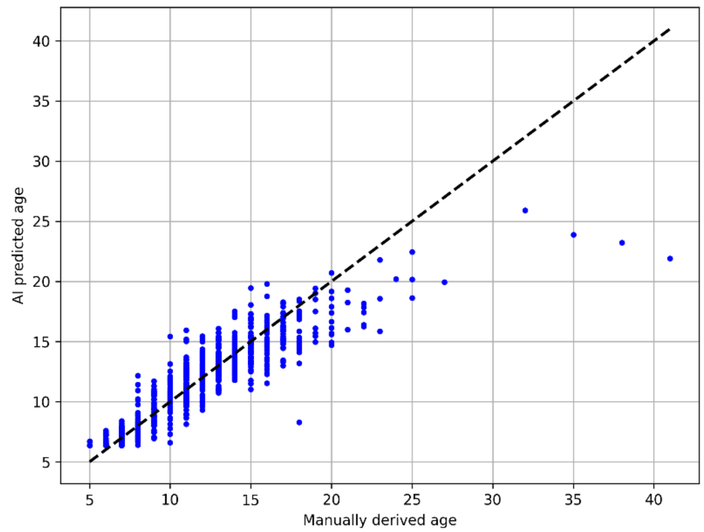


Figure 4. Comparison between manually derived age with AI predicted age.

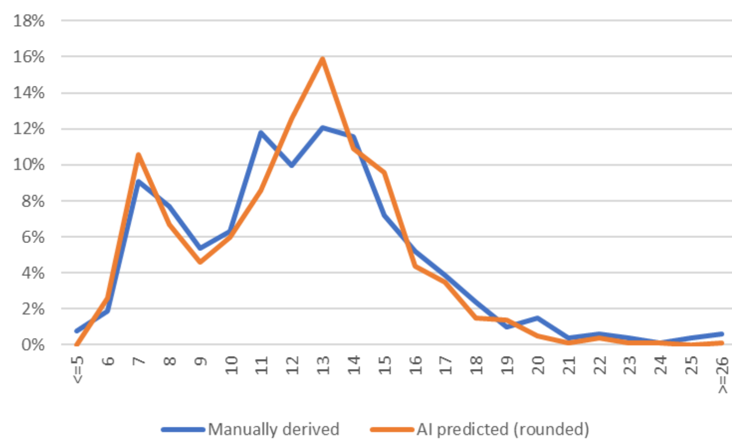


Figure 5. Comparison between manually derived age with AI predicted age – age composition.

ALTERNATIVE MODEL CONFIGURATION

The SRB recommended (SRB024–Rec.13, para. 42) that the Secretariat investigate:

a) Fitting a power function to the AI/CNN vs manual age determination to show how bias increases with age;
b) Training the model with more otoliths from older age classes;
c) Alternative objective functions that put more weight on correctly estimating ages of older individuals;

To further investigate bias in AI-based Pacific halibut age determination, a separate model configuration was tested using alternative objective functions that prioritized accurate age estimation for older individuals. This was accomplished by modifying the loss function to incorporate a weighting scheme based on the logarithm of age.

The alternative model configuration resulted in a slightly higher RMSE (1.945 vs. 1.940 for rounded results) and a lower percentage of correctly predicted ages (28.6% vs. 30.3%), while showing a marginally lower RMSE for older fish (6.24 vs. 6.25 for fish aged 20+). Figure 6 presents a comparison of results between the standard and alternative setups, derived from the secondary test set, along with power function trend lines. The results indicate a degree of bias at older ages. However, it should be noted that statistically significant bias was observed only in age categories 16+, where the number of observations remains low despite an overall increase in sample size (Figure 7). This suggests that the saturation point for achieving optimal accuracy in older age categories may not yet have been reached, and the model could benefit from further improvement by adding more images representing older age categories to the training set. Currently, only 4% of the otoliths used in the model were from fish aged 20 or older.

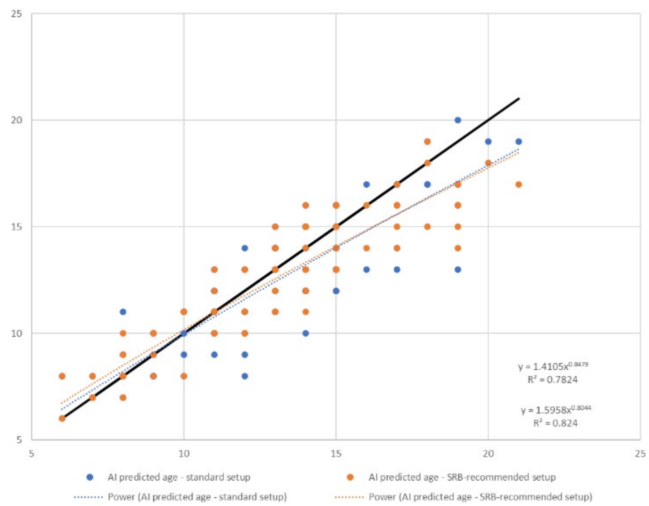


Figure 6. Comparison of results between standard setup and alternative setup derived for secondary test set.

