18th Session of the IPHC Scientific Review Board (SRB018) – *Compendium of meeting documents*

15 – 17 June 2021, Seattle, WA, USA

Commissioners

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

Executive Director

David T. Wilson, Ph.D.

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Report of the 18th Session of the IPHC Scientific Review Board (SRB018)

Meeting held electronically, 15-17 June 2021

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ACRONYMS

AM	Annual Meeting
ARIMA	Auto Regressive Integrated Moving Average
BS	Bering Sea
COVID-19	Novel Coronavirus 2019
CV	Coefficient of Variation
DMR	Discard Mortality Rate
DNA	Deoxyribonucleic Acid
FISS	Fishery-Independent Setline Survey
GOA	Gulf of Alaska
IPHC	International Pacific Halibut Commission
MSAB	Management Strategy Advisory Board
MSE	Management Strategy Evaluation
PCR	Polymerase Chain Reaction
SAA	Size-At-Age
SNP	Single Nucleotide Polymorphisms
SRB	Scientific Review Board
TCEY	Total Constant Exploitable Yield
U.S.A.	United States of America

DEFINITIONS

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

HOW TO INTERPRET TERMINOLOGY CONTAINED IN THIS REPORT

This report has been written using the following terms and associated definitions so as to remove ambiguity surrounding how particular paragraphs should be interpreted.

Level 1: **RECOMMENDED**; **RECOMMENDATION; ADOPTED** (formal); **REQUESTED; ENDORSED** (informal): A conclusion for an action to be undertaken, by a Contracting Party, a subsidiary (advisory) body of the Commission and/or the IPHC Secretariat.

Level 2: **AGREED**: Any point of discussion from a meeting which the Commission considers to be an agreed course of action covered by its mandate, which has not already been dealt with under Level 1 above; a general point of agreement among delegations/participants of a meeting which does not need to be elevated in the Commission's reporting structure.

Level 3: **NOTED/NOTING**; **CONSIDERED**; **URGED**; **ACKNOWLEDGED**: General terms to be used for consistency. Any point of discussion from a meeting which the Commission considers to be important enough to record in a meeting report for future reference. Any other term may be used to highlight to the reader of an IPHC report, the importance of the relevant paragraph. Other terms may be used but will be considered for explanatory/informational purposes only and shall have no higher rating within the reporting terminology hierarchy than Level 3.

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EXECUTIVE SUMMARY

The 18th Session of the International Pacific Halibut Commission (IPHC) Scientific Review Board (SRB018) was held electronically from 15 to 17 June 2021. The meeting was opened by the Chairperson, Dr Sean Cox (Canada), and the Executive Director, Dr David Wilson.

The following are a subset of the complete recommendations/requests for action from the SRB018, which are provided in full at Appendix IV.

RECOMMENDATIONS

(para. 4) ***NOTING*** *that the core purpose of the SRB018 is to review progress on the IPHC science program, and to provide guidance for the delivery of products to the SRB019 in September 2021, the SRB* ***RECALLED*** *that formal recommendations to the Commission would not be developed at the present meeting, but rather, these would be developed at the SRB019.*

REQUESTS

IPHC Fishery-independent setline survey (FISS): 2022-24 FISS design evaluation

SRB018–Req.1 (para. 13) The SRB **REQUESTED** plots by survey area of WPUE vs. depth from both FISS and commercial fisheries to help understand if there is part of the Pacific halibut stock in deeper waters not covered by the FISS.

SRB018–Req.2 (para. 14) The SRB **REQUESTED** that the IPHC Secretariat conduct a preliminary comparison, to be presented at SRB020, between male, female, and sex-aggregated analysis of the FISS data using the spatial-temporal model.

SRB018–Req.3 (para. 15) The SRB **REQUESTED** that the shiny-tool to investigate data and model outputs for the FISS be made available to the SRB by SRB019.

Pacific halibut stock assessment: 2021

SRB018–Req.4 (para. 24) The SRB **REQUESTED** an analysis of annual surplus production and the fraction of that production harvested.

Management Strategy Evaluation: update

SRB018–Req.7 (para. 36) The SRB **REQUESTED** that the IPHC Secretariat prioritize tasks for the MSE Program of Work that lead to adoption of a well-defined management procedure, taking into account interdependencies among tasks and presenting tasks as linked sets.

