IPHC–2024–SRB024–00
Last Update: 28 May 2024

24th Session of the IPHC Scientific Review Board (SRB024) – *Compendium of meeting documents*

18-20 June 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.

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INTERNATIONAL PACIFIC
HALIBUT COMMISSION

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DRAFT: AGENDA & SCHEDULE FOR THE 24th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB024)

Date: 18-20 June 2024
Location: Seattle, WA, USA, & Remote Meeting
Venue: IPHC HQ & Adobe Connect
Time: 09:00-17:00 (18-19th), 09:00-12:00 (20th) 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 23rd Session of the SRB (SRB023) (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 24th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB024)

SCHEDULE FOR THE 24th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB024)

Tuesday, 18 June 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 23rd Session of the SRB (SRB023) 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 4.1.3 Biology and ecology	I. Stewart A. Hicks J. Planas
12:30-13:30	Lunch	
13:30-16:00	4.1 continued.	
16:00-17:00	SRB drafting session	SRB members
19:00-21:30	SRB Dinner (Location TBA)	

Wednesday, 19 June 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	4.2 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
12:30-13:30	Lunch	
13:30-16:00	5. MANAGEMENT SUPPORTING INFORMATION	As needed
16:00-17:00	SRB drafting session	SRB members

Thursday, 20 June 2024

Time	Agenda item	Lead
09:00-10:30	SRB drafting session	SRB members
10:30-11:30	Time for all participants to review the draft report	All
11:30-12:30	6. ADOPTION OF THE REPORT OF THE 24th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB024)	S. Cox
12:30-13:30	Lunch and departure	

Last updated: 21 May 2024

LIST OF DOCUMENTS FOR THE 24th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB024)

Document	Title	Availability
IPHC-2024-SRB024-01	Agenda & Schedule for the 24th Session of the Scientific Review Board (SRB024)	✓ 26 Mar 2024 ✓ 22 Apr 2024 ✓ 21 May 2024
IPHC-2024-SRB024-02	List of Documents for the 24th Session of the Scientific Review Board (SRB024)	✓ 26 Mar 2024 ✓ 22 Apr 2024 ✓ 21 may 2024
IPHC-2024-SRB024-03	Update on the actions arising from the 23rd Session of the SRB (SRB023) (IPHC Secretariat)	✓ 17 May 2024
IPHC-2024-SRB024-04	Outcomes of the 100th Session of the IPHC Annual Meeting (AM100) (D. Wilson)	✓ 17 May 2024
IPHC-2024-SRB024-05	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)	✓ 17 May 2024
IPHC-2024-SRB024-06	2025-27 FISS design evaluation (R. Webster)	✓ 17 May 2024
IPHC-2024-SRB024-07	IPHC Secretariat MSE Program of Work (2024) and an update on progress (A. Hicks & I. Stewart)	✓ 17 May 2024
IPHC-2024-SRB024-08	Development of the 2024 Pacific halibut (*Hippoglossus stenolepis*) stock assessment (I. Stewart & A. Hicks)	✓ 15 May 2024
IPHC-2024-SRB024-09	Report on current and future biological and ecosystem science research activities (J. Planas)	✓ 15 May 2024
Information papers		
IPHC-2024-SRB024-INF01	Using artificial intelligence (AI) for supplementing Pacific halibut age determination from collected otoliths (B. Hutniczak, J. Forsberg, K. Sawyer Van Vleck, & K. Magrane)	✓ 21 May 2024

UPDATE ON THE ACTIONS ARISING FROM THE 23ND SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB023)

PREPARED BY: IPHC SECRETARIAT (17 MAY 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 SRB023.

BACKGROUND

At the SRB023, the members recommended/requested a series of actions to be taken by the IPHC Secretariat, as detailed in the SRB023 meeting report (IPHC–2023–SRB023–R) available from the IPHC website, and as provided in Appendix A.

DISCUSSION

During the 24th Session of the SRB (SRB024), 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-SRB024-03, 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 (SRB023).
2) **AGREE** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB024.

APPENDICES

Appendix A: Update on actions arising from the 23rd Session of the IPHC Scientific Review Board (SRB023).

APPENDIX A

Update on actions arising from the 23rd Session of the IPHC Scientific Review Board (SRB023)

RECOMMENDATIONS

Action No.	Description	Update
	International Pacific Halibut Commission 5-year program of integrated research and monitoring (2022-26)	
SRB023–Rec.01 (para. 17)	The SRB **AGREED** that AI techniques may improve efficiency of age estimation and **RECOMMENDED** continued research and cross-validation of AI-based aging.	***Ongoing*** **Update**: See paper **IPHC-2024-SRB024-INF01**
	Research: Pacific halibut stock assessment	
SRB023–Rec.02 (para. 19)	**NOTING** that the inclusion of whale depredation in the assessment requires many assumptions and results in only small changes to the TCEY, the SRB **RECOMMENDED** that whale depredation not be included in the 2023 stock assessment model.	***Completed*** **Update**: Whale depredation was not included in the 2023 stock assessment and will be revisited in the future.
SRB023–Rec.03 (para. 20)	The SRB **RECOMMENDED** that the Secretariat investigate approaches (e.g. simulation testing) to estimating uncertainty (or bounding the minimum level of uncertainty) in different assessment outputs: e.g. coastwide and Biological Region spawning stock biomass (see related actions under Section 4.2).	***Completed*** **Update**: Simulation results provided in IPHC-2024-SRB024-08.
SRB023–Rec.04 (para. 21)	The SRB **RECOMMENDED** continuing annual sex ratio sampling while the stock is declining given that estimated SSB remains sensitive to these data.	***Completed*** **Update**: Sex ratio sampling is ongoing with 2023 samples to be processed for the 2024 stock assessment.
	Research: Management strategy evaluation	
SRB023–Rec.05 (para. 24)	The SRB **RECOMMENDED** that an objective to maintain spatial population structure be added or redefined to maintain the spawning biomass in a Biological Region above a defined threshold	***In Progress*** **Update**: This secondary objective is presented in document **IPHC-2024-**

	relative to the dynamic unfished equilibrium spawning biomass in that Biological Region with a pre-defined tolerance. The percentage and tolerance may be defined based on historical patterns and appropriate risk levels recognizing the limited fishery control of biomass distribution.	**SRB024-07** and will be discussed at SRB024.
SRB023–Rec.06 (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.	***In Progress*** **Update**: This priority objective was discussed with the MSAB at MSAB019, is presented in document **IPHC-2024-SRB024-07**, and will be discussed with the SRB at SRB024.
SRB023–Rec.07 (para. 26)	The SRB **RECOMMENDED** continued examination, within the MSE, of FISS scenarios that are better representative of the levels of uncertainty and bias that may result from future reductions in FISS sampling.	***In Progress*** **Update**: The design of simulations to conduct in 2024 is presented in documents **IPHC-2024-SRB024-07** and **IPHC-2024-SRB024-08**.
SRB023–Rec.08 (para. 27)	**RECOGNIZING** the spatial variability of environmental factors that influence population dynamics, the SRB **RECOMMENDED** that an exceptional circumstance be defined based on regional as well as stock-wide deviations from expectations. For example, an exceptional circumstance could be declared if any of the following are met: a) 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. b) 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 2 or more years. c) Recruitment, weight-at-age, sex ratios, other biological observations, or new research	***Completed*** **Update**: Exceptional circumstances are presented in document **IPHC-2024-SRB024-07**.

	indicating parameters that are outside the 2.5th and 97.5th percentiles of the range used or calculated in the MSE simulations.	
SRB023–Rec.09 (para. 28)	The SRB **RECOMMENDED** that if an exceptional circumstance occurred the following actions would take place: a) A review of the MSE simulations to determine if the OM can be improved and MPs should be re-evaluated. 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.	***Completed*** **Update**: Actions to take if an exceptional circumstance is declared are provided in document **IPHC-2024-SRB024-07**.
SRB023–Rec.10 (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.	***In Progress*** **Update**: Elements of management procedures to evaluate in 2024 are discussed in document **IPHC-2024-SRB024-07**.
SRB023–Rec.11 (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.).	***Completed*** **Update**: The harvest strategy has been updated such that the determination of the coastwide TCEY is the management procedures under investigation using the MSE. See document **IPHC-2024-SRB024-07**.

	Research: Biology and ecology	
SRB023–Rec.12 (para. 36)	**NOTING** that the genomics research is and will continue to be a key element of the Biological and Ecosystem Science Research program, and that the Secretariat wishes to (i) document stock structure, (ii) use genetic markers to quantify movements, (iii) assign individuals of any age, location, season to a genetic population, (iv) annotate markers and use genomic data to between understand genetic and environmental sources of variation in growth, maturity and fecundity, (v) engage in close-kin capture-recapture to estimate stock abundance, the SRB **RECOMMENDED** adding qualified staff to help address these diverse and important activities in a timely fashion.	***In Progress*** **Update**: The IPHC Secretariat is currently studying this recommendation in the context of the goals and objectives of the 5Y-PRIM 2022-2026.
SRB023–Rec.13 (para. 42)	The SRB **RECOMMENDED** that the Secretariat continue to work with collaborators to collect and process genetic samples from juveniles. Collections of younger (pre-reproductive) age classes would be particularly important for anticipated future close-kin capture-recapture work.	***In Progress*** **Update**: The IPHC Secretariat has over the recent years collected genetic samples (fin clips) from juvenile Pacific halibut captured in the NMFS Bottom Trawl Survey in the Gulf of Alaska, Bering Sea and Aleutian Islands. This is the only source of juvenile Pacific halibut biological samples since the FISS captures typically fish that are 5-6 years of age and above. Unfortunately, the Commission did not fund the deployment of IPHC Staff in the NMFS Bottom Trawl Survey in 2024 and no Pacific halibut juvenile samples will be collected.
SRB023–Rec.14 (para. 44)	The SRB **RECOMMENDED** to apply the genetic sampling more broadly, to estimate genetic diversity of the (sub)populations, for example through the effective number of breeding adults by cohort.	***Completed*** **Update**: The Secretariat is not aware of software that is currently available for estimating these

		parameters directly from genotype likelihood data. That being the case, effort would need to be redirected to adapting existing methods that make use of called genotype data.
SRB023–Rec.15 (para. 45)	The SRB **RECOMMENDED** that the compensatory assumption of the stock recruitment models be critically evaluated via a MSE stress test scenario in which recruitment is depensatory at some low spawning biomass.	***In Progress*** **Update**: The IPHC Secretariat is currently addressing this recommendation and results will be presented as part of the MSE presentation during SRB024.
SRB023–Rec.16 (para. 49)	The SRB **RECOMMENDED** that Secretariat proceed to the next step of individual assignment based on K of 4 or K of 5. Based on the large number of loci with low levels of divergence among reporting regions (Manhattan plot in Figure 4 of paper IPHC-2023-SRB023-08) that posterior probabilities of cluster assignment (in a Bayesian context) may be low when all loci are used. The Secretariat should conduct a comparable analysis using only 'outlier loci'.	***Completed*** **Update**: Probabilistic cluster assignment results are provided in document IPHC-2024-SRB024-09.
SRB023–Rec.17 (para. 50)	**RECOGNIZING** that future applications of 'outlier loci' to address SA and MSE objectives will necessitate development of more 'rapid screening approaches' and screening based on fewer loci, the SRB **RECOMMENDED** that the Secretariat work to identify the numbers of loci and locus characteristics (e.g. high levels of diversity and high level of allele frequency variation) so loci may be applied.	***In Progress*** **Update**: The IPHC Secretariat is investigating whether some additional optimization of the assignment testing could be done to determine if assignment accuracy increases with alternative SNP selection strategies.
SRB023–Rec.18 (para. 53)	The SRB **RECOMMENDED** that the Secretariat: a) conduct simulations as a means of assessing the accuracy of group or admixture assignments; b) establish criteria for acceptable group assignment accuracy and that is relevant for	***Completed*** **Update**: Assignment testing results are provided in document **IPHC-2024-SRB024-09**.

	assignment of individuals as a 'pure' or 'admixed'. Thus, observations, though made with some error would be used as 'observed' estimates to tally over space and across age classes. c) should evaluate what the uncertainty in classification (errors) will mean to their estimates. The SRB draws the Secretariat's attention to a widely cited paper by Manel et al. (2005) in Trends in Ecology and Evolution, where authors compare individual assignment tests to a widely used alternative method (mixed stock analysis). These authors point out that use of individual assignment tests for relative population (or reporting group) compositional estimation can be fraught with problems because assignment error compounds across all individuals.	
	Monitoring: 2024 FISS design evaluation	
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.	***In Progress*** **Update**: FISS design comparisons are presented in **IPHC-2024-SRB024-06**. Proposals for stock assessment evaluation and MSE investigations of these designs are provided for SRB review in **IPHC-2024-SRB024-08** and **IPHC-2024-SRB024-07**.
SRB023–Rec.20 (para. 62)	The SRB **RECOMMENDED** that the life-histories, particularly population age structure, lengths-at-age, and weight-at-age continue to be monitored in the FISS and fishery to obtain a proxy of total mortality, cohort resonance, and reproductive potential as well as to detect longer term trends in life histories.	***Ongoing***

	Updates to space-time modelling	
SRB023–Rec.21 (para. 63)	The SRB **NOTED** that the switch from a hurdle model to a Tweedie distribution reduces model parameters and overall Deviance Information Criterion (DIC) and reduces run times and **RECOMMENDED** that the Secretariat continue investigating whether the space-time model can be successfully transitioned to a Tweedie distribution for all regulatory areas.	***Ongoing*** **Update**: Further results to be presented at SRB024.
	Management Supporting Information	
SRB023–Rec.22 (para. 64)	**NOTING** the presentation demonstrating how secondary FISS objectives influence choices for future FISS designs that may have already been endorsed by the SRB based only on primary objectives, the SRB **RECOMMENDED** that the MSE include some scenarios in which the FISS is skipped (as similarly requested above in paras. 62 and 63) because of occasional (or functional) economic constraints on executing full FISS designs. Such simulation scenarios would provide some indication of the potential scale of impacts on MP performance of maintaining long-term revenue neutrality of the FISS.	***In Progress*** **Update**: A proposal for MSE investigations of FISS design scenarios is provided for SRB review in **IPHC-2024-SRB024-07**.

REQUESTS

Action No.	Description	Update
	Research: Biology and ecology	
SRB023–Req.01 (para. 37)	**NOTING** that future applications of genomic data will necessitate more expansive sampling geographically and demographically to achieve IPHC goals, the SRB **REQUESTED** that the Secretariat establish explicit long-term objectives for use of genomic data and work with staff, fishermen, and agency collaborators to establish a short and long-term sampling program and data and sample archival plan to ensure samples are available to address Secretariat objectives.	***In Progress*** **Update**: The IPHC Secretariat is currently implementing long-term objectives for the collection of genetic samples coastwide that include the collection of fin clips from sampled commercial landings (since 2017; used to generate sex ratio information by genotyping), from all fish sampled in the FISS (since 2016) and

		from all research projects that have involved the capture of Pacific halibut (since 2016). An important source of genetic samples from juvenile Pacific halibut derives from the NMFS Ground Trawl Survey in the Gulf of Alaska, Bering Sea and Aleutian Islands (since 2019). Unfortunately, the Commission did not fund the deployment of IPHC Staff in the NMFS Bottom Trawl Survey in 2024 and no juvenile Pacific halibut samples will be collected this year.
SRB023–Req.02 (para. 41)	**NOTING** paper IPHC-2023-SRB023-08 (subsection 1.1 - Identification of Pacific halibut juvenile habitat), and that the narrative describes work to be conducted but does not explicitly identify research objectives or hypotheses that the data would be used to address, the SRB **REQUESTED** that objectives/hypotheses be developed for SRB024 where hypotheses could include: a) regions with larger amounts of juvenile rearing habitat and larger number of juveniles would realize numerically larger levels of recruitment to the adult population; b) b) genotypes of juveniles from rearing habitats could be assigned to specific spawning areas.	***In Progress*** **Update**: The IPHC Secretariat conducted initial work on Pacific halibut juvenile habitat identification with the involvement of the 2023 IPHC Intern and is in the process of investigating avenues to continue this work.
SRB023–Req.03 (para. 43)	**NOTING** paper IPHC-2023-SRB023-08 (subsection 1.2 - wire tagging of U32 Pacific halibut), where the narrative describes numbers of fish tagged and recovered, no information is provided summarizing distances moved by size/age and location, the SRB **REQUESTED** that information be provided during SRB024, including background on statistical methods for analysis of data.	***Completed*** **Update**: The IPHC Secretariat will provide information on movement of tagged fish and plans to use these data to inform on survival during SRB024.

SRB023–Req.04 (para. 51)	The SRB **ACKNOWLEDGED** Table 1 in paper IPHC-2023-SRB023-08, produced in response to SRB022 inquiry, and that discrepancies in the genetic diversity measure Fis (deviation of observed and expected heterozygosity) across collection years within reporting regions. The Secretariat estimates Fis on a collection year by year basis and overall years for each region. The SRB **REQUESTED**: a) further investigation of the disparity in Fis for reporting regions (yearly vs total). Higher positive Fis could indicate admixture of individuals from genetically differentiated groups; b) investigations into discrepancies between estimates of Fis, observed heterozygosity (Ho), and expected heterozygosity (He).	***Completed*** **Update**: Results on genetic diversity measures are provided in document IPHC-2024-SRB024-09.
SRB023–Req.05 (para. 52)	The SRB **NOTED** that the Secretariat proposes to conduct individual admixture (i.e. among IPHC reporting regions) estimation using software NGSadmix and individual assignment testing using WGSassign, both of which are amenable to low coverage sequence data, to estimate proportional contributions of reporting groups to unknown individuals. This analysis would be conducted after 'best supported' number of genetic groups (K) has been established. The SRB **REQUESTED** that admixture analyses and assignment testing be conducted and reported at SRB024, including estimates of assignment accuracy.	***Completed*** **Update**: Results on admixture analyses and assignment testing are provided in document **IPHC-2024-SRB024-09**.
	Monitoring: 2024 FISS design evaluation	
SRB023–Req.06 (para. 57)	The SRB **REQUESTED** that the Commission **NOTE** the addition of cost estimates to the presentation of alternative FISS designs. The short-term risk implications in 2024 to the stock and TCEY of a drastically reduced FISS design (e.g. approx. revenue neutral Design 9 with efficiencies) are probably not profound given that the estimated current abundance is still above the implied B36% target. Impacts may appear more in the estimates of stock distribution since	***Completed*** **Update**: Request (**IPHC-2023-SRB023-R**) provided to the Commission, see AM100 Collection of Documents

	unsampled areas will be more dependent on the space-time model than actual data.	
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).	***Completed*** **Update**: Request (**IPHC-2023-SRB023-R**) provided to the Commission, see AM100 Collection of Documents
SRB023–Req.08 (para. 61)	The SRB **REQUESTED** that simulations above (para. 60) include: a) a relationship in which the FISS CV is relatively higher at lower stock abundance (i.e. the current CV issue is a function of stock abundance rather than a short-term condition); b) target regulatory area CVs of 15%, 20%, 25%, and 30%;	***In Progress*** **Update**: FISS design comparisons are presented in **IPHC-2024-SRB024-06**. Proposals for stock assessment evaluation and MSE investigations of these designs are provided for SRB review in **IPHC-2024-SRB024-08** and **IPHC-2024-SRB024-07**.

	coastwide target CV of 15% without controlling specific regulatory area CVs.	

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

PREPARED BY: IPHC SECRETARIAT (17 MAY 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-SRB024-04 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.

IPHC Financial Regulations (2024)

AM100–Req.02 (para. 116) The Commission **ADOPTED** the International Pacific Halibut Commission Financial Regulations (2024), as provided in IPHC-2024-FAC100-08, by consensus, and **REQUESTED** that the IPHC Secretariat finalise and publish them accordingly.

IPHC Rules of Procedure (2024)

AM100–Req.03 (para. 117) The Commission **ADOPTED** the IPHC Rules of Procedure (2024), as provided in IPHC-2024-FAC100-09, by consensus, and **REQUESTED** that the IPHC Secretariat finalise and publish them accordingly.

Review of the draft and adoption of the report of the 100th Session of the IPHC Annual Meeting (AM100)

AM100–Req.04 (para. 126) The Commission **REQUESTED** that the IPHC Secretariat finalise and publish the IPHC *Pacific Halibut Fishery Regulations (2024)* as soon as possible, **NOTING** that only minor editorial and formatting changes are permitted beyond the decisions made by the Commission at the AM100.

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; 17 MAY 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 23rd Session of the Scientific Review Board (SRB023) in September 2023, the SRB provided the following recommendation to the Commission.

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

SRB023–Rec.01 (para. 17) The SRB **AGREED** that AI techniques may improve efficiency of age estimation and **RECOMMENDED** continued research and cross-validation of AI-based aging.

Responding to this recommendation, the Secretariat prepared an update on the progress in using artificial intelligence/AI for ageing. See paper IPHC-2024-SRB024-INF01, AI project update.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2024-SRB024-05 which provides the IPHC 5-year program of Integrated Research and Monitoring (2022-26) with potential updates.

APPENDICES

Nil

2025-27 FISS design evaluation

PREPARED BY: IPHC SECRETARIAT (R. WEBSTER, I. STEWART, K. UALESI, & D. WILSON; 17 MAY 2024)

Part 1: 2025-27 FISS design evaluation

PURPOSE

To present the SRB with potential FISS designs for 2025-27, including a preliminary cost evaluation of the 2025 designs.

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 National Marine Fishery Service (NMFS) bottom trawl survey (Webster et al. 2020).

Through examination of commercial logbook data and information from other sources, it became clear by 2010 that the historical FISS design had gaps in coverage of Pacific halibut habitat that had the potential to lead to bias in estimates derived from its data. These gaps included deep and shallow waters outside the FISS depth range (0-20 fathoms and 275-400 fathoms), and unsurveyed stations on the 10 nmi grid within the 20-275 fathom depth range within each IPHC Regulatory Area. This led the IPHC Secretariat to propose expanding the FISS to provide coverage of the unsurveyed habitat with 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 as noted above, 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 1.1) from which an optimal subset of stations can be selected when devising annual FISS designs. This station selection process began in 2019 for the 2020 FISS and continues with the current review of design proposals for 2024-26. 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 1.1). 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 sampling 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 1.2) 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 1.3). 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.

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 filled in 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. 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 1.1)

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

The primary purpose of the annual FISS is to sample Pacific halibut to provide data for the stock assessment (abundance indices, biological data) and estimates of stock distribution for use in 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 1.1 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 1.1) to the SRB for three subsequent years at the June meeting based on analysis of prior years' data. Commencing in 2024, this will include 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 1.1) 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 1.1) 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) are possible at the Annual Meeting of the Commission;
    - The endorsed design for current year is then modified (if necessary) to account for any additional tertiary objectives or revision to inputs into 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 years, revisions to designs for the second and third years are expected during subsequent review periods as additional data are collected. Having design proposals available for three years instead of the next year only assists the Secretariat with medium-term planning of the FISS, and allows reviewers (SRB, Commissioners) and stakeholders to see more clearly the planning process for sampling the entire FISS footprint over multiple years.

POTENTIAL DESIGNS FOR 2025-27

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-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.

The block designs shown in Figures 1.4 to 1.6 for 2025-27 (called the **Base Block design**) were presented to Commissioners at IM099 as potential designs for 2024-26, 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 involve achieve lower net costs through reductions in spatial coverage:

- **Core Block design** (Figures 1.7 to 1.9): 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 1.10): 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 area. As CVs are generally greater in the terminal year of the time series and that year is generally the most relevant for informing management, the CV values in Table 1.2 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 1.2. Projected coefficients of variation (CVs, %) 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

Base Block design: Projected terminal year CVs for the Base Block design 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 1.2). 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. 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 ‘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 maintain in the core areas, projected CVs for IPHC Regulatory Areas 2B, 2C, 3A and 3B remain at 15% or less with this design (Table 1.2). 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.

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 1.2). 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.

Table 1.3 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 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 1.3. Comparison of preliminary projected net revenue for the 2025 Base Block, Core Block and Reduced Core designs.

Design	With Seacat	Without Seacat
Base Block	$1,542,000	--$1,407,000
Core Block	-$900,000	-$805,000
Reduced Core	-$644,000	-$569,000

DISCUSSION

At AM100 (IPHC-2024-AM100-13), IPHC Secretariat staff recommended that the Commission endorse block designs for all future planning as a viable alternative to the randomised sampling in use in 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 1.4 to 1.6.

The Base Block design has a projected net loss of $1,407,000 without oceanographic monitoring and therefore will rely on supplementary funding for implementation. Depending on 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 vary somewhat in spatial scope from the design presented in Figure 1.4.

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. 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-SRB024-06, which presented an evaluation of design options for 2025-27, including options accounting for the secondary FISS objective of long-term revenue neutrality;

2) **ENDORSE** the Base Block design for 2025 (Figure 1.4) provided that sufficient supplementary funding is available to cover the projected net revenue loss.

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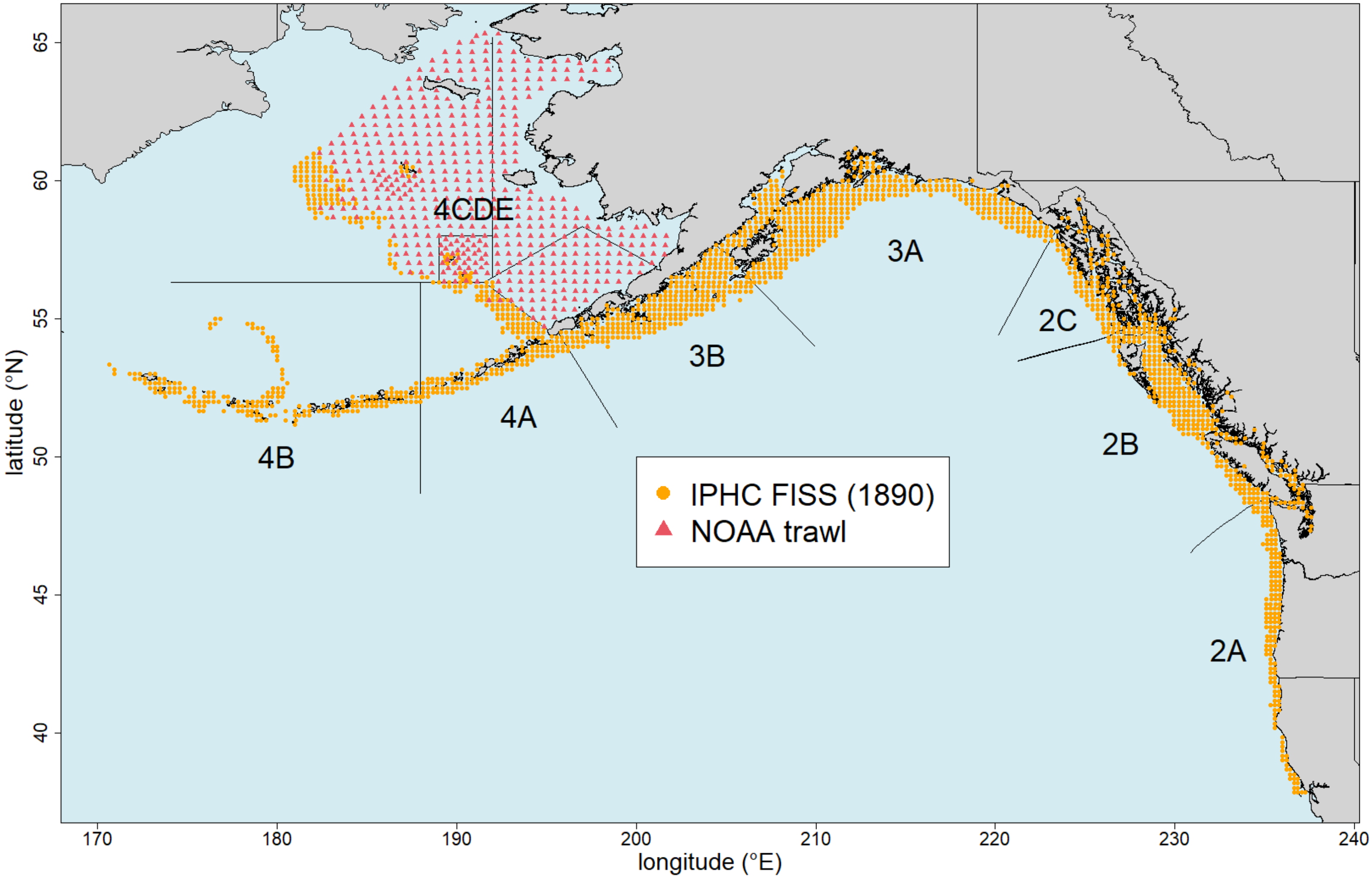

Figure 1.1. Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs. Red triangles represent the locations NOAA trawl stations used to provide complementary data for Bering Sea modelling.

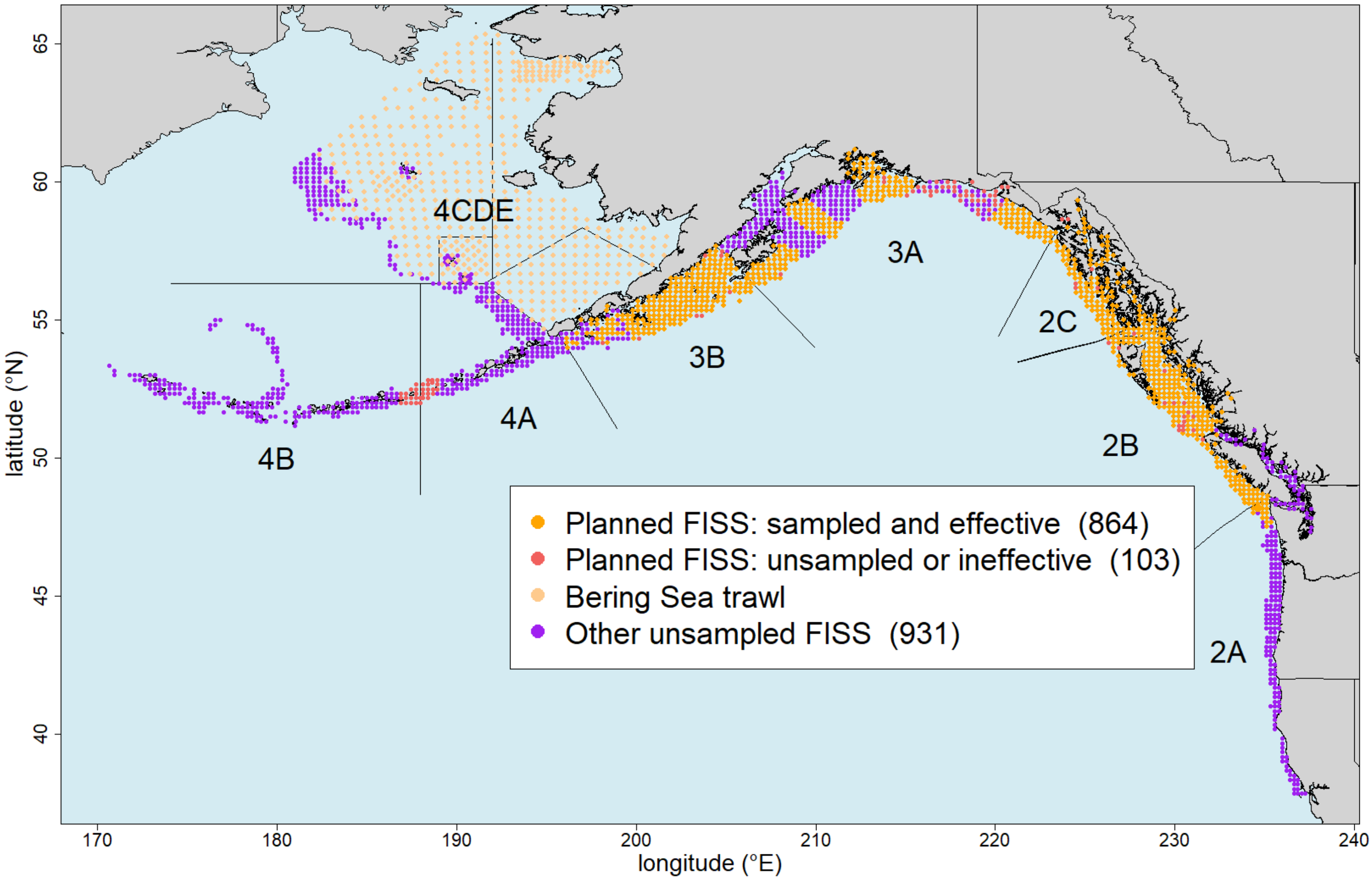

Figure 1.2. Implemented 2023 FISS design, with successfully fished (effective) stations shown in orange circles.