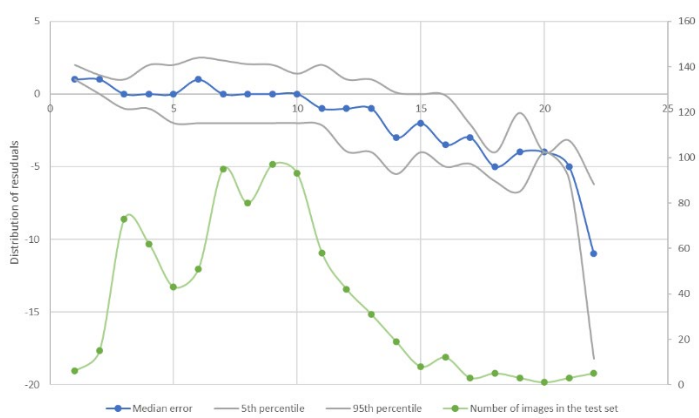


Figure 7. Distribution on residuals and number of images by age in the test set.

Conclusions

In conclusion, the ongoing advancement of AI technologies in the field of marine science offers considerable potential to enhance the efficiency of age determination of Pacific halibut using otolith images. Preliminary results presented here suggest that AI could serve as a promising alternative to the current ageing protocol, which relies entirely on manual age reading. AI is also evolving rapidly, and adapting to new developments may further improve results over time However, it is important to continue verifying whether achieved accuracy of CNN-based predictions do not learn biased prediction rules based on changes in the relationship between age and covariates used by the model, noise or other irrelevant imaging artefacts present in the data (Ordoñez et al., 2020). Therefore, it is key to continuously diagnose performance problems and find ways to fix them (Belcher et al., 2023; Norouzzadeh et al., 2018). Moreover, the automated ageing process will still depend on trained readers for training the model with inputs that capture temporal changes, which is increasingly important in the face of changing environmental conditions and climate change.

LITERATURE

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

Belcher, B. T., Bower, E. H., Burford, B., Celis, M. R., Fahimipour, A. K., Guevara, I. L., Katija, K., Khokhar, Z., Manjunath, A., Nelson, S., Olivetti, S., Orenstein, E., Saleh, M. H., Vaca, B., Valladares, S., Hein, S. A., & Hein, A. M. (2023). Demystifying image-based machine learning: a practical guide to automated analysis of field imagery using modern machine learning tools. *Frontiers in Marine Science*, *10*(June), 1–24. https://doi.org/10.3389/fmars.2023.1157370

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

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

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

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

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

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

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

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

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

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

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

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

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

Norouzzadeh, M. S., Nguyen, A., Kosmala, M., Swanson, A., Palmer, M. S., Packer, C., & Clune, J. (2018). Automatically identifying, counting, and describing wild animals in camera-trap images with deep learning. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(25), E5716–E5725. https://doi.org/10.1073/pnas.1719367115

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

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

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

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

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

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

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

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

APPENDIX A
COUNTS OF OTOLITHS AGED BY THE IPHC

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

1998	surface/BB	8,587	14,395	1,145	98		
1999	surface/BB	11,971	12,858	3,029	70	3,672	
2000	surface/BB	14,122	13,982	1,209	46	2,706	
2001	surface/BB	14,731	13,181	2,952	27	2,609	
2002	BB	13,635	17,932	761	24	2,349	
2003	BB	12,626	13,915	3,876	79	2,754	
2004	BB	14,474	11,798	897	450	3,288	
2005	BB	12,651	14,650	2,028	643	3,183	
2006	BB	14,976	13,399	2,621	679	3,179	
2007	BB	16,285	13,964	3,930	455	3,026	
2008	BB	15,545	13,460	1,527	304	1,500	
2009	BB	15,706	13,583	4,922	276	1,500	
2010	BB	14,080	16,106	1,915	21	1,500	625
2011	BB	14,451	11,391	4,592	26	1,500	676
2012	BB	17,896	12,902	1,639	9	1,500	1164
2013	BB	12,717	11,039	2,044	19	1,503	1020
2014	BB	16,194	12,606	1,476	22	1,500	1096
2015	BB	15,815	12,312	2,133	24	1,500	1072
2016	BB	15,113	11,618	742	21	1,502	902
2017	BB	12,565	10,821	1,384	15	1,500	756
2018	BB	12,935	11,013	576	39	1,499	798
2019	BB	17,716	10,711	1,640	34	1,497	925
2020	BB	10,323	10,568		34	1,413	577
2021	BB	12,253	11,051	1,444	38	1,500	547
2022	BB	9,702	10,942	1,902	39	2,334	519
2023	BB	8,506	10,932	(3,147)		(1,958)	

Notes:

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

INTERNATIONAL PACIFIC HALIBUT COMMISSION

INTERIM: HARVEST STRATEGY POLICY

(2024)

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

Commissioners

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

Executive Director

David T. Wilson, Ph.D.

DISTRIBUTION:
Members of the Commission
IPHC Secretariat

BIBLIOGRAPHIC ENTRY
IPHC 2024. Interim: IPHC Harvest Strategy Policy
IPHC–2024–HSP, 17 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: https://www.iphc.int/

NOTE: The following is an interim document based on an amalgamation of current IPHC practices and best practices in harvest strategy policy. It is not intended to be a definitive policy, noting that the IPHC is yet to adopt a formal harvest strategy for Pacific halibut. It is expected that over the coming year, the IPHC will develop and implement a harvest strategy, and that this policy document will then be updated accordingly.