Biological and ecosystem sciences research

SRB018–Req.9 (para. 40) The SRB **REQUESTED** that the IPHC Secretariat provide information on the age distribution of all females collected to characterize reproductive development throughout the annual cycle in order to refine efforts to identify potential skip-spawning females.

SRB018–Req.10 (para. 41) The SRB **REQUESTED** that planned studies on fecundity assessment are prioritized and that the sampling design be developed in coordination with the SA to ensure that the results are as informative as possible for assessment purposes. Effective sample stratification along age, weight and length gradients that maximise the contrast in the effect of these variables will be key to precise estimates of fecundity. Oocyte diameter in contrast may be a important covariate to provide but cannot be used in stratification. The primary goal of the fecundity research should be to estimate the exponent of the fecundity vs. weight relationship for incorporation in the SA.

SRB018–Req.12 (para. 43) The SRB **REQUESTED** that the Secretariat use these gene regions and align sequences to the whole genome sequence data. Specifically, the Secretariat should

investigate whether there is sequence variability within gene coding regions or in regions around gene coding regions that may be transcriptional modifiers (e.g. promoters). If genetic variation exists in or near these genes, these variable base pair position(s) (i.e. single nucleotide polymorphisms or SNPs) should be incorporated in other aspects of the Secretariat research; for example for research activities under the Migration and Population Dynamics Research area.

SRB018–Req.13 (para. 44) The SRB **REQUESTED** that the analysis of seasonal patterns in gonad development be explicitly tied to the development/improvement of the maturity ogive (the vector of proportion mature at age that SA requires).

Pacific halibut fishery economics update

SRB018–Req.14 (para. 52) The SRB **NOTED** that, without a clearer understanding of the Commissions purpose for future use of this work, it is difficult to provide guidance on prioritising model development (e.g. improve spatial resolution, incorporate dynamic / predictive processes, adding more detail on subsistence and recreational fisheries, including uncertainty in the assessment). The SRB therefore **REQUESTED** specific guidance and clarification from the Commission on the objectives and intended use of this study.

In addition, the SRB provided the following endorsement of the proposed FISS design for 2022:

(Para 16) The SRB **ENDORSED** the final 2022 FISS design as presented in Fig. 2, and provisionally **ENDORSED** the 2023-24 designs (Figs. 3 and 4), recognizing that these will be reviewed again at subsequent SRB meetings.

1. OPENING OF THE SESSION

1. The 18th Session of the International Pacific Halibut Commission (IPHC) Scientific Review Board (SRB018) was held electronically from 15 to 17 June 2021. The list of participants is provided at Appendix I. The meeting was opened by the Chairperson, Dr Sean Cox (Canada), and the Executive Director, Dr David Wilson.

2. The SRB **RECALLED** its mandate, as detailed in Appendix VIII, Sect. I, para. 1-3 of the IPHC Rules of Procedure (2021):

    1. *The Scientific Review Board (SRB) shall provide an independent scientific peer review of Commission science/research proposals, programs, and products, including but not limited to:*
        - *a. Data collection;*
        - *b. Historical data sets;*
        - *c. Stock assessment;*
        - *d. Management Strategy Evaluation;*
        - *e. Migration;*
        - *f. Reproduction;*
        - *g. Growth;*
        - *h. Discard survival;*
        - *i. Genetics and Genomics.*
    2. *Undertake periodic reviews of science/research strategy, progress, and overall performance.*
    3. *Review the recommendations arising from the MSAB and the RAB.*

2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

3. The SRB **ADOPTED** the Agenda as provided at Appendix II. The documents provided to the SRB are listed in Appendix III. Participants were reminded that all documents for the meeting were published on the IPHC website, 30 days prior to the Session: https://www.iphc.int/venues/details/18th-session-of-the-iphc-scientific-review-board-srb018

3. IPHC PROCESS

3.1 SRB annual workflow

4. **NOTING** that the core purpose of the SRB018 is to review progress on the IPHC science program, and to provide guidance for the delivery of products to the SRB019 in September 2021, the SRB **RECALLED** that formal recommendations to the Commission would not be developed at the present meeting, but rather, these would be developed at the SRB019.