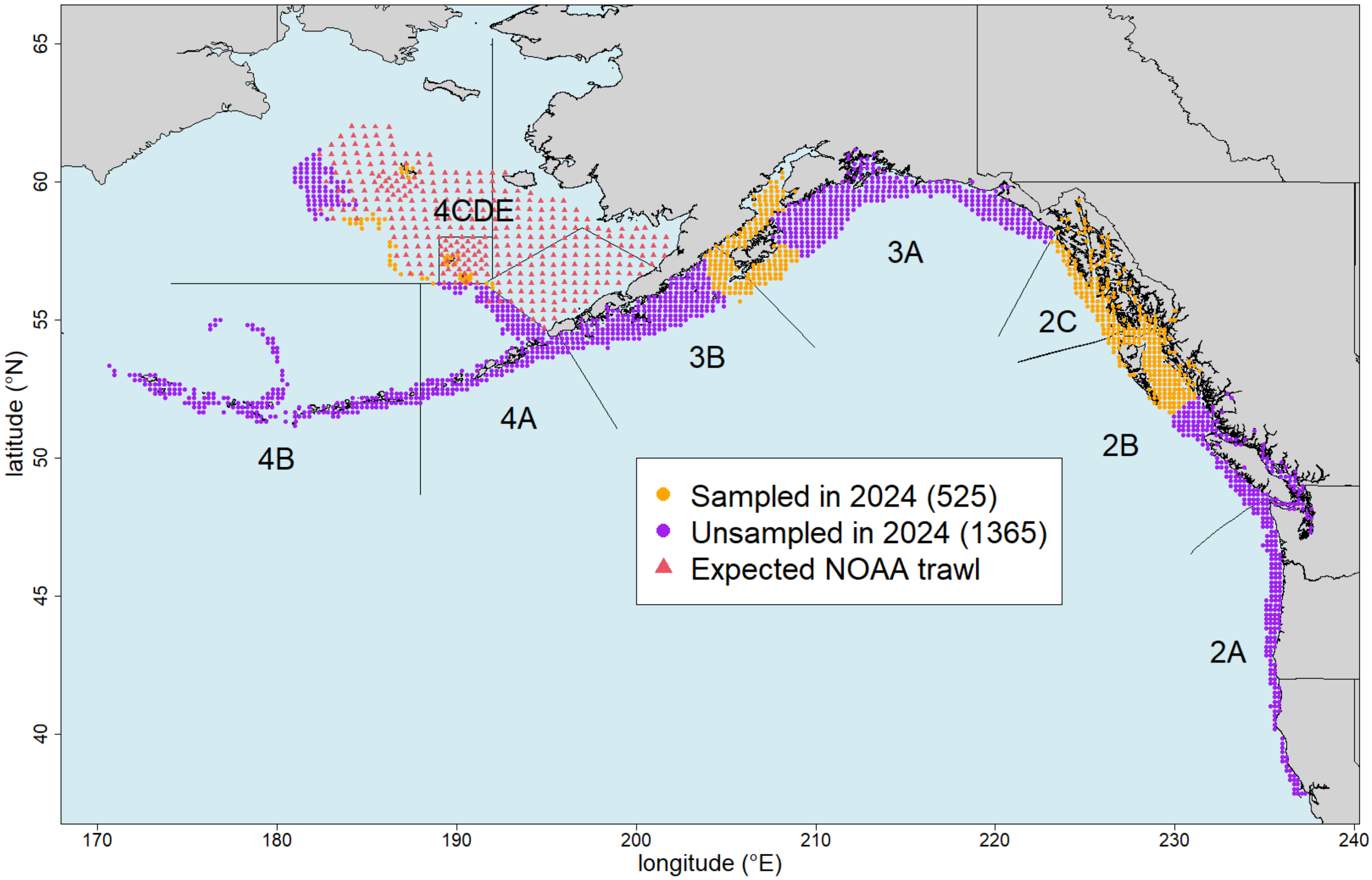

Figure 1.3. Adopted 2024 FISS design, with planned FISS stations shown as orange circles.

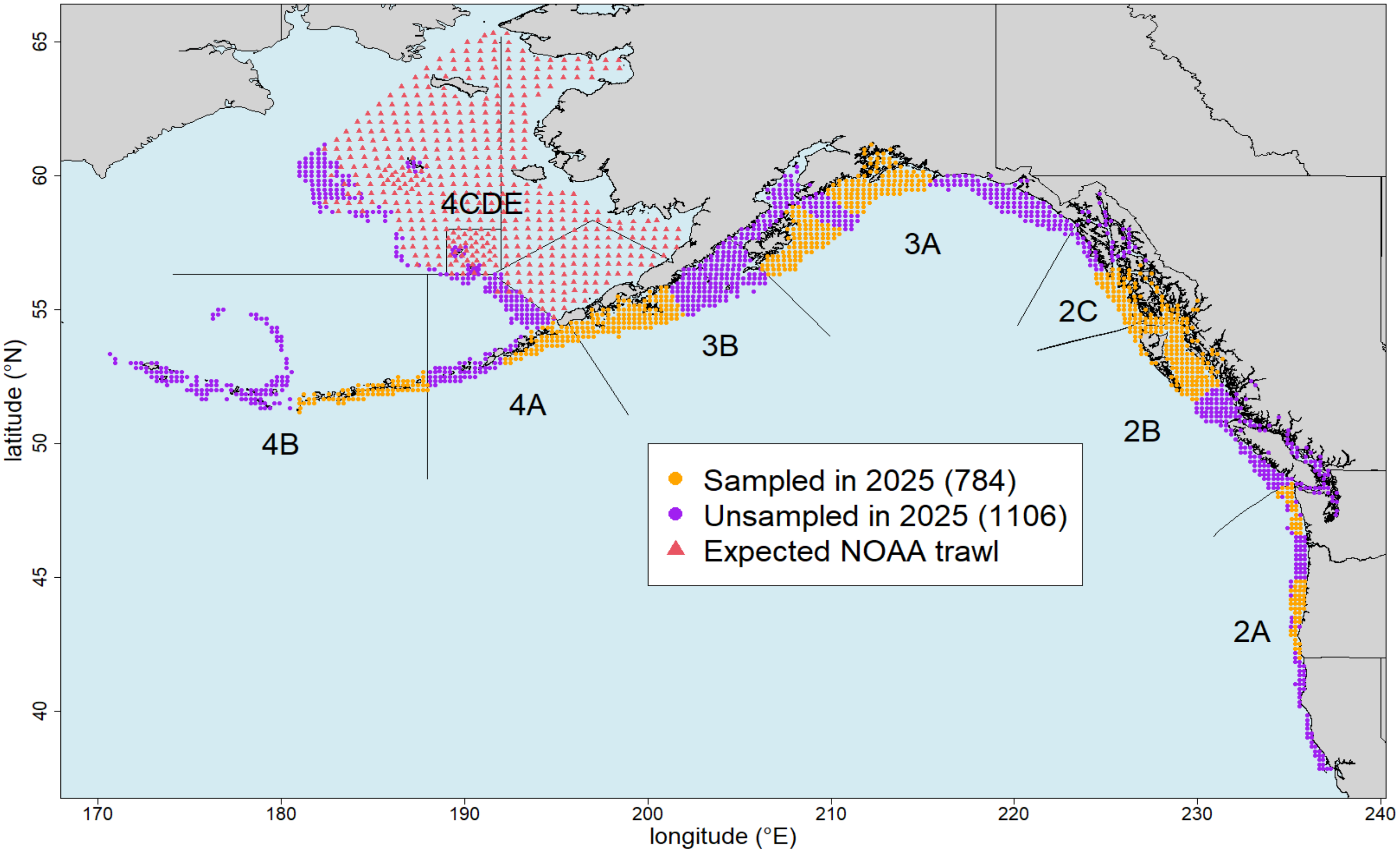

Figure 1.4. Base Block design for 2025 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

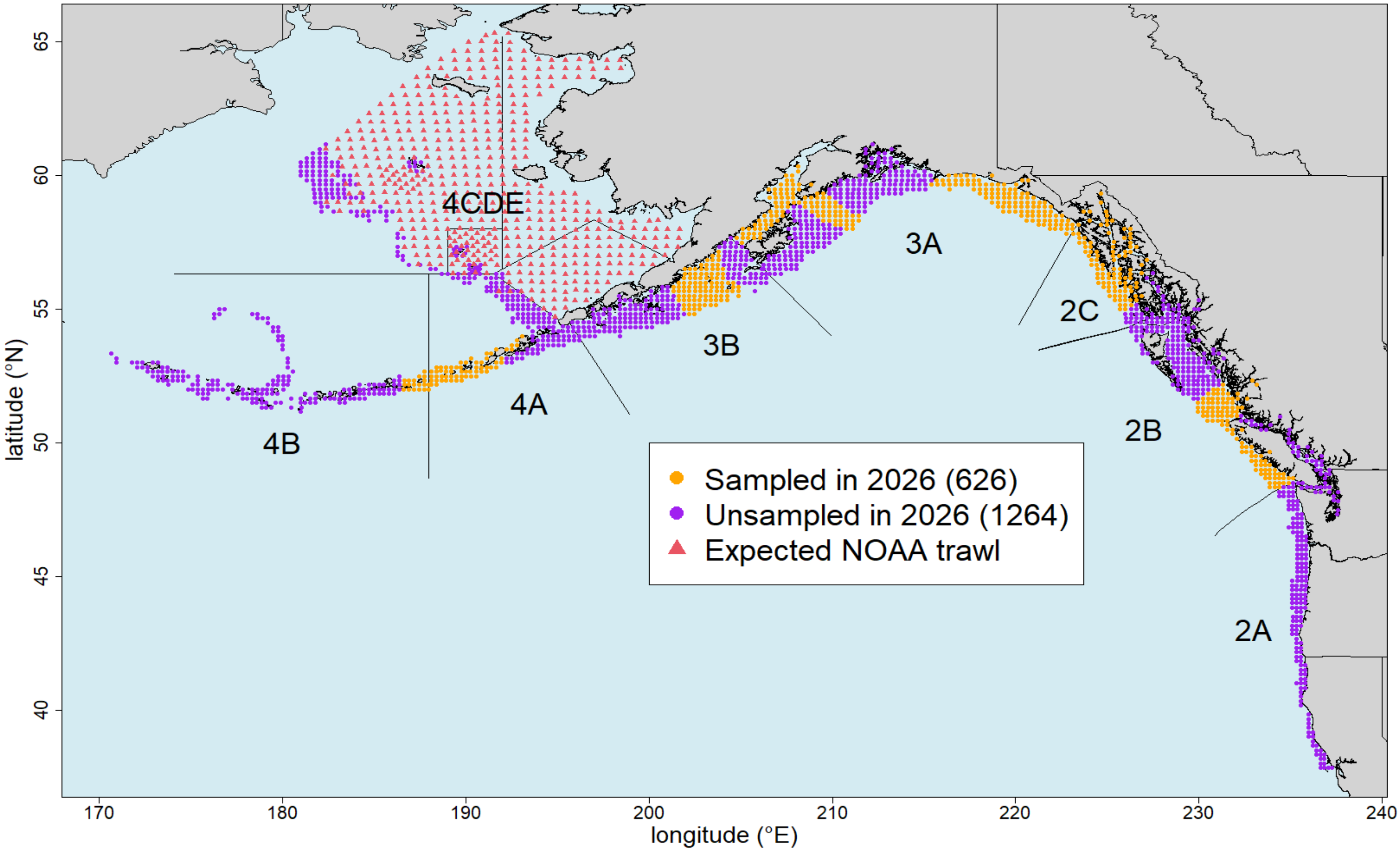

Figure 1.5. Base Block design for 2026 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

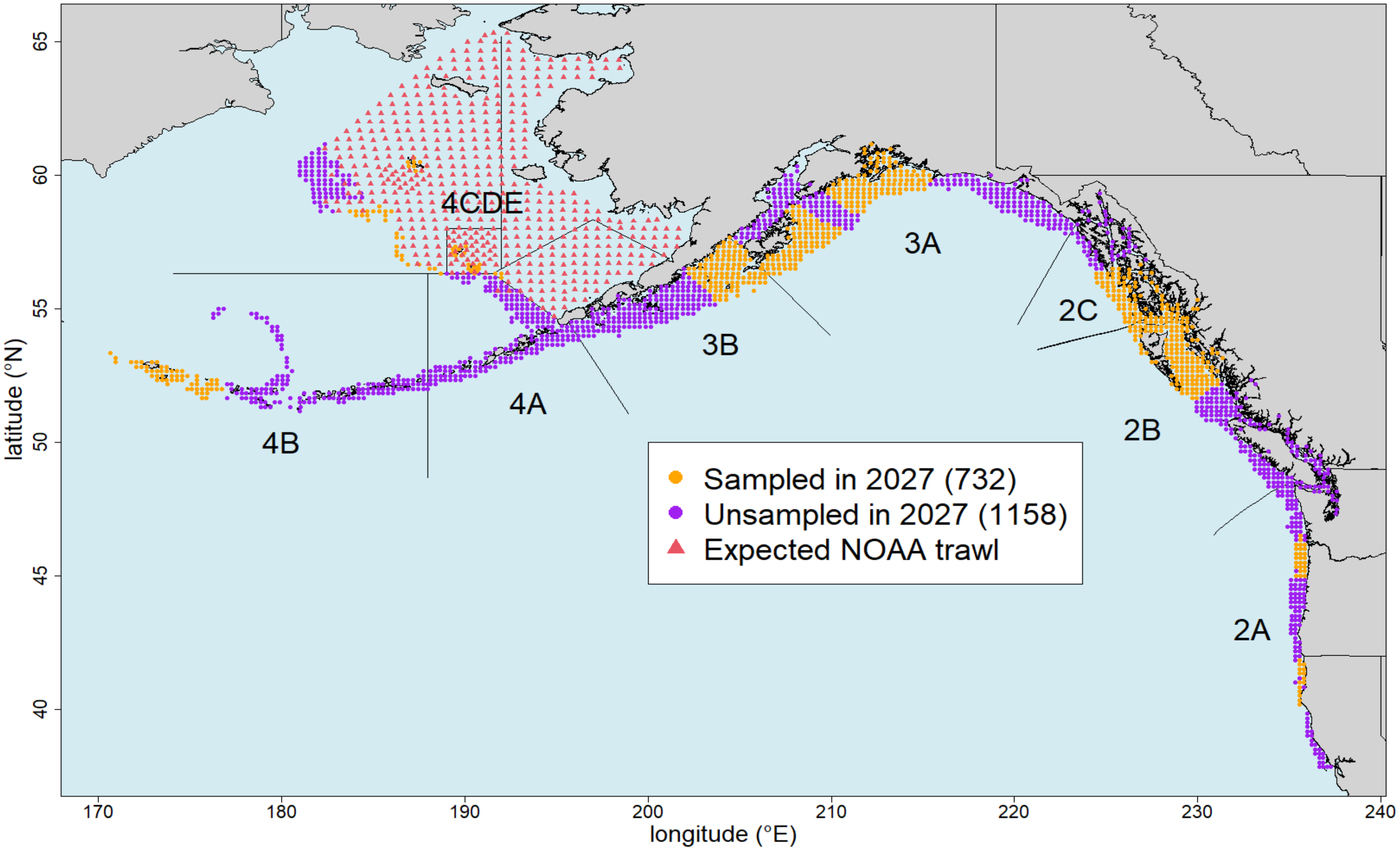

Figure 1.6. Base Block design for 2027 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and previously implemented subareas elsewhere.

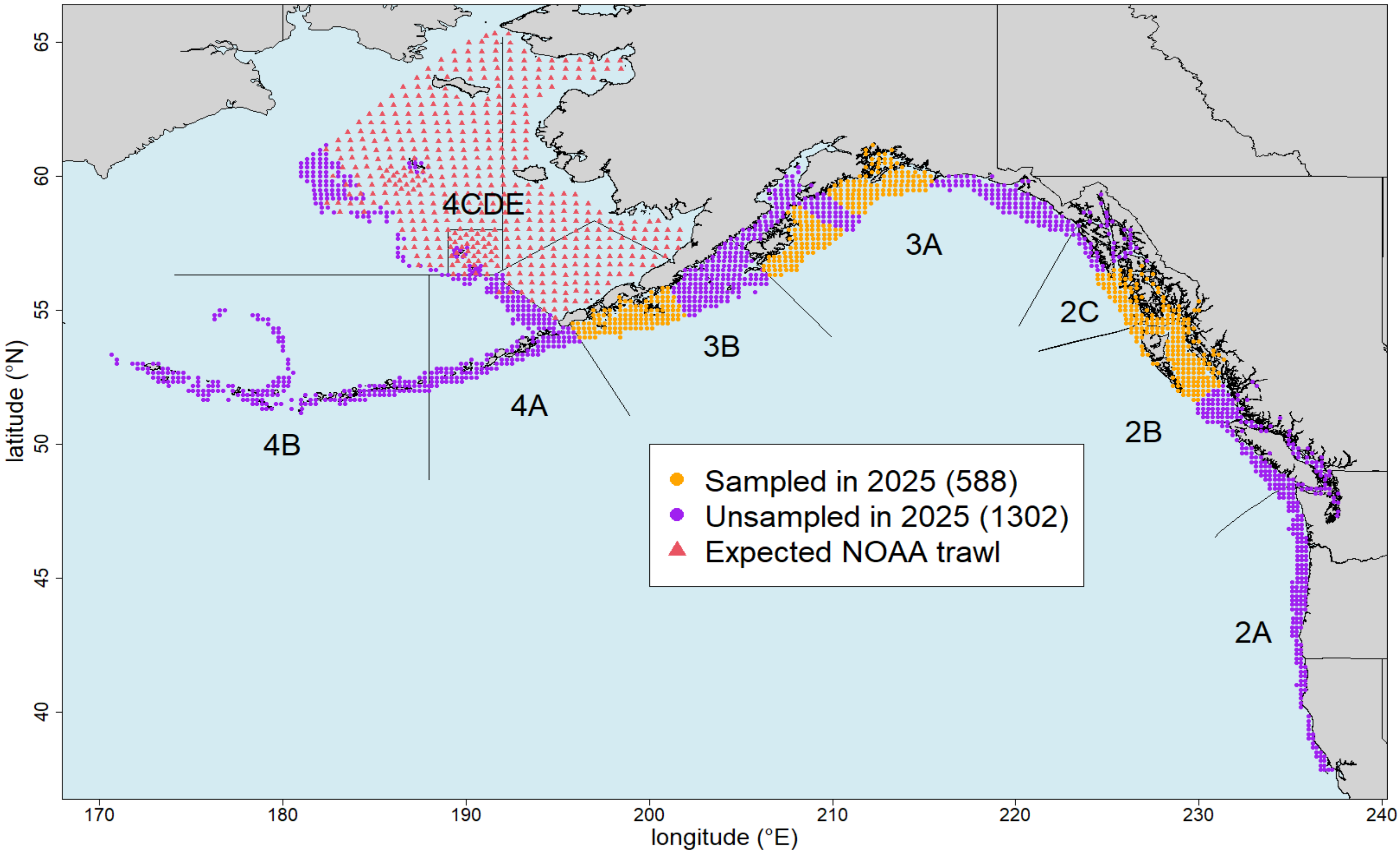

Figure 1.7. Core Block design for 2025 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

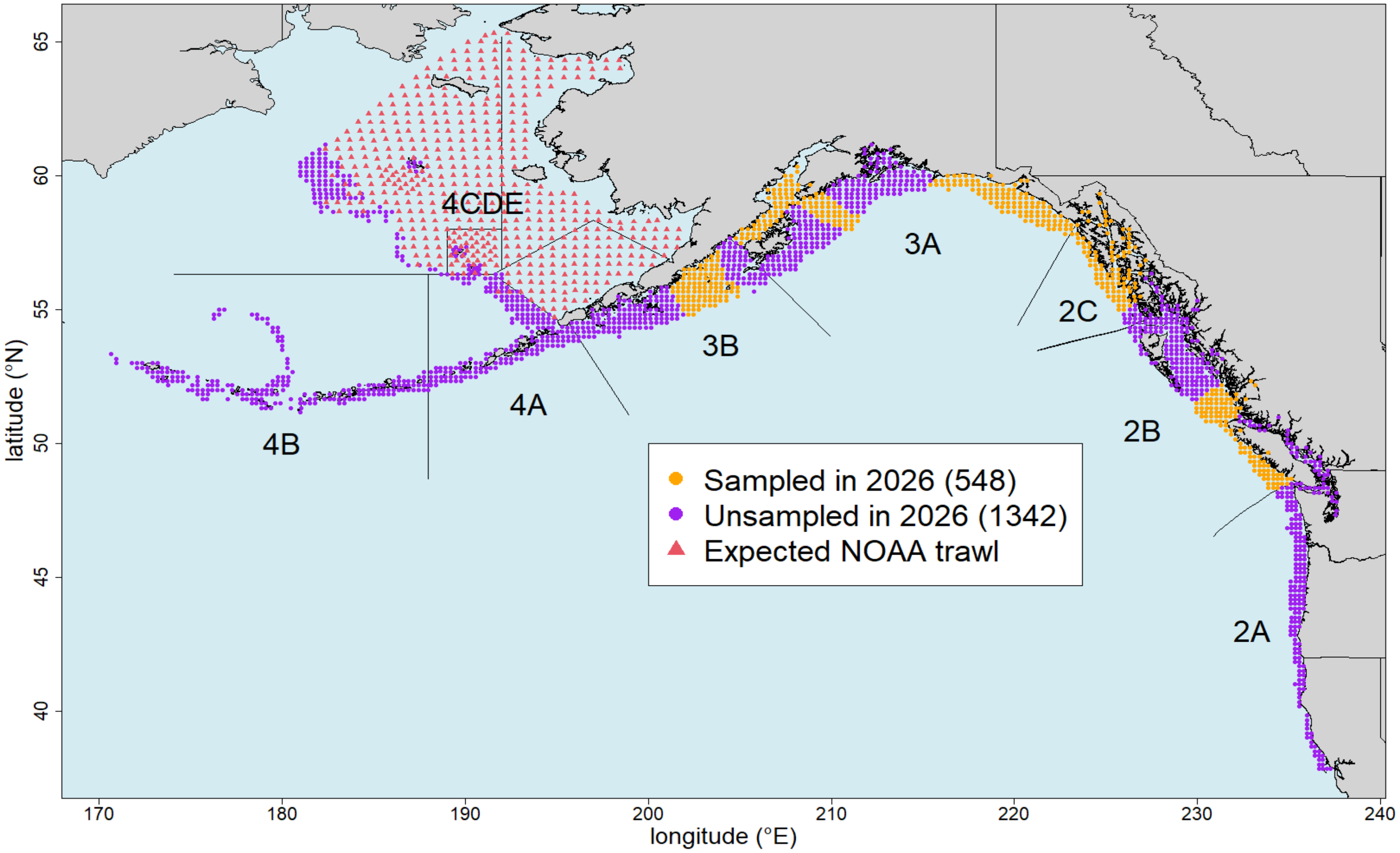

Figure 1.8. Core Block design for 2026 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

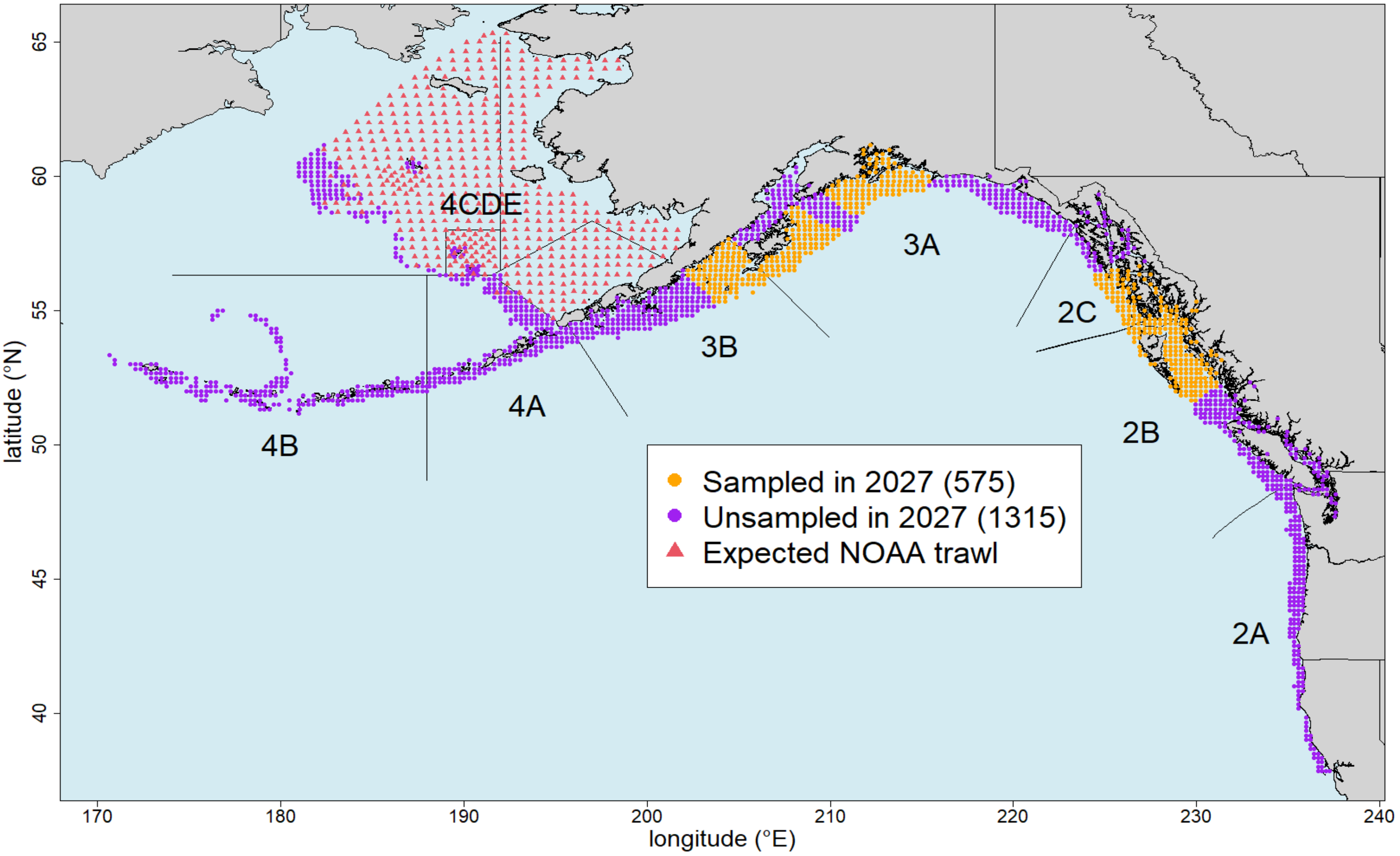

Figure 1.9. Core Block design for 2027 (orange circles). Design is based on fishing 2-4 complete blocks of stations (charter regions) in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

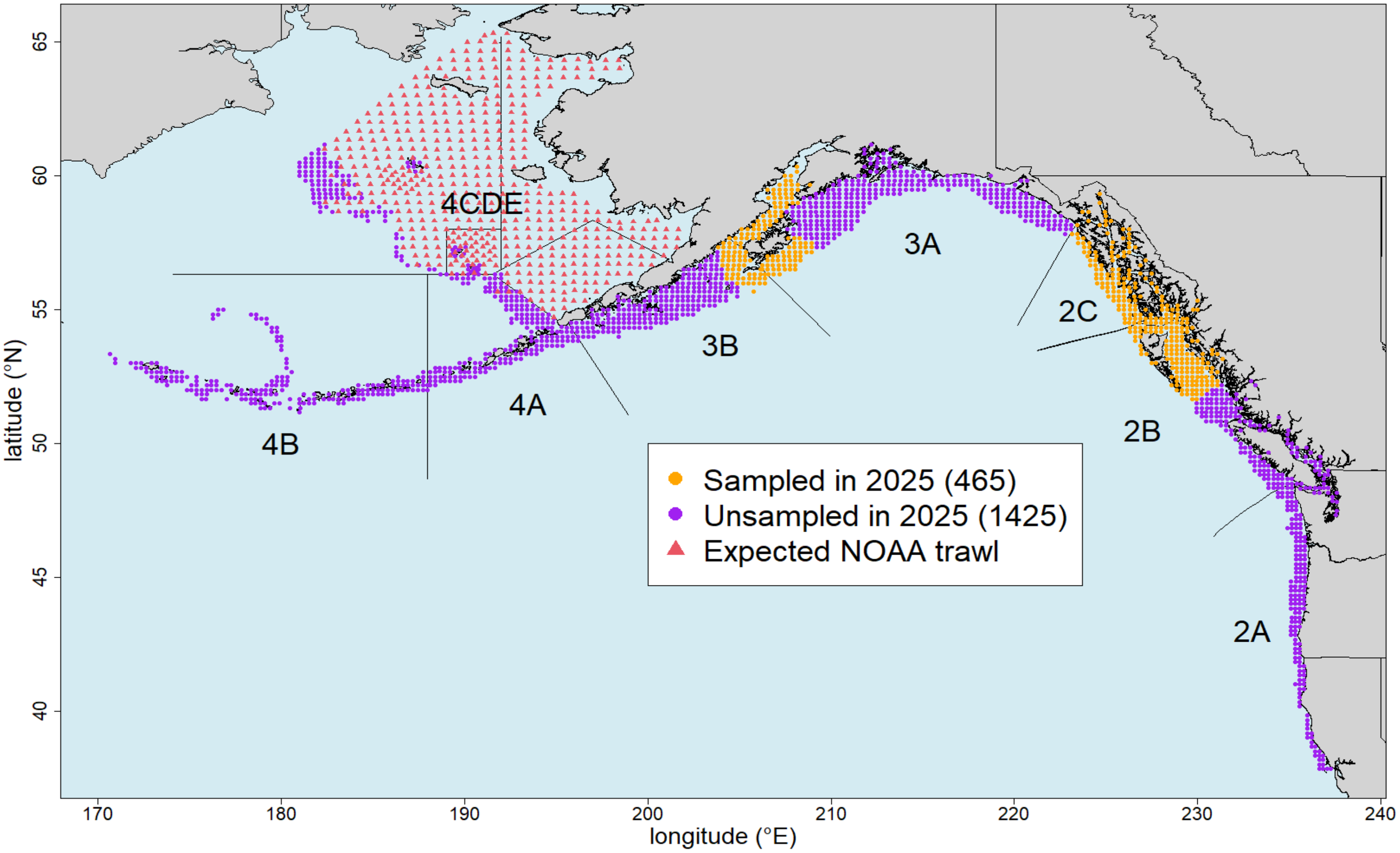

Figure 1.10. Reduced Core design for 2025-27 (orange circles). Design is based on fishing only the current highest revenue blocks of stations in the core areas (2B, 2C, 3A and 3B) and no FISS sampling elsewhere to reduce costs.

Part 2: Modelling updates

PURPOSE

To compare space-time model output from fitting a Tweedie model to survey catch data to the current model's output.

BACKGROUND

At SRB021, the Scientific Review Board recommended that the Secretariat explore other parameterizations of the space-time model used for modelling Pacific halibut survey catch rates. From paragraph 20 in IPHC-2022-SRB021-R:

> *"**NOTING** that the 'hurdle' model structure (separate modeling of presence/absence and abundance conditional on presence) of the space-time model used to analyze the FISS may not be the most efficient approach, the SRB **RECOMMENDED** that the Secretariat explore other approaches such as the use of mixture models or the 'Tweedie' distribution."*

The 'hurdle' (or delta) model structure is described in Webster et al. (2020), and involves specifying separate model components for the probability of a catch rate (weight or numbers per unit effort) of zero (a Bernoulli process) and for the non-zero observations (a gamma process). For this document, we refer to this as the "delta-gamma" model. While the two components share a common spatio-temporally correlated error structure, model covariates are generally included in both model components (zeros and non-zeros), increasing model complexity and likely leading to longer times for model fitting than simpler models.

The Tweedie model as implemented in R-INLA (the R package currently used for space-time modelling of FISS data) is a compound Poisson-gamma model (see https://inla.r-inla-download.org/r-inla.org/doc/likelihood/tweedie.pdf). The model has two hyperparameters, p and φ ("dispersion") compared to one hyperparameter for the delta-gamma model currently in use (the gamma variance or precision parameter) but as noted requires fewer covariate parameters. Both models have the same two parameters specifying spatial dependence and a single temporal correlation parameter. However, the current model has two hyperparameters for the random walk models of depth (one for each model component) and a scalar parameter linking the space-time model errors between the model components. Thus, the Tweedie model has one fewer hyperparameter, along with a reduction in the number of fixed effects parameters present in some models (e.g., distance from shelf edge in IPHC Regulatory Area 4CDE, gear effect in areas with recent snap/fixed gear comparisons).

Preliminary modelling (IPHC-2023-SRB023-09) of all-sizes WPUE data from 1993-2022 for three IPHC Regulatory Areas (2C, 3B and 4A) yielded estimates of times series that were very close to those from the existing model, but with significant reductions in model run time. In this report, we present comparisons between Tweedie and delta-gamma models for O32 WPUE data from all IPHC Regulatory Areas for 1993-2023.