ACRONYMS

HCR	Harvest Control Rule
HSP	Harvest Strategy Policy
IPHC	International Pacific Halibut Commission
LIM	Limit
MP	Management Procedure
MSAB	Management Strategy Advisory Board
MSE	Management Strategy Evaluation
NER	Net economic returns
OM	Operating Model
SB	Spawning Biomass (female)
SPR	Spawning Potential Ratio
SRB	Scientific Review Board
TCEY	Total Constant Exploitable Yield
THRESH	Threshold
U.S.A.	United States of America

DEFINITIONS

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

TABLE OF CONTENTS

Chapter 1 INTRODUCTION

The *IPHC Harvest Strategy Policy* (HSP) provides a framework for applying a consistent and transparent science-based approach to setting mortality limits for Pacific halibut (*Hippoglossus stenolepis*) fisheries throughout the Convention Area while ensuring sustainability of the Pacific halibut population.

It defines biological and economic objectives that apply to the development of a harvest strategy for Pacific halibut. It also identifies reference points for use in the harvest strategy to achieve the Commission's stated objectives. This policy, together with the *Protocol amending the Convention between Canada and the United States of America for the preservation of the [Pacific] halibut fishery of the northern Pacific Ocean and Bering Sea (1979)*[1], provides the basis to manage the risk to Pacific halibut fisheries and the Pacific halibut population.

A harvest strategy developed under this policy will take available information about the Pacific halibut resource and apply a consistent and transparent science-based approach to setting mortality limits. A harvest strategy consistent with this policy will provide all interested sectors with confidence that the Pacific halibut fisheries are being managed for long-term economic viability while ensuring long-term ecological sustainability of the Pacific halibut population. The implementation of a clearly specified harvest strategy will also provide the fishing industry with a more certain operating environment.

1.1 SCOPE

The IPHC Harvest Strategy Policy applies to the Pacific halibut population managed by the IPHC, and where overlap with domestic jurisdictional management exists (e.g. managed jointly by the IPHC and Contracting Party domestic agencies) the IPHC will seek to apply and encourage the adoption of this policy in negotiating and implementing joint or cooperative management arrangements.

The IPHC is responsible for determining the mortality limit in each of eight (8) IPHC Regulatory Areas (Figure 1). The mortality limit in each IPHC Regulatory Area consists of all fishing mortality of all sizes and from all sources, except for discard mortality of under 26-inch (U26) Pacific halibut from non-directed commercial fisheries. This mortality limit without U26 non-directed commercial discard mortality has been termed the Total Constant Exploitation Yield, or the TCEY, but mortality limit is used here.

Mortality limits for each sector within an IPHC Regulatory Area, and all sizes of non-directed commercial discard mortality, are determined by Contracting Party domestic agencies. Therefore, this Harvest Strategy Policy is specific to the mortality limit in each IPHC Regulatory Area.

[1] https://www.iphc.int/uploads/pdf/basic-texts/iphc-1979-pacific-halibut-convention.pdf

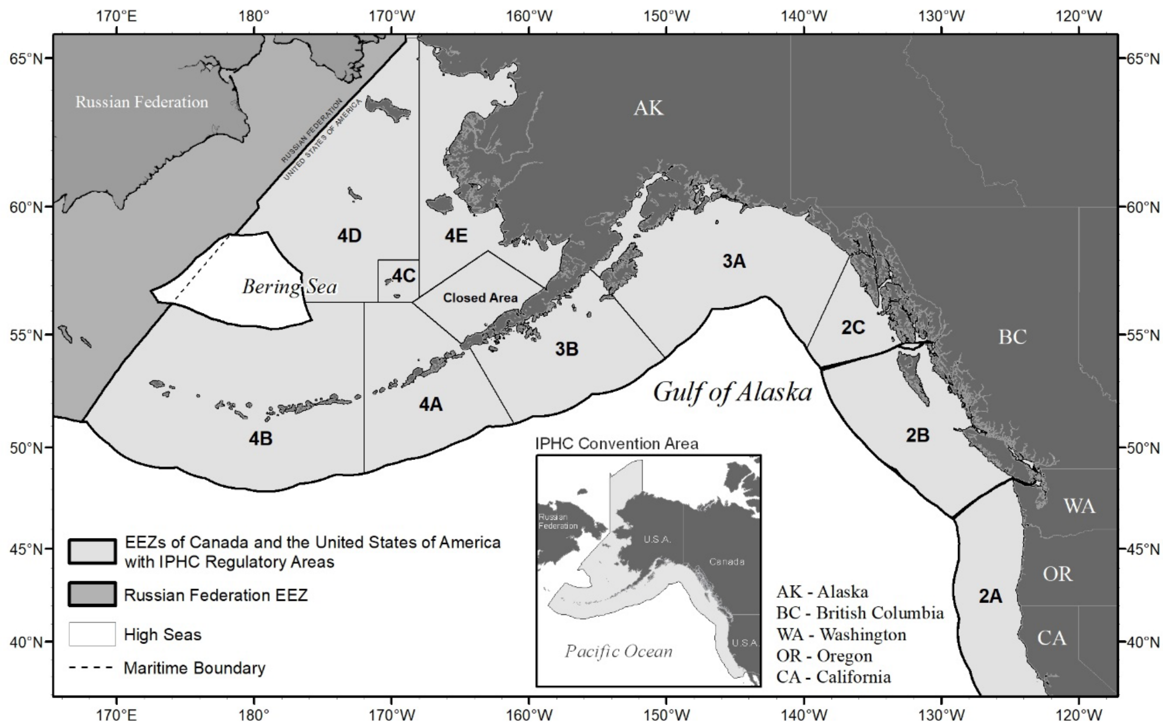


Figure 1. IPHC Regulatory Areas where 4C, 4D, 4E, and the closed area are considered one IPHC Regulatory Area (4CDE). The IPHC Convention Area is shown in the inset.