3.2 Update on the actions arising from the 17th Session of the SRB (SRB017)

5. The SRB **NOTED** paper IPHC-2021-SRB018-03, which provided the SRB with an opportunity to consider the progress made during the intersessional period, on the recommendations/requests arising from the SRB017.

6. The SRB **AGREED** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB018 into a consolidated list for future reporting.

3.3 Outcomes of the 97th Session of the IPHC Annual Meeting (AM097)

7. The SRB **NOTED** paper IPHC-2021-SRB018-04 which detailed the outcomes of the 97th Session of the IPHC Annual Meeting (AM097), relevant to the mandate of the SRB, and **AGREED** to consider how best to provide the Commission with the information it has requested, throughout the course of the current SRB meeting.

3.4 Observer updates

8. The SRB **NOTED** updates from the two science advisors, who provided brief overviews of some of the points of clarification being sought from the present SRB meeting. These included, but were not limited to: 1) COVID-19 impacts; 2) MSE timelines (to be considered at the SS011, 22 June 2021); 3) spatial dynamics of the stock, 4) fishery economics process for SRB review, 5) effects of past physical environment (temperature) and recruitment as potential importance to stock assessment; 6) expression of appreciation for IPHC Secretariat efforts to tie stock assessment and MSE needs to current and future biological and ecosystem science research initiatives.

4. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS)

4.1 2022-24 FISS design evaluation

9. The SRB **NOTED** paper IPHC-2021-SRB018-05, which proposed designs for the IPHC's Fishery-Independent Setline Survey (FISS) for the 2022-24 period, and an evaluation of those designs, for review by the Scientific Review Board.
10. The SRB appreciated the analysis of parameter stability and **NOTED** that changes in parameter estimates are minor and consistent with expectations based on new data being added each year.
11. The SRB **NOTED** the full FISS sampling grid which consists of 1890 stations (Fig. 1) from which an optimal subset of stations can be selected when devising annual FISS designs. In the Bering Sea, the full FISS design does not provide complete spatial coverage, and FISS data are augmented with calibrated data from NOAA-Fisheries and Alaska Department of Fish and Game (ADFG) trawl surveys (stations can vary by year – 2019 designs are shown in Fig. 1).