RESULTS

Table 2.1 presents comparisons between the model output of the delta-gamma and Tweedie models for three IPHC Regulatory Areas. For all but IPHC Regulatory Area 3B, the DIC values imply that the Tweedie models provides a poorer fit (higher DIC), while producing similar estimates of parameters for temporal and spatial dependence.

The greatest difference in DIC was for IPHC Regulatory Area 4CDE. This is an area with many zero catches on the Bering Sea flats, and the model fits seemed to benefit from the greater flexibility in modelling the zero-generating process afforded by the delta-gamma model.

We did not compare model run times in Table 2.1 as the modelling computer was replaced between the delta-gamma and Tweedie model runs, confounding any comparisons. We note that hardware improvements together with software and coding updates mean that the delta-gamma model is now running more efficiently than in past years, and computing time improvements offered by the simpler Tweedie model are likely to be less important than implied by the preliminary results in IPHC-2023-SRB023-09.

Figures 2.1, and 2.2 compare the time series estimates by IPHC Regulatory Area and Biological Region respectively. Both model types estimate very similar values in all years except when data are sparse such as the early years in IPHC Regulatory Areas 2A, 4A, 4B time series. Our understanding of the stock trends is not meaningfully affected by the choice of model.

DISCUSSION

While initial results from fitting Tweedie models were very promising (IPHC-2023-SRB023-09), the models results presented here do not make a compelling case for changing the production version of the IPHC's space-time model from the delta-gamma to Tweedie. We note that the preliminary modelling was undertaken using all-sizes WPUE data, rather than the O32 data used here. All-sizes WPUE generally has fewer zero values and may benefit less from the more flexible structure of the delta-gamma model than O32 WPUE data.

We intend to repeat the comparisons following the 2024 FISS, potentially expanding the scope to include all three variables we routinely model (O32 WPUE, all-sizes WPUE and all-sizes NPUE). Results will be reported at SRB026.

Table 2.1. Comparison of DIC, model run time, and model parameter estimates (posterior means with standard deviations in parentheses) for common parameters between the current delta-gamma model and the Tweedie model.

IPHC Regulatory Area	Parameter	Description	Delta-gamma	Tweedie	Difference
4CDE	DIC	Model fit	72 091.8	74 157.6	−2 065.7
	ρ	Temporal correlation	0.913 (0.013)	0.897 (0.009)	
	θ_1	Spatial correlation	−6.76 (0.13)	−6.99 (0.10)	
	θ_2	Spatial correlation	5.08 (0.13)	5.23 (0.08)	
4B	DIC	Model fit	21 878.2	21 927.8	−49.6
	ρ	Temporal correlation	0.914 (0.010)	0.904 (0.012)	
	θ_1	Spatial correlation	−7.89 (0.11)	−7.57 (0.18)	
	θ_2	Spatial correlation	5.73 (0.10)	6.03 (0.13)	
4A	DIC	Model fit	41 672.5	42 188.2	−515.7
	ρ	Temporal correlation	0.954 (0.008)	0.949 (0.006)	
	θ_1	Spatial correlation	−7.73 (0.10)	−7.15 (0.12)	
	θ_2	Spatial correlation	5.51 (0.07)	5.66 (0.12)	
3B	DIC	Model fit	86 994.3	86 979.7	14.6
	ρ	Temporal correlation	0.953 (0.007)	0.933 (0.010)	
	θ_1	Spatial correlation	−6.76 (0.14)	−5.97 (0.07)	
	θ_2	Spatial correlation	4.90 (0.07)	4.88 (0.08)	
3A	DIC	Model fit	148 692.7	148 741.8	−49.1
	ρ	Temporal correlation	0.963 (0.004)	0.961 (0.004)	
	θ_1	Spatial correlation	−7.32 (0.12)	−6.72 (0.08)	
	θ_2	Spatial correlation	5.39 (0.13)	5.45 (0.08)	
2C	DIC	Model fit	55 653.8	55 816.9	−163.2
	ρ	Temporal correlation	0.959 (0.006)	0.960 (0.005)	
	θ_1	Spatial correlation	−8.57 (0.21)	−7.86 (0.29)	
	θ_2	Spatial correlation	6.46 (0.16)	6.48 (0.19)	
2B	DIC	Model fit	81 323.8	81 453.4	−129.7
	ρ	Temporal correlation	0.951 (0.005)	0.953 (0.006)	
	θ_1	Spatial correlation	−7.61 (0.18)	−7.03 (0.15)	
	θ_2	Spatial correlation	5.71 (0.11)	5.71 (0.12)	
2A	DIC	Model fit	23 582.9	23 763.9	−181.0
	ρ	Temporal correlation	0.924 (0.010)	0.924 (0.010)	
	θ_1	Spatial correlation	−8.03 (0.22)	−8.16 (0.27)	
	θ_2	Spatial correlation	5.90 (0.16)	6.21 (0.19)	

References

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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). 2024-26 FISS Design Evaluation. IPHC-2023-SRB023-09. 24 p.

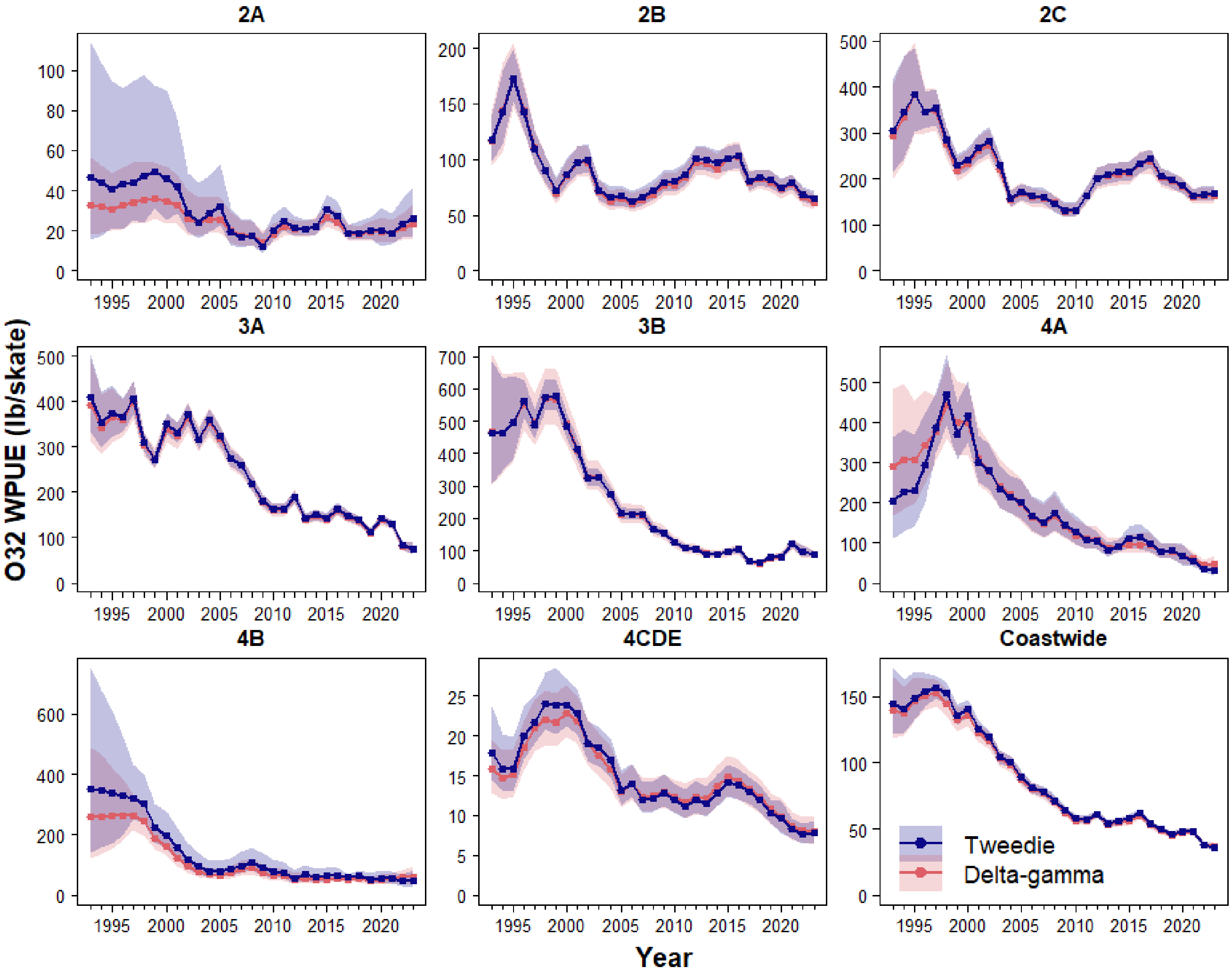

Figure 2.1. Comparison of estimated time series (posterior means by year) of O32 WPUE for the current delta-gamma model and the Tweedie model, by IPHC Regulatory Area. Shaded regions represent 95% posterior credible intervals.

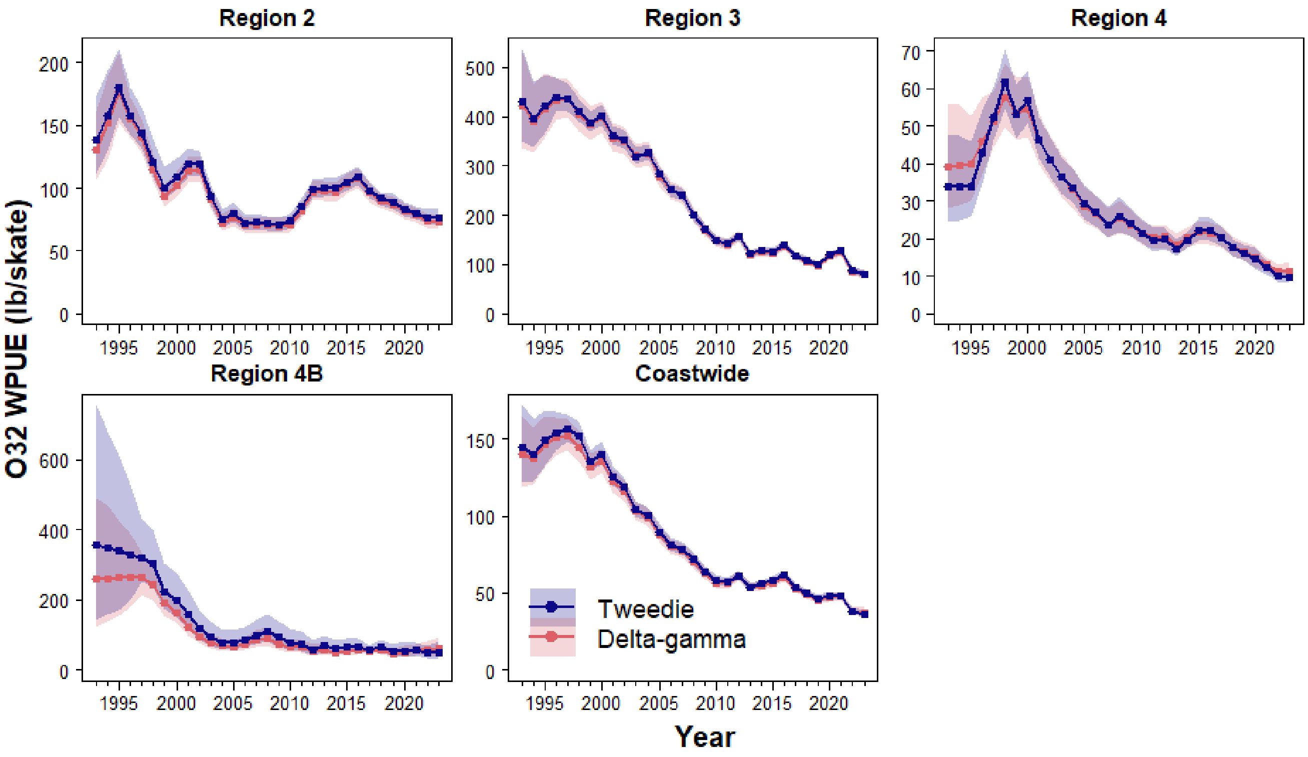

Figure 2.2. Comparison of estimated time series (posterior means by year) of O32 WPUE for the current delta-gamma model and the Tweedie model, by IPHC Biological Region. Shaded regions represent 95% posterior credible intervals.

IPHC Secretariat MSE Program of Work (2024) and an update on progress

PREPARED BY: IPHC SECRETARIAT (A. HICKS, I. STEWART; 17 MAY 2024)

PURPOSE

To provide the Scientific Review Board (SRB) with an update on Management Strategy Evaluation (MSE) progress and an MSE program of work for 2024.

1 INTRODUCTION

Work from the Management Strategy Evaluation (MSE) Program of Work for 2023–2025 that has been completed is reported in documents IPHC-2024-MSAB019-06 and IPHC-2024-MSE-01. This includes updating the operating model (OM), defining exceptional circumstances and actions to take when an exceptional circumstance occurs, investigating the environmental and fishing effects on the abundance and distribution of Pacific halibut, and evaluating a wide range of fishing intensities (SPR=34% to SPR=56%). Updates to the MSE Program of Work for 2023–2025 are being considered by the Commission.

> **IPHC-2024-AM100-R, 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*.

The potential additions to the MSE Program of Work discussed in this paper support the development of a harvest strategy policy document.

2 HARVEST STRATEGY POLICY

A Harvest Strategy Policy (HSP) provides a framework for applying a science-based approach to setting harvest levels. At IPHC, this would be specific to the TCEY for each IPHC Regulatory Area throughout the Convention Area. 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.

Adopting an HSP is important for any fisheries management authority because it outlines the long-term vision for management and specifies the framework for a consistent and transparent science-based approach to setting mortality limits. An HSP:

- identifies an appropriate method to manage natural variability and scientific uncertainty,
- accounts for risk and balances trade-offs,
- reduces the time needed to make management decisions,
- ensures long-term sustainability and profitability,
- increases market stability due to a more predictable management process,

- adheres to the best practices of modern fisheries management that is consistent with other fisheries management authorities and certification agencies, and
- allows for the implementation of the precautionary approach.

Overall, an HSP spells out the management process, which benefits the fish, the stakeholders, and other interested parties.

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.

An HSP can be divided into three components: management procedure, harvest strategy, and policy (Figure 1). A management procedure is an agreed upon procedure that determines an output that meets the objectives defined for management. The MP is reproducible and codified such that it can be consistently calculated. The harvest strategy component contains the MP but is broader and encompasses the objectives as well as additional procedures that produce the final necessary outputs but may not be procedural and pre-defined. For example, at the IPHC the harvest strategy consists of the procedure to determine the coastwide TCEY as well as the concept of distributing the TCEY to each IPHC Regulatory Area. Currently, the determination of the coastwide TCEY is defined using a harvest control rule and reference fishing intensity, but there is not an agreed upon procedure to distribute the TCEY. However, a reference TCEY distribution, calculated using a defined procedure, may be useful to inform the decision-making process. The policy component is the aspect of decision-making where management may deviate from the outputs of the harvest strategy 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, for example. At IPHC, the policy component occurs at the Annual Meeting of the IPHC where stakeholder input is considered along with scientific information to determine the mortality limits for each IPHC Regulatory Area.

Some additional MSE work would be useful for drafting an HSP document for adoption, noting that the HSP may be updated at any time following additional MSE-related work. The MSE tasks to complete are outlined in this document along with other tasks that may be useful for Commission decisions.

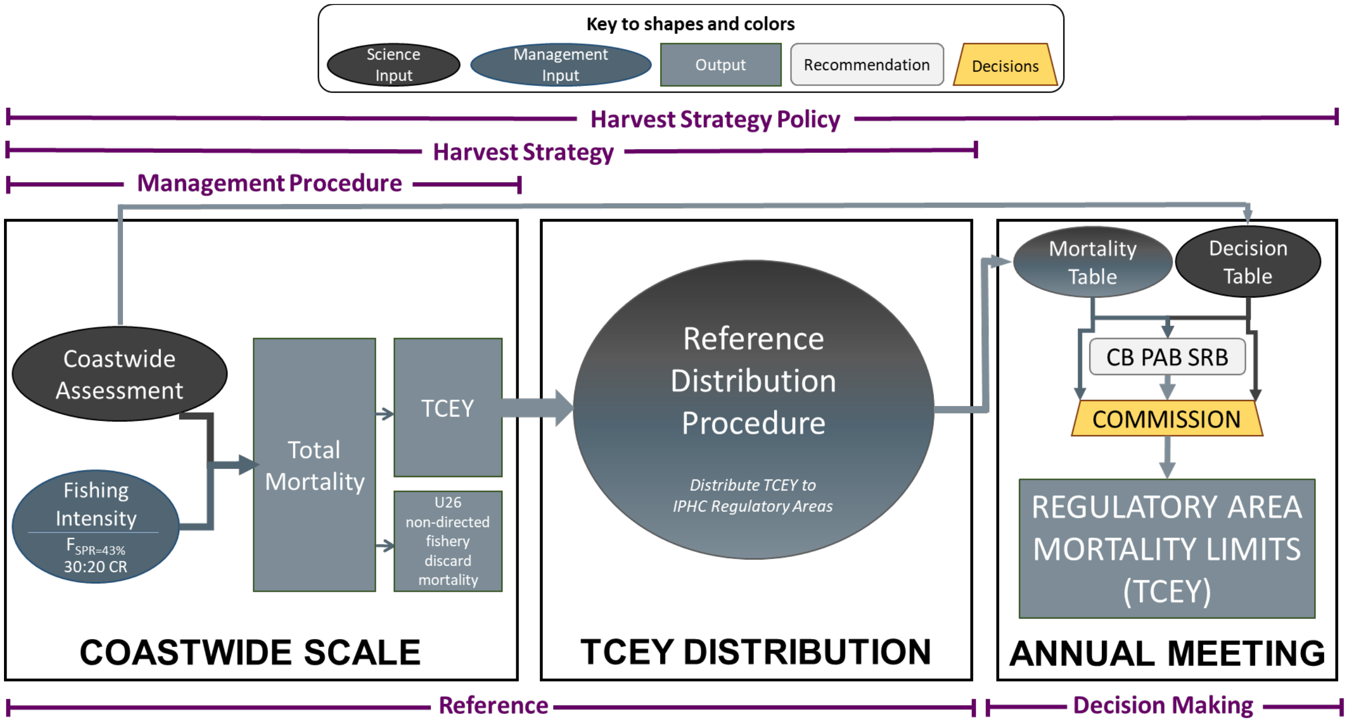

Figure 1. Illustration of the interim harvest strategy policy for the IPHC showing the coastwide scale (management procedure), the TCEY distribution (part of the harvest strategy), and the policy component that mainly occurs at the Annual Meeting.

2.1 Exceptional Circumstances

An exceptional circumstance is an event that is beyond the expected range of the MSE evaluation and triggers specific actions that should be taken to re-examine the harvest strategy. Exceptional circumstances, and actions taken if one or more 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 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). The following potential triggers for an exceptional circumstance have been defined.

> **IPHC-2023-SRB023-R, para. 27:** ***RECOGNIZING*** *the spatial variability of environmental factors that influence population dynamics, the SRB* ***RECOMMENDED*** *that an exceptional circumstance be defined based on regional as well as stockwide deviations from expectations. For example, an exceptional circumstance could be declared if any of the following are met:*

> *a) 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.*
>
> *b) 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 2 or more years.*
>
> *c) 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*.

Furthermore, the following actions may take place if an exceptional circumstance is declared.

> **IPHC-2023-SRB023-R, para. 28:** *The SRB* ***RECOMMENDED*** *that if an exceptional circumstance occurred the following actions would take place:*
>
> *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 FISS coastwide modelled NPUE was compared to projections from the 2023 OM to determine if an exceptional circumstance has occurred (Figure 2). Predictions intervals from the OM were calculated by simulating 100 indices from 125 OM simulations to incorporate the uncertainty in the FISS index. The current interim reference fishing intensity associated with an SPR of 43% was used because that is the current interim MP and includes decision-making variability to account for departing from that fishing intensity. The 2023 observation from the FISS space-time model is within the 95% prediction interval from the OM, thus an exceptional circumstance has not occurred.

Using similar methods as with the coastwide FISS index, the predicted stock distribution from MSE simulations with an SPR of 43% was compared to the observed stock distribution in 2023 (Figure 3). The observations in 2023 depart from the predictions in Biological Regions 2 and 3. This happens in some previous years and may indicate that there is more uncertainty than the OM is modelling.

Other factors, such as updates to parameters, are considered when determining exceptional circumstances. One important current research project is the examination of maturity-at-age. If the updated maturity-at-age is much different than assumed in the 2023 OM, that may require an update to the OM. This will be evaluated when the new results are available.

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. 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 of other factors that are not part of the MSE and not reflective of Pacific halibut stock dynamics. The response in these two cases may be different.

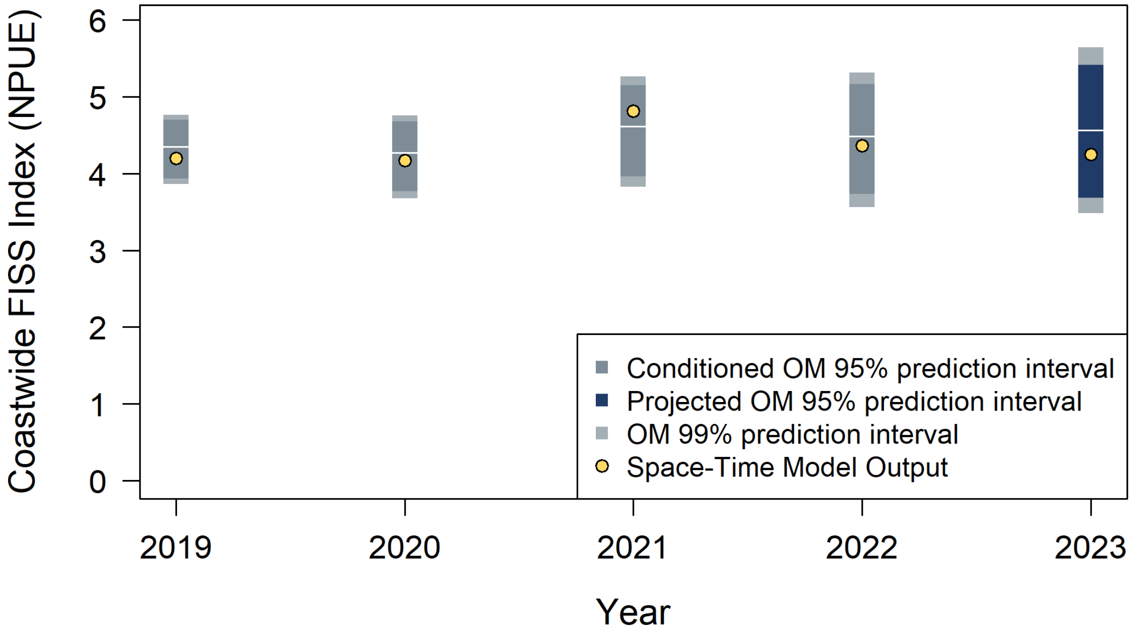

Figure 2. Prediction intervals of the coastwide FISS NPUE index from the 2023 OM (conditioned on data through 2022) projected to 2023 using an SPR of 43, decision-making variability, estimation error, and observation error plotted along with the FISS all-sizes NPUE index from the space-time model (yellow dot). The dark blue box is the 95% prediction interval for all-sizes NPUE from the projected 2023 OM. Lighter extensions of each box show the 99% prediction interval.

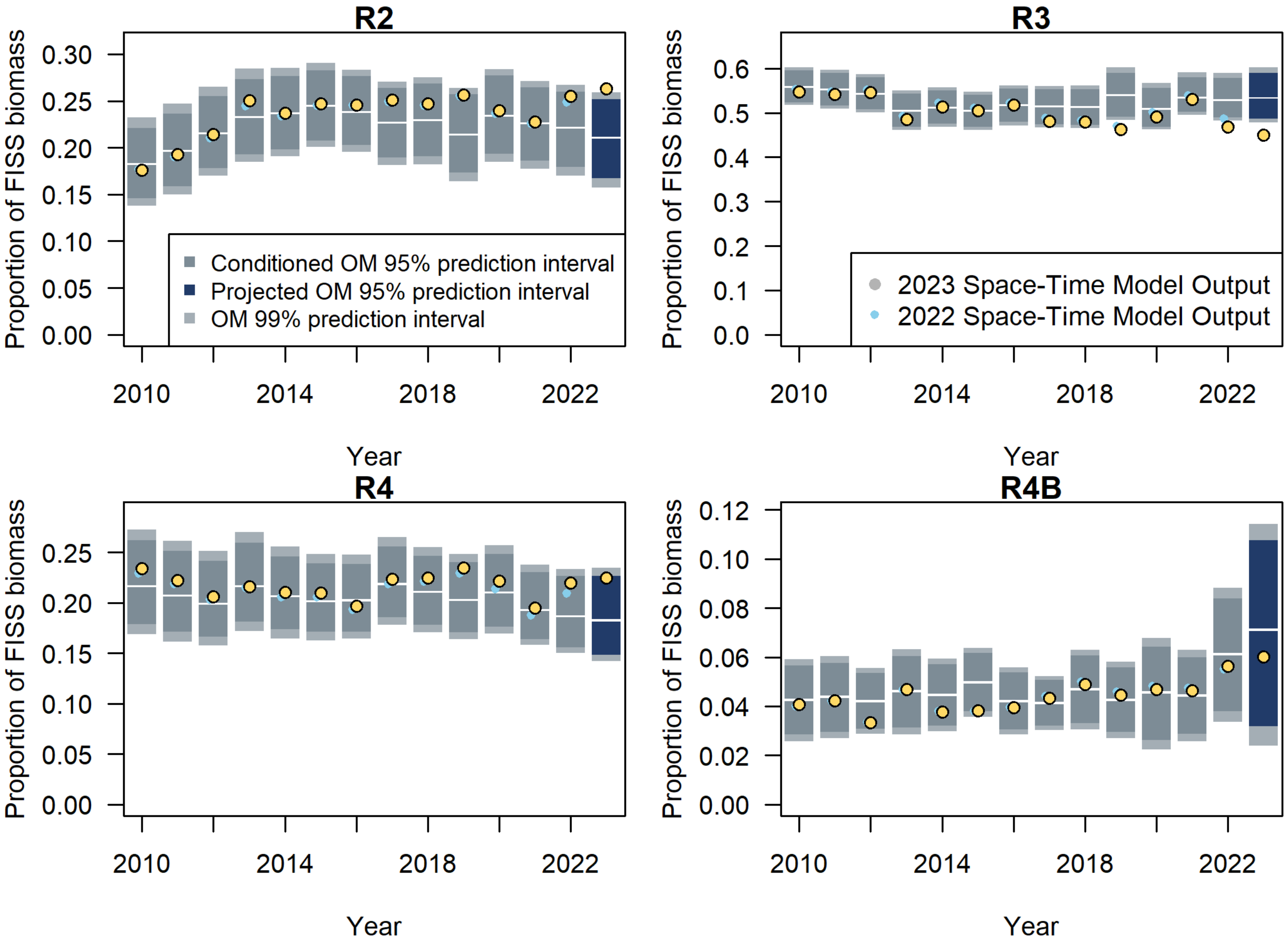

Figure 3. Prediction intervals of the proportion of FISS all-sizes biomass in each Biological Region (stock distribution) from the 2023 OM projected to 2023 using an SPR of 43, decision-making variability, estimation error, and observation error plotted along with the FISS all-sizes stock distribution from the space-time model (yellow dot). The dark blue box is the 95% prediction interval for stock distribution from the projected 2023 OM. Lighter extensions of each box show the 99% prediction interval. Estimated stock distribution from the 2022 space-time model are shown in light blue (which were used when conditioning the OM).

3 GOALS AND OBJECTIVES

The Commission defined a small set of priority coastwide objectives and associated performance metrics for current evaluations.

> **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).

3.1 Performance metric for multi-year assessments

The MSAB018 also requested that new performance metrics be developed for evaluating assessment frequency.

> **IPHC-2023-MSAB019-R, para.** 38. *The MSAB* ***REQUESTED*** *new performance metrics representing the change in the TCEY in non-assessment years and the change in TCEY in assessment years be developed for the evaluation of multi-year assessment MPs*.

Current performance metrics describing the interannual variability in the TCEY include the average annual variation (AAV) and the probability that 3 or more years of a 10-year period have a change in the TCEY greater than 15% from one year to the next (Appendix A). Additional metrics may be useful in understanding the performance of an MP using biennial or triennial assessments, especially if the TCEY is held constant during non-assessment years. The current performance metrics, averaged over a 10-year period, regardless of the assessment frequency, are still useful and simply represent the variability over that 10-year period.

Annual Change (AC) is one performance metric that shows interannual variability in the TCEY and measures the relative percent change in the TCEY from the previous year (see Appendix A for a mathematical description). Figure 4 shows the AC for annual, biennial, and triennial assessment frequencies from simulations performed in 2022 with two empirical rules used to determine the coastwide TCEY in non-assessment years (see IPHC-2023-MSE-01):

a. The same coastwide TCEY from the previous year until a stock assessment is available.
b. Update the coastwide TCEY proportionally to the change in the coastwide FISS O32 WPUE.

The years with an assessment show a wider range of annual change in the TCEY because estimation error from the assessment is greater than fixing the TCEY or changing the TCEY in proportion to the change in the O32 FISS WPUE (noting that a less precise FISS WPUE index would result in more variability in non-assessment years).

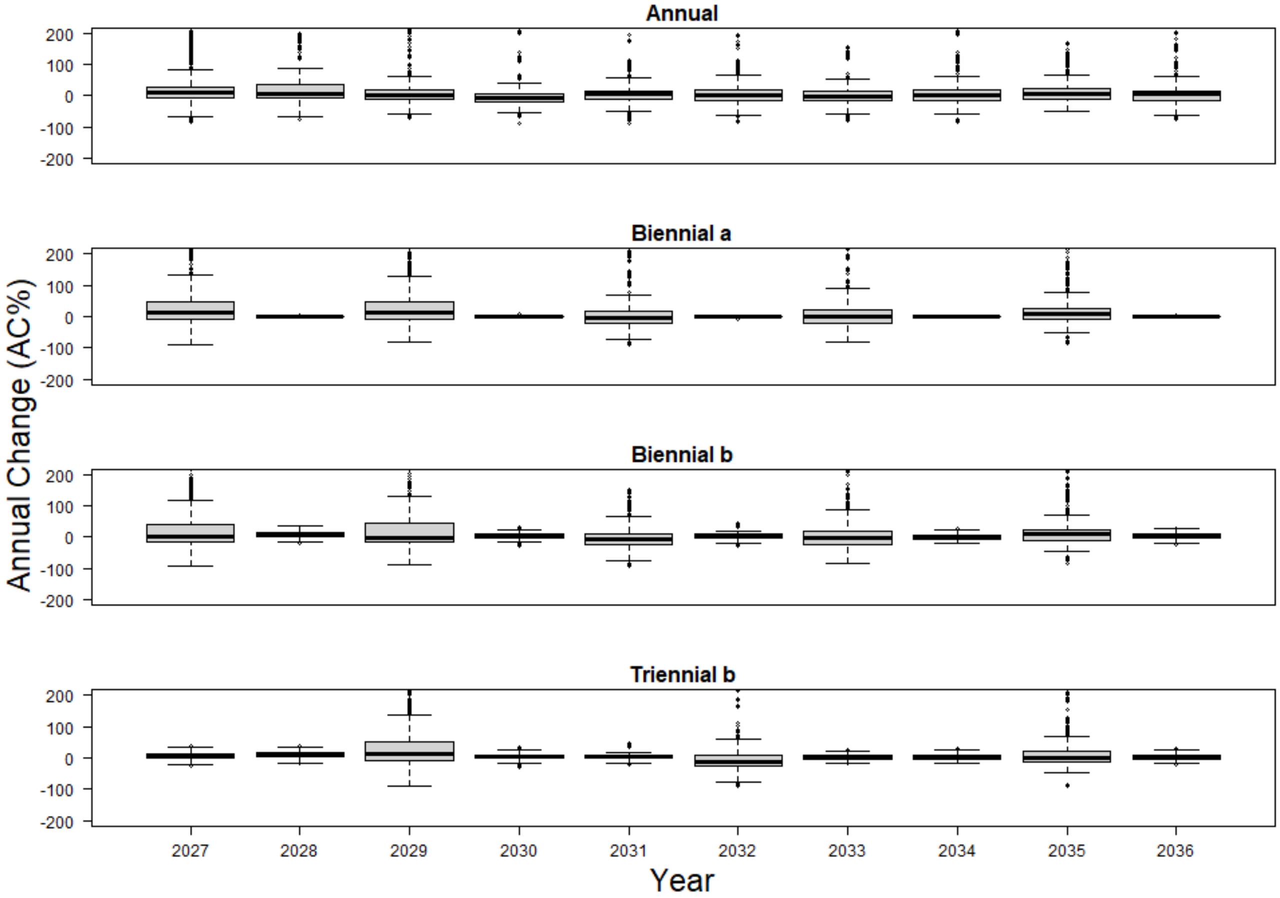

Figure 4. Boxplots of the annual change (AC) in percentage for annual, biennial, and triennial assessment frequencies. The biennial assessment frequency used a static TCEY in non-assessment years (a) and the biennial and triennial assessment frequencies use a proportional change determined from the O32 FISS WPUE (b).