1.2 What is a Harvest Strategy Policy (HSP)?

Being a framework, the harvest strategy policy encompasses the entire process of the harvest strategy and decision-making process to determine mortality limits (Figure 2) as well as other important considerations such as objectives, key principles, and responses to specific events. To determine mortality limits, the process begins with determining the coastwide scale of fishing mortality (the MP) followed by the process for distributing the TCEY among IPHC Regulatory Areas (part of the harvest strategy). The final step of the HSP, which is not part of the MP, is the decision-making process that occurs at the Annual Meeting of the IPHC. The final mortality limits may deviate from those determined from the management procedure, resulting in less transparency in the process.

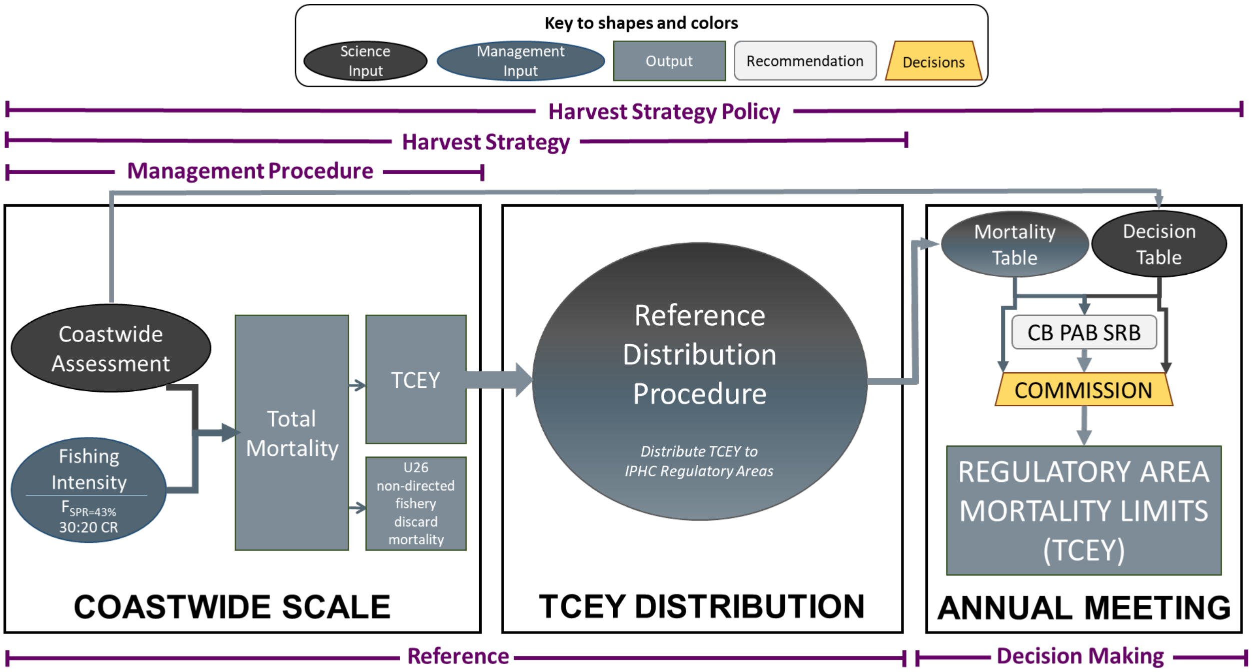


Figure 2. Illustration of the interim IPHC harvest strategy policy process to determine mortality limits showing the coastwide scale component as the management procedure along with the TCEY distribution component that comprise the harvest strategy. The TCEY distribution and Annual Meeting components make up the Commission decision-making process, which considers inputs from many sources and may deviate from the management procedure.

1.3 WHAT IS A HARVEST STRATEGY?

A harvest strategy, which may also be referred to as a management strategy, is the decision framework necessary to achieve defined biological and economic objectives for Pacific halibut. A harvest strategy will outline:

- Objectives and key principles for the sustainable and profitable use of Pacific halibut.
- Reference points and other quantities used when applying the harvest strategy.
- Processes for monitoring and assessing the biological conditions of the Pacific halibut population and economic conditions of Pacific halibut fisheries in relation to biological and fishery reference levels (a reference point or points).
- Pre-determined rules that determine fishing mortality according to the biological status of the Pacific halibut stock and economic conditions of the Pacific halibut fishery (as defined by monitoring and/or assessment). These rules are referred to as harvest control rules or decision rules.

A management procedure (MP) contains many of the components of a harvest strategy and is sometimes synonymous with harvest strategy. Here, we define an MP as different from a harvest strategy in that each component of an MP is more formally specified and has been shown to meet the objectives through simulation testing while also being robust to uncertainty and variability. Harvest strategy is a more general concept and refers to the entire process needed for determining reference mortality limits (i.e. the TCEY for each IPHC Regulatory Area) that are then subject to the decision-making step. Some steps, such as the distribution of the TCEY, may not have been simulation tested and are subject to negotiation and decision-making. Simulation testing MPs using MSE models with decision-making variability ensure that a harvest strategy policy is robust to this uncertainty.

Management Procedure (MP): A formulaic procedure to determine a management outcome (e.g. mortality limit) that has been simulation tested and produces a repeatable outcome.

Harvest Strategy: The entire process to produce endpoint reference management outcomes (e.g. TCEYs for each IPHC Regulatory Area) which may have some components that are not simulation tested and subject to uncertainty. This outcome informs the decision-making process.