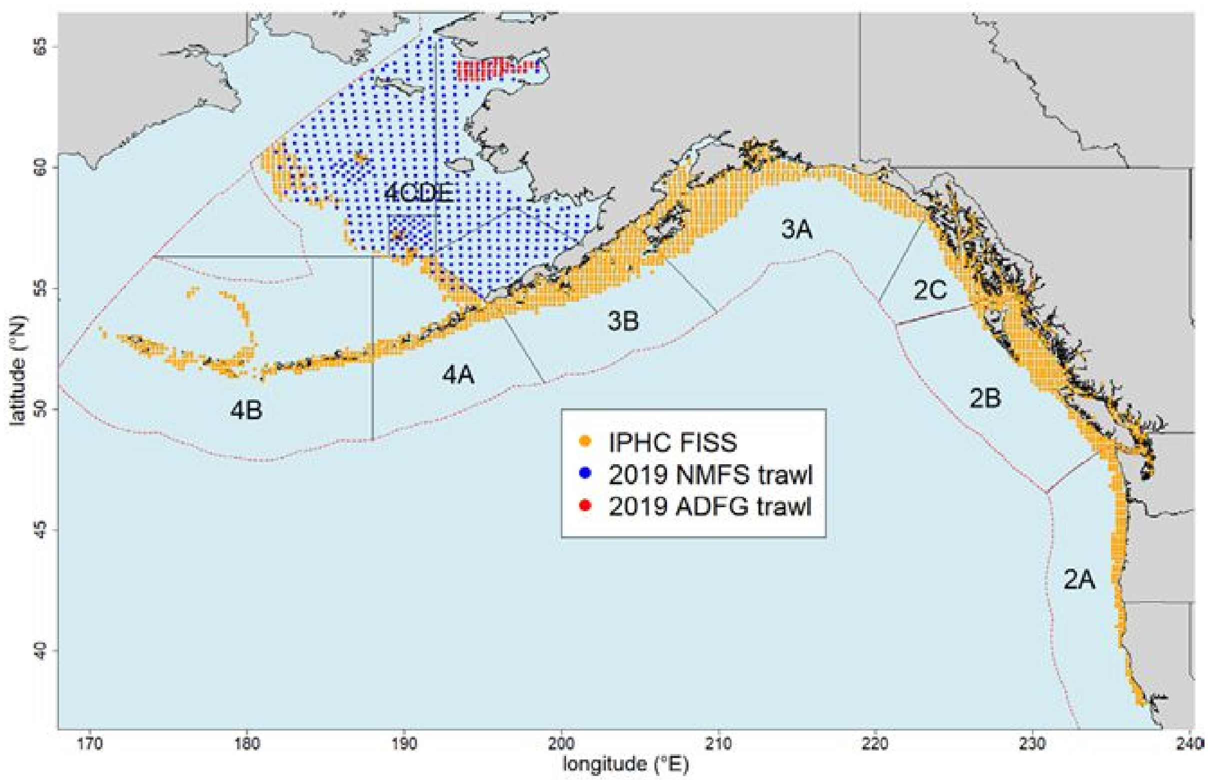

Figure 1. Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs, and other colours representing trawl stations from 2019 NMFS and ADFG surveys used to provide complementary data for Bering Sea modelling.

12. The SRB **NOTED** that plots of forecast vs subsequently observed values scaled to their respective mean for a given year could also be added to the Space-time Model Explorer tool for review by the SRB.
13. The SRB **REQUESTED** plots by survey area of WPUE vs. depth from both FISS and commercial fisheries to help understand if there is part of the Pacific halibut stock in deeper waters not covered by the FISS.
14. The SRB **REQUESTED** that the IPHC Secretariat conduct a preliminary comparison, to be presented at SRB020, between male, female, and sex-aggregated analysis of the FISS data using the spatial-temporal model.
15. The SRB **REQUESTED** that the shiny-tool to investigate data and model outputs for the FISS be made available to the SRB by SRB019.
16. The SRB **ENDORSED** the final 2022 FISS design as presented in Fig. 2, and provisionally **ENDORSED** the 2023-24 designs (Figs. 3 and 4), recognizing that these will be reviewed again at subsequent SRB meetings.
17. The SRB **NOTED** that following the changes to the endorsed design for 2020, changes to the 2022 design would increase the risk of the bias component in the model by an unknown quantity.