Potential performance metrics to report when evaluating assessment frequency are:

- Reporting the average annual variability (AAV) calculated separately for only the years with an assessment and only the years without an assessment. This can be challenging because the same years need to be compared otherwise the performance metric is confounded with change in the population. This reduces the number of comparable years in a ten-year period, reducing the usefulness of an average.

- The percent change in the TCEY from the previous year calculated separately for assessment years and non-assessment years summarized over a 10-year period and all simulations. As with the AAV, this can be challenging to make sure that the same years are included in the calculation to avoid confounding from other factors.
- The maximum annual change observed in a ten-year period. As with other metrics, assuring that the same years are compared is essential, if separating by assessment and non-assessment years.

The biggest challenge with developing a performance metric to measure changes in assessment years is defining a statistic that is consistent across all MPs and can be summarized in a way that allows for the MPs to be evaluated against each other. With annual, biennial, and triennial MPs, the statistic is reduced to only two comparable years in a ten-year period.

It is important to consider the objective when developing performance metrics, and sometimes multiple performance metrics may be useful to the evaluation. With a well-defined measurable objective, a performance metric is easily defined. Regarding assessment frequency, one consideration is whether a stable period with an occasional larger biennial or triennial change is preferable to an annual assessment and potentially smaller changes in the TCEY. A discussion occurred at MSAB019, and the following notes and recommendation were made:

> **IPHC-2024-MSAB019-R, para. 44:** *The MSAB* ***NOTED*** *that various performance metrics were presented that may be used to evaluate interannual variability in the TCEY. These include average annual variation (AAV), annual change (AC), and maximum change. The AC may be specified as a probability of exceeding a value for any number of years, which may be useful to evaluate the assessment frequencies other than annual.*
>
> **IPHC-2024-MSAB019-R, para. 45:** *The MSAB* ***NOTED*** *that a performance metric indicating the duration of stability (e.g. the number of consecutive years below a threshold) may be useful to evaluate the interannual variability in the TCEY, especially across different assessment frequencies.*
>
> **IPHC-2024-MSAB019-R, para. 47:** *The MSAB* ***REQUESTED*** *that the Secretariat report performance metrics noted in paragraph 44 and 45 over ten (10) and fifteen (15) year periods.*

3.2 An objective related to absolute spawning biomass

The spawning biomass reference points in the conservation objective to “maintain the long-term coastwide female spawning stock biomass above a biomass limit reference point...” and in the objective to “maintain the long-term coastwide female spawning stock biomass at or above a biomass reference point…” use relative spawning biomass, which is the estimated female spawning biomass divided by the estimated unfished female spawning biomass (dynamic relative spawning biomass, RSB). Furthermore, unfished female spawning biomass is estimated as the unfished spawning biomass that would have occurred if there was no fishing up to the year of interest. This metric, dynamic unfished spawning biomass (or dynamic B_0) reflects the changes in the population due to natural variability in the population, and therefore RSB measures only the effects of fishing. RSB is useful for managing a fish species because it is consistent with other reference points (e.g. SPR), accounts for changes in biology, incorporates variation in recruitment, and allows for a clear determination of “overfished” without confounding stock changes with natural variability.

Pacific halibut have seen large changes in average weight-at-age and high variability in recruitment, which have changed the stock dynamics considerably. Figure 5 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 6), 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 5) 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 predicts a greater than 70% chance that the spawning biomass in any of the next three years will be less than the spawning biomass in 2023. The long-term average RSB when fishing consistently at an SPR of 43% would be near 38%.

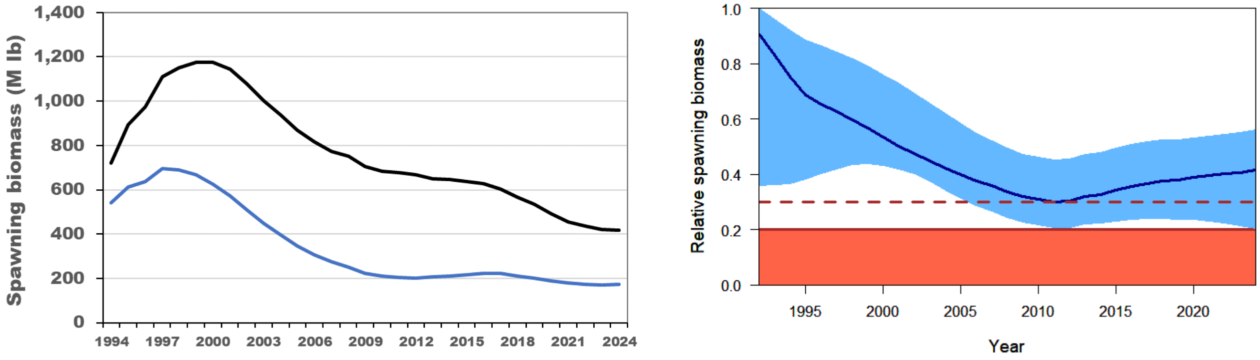

Figure 5. Dynamic unfished spawning biomass (black line) and current spawning biomass (blue line) from the 2023 stock assessment (left) and dynamic relative spawning biomass (right) with an approximate 95% credible interval in light blue and the control rule limit ($B_{20\%}$) and trigger ($B_{30\%}$) in red. Figures from IPHC-2024-SA-01.

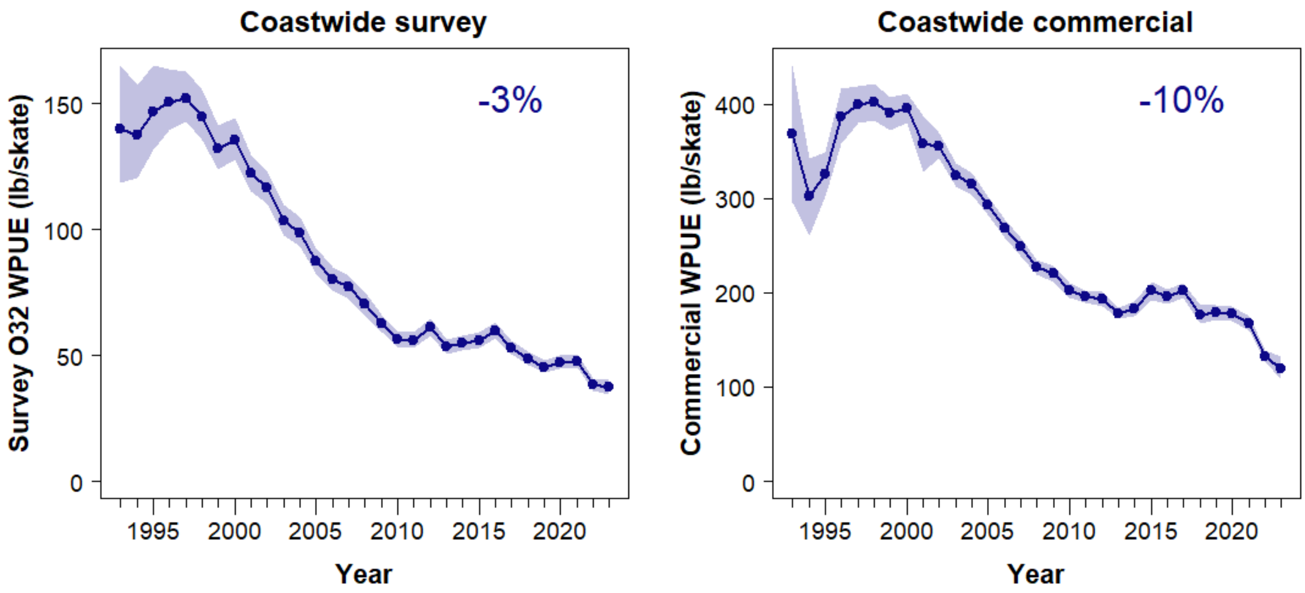

Figure 6. The coastwide FISS O32 WPUE index (left) and coastwide commercial WPUE (right) showing the percent change in the last year (from IPHC-2024-SA-02). Based on past calculations, additional logbooks collected in 2024 will likely further reduce the decline in commercial WPUE to -12%.

Recent Commission decisions (2023 and 2024) have set coastwide TCEYs less than the reference TCEY suggested by the stock assessment and current interim management strategy, noting the following.

> **IPHC-2024-AM100-R, para 38**. *The Commission* ***NOTED*** *that the estimated absolute spawning biomass is at a 35-year low and likely to remain low for several more years given recruitments currently in the water.*
>
> **IPHC-2024-AM100-R, para 56**. *The Commission* ***NOTED*** *that:*
>
> *a) the status quo coastwide TCEY of 36.97 million pounds corresponds to a 45/100 chance of stock decline over the next 1-3 years;*
>
> *b) coastwide TCEYs at or above 39.1 million pounds would have a greater than a 50% chance of stock decline over the next three years;*
>
> *c) fishing at the reference level (F43%) would equate to a coastwide TCEY of 48.9 million pounds in 2024 and have a high likelihood of stock decline over one-year (74/100) and three-years (72%).*
>
> **IPHC-2024-AM100-R, para 57**. *The Commission* ***NOTED*** *several additional risks not included in the harvest decision table:*
>
> *a) the estimated absolute spawning biomass is at a 30+-year low and likely to remain low for several more years given recruitments currently in the water;*
>
> *b) low 2023 catch-rates in the FISS and directed commercial fisheries compared to those observed over the last 30 years;*

> *c) Biological Region 3 is currently at the lowest observed proportion of the coastwide biomass since 1993 (the full historical range is unknown), and uncertainty associated with changes to the ecosystem and climate remains high.*
>
> **IPHC-2024-AM100-R, para 59**. *The Commission **NOTED** the wide uncertainty intervals around the estimated spawning biomass and that once a mortality limit is selected there is a correspondingly large amount of uncertainty in the actual fishing intensity.*
>
> **IPHC-2024-AM100-R, para 88**. *The Commission **NOTED** that the adopted mortality limits for 2024 correspond to a 41% probability of stock decline through 2025, and a 41% probability of stock decline through 2027.*
>
> **IPHC-2024-AM100-R, para 89**. *The Commission **NOTED** that the adopted mortality limits for 2024 correspond to a fishing intensity of F52%, equal to the estimate for 2023.*

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 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 made a recommendation to re-evaluate what they called the target objective. This is objective (b): to maintain the relative spawning biomass above $B_{36\%}$.

> **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 the Commission noted historically low observed fishery catch rates in 2022 and 2023.

> **IPHC-2023-AM099-R, para 56.** *The Commission **NOTED** that there are additional risks associated with the stock condition and mortality limit considerations for 2023 that are not quantitatively captured in the decision table, these include:*
>
> > *a) Historically low observed fishery catch rates corresponding to reduced efficiency/performance in 2022;*

The threshold 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. Setting an absolute spawning biomass to avoid low catch-rates may also *de facto* protect the stock from serious harm (i.e. avoid dropping below the current relative spawning biomass limit of 20%).

A second approach is to define an objective based on catch-rates in the fishery. If an efficient fishery is the objective, then 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.

An alternative way to think about this 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 that could be in units of spawning biomass, fishery CPUE, FISS WPUE, or some other estimable quantity. Note that a fishery limit reference point is a different objective than 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. As mentioned above, 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 may be phrased as:

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

The threshold may be an absolute value of spawning biomass or a defined static biomass reference point such as the spawning biomass in 2023. It is important to first decide if this is a useful general objective. If it is, then specifying a measurable objective would require defining the threshold, the term, and a tolerance. From that, a performance metric would be developed.

At MSAB019, the following notes and recommendations were made.

> **IPHC-2024-MSAB019-R, para. 48:** *The MSAB* ***NOTED*** *that the estimated stock status of Pacific halibut is above a relative spawning biomass of 36% (a priority objective of the Commission, para. 23b), but the FISS WPUE, commercial WPUE, and estimated absolute spawning biomass are at their lowest values observed in many decades.*
>
> **IPHC-2024-MSAB019-R, para. 49:** *The MSAB* ***NOTED*** *that a healthy stock can be defined with relative spawning biomass, absolute spawning biomass, a robust age structure, and rotund weight-at-age.*
>
> **IPHC-2024-MSAB019-R, para. 50:** *The MSAB* ***NOTED*** *that from MSE simulation results when fishing at the current reference FSPR=43% there is a 1 in 5 chance in the long-term and a 1 in 3 chance in the short-term that the spawning biomass will be less than that observed in 2023.*
>
> **IPHC-2024-MSAB019-R, para. 51:** ***NOTING*** *paragraph 48, the MSAB* ***RECOMMENDED*** *developing an objective and identifying a management procedure that addresses the current circumstances and differences in perception of the stock status.*

3.3 Spatial spawning biomass

Maintaining spatial population structure is an important objective that is currently defined in Appendix A, but is not a priority objective of the Commission. This objective uses *ad-hoc* defined percentage of spawning biomass to maintain in each Biological Region. The SRB recently made a recommendation to update this objective.

> **IPHC-2023-SRB023-R, para. 24:** *The SRB* ***RECOMMENDED*** *that an objective to maintain spatial population structure be added or redefined to maintain the spawning biomass in a Biological Region above a defined threshold relative to the dynamic unfished equilibrium spawning biomass in that Biological Region with a pre-defined tolerance. The percentage and tolerance may be defined based on historical patterns and appropriate risk levels recognizing the limited fishery control of biomass distribution.*

Recent MSE simulations showed that the percentage of spatial spawning biomass in each Biological Region is affected by the fishery and the environment (e.g. fitted PDO relationships in the OM), and each Biological Region is affected differently by these two sources. Figure 7 shows that the percentage of the spawning biomass in Regions 2 and 4B are affected by fishing and the environment, in Region 3 is mostly affected by the environment, and in Region 4 is mostly affected by fishing. The regional relative spawning biomass will be examined and reported at the 25th Session of the Scientific Review Board (SRB025).

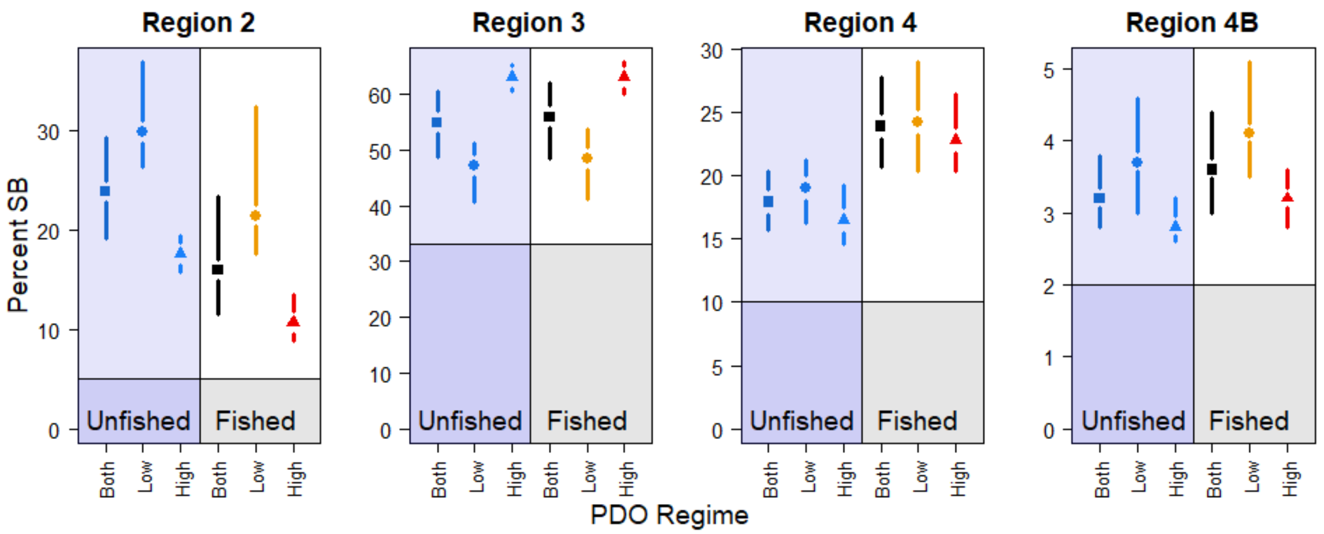

Figure 7. Percentage of spawning biomass in each Biological Region when fished with an SPR of 43% and integrated over a range of distribution procedures (no estimation error, no observation error, and no implementation error), and when not fished. The PDO is modelled with cyclical low and high periods in “Both”, is persistently low in “Low”, and is persistently high in “High”. The darker shaded area indicates the area below the threshold in the spatial conservation objective (Appendix A).

4 MANAGEMENT PROCEDURES

The SRB made a recommendation at SRB023 providing guidance on management procedures (MPs) to evaluate.

> **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 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 available.

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 simpler approach to determine the coastwide TCEY that is tuned to meet the objectives. This could be an empirical approach, or a simpler statistical model. Stock assessments would be completed periodically to determine the status of the stock and verify that the management procedure is working appropriately.

4.2 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%. The percent change in the adopted coastwide TCEY ranged from -10% to 8% across years and ranged from -21% to 29% for the coastwide reference TCEY across years (Table 1).

Decision-making since 2015 has reduced the interannual variability in the coastwide TCEY, compared to the reference, over the last ten years. The adopted TCEYs have a smaller range than the reference TCEYs and tend to cluster around 39 million pounds (Figure 8). 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 8). 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.

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 (Appendix B).

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.

	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%

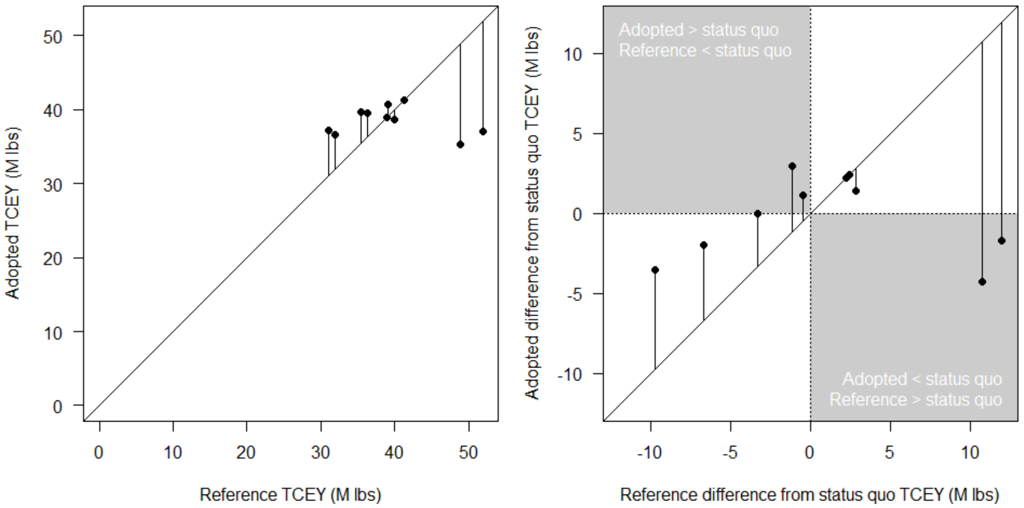

Figure 8. The adopted TCEY vs the reference TCEY (left) and the adopted difference from the status quo TCEY vs the reference difference from the status quo TCEY (right) for the last ten years (2015–2024). The 1:1 line shows when the two are equal. The grey quadrants in the right plot show when the adopted and reference TCEY differences from the status quo are opposite.

Past considerations of constraints included the following:

- A maximum 15% change in the coastwide TCEY in either direction from one year to the next.
- A slow-up/fast-down approach where the 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.
- A multi-year TCEY set constant for a specified number of years.
- An additional component to any constraint specifying to not exceed a maximum fishing intensity consistent with an SPR of 35% (the approximate SPR_{MSY}; see IPHC-2019-SRB015-11 Rev_1).

The specifications of these constraints can easily be tested and tuned to best meet conservation and fishery objectives.

4.3 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 at least 35% and 52% (interim reference SPR is currently 43%) will be investigated.

Some results of the evaluation of SPR values were presented in IPHC-2024-MSAB019-06. However, it should be standard to test a range of SPR values when modifying other elements of the MP. For example, a constraint may have significant effects on the performance metrics, which may be mitigated with different SPR values, if desired. The results in IPHC-2024-MSAB019-06 may provide a guide for the range of SPR values to include in future evaluations.

4.4 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, distribution of the TCEY is a source of uncertainty. There are many options to include distribution of the TCEY in the MSE simulations. In the past, five distribution procedures spanning a range including recent Commission decisions were integrated into the simulations.

An alternative approach is to use the observed distribution of the TCEY in recent years to define distributions of the potential TCEY or percentage of TCEY in each IPHC Regulatory Area. This approach allows progress to be made in evaluating other components of the harvest strategy pending a formal agreement on a distribution procedure, but still includes some uncertainty during testing. Different methods may be applicable for different IPHC Regulatory Areas based on the recent history of management decisions.

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 9). The distribution of the TCEY to

IPHC Regulatory Areas 2A and 2B could simply assume 1.65 Mlbs for 2A and randomly draw a percentage from a distribution of percentages ranging from 17% to 21% for 2B with the mode of the distribution at 18.3% (Figure 10).

The TCEY in IPHC Regulatory Areas in Alaska could be distributed after the TCEY has been distributed to IPHC Regulatory Areas 2A and 2B. Observed percentages using only Alaskan areas are shown in Table 4. Using the average of these recent observations, a multinomial distribution could be used to randomly draw percentages for each Alaskan IPHC Regulatory Area, as shown in Figure 11.

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%

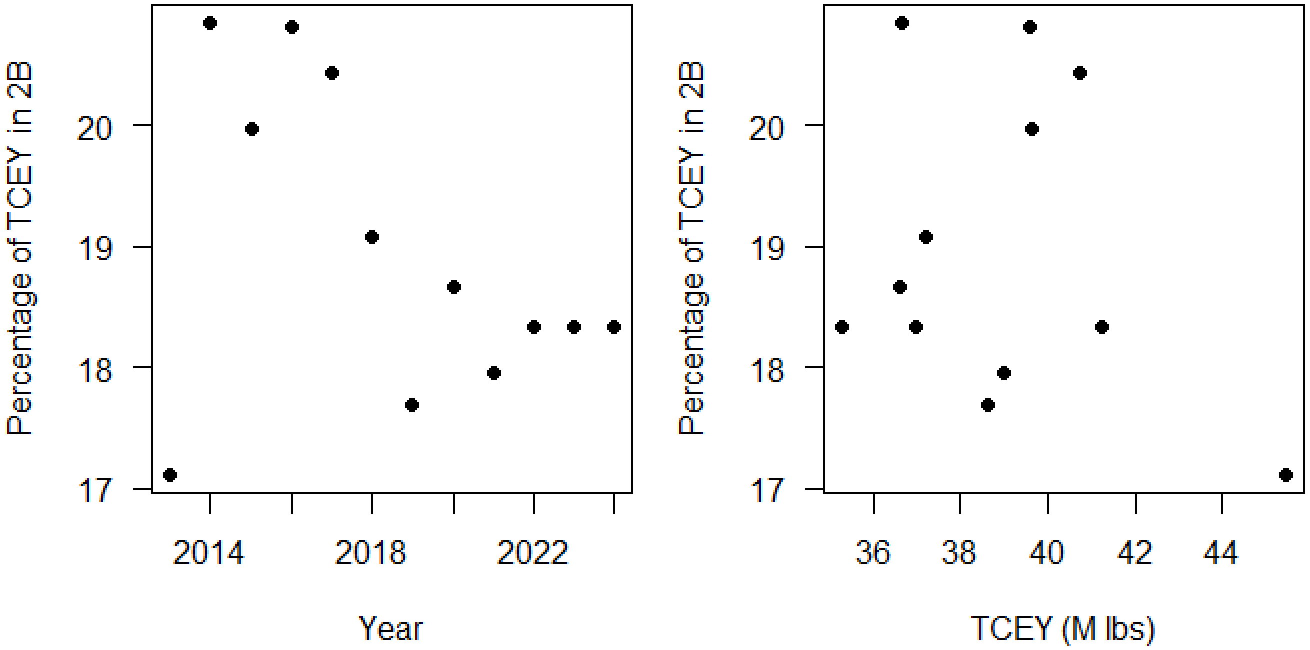

Figure 9. The percentage of the coastwide TCEY in IPHC Regulatory Area 2B plotted against year (left) and the coastwide TCEY (right).

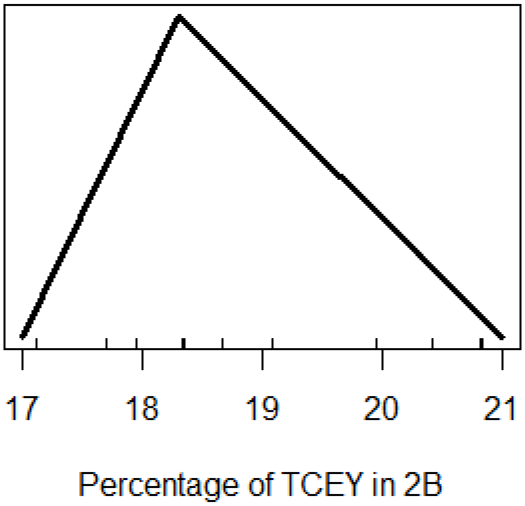

Figure 10. A triangle distribution ranging from 17% to 21% potentially to be used to randomly draw the percentage of the coastwide TCEY in 2B in MSE simulations. The ticks above the axis on the bottom show observed percentages from the past twelve years.

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%

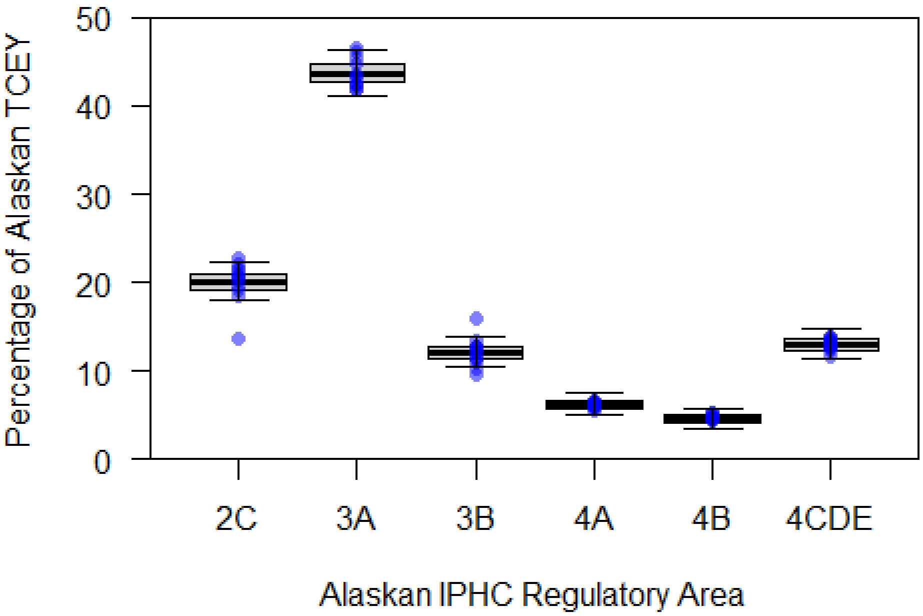

Figure 11. Observed percentage of the TCEY in Alaskan IPHC Regulatory Areas from 2013–2024 (blue points) and simulated percentage of the TCEY in Alaskan IPHC Regulatory Areas showing the median (thick black horizontal line), the central 50% (black box), and the 5th and 95th percentiles of the simulated distribution (black lines).

4.5 Additional MPs to evaluate

There are an endless number of MPs that could be evaluated with the MSE framework. Some potential MPs of interest include evaluating different triggers in the control rule (currently 30%) resulting in reductions in fishing intensity, an element related to maintaining the absolute spawning biomass above a threshold, and specific procedures for distribution of the TCEY to IPHC Regulatory Areas.

An MP to maintain the absolute spawning biomass above a threshold could be similar to the control rule currently used for stock status. A ramp could reduce the fishing intensity when the absolute spawning biomass (or catch-rates) fall below a specified threshold. Alternatively, a reduced reference fishing intensity could be used to avoid low stock sizes and be tuned to meet current Commission objectives, including the potential objective to avoid low absolute spawning biomass or catch-rates.

The distribution of the TCEY to IPHC Regulatory Areas is not a part of the MP in the harvest strategy, but it is a required output of the harvest strategy. Investigating methods to produce a reference TCEY distribution to inform the decision-making process may be useful to assist the Commission. This could be one part of the products presented at the Annual Meeting.

5 OTHER ANALYSES

The MSE framework is a generalized framework that can be used to evaluate any part of the harvest strategy. A management procedure includes how data are collected and analysed, how those data are synthesized in an estimation model (e.g. stock assessment), and the rules that determine how the TCEY is calculated. Any of these elements can be evaluated using the MSE framework.

Additionally, assumptions in the operating model can be tested as scenarios to indicate the effect on management outcomes and the robustness of a management procedure. Assumptions about the biology and life-history of Pacific halibut can be changed, such as the effect of the environment, or assumptions about how the fisheries operate (e.g., selectivity) can be modified. These are elements that are not under the control of the Commission, but instead are a source of uncertainty that is important to incorporate.

5.1 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 in 2022, 2023, and 2024 to maintain revenue neutrality and future reductions may be necessary. The Commission is interested in understanding how FISS designs may affect management outcomes, as noted in the report from the 99th Interim Meeting (IM099).

> **IPHC-2023-IM099-R, para. 38:** *The Commission* ***NOTED*** *that:*
>
> *a) to understand how reductions in the FISS design may affect management outcomes, the evaluation of FISS design scenarios using the MSE framework was recommended by the SRB at SRB023;* [see IPHC-2023-SRB023-R paragraphs 29 and 64].

There were many recommendations and requests from SRB023 related to the investigation of FISS design scenarios.

> **IPHC-2023-SRB023-R ,para. 26:** *The SRB* ***RECOMMENDED*** *continued examination, within the MSE, of FISS scenarios that are better representative of the levels of uncertainty and bias that may result from future reductions in FISS sampling.*
>
> **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.*
>
> **IPHC-2023-SRB023-R, para. 57:** *The SRB* ***REQUESTED*** *that the Commission NOTE the addition of cost estimates to the presentation of alternative FISS designs. The short-term risk implications in 2024 to the stock and TCEY of a drastically reduced FISS design (e.g. approx. revenue neutral Design 9 with efficiencies) are probably not profound given that the estimated current abundance is still above the implied B36% target. Impacts may appear more in the estimates of stock distribution since unsampled areas will be more dependent on the space-time model than actual data.*
>
> **IPHC-2023-SRB023-R ,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.*
>
> **IPHC-2023-SRB023-R, 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).*
>
> IPHC-2023-SRB023-R, **para. 61:** *The SRB **REQUESTED** that simulations above (para. 60) include: a) a relationship in which the FISS CV is relatively higher at lower stock abundance (i.e. the current CV issue is a function of stock abundance rather than a short-term condition); b) target regulatory area CVs of 15%, 20%, 25%, and 30%; c) coastwide target CV of 15% without controlling specific regulatory area CVs.*
>
> IPHC-2023-SRB023-R, **para. 64:** ***NOTING*** *the presentation demonstrating how secondary FISS objectives influence choices for future FISS designs that may have already been endorsed by the SRB based only on primary objectives, the SRB **RECOMMENDED** that the MSE include some scenarios in which the FISS is skipped (as similarly requested above in paras. 62 and 63) because of occasional (or functional) economic constraints on executing full FISS designs. Such simulation scenarios would provide some indication of the potential scale of impacts on MP performance of maintaining long-term revenue neutrality of the FISS.*

The MSE framework is capable of examining FISS designs, given the necessary inputs. Changes to the FISS design affect the estimation uncertainty (i.e. stock assessment) and possibly some management inputs, such as stock distribution. Outcomes from simulations investigating the outcomes of the stock assessment given different FISS design assumptions (see IPHC-2024-SRB024-08) will be used as inputs to the MSE simulations, following the recommendation in paragraph 60 from SRB023. Three (3) FISS trends and three (3) FISS designs will be tested, as is being done with the stock assessment (IPHC-2024-SRB024-08).

Table 5. Design matrix for proposed simulations of FISS design effects on the stock assessment to inform MSE simulation to investigate FISS design effects on management outcomes (reproduced from IPHC-2024-SRB024-08).

'True' FISS trend	Estimation model	Inference
No trend	No trend, base block design, 3 years No trend, core design, 1 & 3 years No trend, educed core, 1 & 3 years	Effect of increased CV due to reduced designs
+15% over 3 years	+15%, base block design, 3 years No trend, core design, 3 years No trend, reduced core, 3 years	Effect of failing to identify an increasing trend
-15% over 3 years	-15%, base block design, 3 years No trend, core design, 3 years No trend, reduced core, 3 years	Effect of failing to identify a decreasing trend

As mentioned in IPHC-2024-SRB024-08, 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.