Chapter 2 OBJECTIVES AND KEY PRINCIPLES

A goal of the IPHC Harvest Strategy Policy is the long-term sustainable and profitable use (optimum yield) of Pacific halibut through the implementation of a harvest strategy that maintains the stock at sustainable levels while maximising economic returns.

To achieve this goal the IPHC will implement a harvest strategy that minimises risk to the stock and pursues maximum economic yield (MEY) for the directed Pacific halibut fisheries. Maximising the net economic return from the fishery may not always equate with maximising the profitability of the fishery. Net economic return may consider inter-annual stability to maintain markets, and economic activity may also arise from recreational and Indigenous fishing, and the need to share the resources appropriately will be considered where necessary. Priority objectives to achieve this goal include:

- maintain Pacific halibut female spawning biomass, above a female spawning biomass limit where the risk to the stock is regarded as unacceptable (SB_{LIM}), at least 95% of the time;
- maintain Pacific halibut female spawning biomass, at least 50% of the time, at or above a reference (fixed or dynamic) female spawning biomass that optimises fishing activities on a spatial and temporal scale relevant to the fishery;
- optimise average coastwide yield given the constraints above;
- limit annual changes in the coastwide mortality limit (TCEY).

The harvest strategy will ensure fishing is conducted in a manner that does not lead to *overfishing*. Overfishing is defined as where the stock is subject to a level of fishing that would move it to an *overfished* state, or prevent it from rebuilding to a 'not overfished' state, within a specific time-frame and probability. Where it is identified that overfishing of the stock is occurring, action will be taken immediately to cease that overfishing and action taken to recover the overfished stock to levels that will ensure long-term sustainability and productivity to maximise NER.

The harvest strategy will also ensure that if the stock is overfished, the fishery must be managed such that, with regard to fishing impacts, there is a high degree of probability the stock will recover. If the stock is assessed to be below the female spawning biomass limit reference point (i.e. *overfished*), a stock rebuilding strategy will be developed to rebuild the stock to the limit female spawning biomass level, whereby the harvest control rules would then take effect to build the stock further to target female spawning biomass levels.

Overfished: when the estimated probability that female spawning stock biomass is below the limit reference point (SB_{LIM}) is greater than 50%.

Overfishing: where the stock is subject to a level of fishing that would move it to an overfished state, or prevent it from rebuilding to a '*not overfished*' state, within a specific time-frame and probability, to be determined.

Chapter 3 DEVELOPMENT OF THE HARVEST STRATEGY

The following requirements provide the basis for a transparent and systematic approach used when developing the harvest strategy to assist in meeting the objectives of the Harvest Strategy Policy.

3.1 ACCOUNTING FOR FISHING MORTALITY ON ALL SIZES AND FROM ALL SOURCES

The harvest strategy accounts for all known sources of fishing mortality on the stock and all sizes of Pacific halibut mortality, including directed commercial, recreational, subsistence, and fishing mortality under the management of another jurisdiction, such as non-directed fishing mortality. Discard mortality of released fish is accounted for using best available knowledge.

3.2 VARIABILITY IN THE ENVIRONMENT AND BIOLOGICAL CHARACTERISTICS

The productivity of Pacific halibut is affected by variability in the environment and by natural changes in biological characteristics. The environment fluctuates naturally and is altered due to climate change and other factors, which may affect biological characteristics such as size-at-age and recruitment of age-0 fish. The following types of variability were considered when developing the harvest strategy for Pacific halibut. Additional environmental linkages to the ecology and biology of Pacific halibut should be considered as knowledge improves.

- Variability in recruitment of age-0 Pacific halibut due to unknown causes
- Variability in average recruitment of age-0 Pacific halibut due to the environment (e.g. Pacific Decadal Oscillation, PDO).
- Variability in the distribution of age-0 recruits linked to the PDO.
- Changes in weight-at-age due to unknown causes
- Variability in movement throughout the Convention Area due to the environment (e.g. linked to the PDO).

The potential impacts of climate change were taken into account when developing the harvest strategy policy and future research on the potential effects of climate change on Pacific halibut fisheries and stocks will be incorporated as necessary.

3.3 MONITORING STANDARDS

[To be completed] This section describes standards for monitoring. For example, FISS, port sampling, catch monitoring, etc.

3.4 ESTABLISHING AND APPLYING DECISION RULES

The harvest strategy developed under this policy specifies all required management actions or considerations for Pacific halibut, at the stock or IPHC Regulatory Area level, necessary to achieve the ecological and economic management objectives for the fishery. Specifics are provided in Chapter 4.

3.5 Balancing risk, cost and catch

This policy establishes a risk-based management approach, which provides for an increased level of caution when establishing control rules in association with increasing levels of uncertainty about stock status.

In the context of this policy, the risk, cost, and catch trade-off, refers to a trade-off between the amount of resources invested in data collection, analysis and management of Pacific halibut, and the level of catch (or fishing mortality) applied. Fishing mortality should always be constrained to levels at which scientific assessment indicates Pacific halibut is not exposed to an 'unacceptable ecological risk' (that is the risk that stocks will fall below the limit reference point).

The management decision to be taken in this context is whether investment of more resources in data collection and analyses and/or additional management will increase the understanding of the risk to a species or stock from fishing and provide confidence in the sustainability of a higher level of fishing pressure or catch. In the absence of this additional information–and associated improved understanding of a stock, it may be necessary to reduce the fishing effort in order to manage the risk. Decisions about investment in managing risk versus the economic return of the catch taken will be transparently made, clearly documented and publicly available.