5.2 Depensation Stress Test

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). The Beverton-Holt stock-recruit curve in Figure 12 shows the recruits vs. spawners and recruits-per-spawner vs spawners without and with depensation. The inverse density dependence can be seen at low population sizes with depensation.

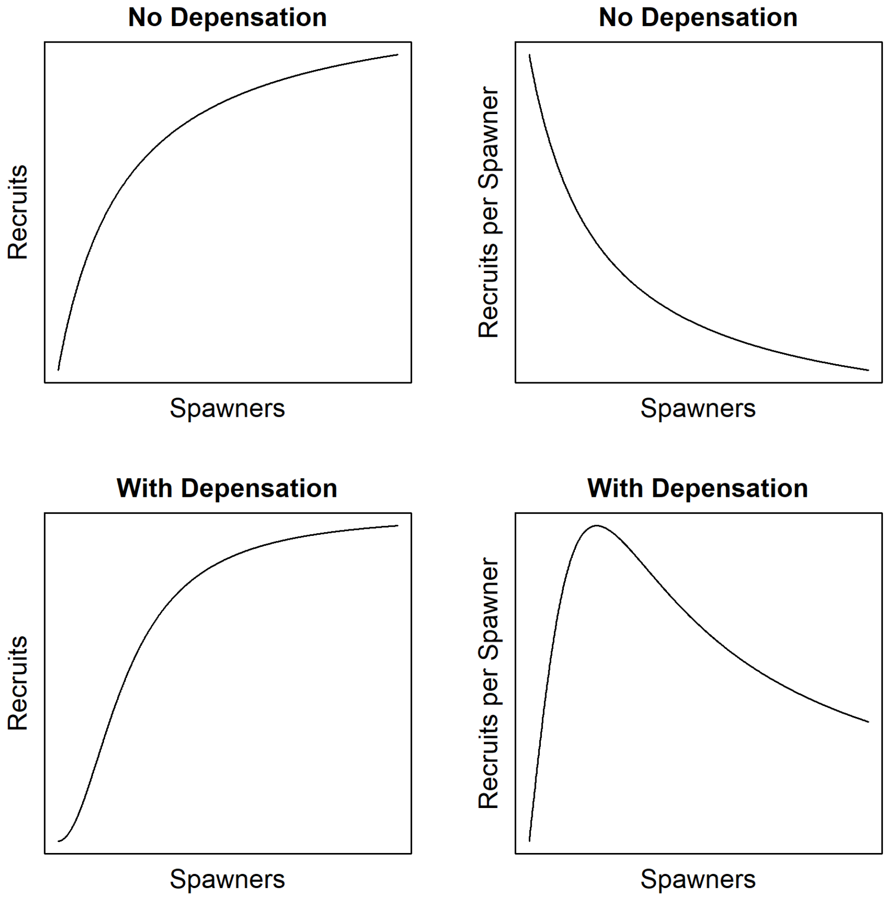

Figure 12. Theoretical Beverton-Holt stock-recruit curves (recruits vs spawners) without and with depensation (left) and for recruits-per-spawner vs spawners (right).

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). Table 6 lists some mechanisms for depensation and whether they are likely to result in depensation in the Pacific halibut stock.

Table 6. Mechanisms for depensation and if it is likely for the Pacific halibut population.

Mechanism	**For Pacific halibut**
Environmental effects (poor/good recruitment regimes)	**Possible** given the effect of the environment on life-history characteristics
Predator/prey interactions and increase in M	**Probably not likely** given that Pacific halibut are a generalist and have a wide range. Similar predators (e.g. arrowtooth flounder) may have some effect if the Pacific halibut population is low.
Reduced probability of fertilization	**Probably not likely** until very low population size given that the life-history of Pacific halibut is to migrate to spawning areas.
Impaired group dynamics	**Probably not likely** given that Pacific halibut are capable of making long feeding and spawning migrations.

The SRB recommended examining the effects of possible depensation in the Pacific halibut stock using the MSE framework.

> **IPHC-2023-SRB023-R**, ***para. 45:*** *The SRB* ***RECOMMENDED*** *that the compensatory assumption of the stock recruitment models be critically evaluated via a MSE stress test scenario in which recruitment is depensatory at some low spawning biomass.*

The ensemble stock assessment uses four models, of which two use a short time-series starting in 1992. These three decades of data span mostly high PDO years, making it difficult to examine the spawner-recruit relationships in different environmental regimes. Therefore, we examine estimates of recruitment and spawning biomass from only the two long models. The estimated spawning biomass is different historically with the long coastwide (long CW) model estimating lower spawning biomass than the long areas-as-fleets (long AAF) model (Figure 13). This is largely due to the uncertainty in spatial dynamics due to poor data from much of the geographical range in the historical period and has been explored in the stock assessment. Plots of estimated recruits-per-spawner vs spawning biomass do not show depensation, but there are no data at low spawning biomass levels. Separating this relationship by PDO regime does not show depensation for one particular PDO regime.

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% (see section 3.2) 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 will be theoretical to conduct a “stress-test” and show the potential effects if present.

We propose to conduct at least six (6) simulations using the MSE framework to examine the effects of depensation. These are a “No Depensation” assumption and a “Depensation” assumption crossed with three levels of fishing intensity (low, current reference, and high). The level of depensation is yet to be determined, but alternative values may be examined until an effect is seen. The low fishing intensity will be 52%, corresponding to recent adopted TCEYs. The reference fishing intensity is SPR=43% and a high fishing intensity will be the fishing intensity associated with the proxy MSY (SPR=35%). Higher fishing intensities and removing the 30:20 control rule may be implemented to force low spawning biomasses and induce an effect of depensation. However, high fishing intensities that would result in depensation are unlikely to be realized in the management of Pacific halibut (see Section 3.2).

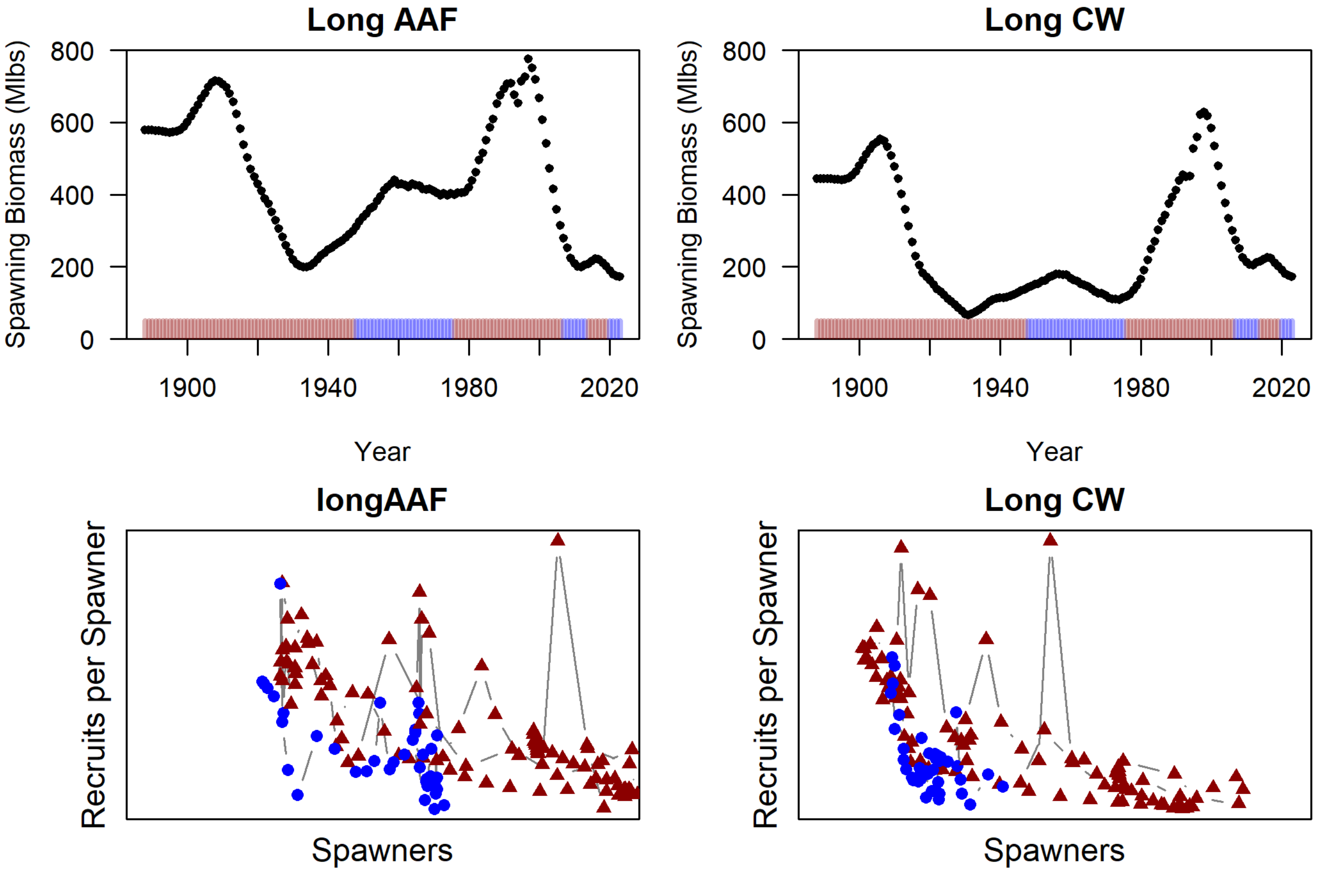

Figure 13. Estimated spawning biomass time-series for the two stock assessment long models (top) with low (blue) or high (red) PDO indices shown, and recruits-per-spawner plotted against spawning biomass (bottom) for the two stock assessment long models (top) with low PDO (blue) or high PDO (red) years.

RECOMMENDATION/S

That the SRB:

1) **NOTE** paper IPHC-2024-SRB024-07 presenting recent MSE work including exceptional circumstances, goals and objectives, management procedures, and additional analyses.
2) **REQUEST** any additional exceptional circumstances using fishery-dependent data.
3) **REQUEST** 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) **REQUEST** empirical rules to simulate with biennial and triennial assessment frequencies.
5) **REQUEST** examining alternative methods to simulate the uncertainty in the distribution of the TCEY.
6) **REQUEST** modifications to the proposed FISS design simulations and guidance on conducting them with the MSE framework.
7) **REQUEST** modifications to the proposed simulations investigating depensation.
8) **REQUEST** any further analyses to be provided at SRB025.

REFERENCES

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APPENDICES

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

Appendix B: Recommendations and requests from the 19th Session of the Management Strategy Advisory Board (MSAB019)

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* $\left(\overline{\frac{TCEY_A}{TCEY}}\right)$
	Maintain a minimum TCEY for each Regulatory Area	Minimum $TCEY_A$	Short-term		*Median Min(TCEY)*
	Maintain a percentage of the coastwide TCEY for each Regulatory Area	Minimum $\%TCEY_A$	Short-term		*Median Min(%TCEY)*
2.3. LIMIT VARIABILITY IN MORTALITY LIMITS	Limit annual changes in the coastwide TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Median coastwide Average Annual Variability (AAV)	Short-term		*Median AAV*
	Limit annual changes in the Regulatory Area TCEY	Annual Change (*AC*) > 15% in any 3 years	Short-term		$P(AC_3 > 15\%)$
		Average AAV by Regulatory Area (AAV_A)	Short-term		*Median* AAV_A

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

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

APPENDIX B
RECOMMENDATIONS AND REQUESTS FROM 19TH SESSION OF THE MANAGEMENT STRATEGY ADVISORY BOARD (MSAB019)

IPHC-2024-MSAB019-R, para 32: The MSAB **REQUESTED** that outreach materials be developed by the Secretariat that synthesize the effect of the PDO (e.g. via recruitment) on the coastwide and regional stock dynamics and the relative effect of fishing in simple terms with interpretation and consequences of the outcomes. This may be a pamphlet or a short document to be reviewed via email by MSAB members before the 100th Session of the IPHC Interim Meeting (IM100).

IPHC-2024-MSAB019-R, para 39: The MSAB **REQUESTED** that the evaluation of annual, biennial, and triennial assessments include, but is not limited to, the following concepts.

a) Annual changes in the coastwide TCEY is driven by an empirical rule in non-assessment years of a multi-year MP;

b) A constraint on the coastwide TCEY to reduce inter-annual variability and the potential for large changes in every year or only assessment years. This may be a 10%, 15%, or 20% constraint, a slow-up fast-down approach, or similar approach;

c) SPR values ranging from 35% to 52%.

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.

IPHC-2024-MSAB019-R, para 42: The MSAB **REQUESTED** that the Commission provide guidance on whether and how to incorporate distribution in the MSE simulations. Three potential options are:

a) Integrating over multiple distribution procedures;

b) Use a single distribution procedure and add uncertainty;

c) Use recent years to define percentage of TCEY in each IPHC Regulatory Area and add uncertainty.

IPHC-2024-MSAB019-R, para 47: The MSAB **REQUESTED** that the Secretariat report performance metrics noted in paragraph 44 and 45 over ten (10) and fifteen (15) year periods.

IPHC-2024-MSAB019-R, para 51: NOTING paragraph 48, the MSAB **RECOMMENDED** developing an objective and identifying a management procedure that addresses the current circumstances and differences in perception of the stock status.

IPHC-2024-MSAB019-R, para 52: The MSAB **RECOMMENDED** adopting the following exceptional circumstances:

a) 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.

b) 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 for two or more consecutive years.

c) 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.

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.

IPHC-2024-MSAB019-R, para 55: The MSAB **RECOMMENDED** adopting the follow actions if an exceptional circumstance occurs:

a) 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 a possibly updated OM.

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 reexamination of the MSE.

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

IPHC-2024-MSAB019-R, para 56: The MSAB **REQUESTED** that the Secretariat assist with hosting an ad-hoc working group (in accordance with the MSAB Terms of Reference and Rules of Procedure (Appendix V, Sect. V, para 10), in 2024 to discuss potential management procedures that include adjusting fishing intensity at low spawning biomass, low FISS WPUE, low commercial fishery catch-rates, or low productivity.

IPHC-2024-MSAB019-R, para 57: The MSAB **RECOMMENDED** a one- to two-day hybrid MSAB meeting in the fall of 2024, prior to the 100th Session of the IPHC Interim Meeting (IM100), to discuss results from the ad-hoc working group (para. 56) and review any simulation designs and results.

IPHC-2024-SRB024-08

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

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 15 MAY 2024)

PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with a response to recommendations and requests made during SRB023 (IPHC-2023-SRB023-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.

For 2024, the Secretariat plans to conduct 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.

TIME-SERIES AND SOFTWARE UPDATES

In order to provide comparability between preliminary results and all subsequent steps working toward the final 2024 stock assessment (the annual bridging analysis), this evaluation began with the final 2023 models. First, each of the four assessment models was extended by one year, including projected 2024 mortality from all sources based on the mortality limits set during AM100 (IPHC-2024-AM100-R). Extending the time-series without adding any new data does not affect the historical time-series' estimates but allows for a simple stepwise evaluation of the effects of adding data (including updating from the projected to actual fishery harvest) and any other changes to the models prior to the final version used for management.

Next, the Stock Synthesis (SS) software was updated from the version used for the 2023 stock assessment (3.30.21) to the most recent release (31 January 2023), 3.30.22.01 (Methot Jr et al. 2024). The changes to the software between these two versions had no effect on the Pacific halibut stock assessment (the results were identical to the final 2023 assessment). However, maintaining a current version (when possible and efficient) reduces the likelihood of compatibility issues with plotting and other auxiliary software and reduces the cumulative transitional burden when future changes are added. No appreciable changes were noted in convergence performance, run times or other technical aspects of the software update.

The IPHC continues to rely on SS for its annual tactical stock assessment modelling. During 2024, Secretariat staff explored the capabilites of R-Template Model Builder (RTMB; Kristensen et al. 2016), via a training course hosted by Fisheries and Oceans Canada. TMB forms the basis of most state-space models currently used for stock assessment (e.g., SAM, WHAM; Nielsen and Berg 2014; Nielsen et al. 2021; Stock and Miller 2021), provides a more efficient Auto-Differentiation (AD) algorithm than Automatic Differentiation Model Builder (ADMB; Fournier et al. 2012) as well as extremely efficient capabilities for modelling random effects and sparse matrices. As the Pacific halibut stock assessment models include time-varying processes (i.e. recruitment, selectivity, and catchability) it would be ideal to treat them as random effects, rather than using the penalized likelihood curently employed. However, current development of stock assessment platforms based on TMB has not included sex-specific dynamics that can accommodate dimorphic growth, but several efforts are underway which may result in a platform that could be applicable to Pacific halibut. The Secretariat will continue to stay informed on these and other modelling efforts (e.g., the U.S. National Oceanic and Atmospheric Administration's Fisheries Integrated Modelling System project) and to review the merits of using a generalized stock assessment platform vs. creating a new application specifically built for Pacific halibut. The Management Strategy Evaluation (MSE) operating model (generally based on the structure of the current stock assesment) has and will continue to refine the Secretariat's understanding of key biological processes and technical modelling needs. The co-development of assessment modelling and the MSE fosters data exploration and structural testing, naturally leading to prioritization of hypotheses and research priorities.

Development of the IPHC's stock assesment is highly dependent on the type of management procedure selected by the Commission. This situation has not changed since the 2023 stock assessment was conducted. The stock assesment analysis conducted each fall in order to provide annual management information is based on the current year's data and must be stable and simple enough to be completed in less than two weeks. If a management procedure based on modelled survey trends, or a multi-year procedure is adopted, it may be uneccesary to conduct annual stock assessments. That type of procedure and timeline could allow for the development of more complex stock assessment ensembles/models (including fully Bayesian analyses), given extended development time between assessments. Therefore, the adoption of a management procedure by the IPHC, developments in the MSE process, and strategic planning for the stock assessment modelling platform should be considered together: the long-term focus should be on selecting the most efficient tools to meet management needs as they continue to evolve.

PROJECTION OF SELECTIVITY

In the version of the SS software used for 2024, there are a number of new modelling options. Of these, the ability to propagate the process variability in time-varying selectivity parameters into future projections is directly applicable for the Pacific halibut stock assessment. All four assessment models include time-varying selectivity, bias in the maximum likelihood estimates is accounted for by iteratively solved for the variance parameters (Stewart and Hicks 2022). In recent stock assessments an average of the terminal three years of selectivity was used for all projections. Although the annual selectivity estimated in the four models is not highly variable, estimating projection deviations consistent with the variability estimated for the recent time-series provides the same propagation of variance for time-varying selectivity that is used for recruitment variability.

Using the bridging models described above (with the time-series extended to 2025) as a starting point, selectivity deviations were extended through the three-year projection period and the Coefficient of Variation (CV) of the projected spawning biomass and Spawning Potential ratio (SPR) at the end of the projection period were compared with and without this additional source of uncertainty (Table 1). This change made little difference to the estimated variance of the management quantities; this is likely due to the relatively low current exploitation rates and modest variability in selectivity leading to only minor translation of change in fishery selectivity to population estimates over a short-term projection. However, the change is recommended as it comes at no additional computational cost and will ensure that future combinations of models and data will appropriately reflect the uncertainty in fishery selectivity.

Table 1. Coefficients of variation (CVs) of estimated spawning biomass and Spawning Potential Ratio (SPR) at the end of a three-year projection of 2024 harvest levels using: 1) average selectivity from 2021-2023 and 2) allowing process error to propagate via projecting selectivity deviations from the terminal year to the end of the projection period for each of the four stock assessment models (CW = coastwide, AAF = Areas-As-Fleets).

	Spawning biomass		SPR	
Model	Average Selectivity	Projected deviations	Average Selectivity	Projected deviations
CW short	24%	24%	9%	10%
CW long	20%	20%	14%	14%
AAF short	21%	21%	16%	16%
AAF long	17%	17%	12%	12%

COMMISSION AND SRB REQUESTS AND RESULTS

There were no requests made by the Commission at AM100 specifically relating to the stock assessment. In 2023, the SRB made the following assessment recommendations and requests during SRB023:

1) SRB023–Rec.03 (para. 20):

   *"The SRB **RECOMMENDED** that the Secretariat investigate approaches (e.g. simulation testing) to estimating uncertainty (or bounding the minimum level of uncertainty) in different assessment outputs: e.g. coastwide and Biological Region spawning stock biomass (see related actions under Section 4.2)."*

2) 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.”

3) 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).”

4) SRB023–Req.08 (para. 61):

   *“The SRB **REQUESTED** that simulations above (para. 60) include:*

   a) a relationship in which the FISS CV is relatively higher at lower stock abundance (i.e. the current CV issue is a function of stock abundance rather than a short-term condition);

   b) target regulatory area CVs of 15%, 20%, 25%, and 30%;

   c) coastwide target CV of 15% without controlling specific regulatory area CVs.”

Recommendation 1 – General simulation testing

The SS software has a built in data generating feature that produces a series of randomly generated data sets, matching the original inputs in dimension, using the same distributions and variance as the original data, and centered on the expected values (Methot Jr et al. 2024; Methot and Wetzel 2013). These data sets can then be fit with the original assessment model and provide a ‘self-test’ of the model’s ability to recover the parameter values and management quantities given the structure of the data available and the assumed uncertainty in those data. This approach does not represent a broad simulation test, as the assumptions generating the data match exactly those of the fitted stock assessment. However, the method is a useful check on model performance separated from mismatching assumptions of the population dynamics, data collection or other aspects of the stock assessment.

The secretariat used this tool to test the final 2023 stock assessment, via the creation of 100 bootstrapped data sets for each of the four stock assessment models. Each model was then refit to the bootstrapped data sets and the results compiled and compared to the actual model results from 2023. A range of comparisons were made; however, spawning biomass is reported here as it represents the primary input to management calculations and integrates both the scale and trends recovered by the analysis. The comparisons were made at two levels. First, the distribution of bootstrapped maximum likelihood estimates (MLEs) across the simulations was compared to the actual assessment result and 95% credible interval for each of the four individual models. Second, to represent the actual ensemble approach used to provide management information, each simulation of the four models was integrated using the estimated asymptotic uncertainty and equal weighting. In this comparison the 2.5th, 50th, and 97.5th percentiles across all simulations were compared to the same percentiles from the actual 2023 stock assessment. The results are intended to address the question: If the assessment in its current configuration were conducted repeatedly with new data of the same dimension and quality, how similar would the results be to the actual assessment?

Out of the 400 model fits to the bootstrapped data sets, one model failed to reach a minimum negative log-likelihood and estimate a positive definite Hessian matrix. That simulation was excluded from the set of results presented here as it represented only a small fraction of the total experiment. It is possible that rerunning that model from different initial values and/or with different phasing may have produced a reliable solution.

Based on the 99 remaining simulations all four models recovered the historical trend and the general scale of the Pacific halibut population. However, each of the individual stock assessment models showed some bias either for certain historical periods or across the entire time-series. The coastwide long model simulations overestimated the early time-series and slightly underestimated the latter half of the time-series relative to the 2023 stock assessment from which the data were generated (Figure 1). The long Areas-As-Fleets (AAF) model had a similar pattern of simulated to actual spawning biomass, again slightly underestimating the latter half of the time-series (Figure 2). The simulations from the coastwide short time-series model overestimated the spawning biomass (Figure 3), and a similar pattern occurred for the simulations of the short AAF model (Figure 4). The net effect across all four models was a nearly unbiased ensemble result, with the upper credible interval (97.5th) slightly higher than that estimated from each of the actual assessment models (Figure 5). The ensemble differed from the base assessment by 2-12% across all years for which there were four model results.

This simulation ‘self test’ is helpful in understanding the basic performance of the current stock assessment models and indicates another beneficial aspect of using and ensemble of models rather than a single ‘best’ model to provide management information. Further, this test suggests that it will be important to consider the full ensemble results when simulating and comparing results across potential future Fishery Independent Setline Survey (FISS) designs (See discussion below).

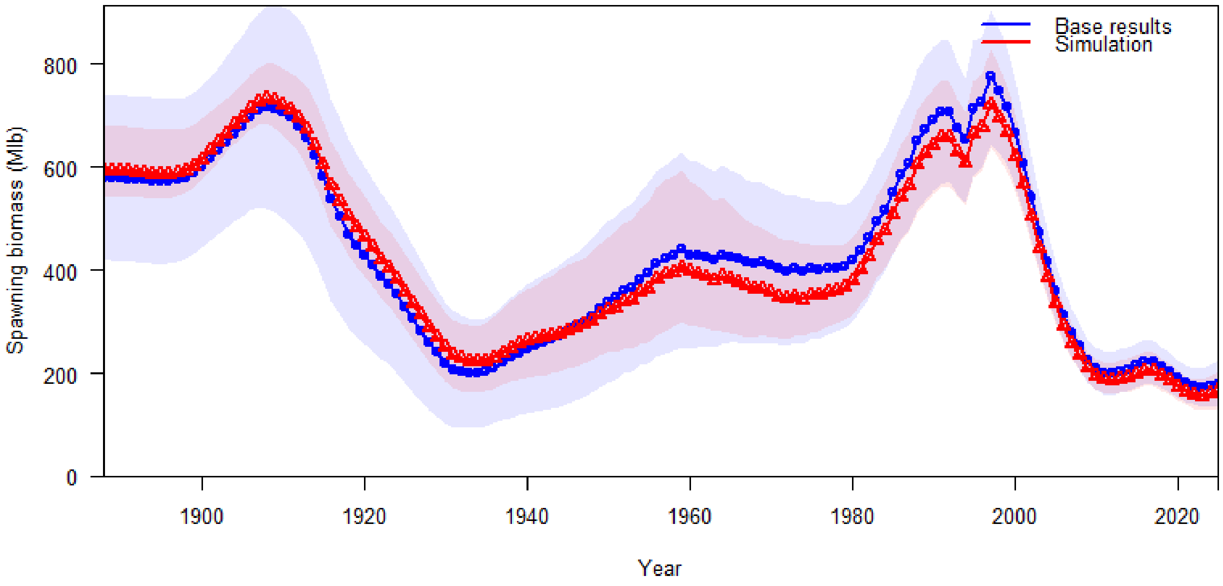

Figure 1. Time series of estimated spawning biomass based on the 2023 long coastwide stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

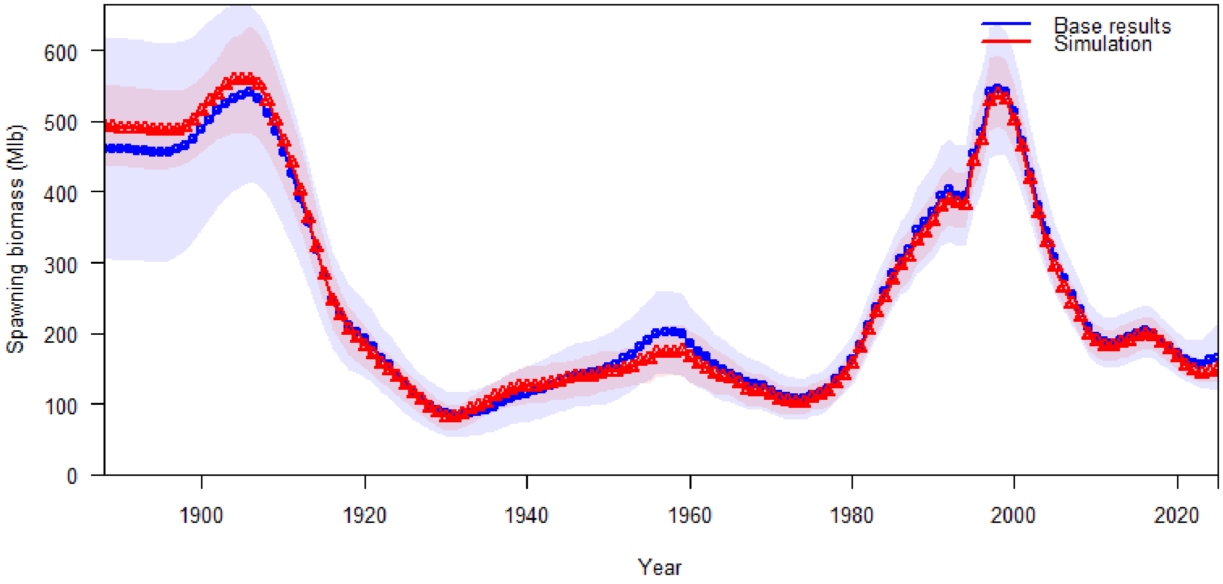

Figure 2. Time series of estimated spawning biomass based on the 2023 long Areas-As-Fleets stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

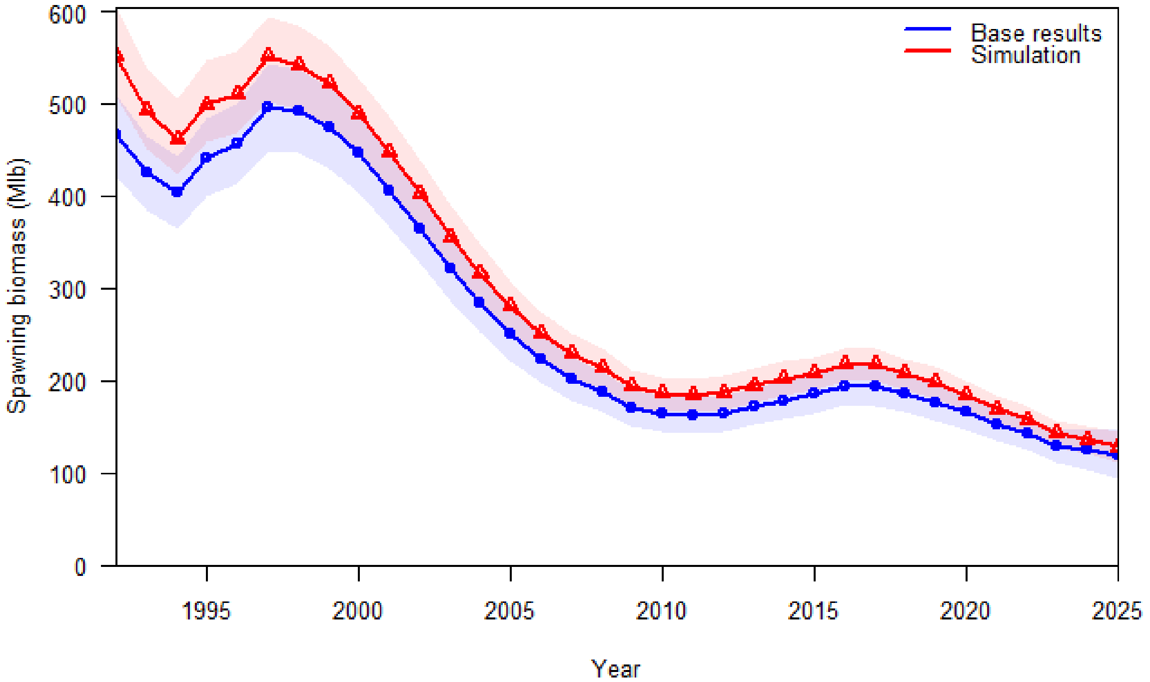

Figure 3. Time series of estimated spawning biomass based on the 2023 short coastwide stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

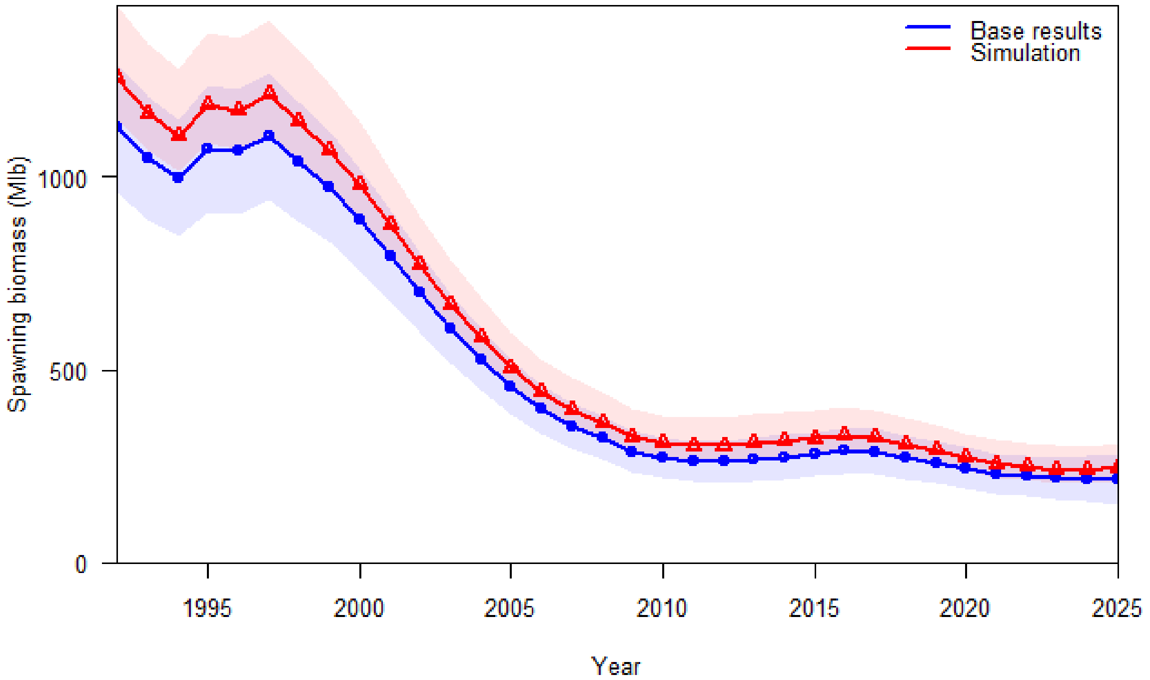

Figure 4. Time series of estimated spawning biomass based on the 2023 short Areas-As-Fleets stock assessment model (extended to 2025) and 95% credible intervals (blue series and shaded region) and the distribution of maximum likelihood estimates from 99 bootstrapped data sets (red series; median and 95% interval).

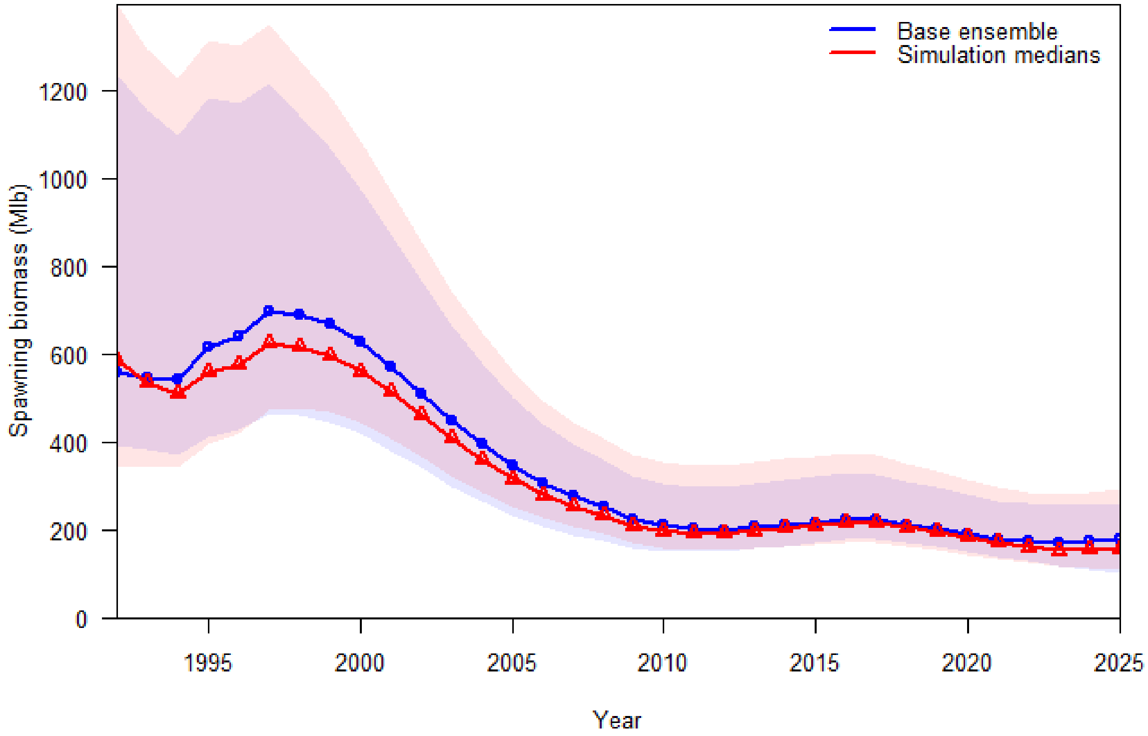

Figure 5. Time series of estimated spawning biomass based on the 2023 stock assessment ensemble (extended to 2025) and 95% credible intervals (blue series and shaded region) and the median across 99 bootstrapped data sets of the 2.5th, 50th, and 97.5th percentiles (red series and shaded region).

Recommendations 2-4 – Simulation testing of FISS designs

The remaining SRB023 requests all focus on evaluating how potential future FISS designs may affect the quality of management decision-making. These requests link projections made using the space-time model with stock assessment estimation and overall MSE performance. This analysis will ultimately have three connected phases: 1) projection of the space-time model under different FISS designs to determine the effect of different levels of sampling on the uncertainty (CV) of the index of abundance; 2) fitting stock assessment models to the results from 1 (and including simulated age composition information) with and without bias in the actual population trend to determine the effect on short-term stock assessment estimates; and 3) use of the stock assessment simulation results from 2 to inform MSE scenarios quantifying the overall effect on long-term management performance of alternative FISS designs. The first phase is fully reported for this meeting (IPHC-2024-SRB024-06). An experimental design for phase two is proposed here, for review and discussion.

For 2025 through 2027 the Secretariat has developed three potential FISS designs (IPHC-2024-SRB024-06):

1) A 'base block design' that will ensure good spatial coverage, low CVs and very low potential for multi-year bias due to sampling all survey stations on a frequent basis. This design was developed on request by the Commission to represent a sustainable long-term design if a baseline of constant funding ($1.5M) were provided.
2) A 'core design' that will provide 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.

The CV of the terminal year of the FISS index will always be higher than that year’s CV after additional years of data have been collected. For example, the CV for 2025 will have greater uncertainty in 2025 than the index of abundance used for 2025 when the data extend through 2027. Therefore, the projection of each potential design was conducted for each terminal year from 2025 through 2027 (see IPHC-2024-SRB024-06) to allow more accurate evaluation of the degree of uncertainty over 1, 2 and 3 years.

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 on previous summary of changes in different areas of the stock, the Secretariat proposes to use +/- 15% bias in the FISS index over 3 years as a basis for investigating 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 reported above.

1) Using the 2024 bridging model, extend the time-series to 2027 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, 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 2025-2027, to create 100 replicate 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 will naturally produce age composition information that is unbiased, given the true trend in the index.

Once the simulated data sets from the ‘true’ states have been constructed, three experiments will be conducted (Table 2). Each experiment will compare the results from the ‘true’ model with models using data representing either unbiased or biased designs. This experiment therefore produces 9 sets of models to be fit crossing the three designs with three trends (Table 2). Specifically, to explore the effects of increased CVs due to reduced designs, models will be fit to a true projection with no trend and unbiased data for each design. To explore the effects of potential bias, the biased core and reduced core designs will be compared to an unbiased base block design given true trends of +/- 15%. If time permits, a subset of unbiased design reductions will be evaluated over only the period through 2025 to illustrate the effect of a 1-year survey reduction on stock assessment results.

For models fitting to data based on the restricted designs (core and reduced core), the sample sizes for the age composition data will be reduced in proportion to the geographic extent of the scenario (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).

Table 2. Design matrix for proposed simulations of FISS design effects on the stock assessment.

'True' FISS trend	Estimation model	Inference
No trend	No trend, base block design, 3 years No trend, core design, 1 & 3 years No trend, educed core, 1 & 3 years	Effect of increased CV due to reduced designs
+15% over 3 years	+15%, base block design, 3 years No trend, core design, 3 years No trend, reduced core, 3 years	Effect of failing to identify an increasing trend
-15% over 3 years	-15%, base block design, 3 years No trend, core design, 3 years No trend, reduced core, 3 years	Effect of failing to identify a decreasing trend

This approach will provide inference on how a reduced FISS might affect the overall results of the stock assessment ensemble. Specifically, we will be able to address the questions: 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 will compare key management inputs between a correctly specified model (the base block design) and those that are either less precise and/or biased. Results will include a characterization of the bias in: the estimated fishing intensity (SPR), the estimated spawning biomass, and the estimated risk of stock decline. The results of this simulation experiment can then be used to inform estimation model performance in future MSE evaluations in the full closed-loop management system.

Although this simulation experiment will be able to quantify some of the effects of potential FISS designs on potential future management, it will be lacking the most important: stakeholder perception of and confidence in the FISS information. Across years in which a range of FISS designs, from very comprehensive (e.g., 1,558 stations in 2019 and 1,489 stations in 2018) to very small (951 stations in 2020 and 864 stations in 2023) have been completed, 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 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 regardless of the quantitative results determined for reduced FISS designs, 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.

OTHER TOPICS

Assessment development during 2024 is occurring in parallel with the ongoing histological maturity study and related analyses (IPHC-2024-SRB024-09). As that project produces results, they will be incorporated into the stock assessment as part of the proposed assessment, as sensitivity analyses, or as supporting information in September 2024. 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.

Various other assessment development topics are ongoing; updates on progress will be provided if available in time for SRB023 and SRB024.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2024-SRB024-08 which provides a response to requests from SRB023, and an update on model development for 2024.

b) **REQUEST** any modifications to the proposed FISS design simulations.

c) **REQUEST** any further analyses to be provided at SRB025, 24-26 September 2024.

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Report on Current and Future Biological and Ecosystem Science Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, 15 MAY 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 SRB023 (IPHC-2023-SRB023-R) in relation to presentation IPHC-2023-SRB023-08:

SRB023–Rec.12 (para. 36) ***NOTING*** *that the genomics research is and will continue to be a key element of the Biological and Ecosystem Science Research program, and that the Secretariat wishes to (i) document stock structure, (ii) use genetic markers to quantify movements, (iii) assign individuals of any age, location, season to a genetic population, (iv) annotate markers and use genomic data to between understand genetic and environmental sources of variation in growth, maturity and fecundity, (v) engage in close-kin capture-*

recapture to estimate stock abundance, the SRB ***RECOMMENDED*** *adding qualified staff to help address these diverse and important activities in a timely fashion.*

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

SRB023–Rec.13 (para. 42) The SRB ***RECOMMENDED*** *that the Secretariat continue to work with collaborators to collect and process genetic samples from juveniles. Collections of younger (pre-reproductive) age classes would be particularly important for anticipated future close-kin capture-recapture work.*

The IPHC Secretariat has over the recent years collected genetic samples (fin clips) from juvenile Pacific halibut captured in the NMFS Bottom Trawl Survey in the Gulf of Alaska, Bering Sea and Aleutian Islands. This is the only source of juvenile Pacific halibut biological samples since the FISS captures typically fish that are 5-6 years of age and above. Unfortunately, the Commission did not fund the deployment of IPHC Staff in the NMFS Bottom Trawl Survey in 2024 and no Pacific halibut juvenile samples will be collected.

SRB023–Rec.14 (para. 44) The SRB ***RECOMMENDED*** *to apply the genetic sampling more broadly, to estimate genetic diversity of the (sub)populations, for example through the effective number of breeding adults by cohort.*

The Secretariat is not aware of software that is currently available for estimating these parameters directly from genotype likelihood data. That being the case, effort would need to be redirected to adapting existing methods that make use of called genotype data.

SRB023–Rec.15 (para. 45) The SRB ***RECOMMENDED*** *that the compensatory assumption of the stock recruitment models be critically evaluated via a MSE stress test scenario in which recruitment is depensatory at some low spawning biomass.*

The IPHC Secretariat is currently addressing this recommendation and results will be presented as part of the MSE presentation during SRB024.

SRB023–Rec.16 (para. 49) The SRB ***RECOMMENDED*** *that Secretariat proceed to the next step of individual assignment based on K of 4 or K of 5. Based on the large number of loci with low levels of divergence among reporting regions (Manhattan plot in Figure 4 of paper IPHC-2023-SRB023-08) that posterior probabilities of cluster assignment (in a Bayesian context) may be low when all loci are used. The Secretariat should conduct a comparable analysis using only 'outlier loci'.*

As part of the procedure for estimating admixture proportions, probabilistic cluster assignments were obtained for these K values. However, most individuals were classified as unassigned (Fig. 6 in this report). Additionally, we anticipate that false signals of structure or noise may be captured if this analysis was repeated with only 'outlier loci', similar to the results observed when a set of loci were selected to perform assignment testing (Fig. 7 in this report).

*SRB023–Rec.17 (para. 50) **RECOGNIZING** that future applications of 'outlier loci' to address SA and MSE objectives will necessitate development of more 'rapid screening approaches' and screening based on fewer loci, the SRB **RECOMMENDED** that the Secretariat work to identify the numbers of loci and locus characteristics (e.g. high levels of diversity and high level of allele frequency variation) so loci may be applied.*

The IPHC Secretariat is investigating whether some additional optimization of the assignment testing could be done to determine if assignment accuracy increases with alternative SNP selection strategies.

*SRB023–Rec.18 (para. 53) The SRB **RECOMMENDED** that the Secretariat:*

a) conduct simulations as a means of assessing the accuracy of group or admixture assignments;

b) establish criteria for acceptable group assignment accuracy and that is relevant for assignment of individuals as a 'pure' or 'admixed'. Thus, observations, though made with some error would be used as 'observed' estimates to tally over space and across age classes.

c) should evaluate what the uncertainty in classification (errors) will mean to their estimates. The SRB draws the Secretariat's attention to a widely cited paper by Manel et al. (2005) in Trends in Ecology and Evolution, where authors compare individual assignment tests to a widely used alternative method (mixed stock analysis). These authors point out that use of individual assignment tests for relative population (or reporting group) compositional estimation can be fraught with problems because assignment error compounds across all individuals.

The IPHC Secretariat has addressed the potential application of cross-validation techniques such as leave-one-out as previously mentioned in SRB022-Rec.20 b) (para. 47) in reference to the proposed assignment testing. Leave-one out has been shown to upwardly bias accuracy assessments of these methods especially when loci are selected on the basis of allele frequencies (Anderson 2010). Therefore, we chose a more conservative approach and followed a training and holdout procedure for assessing assignment testing accuracy (Fig. 7 in this report). For the purposes of admixture assignments (unsupervised clustering) we required at least a membership probability of at least 0.8 and for group assignments (assignment testing) we required at least 0.95. The Secretariat thanks the SRB for the literature recommendation and insight.

SRB023–Req.01 (para. 37) ***NOTING*** *that future applications of genomic data will necessitate more expansive sampling geographically and demographically to achieve IPHC goals, the SRB* ***REQUESTED*** *that the Secretariat establish explicit long-term objectives for use of genomic data and work with staff, fishermen, and agency collaborators to establish a short and long-term sampling program and data and sample archival plan to ensure samples are available to address Secretariat objectives.*

The IPHC Secretariat is currently implementing long-term objectives for the collection of genetic samples coastwide that include the collection of fin clips from sampled commercial landings (since 2017; used to generate sex ratio information by genotyping), from all fish sampled in the FISS (since 2016) and from all research projects that have involved the capture of Pacific halibut (since 2016). An important source of genetic samples from juvenile Pacific halibut derives from the NMFS Ground Trawl Survey in the Gulf of Alaska, Bering Sea and Aleutian Islands (since 2019). Unfortunately, the Commission did not fund the deployment of IPHC Staff in the NMFS Bottom Trawl Survey in 2024 and no juvenile Pacific halibut samples will be collected this year.

SRB023–Req.02 (para. 41) ***NOTING*** *paper IPHC-2023-SRB023-08 (subsection 1.1 - Identification of Pacific halibut juvenile habitat), and that the narrative describes work to be conducted but does not explicitly identify research objectives or hypotheses that the data would be used to address, the SRB* ***REQUESTED*** *that objectives/hypotheses be developed for SRB024 where hypotheses could include: a) regions with larger amounts of juvenile rearing habitat and larger number of juveniles would realize numerically larger levels of recruitment to the adult population; b) genotypes of juveniles from rearing habitats could be assigned to specific spawning areas.*

The IPHC Secretariat conducted initial work on Pacific halibut juvenile habitat identification with the involvement of the 2023 IPHC Intern and is in the process of investigating avenues to continue this work.

SRB023–Req.03 (para. 43) ***NOTING*** *paper IPHC-2023-SRB023-08 (subsection 1.2 - wire tagging of U32 Pacific halibut), where the narrative describes numbers of fish tagged and recovered, no information is provided summarizing distances moved by size/age and location, the SRB* ***REQUESTED*** *that information be provided during SRB024, including background on statistical methods for analysis of data.*

The IPHC Secretariat will provide information on movement of tagged fish and plans to use these data to inform on survival during SRB024.

SRB023–Req.04 (para. 51) The SRB ***ACKNOWLEDGED*** *Table 1 in paper IPHC-2023-SRB023-08, produced in response to SRB022 inquiry, and that discrepancies in the genetic diversity measure Fis (deviation of observed and expected heterozygosity) across collection years within reporting regions. The Secretariat estimates Fis on a collection year by year basis* *and overall years for each region. The SRB* ***REQUESTED****: a) further investigation of the disparity in Fis for reporting regions (yearly vs total). Higher positive Fis could indicate admixture of individuals from genetically differentiated groups; b) investigations into discrepancies between estimates of Fis, observed heterozygosity (Ho), and expected heterozygosity (He).*

The disparity in yearly versus total F_{IS} for reporting regions is likely an artifact related to the fact that these values are summarized for all of the SNPs discovered using all of the individuals in dataset as a whole (n=570). We would like to note that we required that SNPs have a minor allele frequency (MAF) of at least 0.01, corresponding to an allele being observed at least 5 times when the sample size is 570. At the individual sample collection level, it is possible for a SNP that is detected in the entire dataset to go unobserved if the 5 occurrences of that allele are observed in other sample collections. Filtering SNPs at the sample collection level by requiring alleles to be observed at least 3 times appears to fix this issue to some extent (Table 1 in this report), but by doing so it means that genetic diversity is summarized for a subset of SNPs specific to each sample collections.

We would like to thank the SRB for pointing out the discrepancies related to b), as in the version of the table presented at SRB023 the columns Ho & He were mislabeled. Table 1 in this report has been revised to correct this error. In the previous table, arithmetic means were used to summarize of these metrics across all SNPs. Noting that the calculation of F_{IS} ($\mathrm{F_{IS}} = 1 - (\mathrm{H_o}/\mathrm{H_e})$) contains a ratio and therefore $\overline{\mathrm{F_{IS}}} \neq 1 - (\overline{\mathrm{H_o}}/\overline{\mathrm{H_e}})$. A weighted mean (by H_e) has been included in Table 1 as well.

SRB023–Req.05 (para. 52) The SRB ***NOTED*** *that the Secretariat proposes to conduct individual admixture (i.e. among IPHC reporting regions) estimation using software NGSadmix and individual assignment testing using WGSassign, both of which are amenable to low coverage sequence data, to estimate proportional contributions of reporting groups to unknown individuals. This analysis would be conducted after 'best supported' number of genetic groups (K) has been established. The SRB* ***REQUESTED*** *that admixture analyses and assignment testing be conducted and reported at SRB024, including estimates of assignment accuracy.*

The unsupervised clustering methods we have presented to date, including that implemented in NGSadmix, have failed to identify discrete genetic clusters and at this point, the best supported value for K is 1. Furthermore, the interrogation of individual assignment probabilities to the genetic groups associated with the various K values testing using NGSadmix, led to most individuals being classified as un-assigned or admixed, in all cases (Fig. 6 in this report). Therefore, we feel it is not appropriate to proceed with establishing reporting groups based on these unsupervised clustering methods when a clear determination on the true number of clusters cannot be made or is not well supported by established model selection metrics or other criteria (Figs. 3 and 5 in this report). We did attempt to establish reporting groups based on the sampling localities and proceeded with conducting assignment testing. We used a simple, training and holdout cross-validation procedure to estimate a 34% assignment accuracy.

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 and IPHC-2023-SRB022-09.

1.1.1. Methods

Additional SNP filtering prior to summarizing genetic diversity metrics for each sample collection has been conducted to address disparities in Table 1 of document IPHC-2023-SRB023-08. In the previously reported table, arithmetic means were used to summarize of these metrics across all SNPs. discovered using all individuals in the dataset (n=570). We have now revised this table to summarize these values only for SNPs that are variable in each sample collection by requiring a minor allele count (MAC) of three within a collection for a SNP to be included (Table 1). Count based filtering may be better suited to smaller sample sizes (or when samples are partitioned into smaller groups). For a minor allele count of three, the rare allele will be observed in at least two individuals regardless of sample size. Summarizing diversity metrics when filtering SNPs specific for each sample collection produces consistently negative F_{IS} (excess heterozygosity) values and less of a discrepancy between averages of yearly and total values.

Area	Collection Year	N	MAC > 3	H_O	H_E	F_{IS}	F_{IS} *(weighted)*
British Columbia	1999	49	4,198,102	0.324	0.308	-0.033	-0.050
	2004	43	3,944,777	0.349	0.323	-0.061	-0.081
	2007	50	4,227,187	0.321	0.307	-0.030	-0.048
	all years	142	7,146,268	0.220	0.210	-0.014	-0.048
Central Gulf of Alaska	1999	50	4,016,629	0.345	0.320	-0.061	-0.079
	2004	50	4,325,411	0.326	0.304	-0.049	-0.069
	2007	50	5,956,646	0.260	0.244	-0.034	-0.065
	2018	49	4,417,614	0.339	0.305	-0.087	-0.112
	all years	199	4,473,598	0.373	0.309	-0.164	-0.210
Bering Sea	2004	43	4,393,404	0.352	0.307	-0.114	-0.148
	2007	50	3,992,723	0.330	0.316	-0.022	-0.043
	all years	93	8,403,542	0.210	0.188	-0.054	-0.118
Central Aleutian Islands	2007	37	3,588,166	0.357	0.338	-0.041	-0.055
	2020	49	4,129,221	0.329	0.311	-0.039	-0.060
	all years	86	5,572,332	0.266	0.254	-0.021	-0.049
Western Aleutian Islands	2020	50	4,065,743	0.335	0.313	-0.045	-0.069
	all years	50	4,065,743	0.335	0.313	-0.045	-0.069

Table 1. Summary of diversity measures estimated from low coverage whole genome sequence data for sample collections of Pacific halibut. The table includes sample sizes (N), number of SNPs with minor allele count (MAC) ≥ 3, values of mean observed heterozygosity (H_O) and mean expected heterozygosity (H_E). Mean F_{IS} (deviation of observed from expected heterozygosity) is reported as an arithmetic and weighted (by H_E) mean. These values are calculated for SNPs with a MAC ≥ 3 in each sample collection.

Population structure

Principal component analysis (PCA) was carried out using PCAngsd (v1.2) (Meisner and Albrechtsen 2018) to estimate a covariance matrix from the lcWGR dataset. A MAF threshold of 0.05 was applied prior to the covariance matrix estimation. Eigendecomposition was performed in R (v4.2.2) (R Core Team 2022) using the *eigen* function. The percent variance explained for each principal component was calculated by dividing each eigenvalue associated with each principal component by the sum of all eigenvalues. To determine an appropriate number of principal components (PCs) to retain for downstream analyses, a scree plot of the first 10 eigenvalues was visually inspected and Cattell's rule (Cattell 1966) was used for this purpose. K-means clustering was performed 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.

To compliment PCA/K-means cluster analysis, we also performed unsupervised model-based clustering and estimated individual admixture proportions using NGSadmix (v33) (Skotte et al. 2013). Similar to the PCA based clustering, we filtered SNPs with a MAF < 0.05 prior to the estimation of individual admixture proportions (cluster membership probabilities). Five replicate runs for each value of K (number of clusters, K=2-8) tested were carried out. CLUMPP (v1.1.2) (Jakobsson and Rosenberg 2007) was used to match cluster labels across the replicate runs for each value of K and obtain a mean of the permuted assignment matrices. The ΔK statistic (Evanno et al. 2005) was used to aid in identifying the best value of K. To assign an individual to a single cluster, we required that the individual's cluster membership probability be at least 0.8 to a single cluster; otherwise, that individual was categorized as unassigned.

Assignment testing

Assignment testing was also performed to assess our ability to develop a SNP panel for accurate assignment of individuals back to our baseline set of populations. We followed a simple training and holdout cross-validation procedure (see Anderson 2010; Waples 2010) by first splitting the data into a training and validation set. We randomly selected half of the individuals from each sample collection (e.g. year and geographic area) to be used for the training set and the remaining samples were set aside for validation purposes. The training set was used to select SNPs that should be informative of an individual's geographic origin and then used these samples to construct reference populations. The validation set was then used to see how the assignment tests would generalize when new samples are compared to the baseline established using the training set. First, we grouped the individuals in the training set by area and estimated pairwise F_{ST} for each SNP between all combinations of geographic areas. Pairwise F_{ST} was estimated by obtaining maximum likelihood estimates of allele and genotype frequencies for each population and calculating F_{ST} defined by Weir and Cockerham (1984) using custom software. We selected SNPs with high levels of differentiation to construct a marker panel for population assignment. Specifically, we selected the top 1,000 SNPs with the highest F_{ST} for each sample collection; however, once a SNP was included in the panel no other SNPs within 10,000 base pairs were considered to avoid selecting tightly linked SNPs containing redundant information. The lists of SNPs from each pairwise comparison were combined and subsequently any duplicate SNPs were removed. Population assignments were carried out using WGSAssign (v1.0.1) (DeSaix et al. 2024). First, a reference set of populations was established by estimating allele frequencies for each geographic area using the samples in the training set, and, second, samples in the validation set were assigned back to the reference set. Assignment accuracy was calculated as the proportion of samples in the validation set that were correctly assigned to the geographic location that they were collected from. We also conducted leave-one-out cross-validation to evaluate self-assignment rates of the fish in the training set back to their population of origin.

1.1.2. Results

Population structure

The genome-wide PCA using the filtered set of 4,793,014 SNPs (MAF ≥ 0.05) revealed a lack spatial population structure (Fig. 1) among spawning groups of Pacific halibut in the Northeastern Pacific Ocean . The top two PCs capture a very small (< 1%) proportion of the total variation in the dataset (Fig. 1). By plotting individual Pacific halibut along the top two PCs, a single cluster of individuals is formed and a considerable degree of overlap of individuals among geographic areas is observed (Fig. 1), suggesting that no distinct genetic groups are apparent in the dataset. K-means clustering analysis also failed to detect discrete genetic groups. For clustering, only the first three PCs were retained following Cattell's rule (Fig. 2). Inspecting model selection measures of total within-clusters sum of squares and BIC, we see a constant and continual decay as larger K-values are tested (Fig. 3). Following the guidance of Jombart et al. (2010) on the use of BIC for selecting the best value of K, we were unable to confidently select an optimal value for K, the true number of clusters in the dataset. This is consistent with the lack of discrete genetic groups observed in Fig. 1.

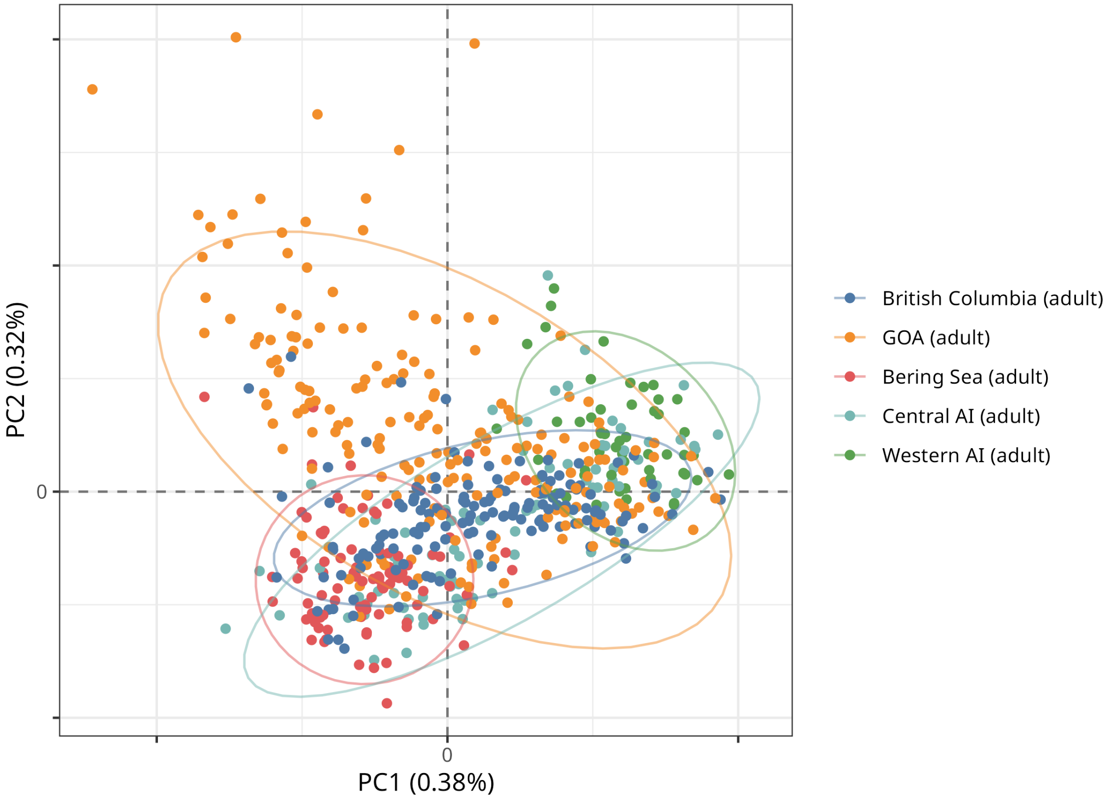


Figure 1. PCA biplot of the first two PC axes for 570 Pacific halibut. Samples are colored by geographic area. Circles represent 95% confidence ellipses.

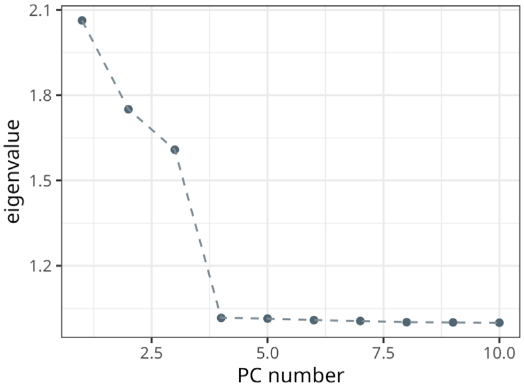


Figure 2. Scree plot of the eigenvalues for the first 10 principal components (PCs).

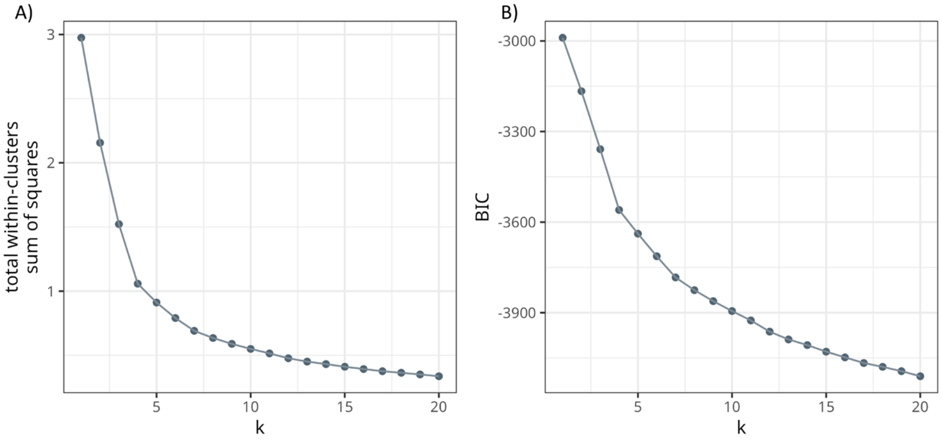


Figure 3. Plots of total within-clusters sum of squares (A) and Bayesian information criterion (B) for each value of K tested (1-20).

The estimation of admixture proportions and clustering implemented in NGSadmix revealed a similar lack of population structure among the sample collections used in this study since no clear groupings of samples were identified across all values of K tested (Fig. 4). Comparing values of *ΔK* across all values of K tested we observed the largest value associated with K=2, suggesting that the best supported number of clusters is 2 (Fig. 5). However, it is important to note that while *ΔK* can be a very reliable metric for identifying the true number of genetic clusters in certain scenarios, it cannot identify the best number of clusters when there is only a single cluster (i.e. when K=1) (Evanno et al. 2005) such as in the present study. The lack of population structure is also supported when examining the cluster membership coefficients of the individual samples. While the fewest number of individuals were classified as unassigned when partitioning the dataset into two clusters (K=2), it is important to note that the majority of the individuals in the dataset remained unassigned for this value of K (Fig. 6). As the value of K increased, almost all of the individuals were classified as unassigned (Fig. 6). This is most likely due to the fact that as K increases, the probabilistic assignments must be split among more categories and larger values exceeding our threshold of 0.8 are less likely to be observed by chance. The results of the unsupervised clustering performed in NGSadmix also failed to detect discrete genetic groups of Pacific halibut in the northeast Pacific Ocean much like the PCA and K-means clustering analyses performed.