3.6 Reference points and proxies

A reference point is a specified level of an indicator used as a basis for managing Pacific halibut. The reference point should reflect acceptable levels of biological impact on the stock and the desired economic outcomes from the fishery. A reference point will often be based on indicators of either the total or female spawning stock size (relative or absolute spawning biomass), the amount of harvest (fishing mortality), or on other factors such as economic return from the fishery.

A harvest strategy for Pacific halibut shall be based on 'threshold' reference points and 'limit' reference points. A threshold reference point is a level that achieves the policy objectives if the indicator is at or above that level. When the stock is at or above a threshold reference point, optimal yield is possible. A biological limit reference point indicates a point beyond which the long-term health of the stock or the commercial fishery is considered unacceptable and should be avoided. Fishing when the Pacific halibut population is below the biological limit reference point places the Pacific halibut stock at a range of biological risks, including an unacceptable risk to recruitment and productivity, and an increased risk that the stock will fail to maintain its ecological function, although risk of extinction is not a major concern. A fishery limit reference point indicates a stock level below which the fishery is unlikely to remain profitable. Proxy reference points are described in Table 1.

Spawning biomass reference points may be dynamic or absolute calculations. A dynamic calculation pertains to relative spawning biomass (RSB) being relative to the spawning biomass that would have occurred if fishing had not occurred, but other variability had occurred (e.g. recruitment deviations, changes in size-at-age, etc). This measures the effect of only fishing, rather than the effect of fishing and the environment. An absolute spawning biomass is typically a specified spawning biomass level and may be presented as a number or a value estimated in a particular year. An absolute spawning biomass may be useful as a threshold reference point where being below would result in low catch rates and possibly other concerns. Currently there are no absolute spawning biomass reference points, but they may be a useful contrast to dynamic reference points.

Table 1. Proxy reference points

Reference point	Definition	Proxy
Threshold reference point SB_{THRESH}	The female dynamic spawning biomass level at maximum economic yield (SB_{MEY})	36% of the unfished spawning biomass ($SB_{36\%}$).
Biological limit reference point SB_{LIM}	The female dynamic spawning biomass level where the ecological risk to the population is regarded as unacceptable (i.e. at least 95 percent of the time)	20%of the unfished female spawning biomass ($SB_{20\%}$).

3.7 TECHNICAL EVALUATION OF THE HARVEST STRATEGY

A harvest strategy should be formally tested to demonstrate that it is highly likely to meet the objective and key principles of this policy, and outcomes of that testing should be made publicly available. Management strategy evaluation (MSE), a procedure where alternative management strategies are tested and compared using simulations of stock and fishery dynamics, is one of the best options to test harvest strategies. An MSE should incorporate variability and uncertainty, such as described in Section 3.2, structural uncertainty in operating models (OMs), and represent spatial fishing sectors appropriately. An accepted harvest strategy should, at a minimum, be evaluated using MSE and meet the priority objectives outlined in Chapter 2.

MSE involves determining objectives, identifying MPs to evaluate, simulating those MPs with a closed-loop simulation framework, evaluating the MPs to determine which one best meets the objectives, and finally adopting that MP as part of the harvest strategy. This process takes input from stakeholders through meetings of the Management Strategy Advisory Board (MSAB) and is reviewed by the IPHC Scientific Review Board (SRB).

3.8 RE-EVALUATING THE HARVEST STRATEGY AND MANAGEMENT PROCEDURE

A harvest strategy is a transparent and science-based approach to determining mortality limits and is meant to remain in place for many years. Frequent modifications or departures from the harvest strategy reduce the transparency and science-based approach. Therefore, it is important to specify, as part of the harvest strategy, time periods for re-evaluation of management procedures and to identify exceptional circumstances that would trigger a re-evaluation before that time period.

The IPHC currently operates of a schedule of three-years for full stock assessments, with update stock assessments in the intervening two years, and the MSE OM is updated following each full stock assessment to maintain consistent approaches and paradigms. Therefore, MPs are re-evaluated at a minimum of three years after implementation, if needed. An exceptional circumstance may trigger a re-evaluation before then and are defined as follows.

- The coastwide all-sizes FISS WPUE or NPUE from the space-time model is above the 97.5th percentile or below the 2.5th percentile of the simulated FISS index for two or more consecutive years.
- The observed FISS all-sizes stock distribution for any Biological Region is above the 97.5th percentile or below the 2.5th percentile of the simulated FISS index over a period of two or more years.
- Recruitment, weight-at-age, sex ratios, other biological observations, or new research indicating parameters that are outside the 2.5th and 97.5th percentiles of the range used or calculated in the MSE simulations.

Exceptional circumstances would be reviewed by the SRB to determine if one should be declared.

In the event that an exceptional circumstance is declared, the following actions are to be completed.

- A review of the MSE simulations to determine if the OM can be improved and MPs should be re-evaluated.
- Consult with the SRB and MSAB to identify why the exceptional circumstance occurred, what can be done to resolve it, and determine a set of MPs to evaluate with an updated OM.
- Further consult with the SRB and MSAB after simulations are complete to identify whether a new MP is appropriate.

MSE work is currently ongoing to supplement this interim harvest strategy policy. Current elements of MPs being investigated include not conducting a stock assessment every year and using an empirical rule based on the FISS WPUE in years without a stock assessment to determine the coastwide TCEY. With the harvest strategy currently being evaluated, updates to this interim harvest strategy policy may occur before three years.

Chapter 4 APPLYING THE HARVEST STRATEGY

4.1 JOINTLY-MANAGED DOMESTIC STOCKS

Consistent with the *Protocol amending the Convention between Canada and the United States of America for the preservation of the [Pacific] halibut fishery of the northern Pacific Ocean and Bering Sea* (1979), the IPHC will pursue the sustainable use of Pacific halibut within fisheries managed by other jurisdictions.

4.2 JOINTLY-MANAGED INTERNATIONAL STOCKS

The IPHC Harvest Strategy Policy does not prescribe management arrangements in the case of fisheries that are managed by a Party external to the IPHC Convention. This includes management arrangements for commercial and traditional fishing in the US Treaty Tribes and Canadian First Nations, that are governed by provisions within relevant Treaties. However, it does articulate the IPHC preferred approach.

4.3 STOCK ASSESSMENT

[To be completed] The stock assessment occurs annually, although a full stock assessment, investigating all aspects and potentially making major changes, occurs triennially. The stock assessment will include a summary of the data available for analysis, estimates of current stock size and trend relative to reference points, and short-term projections of various risk metrics (probability of stock decrease, probability of exceeding fishing intensity reference points, etc.) under different levels of future harvest.

4.4 COASTWIDE MORTALITY LIMIT

The coastwide mortality limit is determined using the stock assessment and a fishing intensity (i.e. F_{SPR}) defined by a harvest control rule (Figure 3). The stock assessment estimates the stock status which is used in the harvest control rule to determine if fishing intensity should be reduced from a reference SPR of 43%. The reference SPR is linearly reduced when the stock status is estimated below 30% and is set to 100% (no fishing for directed fisheries) when the stock status is estimated at or below 20%.

4.5 REBUILDING IF THE STOCK BECOMES OVERFISHED

If Pacific halibut is determined to be overfished (when the probability that female spawning stock biomass is below the limit reference point (SB_{LIM}) is greater than 50%), immediate action is required to cease directed fishing and rebuild the stock to levels that will ensure long-term sustainability and productivity, i.e. at or above SB_{LIM}. A rebuilding strategy must be developed to rebuild the stock to above its limit reference point, for agreement by the Commission. A rebuilding strategy will be required until the stock is above the limit reference point with a reasonable level of certainty (at least a 70% probability that the stock has rebuilt to or above the limit reference point). It must ensure adequate monitoring and data collection is in place to assess the status of the stock and rebuilding progress.

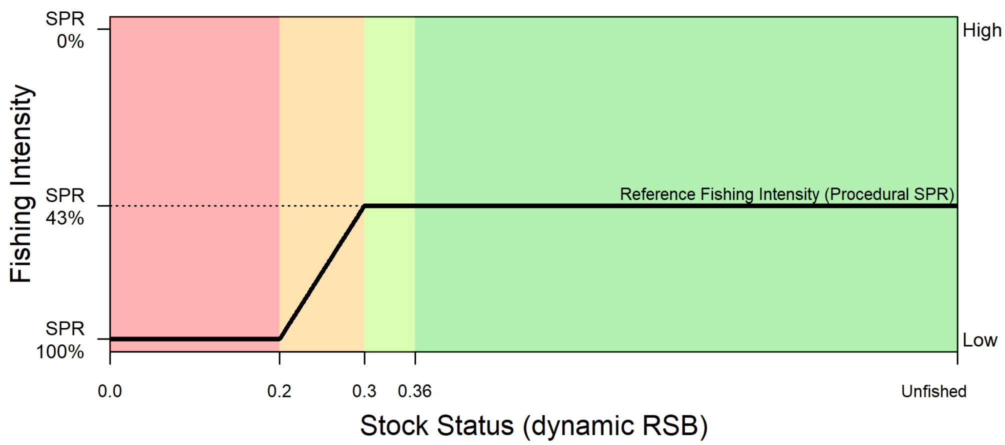


Figure 3. Harvest control rule for the fishing intensity (i.e. F_{SPR}) to determine the coastwide total mortality limit. The stock status is the dynamic relative spawning biomass (RSB) determined from the stock assessment. The reference fishing intensity is $F_{SPR=43\%}$, and is applied when stock status is above the trigger of 30%. SPR is linearly reduced between a stock status of 30% and 20%, and set to 100% when at or below 20% (no directed fishing). A stock status of 20% is also the reference point SB_{LIM}. The threshold RSB, 36%, is related to an objective to maintain the relative spawning biomass at or above $SB_{36\%}$ at least 50 percent of the time. Colours show the area below B_{LIM}, the area 'on the ramp', the area above the trigger and below SB_{THRESH}, and the area above SB_{THRESH}.

Directed fishing and incidental mortality of Pacific halibut, if determined to be overfished, should be constrained as much as possible to levels that allow rebuilding to the limit reference point (SB_{LIM}) within the specified timeframe. Once a stock has been rebuilt to above the limit reference point with a reasonable level of certainty, it may be appropriate to recommence directed fishing, and increase incidental mortality in line with the harvest strategy, noting that the usual harvest strategy requirements regarding the application of the harvest control rule and risk of breaching the limit reference point will apply.

The rebuilding strategy should note where sources of mortality exist that cannot be managed or constrained by the IPHC, and must take this mortality into account. Where practical and appropriate, the IPHC will work with other jurisdictions to ensure other sources of mortality from fishing are reasonably constrained consistent with any catch sharing arrangement.