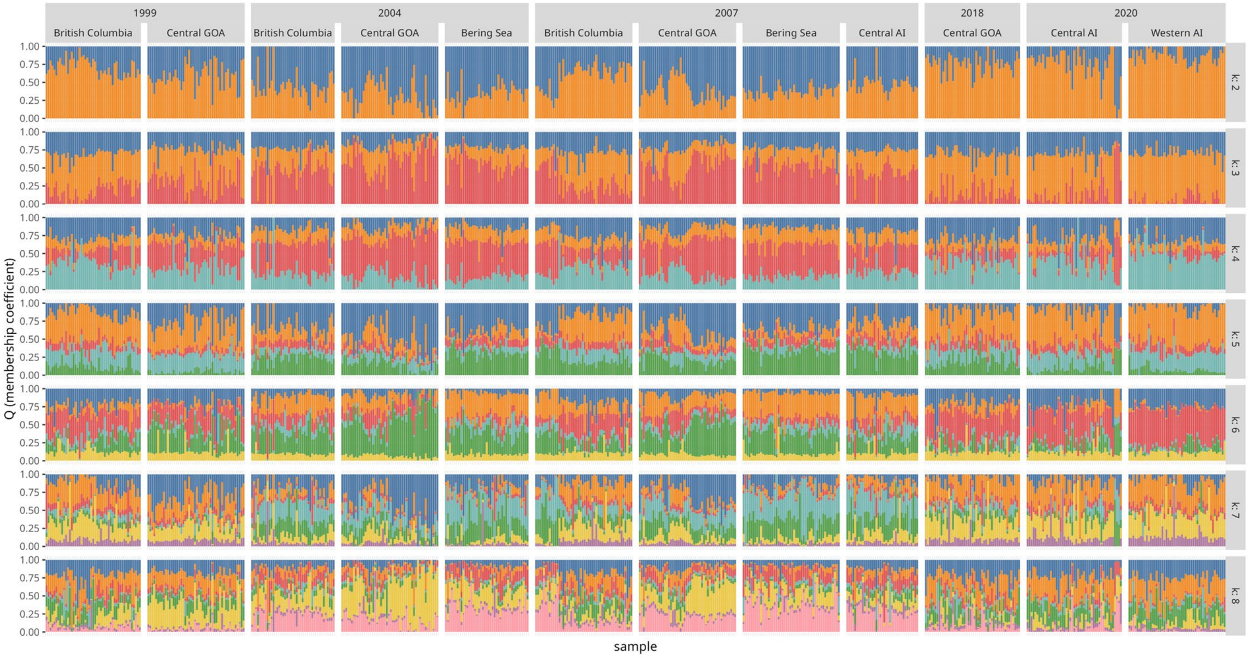


Figure 4. Barplots of individual admixture proportions estimated using NGSadmix for values of K (number of genetic clusters) ranging from 2-8. The color and height of each bar corresponds to the proportion of an individual's ancestry attributed to a specific cluster.

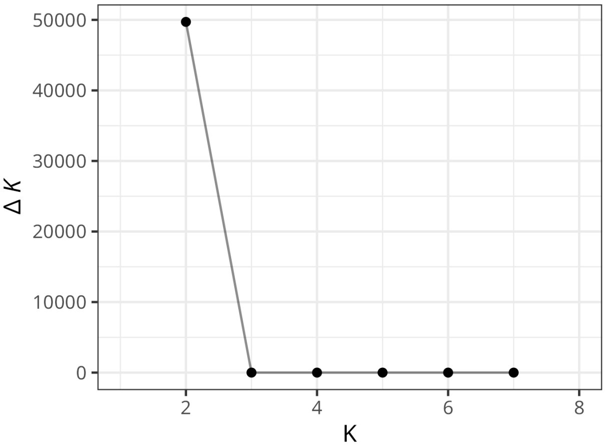
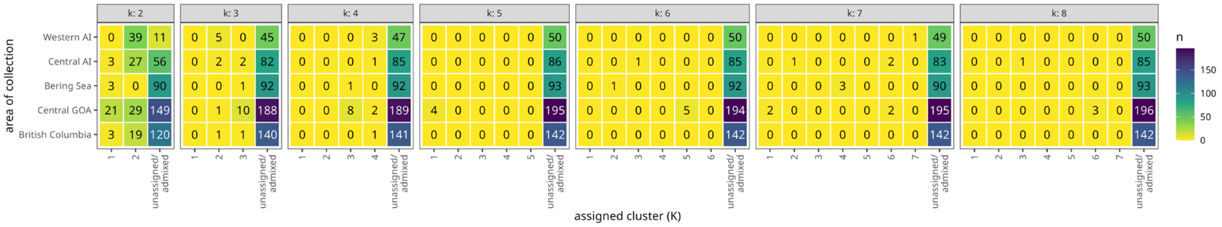


Figure 5. ∆K values for each value of K tested using NGSadmix.



k: 2

area of collection	1	2	unassigned/ admixed
Western AI	0	39	11
Central AI	3	27	56
Bering Sea	3	0	90
Central GOA	21	29	149
British Columbia	3	19	120

k: 3

area of collection	1	2	3	unassigned/ admixed
Western AI	0	5	0	45
Central AI	0	2	2	82
Bering Sea	0	0	1	92
Central GOA	0	1	10	188
British Columbia	0	1	1	140

k: 4

area of collection	1	2	3	4	unassigned/ admixed
Western AI	0	0	0	3	47
Central AI	0	0	0	1	85
Bering Sea	0	0	1	0	92
Central GOA	0	0	8	2	189
British Columbia	0	0	0	1	141

k: 5

area of collection	1	2	3	4	5	unassigned/ admixed
Western AI	0	0	0	0	0	50
Central AI	0	0	0	0	0	86
Bering Sea	0	0	0	0	0	93
Central GOA	4	0	0	0	0	195
British Columbia	0	0	0	0	0	142

k: 6

area of collection	1	2	3	4	5	6	unassigned/ admixed
Western AI	0	0	0	0	0	0	50
Central AI	0	0	1	0	0	0	85
Bering Sea	0	1	0	0	0	0	92
Central GOA	0	0	0	0	5	0	194
British Columbia	0	0	0	0	0	0	142

k: 7

area of collection	1	2	3	4	5	6	7	unassigned/ admixed
Western AI	0	0	0	0	0	0	1	49
Central AI	0	1	0	0	0	2	0	83
Bering Sea	0	0	0	3	0	0	0	90
Central GOA	2	0	0	0	0	2	0	195
British Columbia	0	0	0	0	0	0	0	142

k: 8

area of collection	1	2	3	4	5	6	7	unassigned/ admixed
Western AI	0	0	0	0	0	0	0	50
Central AI	0	0	1	0	0	0	0	85
Bering Sea	0	0	0	0	0	0	0	93
Central GOA	0	0	0	0	0	3	0	196
British Columbia	0	0	0	0	0	0	0	142

Figure 6. Confusion matrices for cluster assignments from each value of K (2 - 8) tested using NGSadmix. We required at least 80% probability for an individual to be assigned to a single cluster, otherwise the individual was classified as unassigned or admixed.

Assignment testing

After combining the top 1,000 SNPs selected from each pairwise population comparison and removing duplicates, the resulting maker panel used for assignment testing contained 8,497 SNPs. Despite following procedures to select a subset of 8,497 SNPs to discriminate among populations (e.g. selecting the SNPs that are most differentiated among groups that we desire to discriminate amongst), we were unable to assign individuals back to their population of origin with a high degree of accuracy. Assignment success of the samples in the validation set was 34.72%. Interestingly, all of the samples in the validation-set were assigned with high confidence (> 95%) to the Central Gulf of Alaska (Fig. 7a). Evaluation of the training set using leave-one-out cross-validation yielded a 100% self-assignment rate of with all of the samples assigning back the geographic area in which they were collected (Fig. 7b). Our interpretation of the results on the complete assignment of the samples in the validation set to one particular geographic area (i.e. Central Gulf of Alaska) is that we are simply capturing noise in the training set due to the lack of genetic structure. The area with the largest number of samples is the Central Gulf of Alaska and, therefore, when split into training and validation sets, a large number of samples are available for accurate estimation of allele frequencies associated with this area. At other sampling localities, splitting the samples into two sets likely leads to less accurate allele frequency estimation for these areas due to smaller sample sizes. The allele frequencies estimated for the Central Gulf of Alaksa may be the most accurate representation of the stock as a whole, and, as a consequence of the general lack of spatial structure, individuals are being assigned to this area with a high degree of confidence.

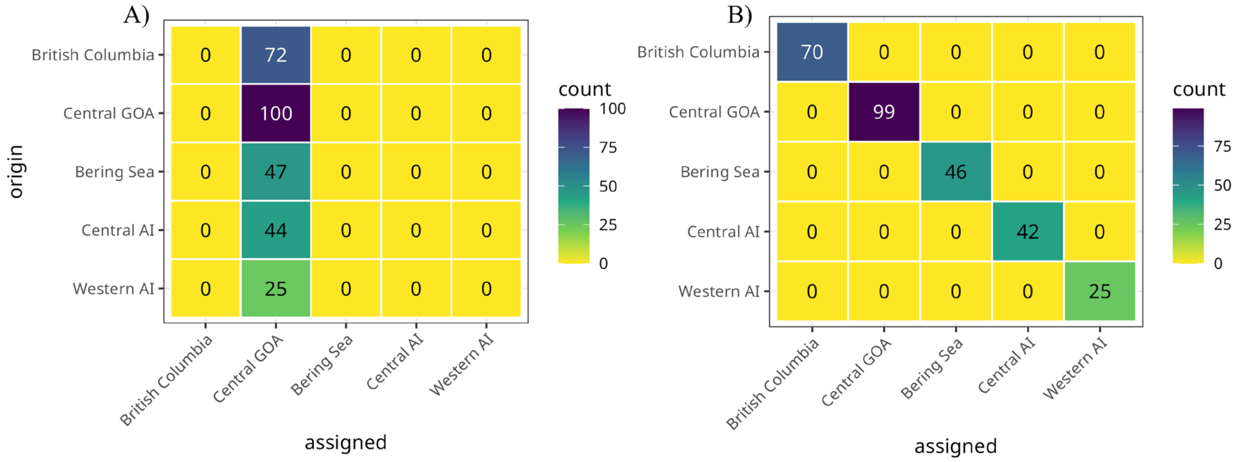


Figure 7. Confusion matrices for individual population assignments using a set of 8,497 SNPs, requiring a minimum assignment probability of 95% for an individual to be assigned to a reference population. Geographic area of origin and assigned population are respectively shown on the x and y axes. A) Count of individuals in the validation set with assignments to the reference populations established using the training set. B) Assignment counts of individuals in the training set that self-assign to the reference populations, established using leave-one-out cross-validation.

1.1.3. Conclusions

The results presented here support the notion that a single genetic group of Pacific halibut inhabits the northeast Pacific Ocean. Unsupervised clustering analyses failed to confidently identify discrete genetic groups, levels of genome-wide differentiation are low among sample collections, and genomic signatures of natural selection are shared among the sample collections included in this study, despite being collected over broad temporal and spatial scales. Furthermore, assignment testing validated with cross-validation techniques indicate limited ability to accurately assign samples back to the location in which they were sampled from. We hypothesize that the absence of distinct genetic groups among our sample collections is due to a considerable degree of geneflow among the areas sampled in this study and, consequently, to the genetically panmictic nature of the sampled Pacific halibut population.

The lack of structure observed here is not surprising given our current knowledge and biology of Pacific halibut. Annual migration rates estimated from tag recovery data suggest that there is ample opportunity for individuals to move among IPHC Regulatory Areas throughout their lives (Webster et al. 2013). Analysis of tag recovery data has shown that approximately 11% of Pacific halibut tags are recovered in a different IPHC Regulatory Area than they are released (Carpi et al. 2021). This varies by regulatory area but for most IPHC Regulatory Areas, the percentage of migrants observed exceeds 10% (Carpi et al. 2021). Additionally, strong oceanographic connectivity between the Bering Sea and Gulf of Alaska has been linked to a considerable degree of larval exchange between these areas. It has been estimated that 47%-58% of larvae originating from spawning grounds in the Western Gulf of Alaska are transported to the Bering Sea (Sadorus et al. 2021). These rates can still be as high as 4.5%-8.6% for larvae originating from spawning grounds in the Eastern Gulf of Alaska (Sadorus et al. 2021).

The concept of a stock and the ability to define management units is central to sound management of marine fishes (Begg et al. 1999; Cadrin 2020). Advances in genomic technology have led to the development of useful and powerful tools that can aid in the delineation of management units (Bernatchez et al. 2017). Despite using very high-resolution genomic methods to characterize genomic variation in spawning groups of Pacific halibut collected over large spatial and temporal scales, the results presented here are consistent with genetic panmixia. However, while it is important to note that we cannot simply prove panmixia exists by failing to reject it, the results presented here are consistent with the current assessment practices of the Pacific halibut stock in IPHC Convention Waters which is treated as a single coastwide stock (Stewart and Hicks 2024).

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 started collecting ovarian samples for histology during the 2022 FISS. The 2022 FISS sampling resulted in a total of 1,023 ovarian samples collected coastwide at 489 distinct FISS stations, with 440 ovarian samples from Biological Region 2, 351 samples from Biological Region 3, 181 from Biological Regions 4, and 51 samples from Biological Region 4B (Fig. 8).

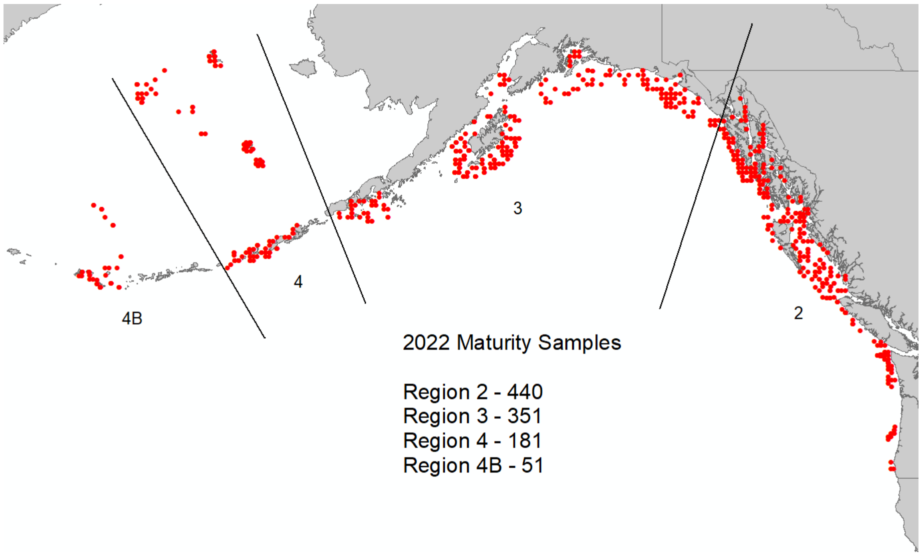


Figure 8. Map of 2022 maturity samples for histology collected on FISS. Red dots indicate a distinct FISS station in which a sample was collected.

When examining the temporal component of sampling (by week), sample collection took place from the end of May (week 21) to beginning of September (week 37) 2022. Biological Region 2 had consistent collection across time (weeks 21 to 32), with Biological Region 3 having a gap in collection from weeks 28 to 31. Sample collections in Biological Regions 4 and 4B were distinctly separated due to the same FISS vessel sampling those two regions (Fig. 9).

When examining the age and length distribution of fish collected for sampling, the distribution of fish appeared to be right-skewed for both parameters, but more pronounced for age (Fig. 10). For the samples collected in 2022, the total range of ages was from 5 to 38 years old, and the total range of lengths was from 50 to 185 cm. The largest proportion of sampled fish was from 7 to 10 years old, and from 80 to 90 cm in length.

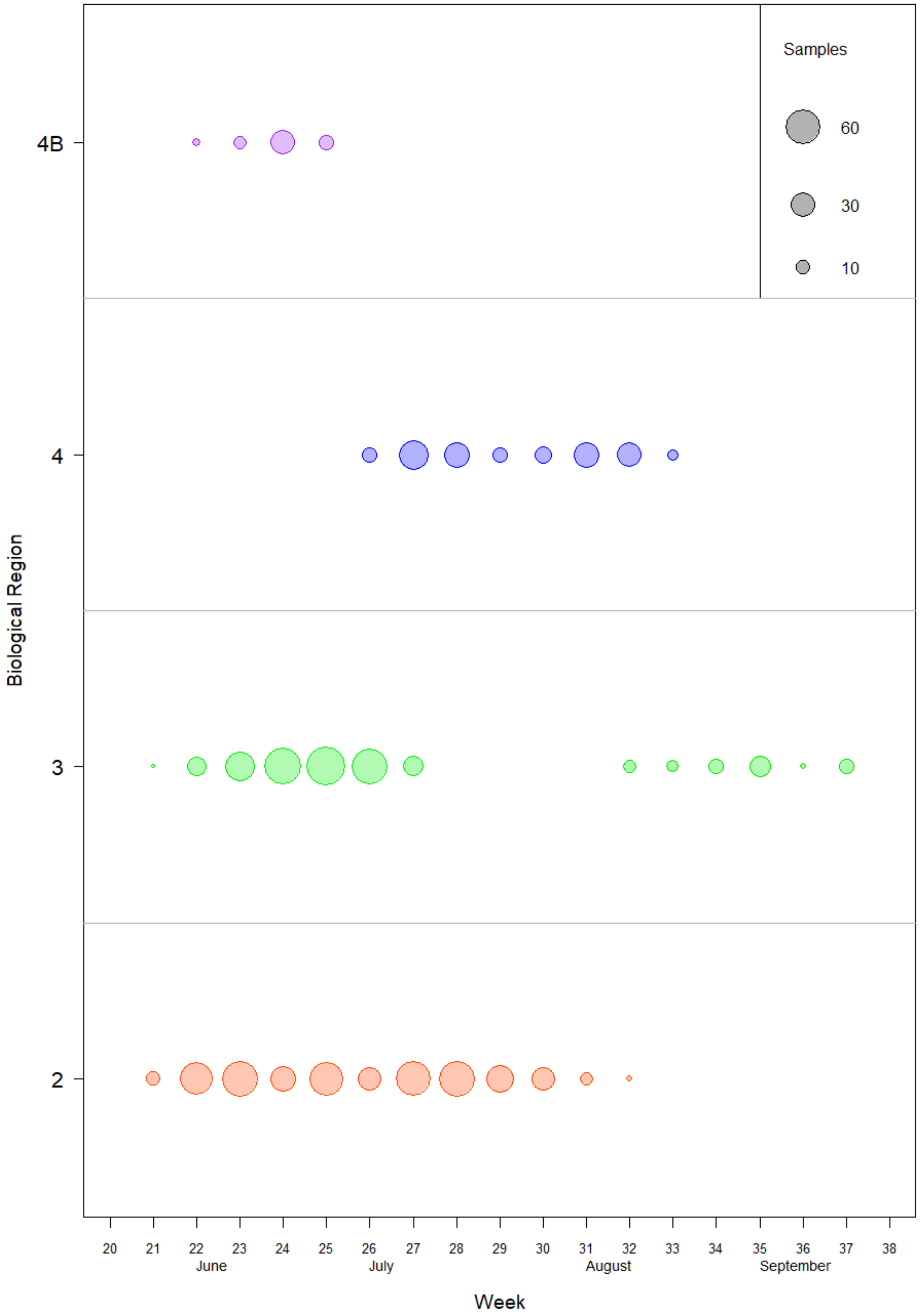


Figure 9. Timing of maturity sample collection on the 2022 FISS. The size of the bubbles indicates the number of samples collected at each bin during week of calendar year.

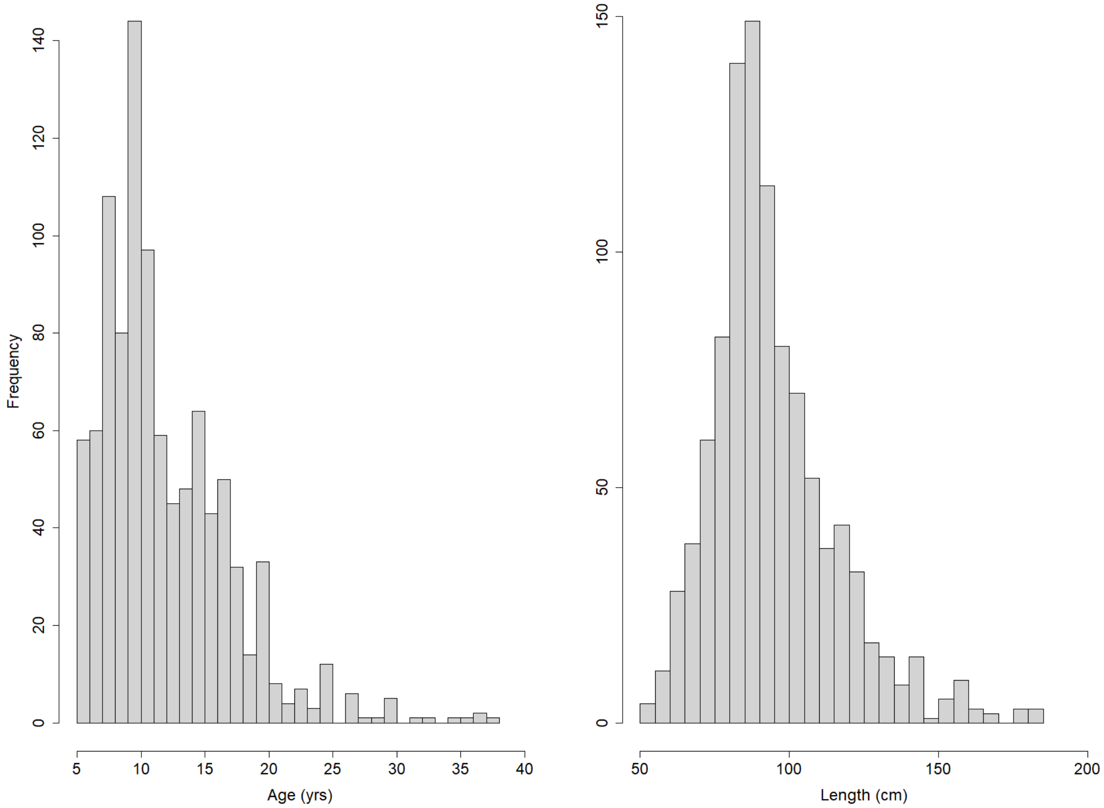


Figure 10. Histograms showing distribution of age and length of female Pacific halibut collected for maturity samples in the 2022 FISS.

Ovarian samples from 2022 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, fork length and net weight) were estimated by fitting generalized linear models 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 2). Preliminary modeling showed the models fitted with log(age) provided a better fit, with the estimated curves better matching the initial steep rise in the proportion of mature females with age, and subsequent slower increase for older fish (Fig. 11a). Likewise, for models that included length or weight only (i.e., not added to a model already including age), log transformation of these variables also improved model fit. Models were fitted using function glm from the stats package (R Core Team 2013) in R 4.3.2.

Significant spatial differences in maturity-at-age, -length, and -weight are apparent across the IPHC Biological Regions, with the inclusion of IPHC Biological Region in all models leading to improved fit as indicated by lower AIC values (Table 2). When comparing Biological Regions 2 and 3, where the majority (>77%) of samples were collected from, Biological Region 2 appears to be showing a lower proportion of mature females at any given age (Fig. 11a) and size (Figs. 12a and 13a) than Biological Region 3 that contains younger and smaller maturing females. Biological Region 4 is showing females maturating at an older age when compared to other Biological Regions (except Biological Region 2 at ages older than 15 years) and has similar maturity-at-size than Biological Region 2. Biological Region 4B has the steepest ogive curve for maturity-at-age, most similar to Biological Region 3, reaching asymptote of 100% mature at the youngest age, and is also showing maturing females at a larger size compared to the other three Biological Regions. These results are the first to identify spatial differences in histological-based maturity schedules for female Pacific halibut across all four IPHC Biological Regions.

	Model	**AIC**
Age	Age	995.99
	Age * Region	894.24
	sqrt(Age) * Region	882.67
	log(Age) * Region	874.06
Length	Length	1038.99
	Length * Region	944.53
	log(Length) * Region	940.03
Weight	Weight	1082.99
	Weight * Region	983.65
	log(Weight) * Region	956.41

Table 2. Generalized linear model comparisons with lower Akaike information criterion (AIC) values indicating better fitting models.

The models estimated maturity curves for each IPHC Biological Region. Noting that sample size was not proportional to population size for each region, we used the estimated regional abundance proportions from IPHC's space-time modeling of FISS numbers per unit effort (NPUE) data as weights in estimating a coastwide maturity ogive (Figs. 11b, 12b, and 13b). The value of the coastwide ogive at each age, length or weight is calculated as the abundance proportion at age, length or weight times the proportion mature at age, length or weight summed across regions. For example, for age, let q_j be the estimate of the abundance proportion for Biological Region *j*, and p_j(age) be the probability of maturity at age *a* estimated from fitting the model including both region and age as explanatory variables. Then the coastwide maturity probability at age is estimated by

$$p_{CW}\left(a\right)=\sum_{j=1}^{4} q_j p_j\left(a\right)$$

The modeled coastwide ogives for both maturity-at-age and -size appear to fall between the maturity ogives for Biological Regions 2 and 3. This is expected as the majority (>77%) of Pacific halibut maturity samples were collected in these two Biological Regions. Maturity is used to assign the numbers of fish at each age in the SA model to either a reproductive or non-reproductive state. The total reproductive output of these fish in the SA is then estimated by multiplying the number of reproductive fish at each age by their average somatic weight and then by the fecundity per age or body weight (currently assumed to be 1 for all body weights and ages). Therefore, defining our coastwide maturity ogive in terms of numbers of fish is consistent with its use in the SA. Conversely, defining it in terms of biomass would require converting back to maturity in numbers for use in the SA. Age, fork length and net weight at 50% maturity were calculated from the coastwide ogive using an optimizing routine in R 4.3.2 (function optim). Age at 50% maturity (A50) was calculated to be 11.3 years, similar to current estimates from macroscopic (field) data of 11.6 years. Length at 50% maturity (L50) and net weight at 50% maturity were calculated to be 91.5 cm and 6.9 kg, respectively. Current estimates of L50 using macroscopic (field) data collection is 97.6 cm (Clark and Hare 2006).

IPHC Secretariat continued to collect ovarian samples in the 2023 FISS and will do so again during the 2024 FISS. The 2023 sampling effort resulted in a total of 1,111 ovarian samples, with 403 from Biological Region 2 and 708 from Biological Region 3. Targets for 2024 are to collect 400 samples in Biological Regions 2 and 3, and 552 in Biological Region 4. These samples will allow us to investigate both spatial and temporal differences in histological-based female Pacific halibut maturity.

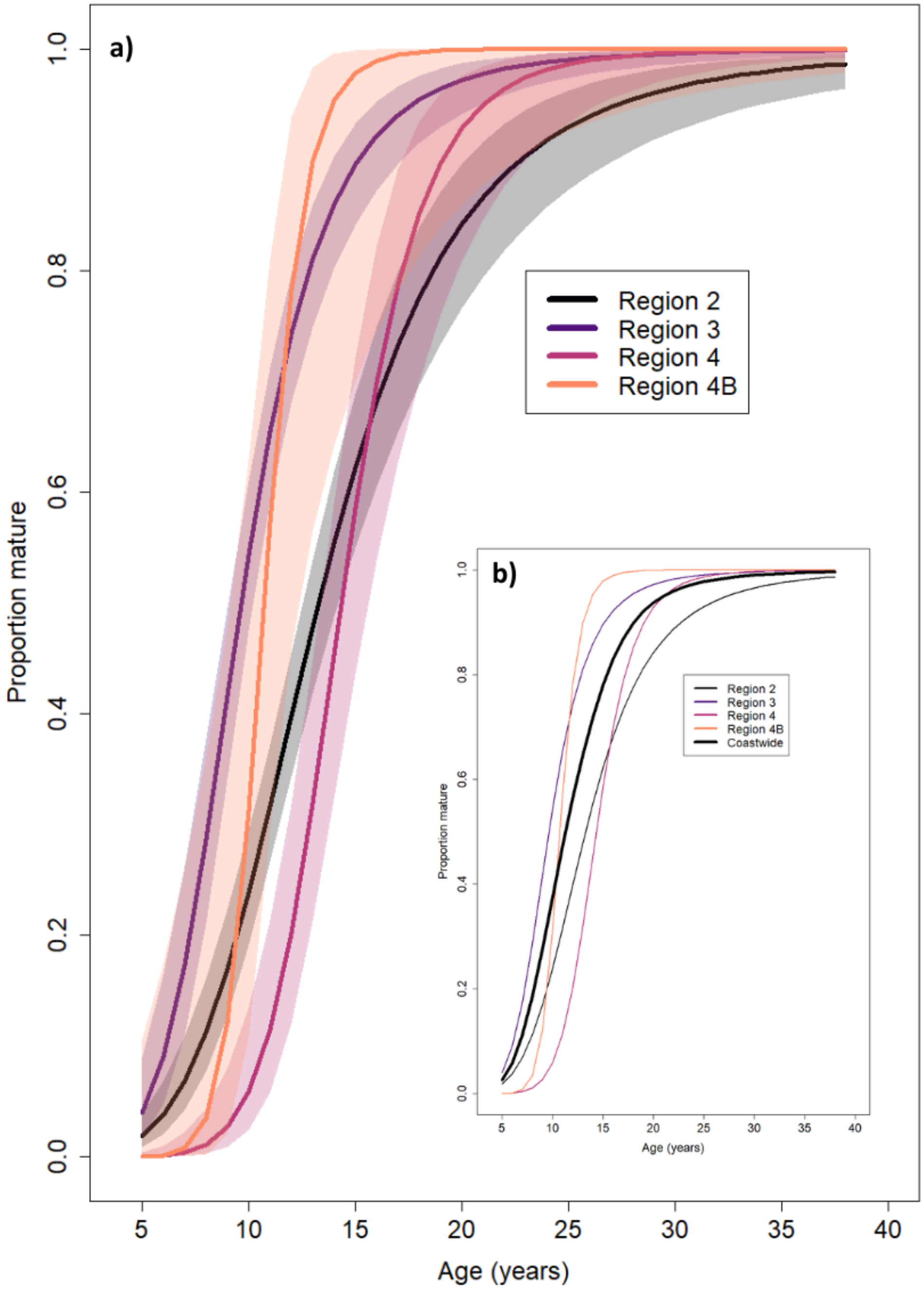


Figure 11. Female Pacific halibut age at maturity by IPHC Biological Region, with color shading indicating 95% CI for each IPHC Biological Region (a). In the inset (b), the coastwide ogive for age generated from estimated regional abundance proportions (thick black line) is shown without the CI to better visualize differences between the coastwide and Biological Region ogives.

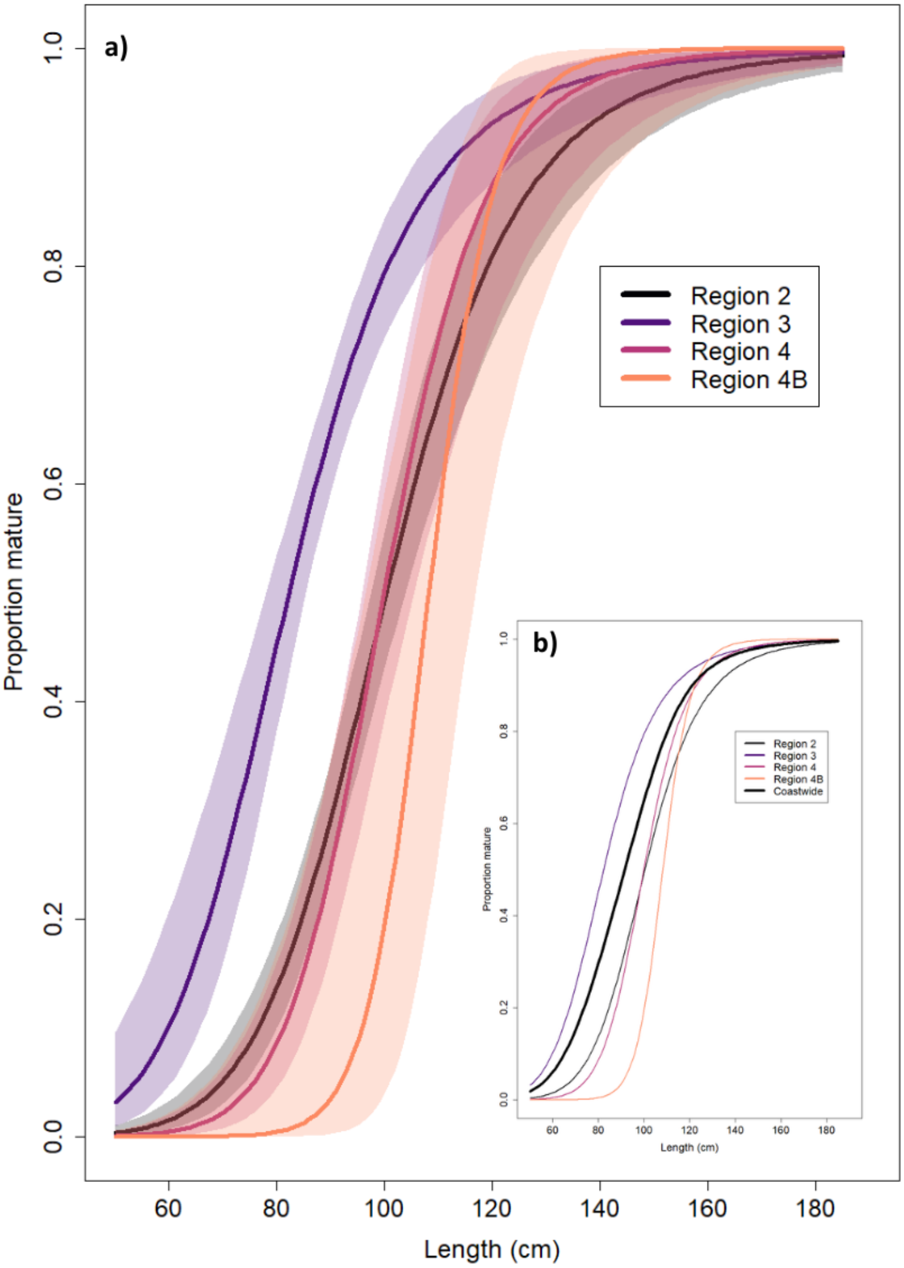


Figure 12. Female Pacific halibut length at maturity by IPHC Biological Region, with color shading indicating 95% CI for each IPHC Biological Region (a). In the inset (b), the coastwide ogive for length generated from estimated regional abundance proportions (thick black line) is shown without the CI to better visualize differences between the coastwide and Biological Region ogives.

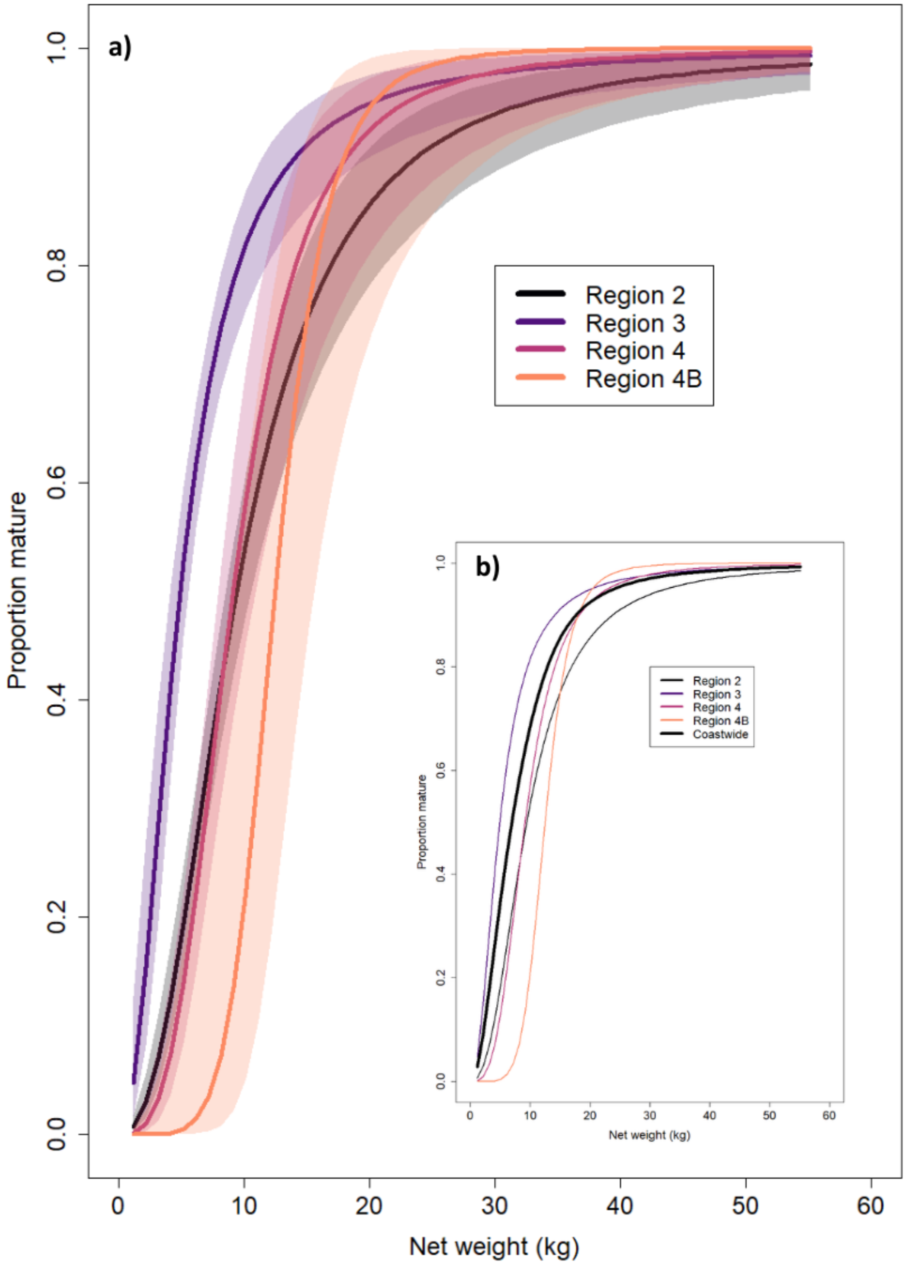


Figure 13. Female Pacific halibut net weight at maturity by IPHC Biological Region, with color shading indicating 95% CI for each IPHC Biological Region (a). In the inset (b), the coastwide ogive for net weight generated from estimated regional abundance proportions thick black line) is shown without the CI to better visualize differences between the coastwide and Biological Region ogives.

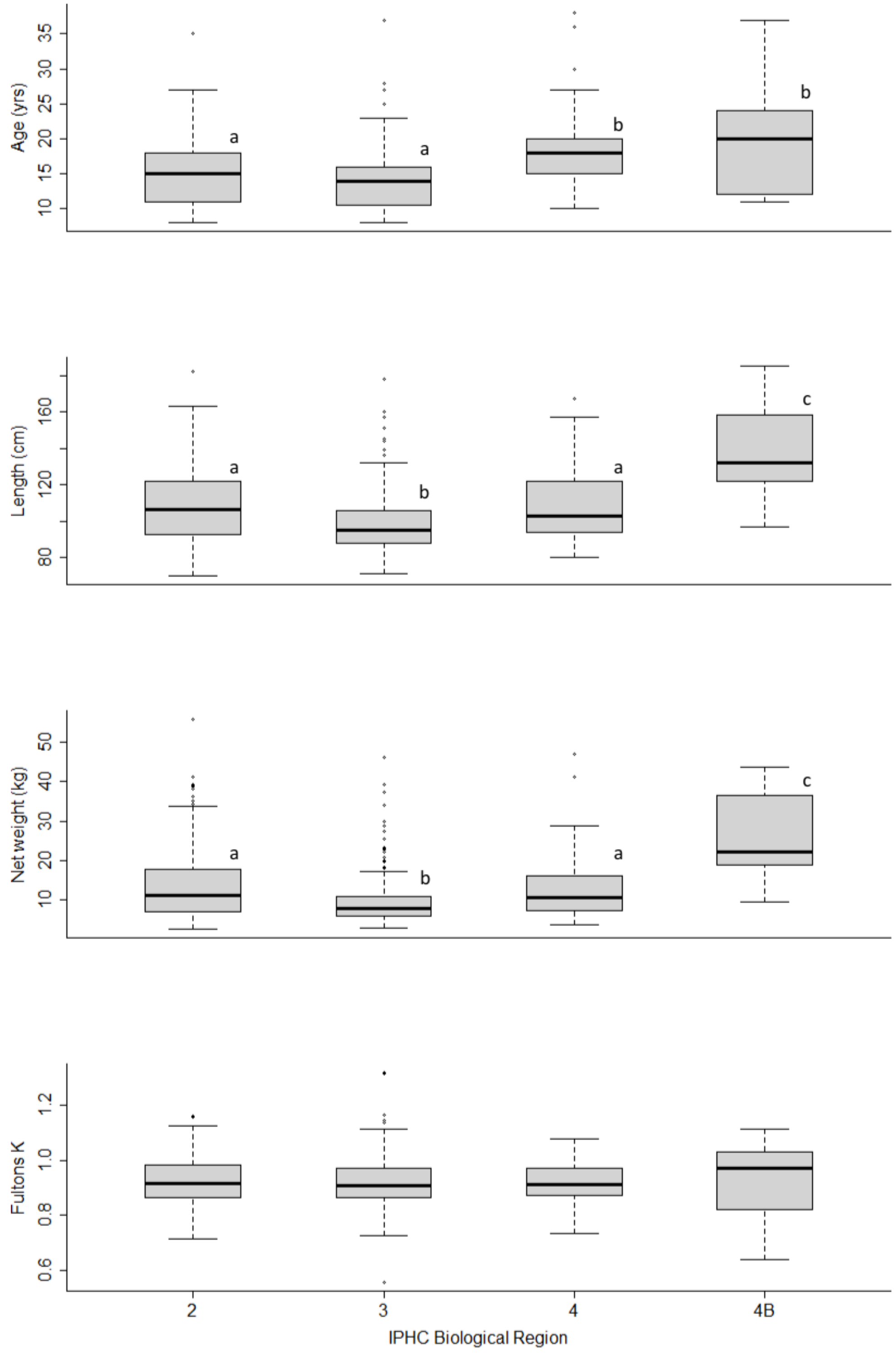


Figure 14. Comparison of age, length, net weight, and Fulton's condition factor (K) for mature individuals by IPHC Biological Region. Different letters indicate statistically significant differences among groups.

To further examine potential differences in maturity ogives among Biological Regions, we compared mature individuals using a one-way analysis of variance (ANOVA) with region as the independent variable and age, length, weight and condition factor (Fulton's K) as dependent variables (Fig. 14). 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. Age, length and weight were log() transformed to meet assumptions of normality and homogeneity. There was a statistically significant difference between Biological Regions for age ($F(3, 461) = 21.66$, $p < 0.001$), length ($F(3, 477) = 40.84$, $p < 0.001$), and weight ($F(3, 477) = 37.39$, $p < 0.001$). No significant difference was found among Biological Regions for Fulton's K ($F(3, 477) = 0.30$, $p = 0.823$). A Tukey HSD post-hoc comparison test (Tukey 1949) revealed that the age of mature females sampled in Biological Regions 4 and 4B was significantly higher than that of fish sampled in Biological Regions 2 and 3 (Fig. 14). No significant differences in age were observed between Biological Regions 2 and 3, nor between Biological Regions 4 and 4B. For length and weight, mature females sampled in Biological Region 3 were significantly smaller than in all other regions, whereas mature females sampled in Biological Region 4B were significantly larger than in all other regions. With no difference in age for mature females between Biological Regions 2 and 3, the difference in modeled maturity-at-age (Fig. 11a) for these two regions is largely driven by the higher proportion of older (18+ years) immature females in Biological Region 2. The mature female size data is in direct comparison to the modeled maturity-at-length and -weight ogives (Figs. 12a and 13a), showing that Biological Region 3 has younger and smaller maturing females and Biological Region 4B has older and larger maturing females when compared to other Biological Regions.

Using ovarian samples collected across the summer months, we were able to compare histological ovarian development among Biological Regions to assist with the interpretation of the differences in maturity ogives across Biological Regions (Fig. 15). Females in Biological Region 2 showed a clear increase in the proportion of mature individuals from May (<20%) until August (>70%), with females advancing from Vtg1 to Vtg3 during this period (Fig. 15). In contrast, the proportion of mature females in Biological Region 3 was already high in May (>75%) and stayed elevated until September, with mature females rapidly advancing through and completing vitellogenesis by that time, as shown by the appearance of females at the GVM stage as early as July (Fig. 15). In Region 4, mature females in July appeared in a lower proportion (approx. 20%) than in Biological Regions 2 and 3 but show clear progression through all stages in vitellogenesis. In August, the proportion of mature females in Biological Region 4 increased to approximately 40%, with mature females showing increasingly more advanced vitellogenic stages reaching even its completion (Fig. 15). With only samples collected in June, mature females in Biological Region 4B appeared to undergo earlier ovarian development than females in other Biological

Regions with ~50% of individuals at Vtg2 or more advanced stages, showing even signs of completion of vitellogenesis. This temporal analysis of ovarian development in mature females across Biological Regions provides useful insights into the existence of obvious differences related to the timing of ovarian development in mature females throughout Convention waters. Although not all Biological Regions were similarly sampled between May and September, we observed progressively earlier advances stages in oocyte development in mature females from Biological Regions 2 to 4B. Therefore, mature females appear to develop progressively faster as they move from the easternmost area sampled (Biological Region 2) to the westernmost area sampled (Biological Region 4B). This is evident when comparing oocyte developmental stages in July across Biological Regions (except June in Biological Region 4B): Vgt1-Vtg3 in Biological Region 2, Vtg1-GVM in Biological Region 3, Vtg1 and a higher proportion of Vtg2 and Vtg3 in Biological Region 4, and a higher proportion of mature females at Vtg2, Vtg3 and GVM stages in Biological Region 4B (June). However, mature females from Biological Regions 2 and 3 are younger than those from Biological Regions 4 and 4B. Therefore, it is also conceivable that older mature females undergo reproductive development faster than younger mature females, irrespective of capture location.

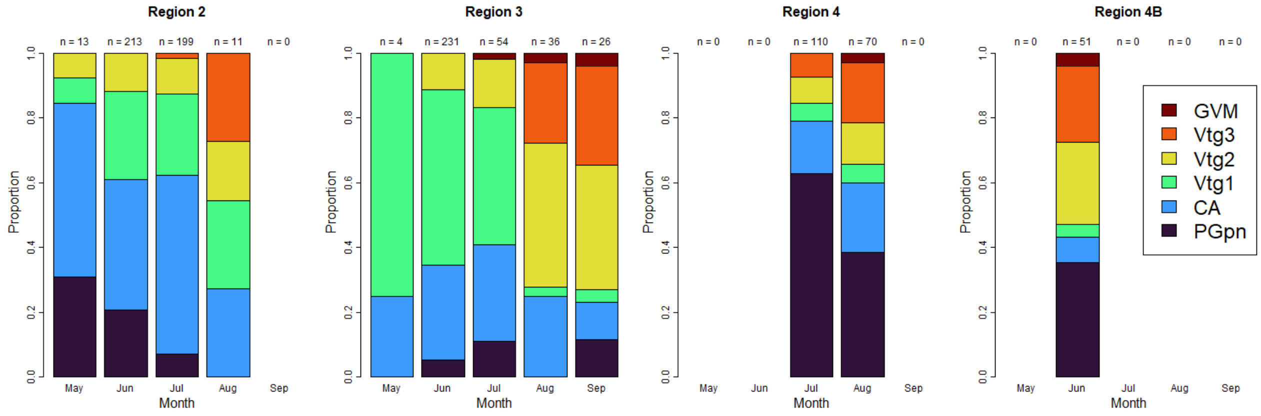


Figure 15. Reproductive development of female Pacific halibut by month sampled and IPHC Biological Region. Number of samples (n) collected by month shown at the top of each figure.

With regards to maturity-at-size, mature females from Biological Region 3, because of their small size, may be allocating most of their energy to ovarian development rather than growth at a young age when compared to fish from other Biological Regions. In contrast, mature females from Biological Region 4B, given that they are older and larger, may undergo rapid ovarian development once they achieve a certain size and age. growing to a larger size at younger age and then rapidly becoming mature around the age of 10 years old. With more years of histological data over a wide geographic range, we hope to be able to compare female reproductive development differences over different space and time scales.

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 FISS. Sampling was conducted in IPHC Biological Region 3, with a total of 456 fecundity samples collected. Using histology, as described in 2.2.1, only samples deemed mature will be processed for fecundity estimations. The IPHC Secretariat will continue to collect ovarian samples during the 2024 FISS, targeting Biological Region 2 (191 samples estimated) and Biological Region 4 (552 samples estimated) due to the reduced FISS coverage.

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. 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. After having reported on experimentally-derived estimates of discard mortality rate in the directed longline fishery (Loher et al., 2022), the second component of this study investigated the relationships among hook release techniques (e.g., gentle shake, gangion cutting, and hook stripping), injury levels, stress levels and physiological condition of released fish, as well as the environmental conditions that the fish experienced during capture. Gentle shake and gangion cutting resulted in the same injury and viability outcomes with 75% of sublegal fish in Excellent condition, while the hook stripper produced the poorest outcomes (only 9% in Excellent condition). Hook stripping also resulted in more severe injuries, particularly with respect to tearing injuries, whereas gentle shake and gangion cutting predominantly resulted in a torn cheek, effectively the injury incurred by the hooking event. Physiological stress indicators (plasma levels of glucose, lactate, and cortisol) did not significant change with viability outcomes, except for higher lactate plasma levels in fish categorized as Dead. Hematocrit was significantly lower in fish that were categorized as Dead. Furthermore, 89% of fish classified as Dead were infiltrated by sand fleas, present in several sets in deeper and colder waters. Our results indicated that avoiding the use of hook strippers and minimizing soak times in areas known to have high sand flea activity result in better survival outcomes. These results have been recently published in the peer-reviewed literature (Dykstra et al., 2024).

4.2. Estimation of discard mortality rates in the charter recreational sector. 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 (~11.5%, with 34 wire, 7 sPAT, 1 sPAT tether) we are investigating ways in which we can use these data to enhance the survivability modeling conducted with the sPAT data. Final data analysis and manuscript preparation are underway.

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.

5.1. Characteristics of the two different catch protection devices and their performance during field tests

5.1.1 Shuttle device. Manufactured in Norway by Sago Solutions AS, two replicate shuttle devices were modeled after the Sago Extreme model but smaller at 80% size (Fig. 16). Their dimensions are 2.60 m (8.5 ft) long by 0.80 m (2.6 ft) in diameter, each weighing approximately 100 kg (220 lb.) when empty. Typically, these devices are set with the gear; however, for this study the units were deployed from the surface, during the haulback event, by threading them onto a blank skate of gear between the control and the treatment skates.

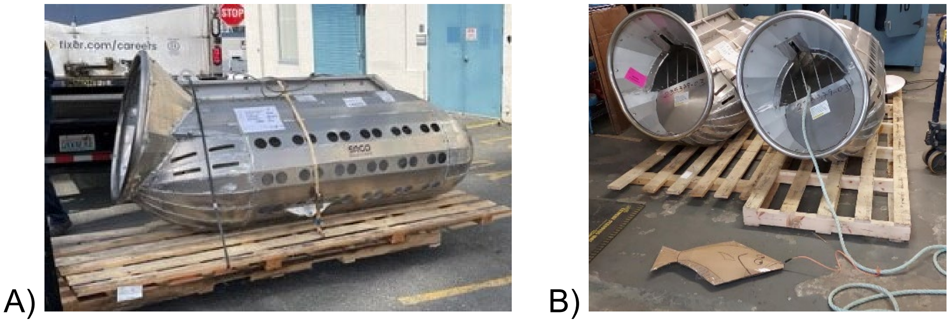


Figure 16. Images of the prototype shuttle devices used in this study in profile (A) and frontal views (B).

Shuttle gear had a standard fixed gear skate of 100 hooks on 5.5 m (18 ft) spacing, a blank half skate (on which to thread and allow the shuttle to reach the bottom before entraining catch) followed by a second skate. Gear was allowed to soak for three hours. During the hauling of gear, the shuttle was spliced onto the blank skate of gear, after which it slid down the groundline while removing fish from the hooks, before encountering the pre-installed stopper device and returning the catch to the surface. Upon reaching the surface the shuttle was hoisted onto the vessel where it was opened, and the fish were released onto the deck (Fig. 17). All fish were released back to the sea after basic data (e.g. species, length, weight, injury) were collected.

Figure 17. Shuttle being retrieved (A), catch entrained in shuttle (B), and catch being released onto the vessel deck (C).

Small adjustments were made to protocols to attach the shuttle safely and efficiently to the groundline, and the introduction of smaller hooks and weaker gangions led to lower levels of damage to the entrained fish. Shuttles had good entrapment of catch, with sets containing the shuttle yielding similar catch rates to the control sets (Fig. 18A), as well as similar size fish of entrained catch (Fig. 18B).

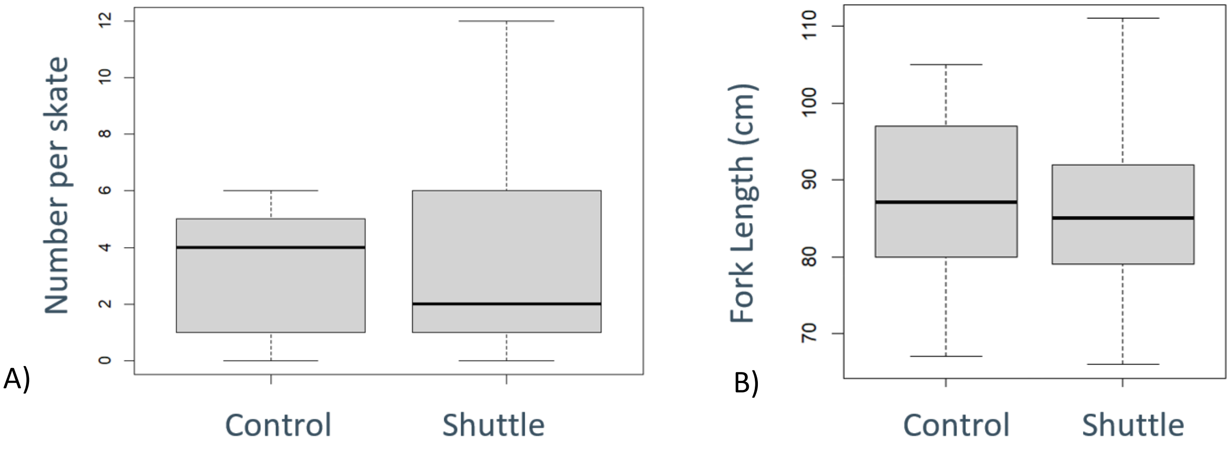


Figure 18. Number of individuals (A), and fork length (B) of Pacific halibut recovered per skate of control gear or retrieved by the shuttle.

5.1.2. <u>Shroud device</u>. Shrouds were constructed in house by modifying a commercially available slinky pot by opening one end and installing a rigid cap in the other end. Shrouds were designed to slide down the branch line during haulback, clustering the snaps (and hooks) and covering any catch present (Fig. 19).

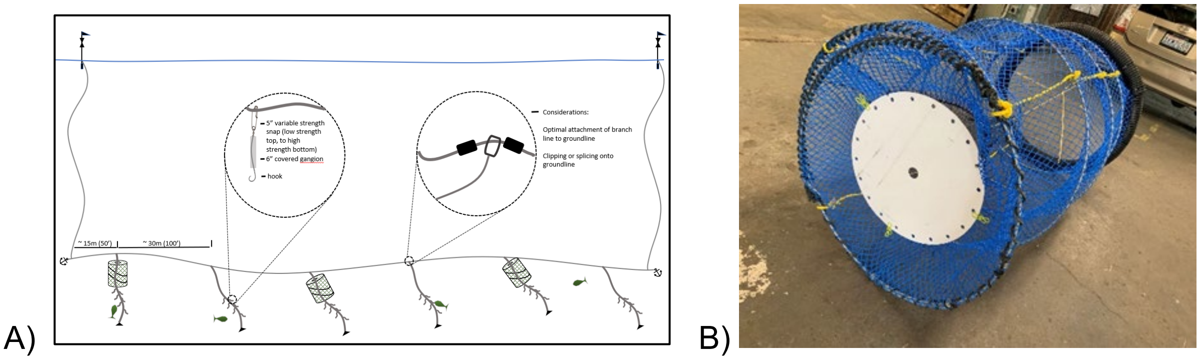


Figure 19. Schematic of shrouded branch line actively fishing on the seabed (A) and a constructed shroud (a modified slinky pot) (B).

Shroud treatments initially consisted of a shortened skate of groundline (180 m (591 ft)), to which six 15 m (48 ft) branch lines (each with 10 hooks snapped on 1.2 m (4 ft) spacing) were attached. Three branches included shrouds to cover the catch, and three control branches had no protective shroud. During testing this was reduced to two shroud-protected branches and two control branches, all with 0.6 m (2 ft) spacing to provide more handling time and to reduce injury risk to crew. Shrouds were deployed during the setting of the gear and were activated to slide down to cover the gear during the hauling/retrieval (Fig. 20) of the gear.

Figure 20. Shroud gear being retrieved A), skate covered by the shroud B), and a Pacific halibut and branchline hooks covered by the shroud C).

Real time adjustments in gear design and setting methods allowed for safe deployment of the branch lines and shrouds. The changes resulted in a very small effective fishing footprint of the gear on the bottom, which combined with high Pacific hagfish (*Eptatretus stoutii*) activity (reducing bait longevity/availability) resulted in minimal catch with which to establish comparisons between controls and treatments. It was concluded that several logistical issues would need to be improved to scale this up to commercial fishing and that even if logistics could be refined, the shrouds would conceivably still avail depredation opportunities to whales at the exposed end of the shroud. Therefore, continued development work on this form of catch protection is not being considered at this time.

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. Field work for this project is planned during the latter part of 2024 or during the summer of 2025.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2024-SRB024-09 which provides a response to Recommendations and Requests from SRB023, and a report on current research activities contemplated within the IPHC’s five-year Program of Integrated Research and Monitoring (2022-26).

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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 2025
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)	$60,374	Stock structure	February 2024-January 2026
Total awarded ($)					**$260,244**		

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

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PURPOSE

In the continuously evolving realm of marine science, the IPHC recognizes the transformative potential of artificial intelligence (AI). This document summarizes the information available on the use of 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 a process for developing the necessary AI services 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 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.

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[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-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).

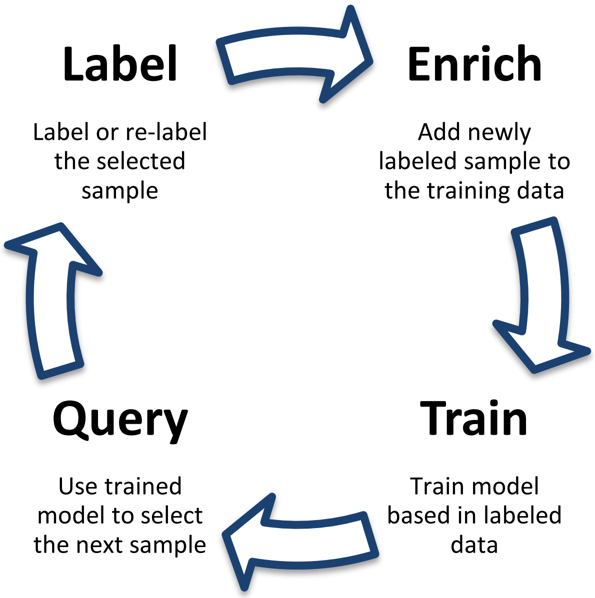

Figure 1: Model framework.

Modeling approach

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

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

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 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

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[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

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 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

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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.

[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.

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).

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]

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

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

[12] Moen et al. (2018) used images 400 by 400 pixels, which required the input layer to be scaled to match the 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-

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.

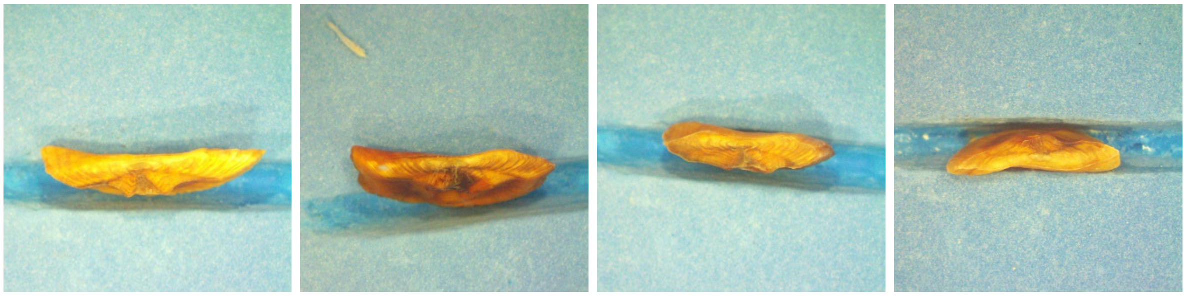

Figure 2: Examples of Pacific halibut otolith images taken for inclusion in the training set.

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.

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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.

[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.

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]

PRELIMINARY RESULTS

The initial model run utilized 2,286 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 (1,360) was used for training purposes. The validation set (240) 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%, 686) was used to assess the performance of the model after training, providing an unbiased evaluation of its generalization capability to new, unseen data. 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 0.00032 and 0.00166 in validation set. The model was trained for 324 epochs (i.e., 224 effective epochs with patience=100). The model achieved RMSE in the test set of 1.82, and 1.84 when applied to rounded results. Correct age was predicted for 30.0% individuals, with an additional 38.5% 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.

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[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.

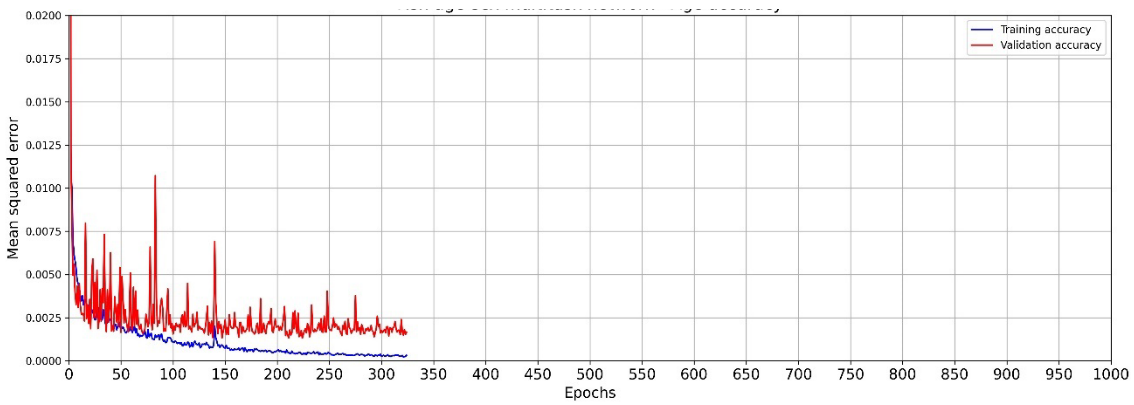

Figure 3: Age accuracy (measured as normalized age MSE) throughout the training process.

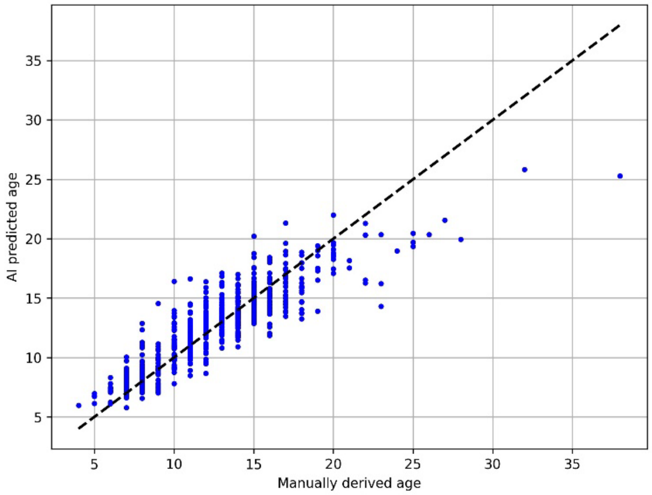

Figure 4: Comparison between manually derived age with AI predicted age.

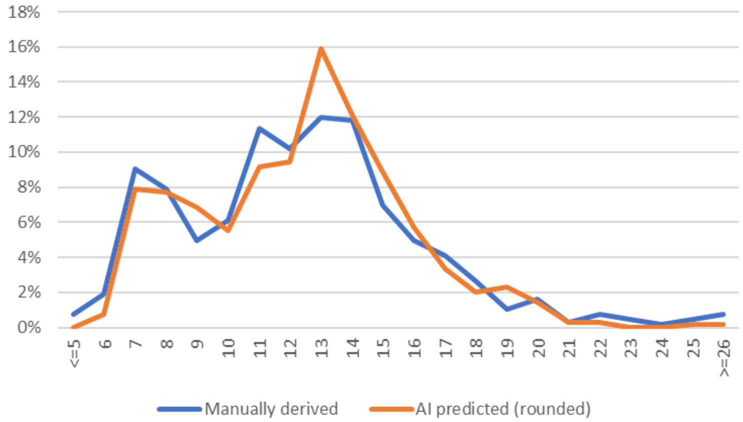

Figure 5: Comparison between manually derived age with AI predicted age – age composition.

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.

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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.