When a rebuilding strategy is being developed, it must include performance measures and detail on how and when these measures will be reported on. Where there is no evidence that a stock is rebuilding, or is going to rebuild in the required timeframe and probability, the IPHC will review the rebuilding strategy and make the result of the review public. If changes to the rebuilding strategy are considered necessary, such changes should be made in a timely manner.

4.5.1 Rebuilding timeframes

Rebuilding timeframes are explicitly related to the minimum timeframe for rebuilding in the absence of commercial fishing. Rebuilding timeframes should take into account Pacific halibut productivity and recruitment; the relationship between spawning biomass and recruitment; and the stock's current level of depletion.

4.6 Mortality limits for each IPHC Regulatory Area

The final outputs of the harvest strategy policy before domestic management is applied are mortality limits for each IPHC Regulatory Area. This component (Figure 2) is part of the harvest strategy but is not part of the management procedure because it is subject to negotiation and decision-making. During this process, the coastwide mortality limit may change as well, which has been accounted for in the MSE by incorporating decision-making variability.

Reference mortality limits for each IPHC Regulatory Area are useful for the decision-making process. These are determined using the coastwide TCEY, stock distribution estimated from the FISS observations, and defined relative harvest rates for each IPHC Regulatory Area (1.0 for IPHC Regulatory Areas 2A, 2B, 3C, and 3A, and 0.75 for IPHC Regulatory Areas3B, 3A, 4CDE, and 4B). Using stock distribution provides insight into where biomass is distributed, and lower relative harvest rates in western areas protects biomass that may still move to eastern areas and may have lower sustainable harvest rates.

4.7 Common outputs used for decision-making

Two outputs are produced as part of the harvest strategy policy to assist the decision-making process at the Annual Meeting (Figure 2): a *mortality table* and a *decision table*.

Mortality table: The mortality table uses the output of the harvest strategy, mortality limits for each IPHC Regulatory Area, and defines the mortality limits for each sector within each IPHC Regulatory Area. Domestic catch-sharing plans and Commission agreements on projecting non-directed discard mortality are used to fill out the details. This table can be produced for any projected year, but is commonly presented for only the first projected year.

Decision table: The decision table is a stock assessment output that provides risk relative to stock trend, stock status, fishery trends, and fishery status for a range of coastwide mortality levels. The decision table is not dependent on the harvest strategy, although the reference F_{SPR} is a provided as a central point of the range and allocation of mortality among IPHC Regulatory Areas and sectors may have a small influence. Alternative coastwide mortality limits are presented on either side of the reference mortality limit. The decision table presents probabilities for different metrics over a three-year projection period.

4.8 Stakeholder and scientific input

Stakeholder and scientific input into the application of the harvest strategy are an important process to support the sustainable and profitable management of the Pacific halibut fishery. Input from both of these sources occurs at meetings throughout the year.

4.8.1 Stakeholder input

Stakeholder input can occur via public testimony at any public IPHC meeting or at meetings of various IPHC subsidiary bodies. In particular, the MSAB, Research Advisory Board (RAB), Conference Board (CB), and Processor Advisory Board (PAB) are populated by individuals representing various interests related to Pacific halibut. Terms of reference and rules of procedure are provided for each subsidiary body.

MSAB: The Management Strategy Advisory Board suggests topics to be considered in the MSE process, provide the IPHC Secretariat with direct input and advice on current and planned MSE activities, and represent constituent views in the MSE process. The MSAB meets at least once per year before the Annual Meeting.

CB: The Conference Board consists of individuals representing Pacific halibut harvesters, organisations, and associations, and provides a forum for the discussion of management and policy matters relevant to Pacific halibut and provides advice to the Commission on these matters. The CB also reviews IPHC Secretariat reports and recommendations, regulatory proposals received by the Commission, and provide its advice concerning these items to the Commission at its Annual Meeting, or on other occasions as requested. The CB meets during the week of the Annual Meeting.

PAB: The Processor Advisory Board represents the commercial Pacific halibut processing industry from Canada and the United States of America and advises the Commission on issues related to the management of the Pacific halibut resource in the Convention Area. The PAB meets during the week of the Annual Meeting.

RAB: The Research Advisory Board, composed of members of the Pacific halibut community, suggests research topics to be considered for incorporation in the IPHC integrated research and monitoring activities and comments upon operational and implementation considerations of those research and monitoring activities. The RAB also provides the IPHC Secretariat staff with direct input and advice from industry on current and planned research activities contemplated for inclusion in the IPHC 5-Year program of integrated research and monitoring. The RAB meets once per year, typically before the Interim Meeting.

4.8.2 Scientific input

Scientific input occurs through independent, external reviews, including, but not limited to, semi-annual meetings of the Scientific Review Board (SRB). The SRB reviews science/research proposals, programs, products, strategy, progress, and overall performance, as well as the recommendations arising from the MSAB and RAB.

4.9 ANNUAL PROCESS

A series of meetings occurs throughout the year, leading up the Annual Meeting in January when mortality limit decisions are made. The MSAB meets at least once a year in spring to provide guidance on the MSE and may also meet in autumn if necessary. The SRB meets in June and September to peer review IPHC science products, including the stock assessment and MSE. The CB and the PAB meet during the week of the Annual Meeting to advise the Commission on issues related to the management of the Pacific halibut resource in the Convention Area.

An Interim Meeting, typically late November, precedes the Annual Meeting and is when the stock assessment, stock projections, and harvest decision table are first presented. The final stock assessment, stock projections, and harvest decision table are presented at the Annual Meeting, typically in late January, to support mortality limit decisions.