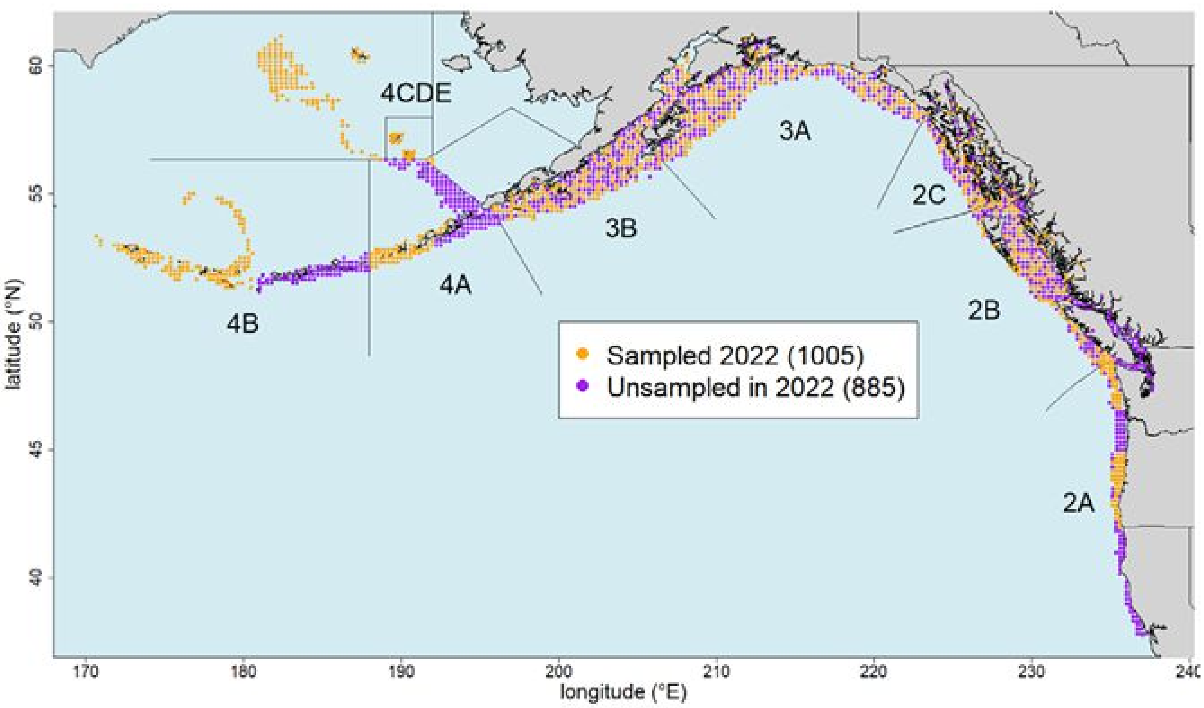

Figure 2. Endorsed minimum FISS design in 2022 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

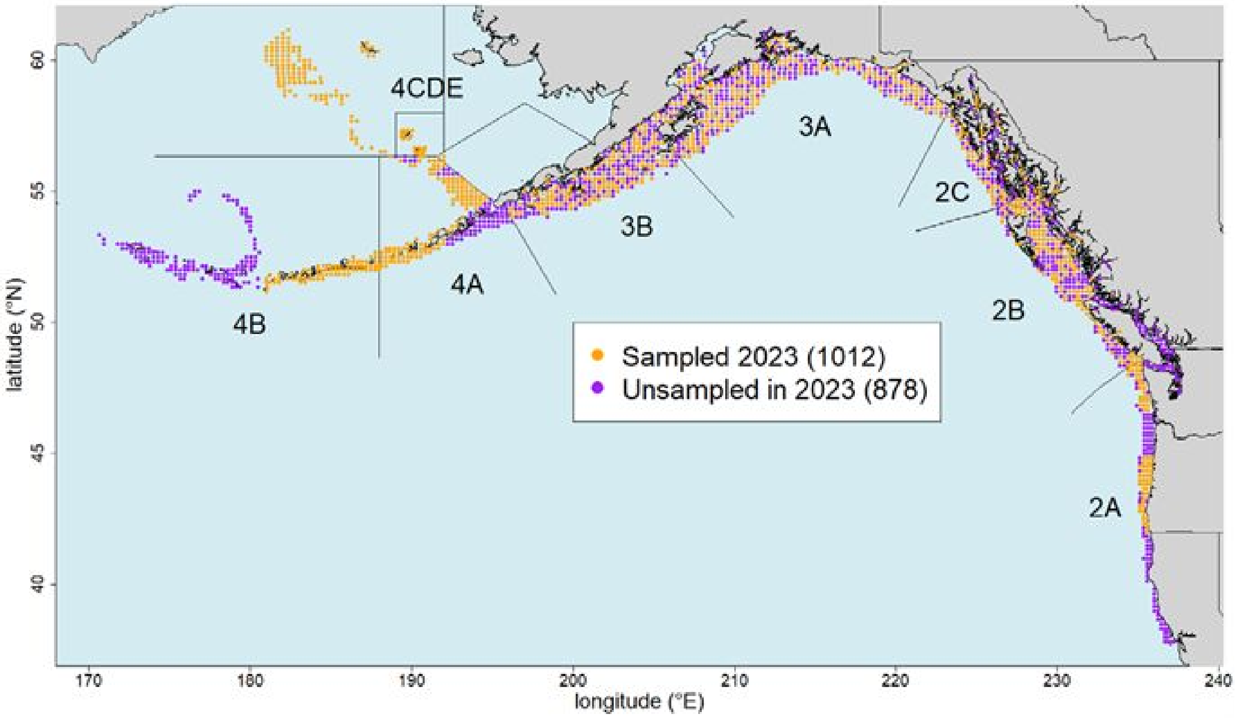

Figure 3. Proposed minimum FISS design in 2023 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

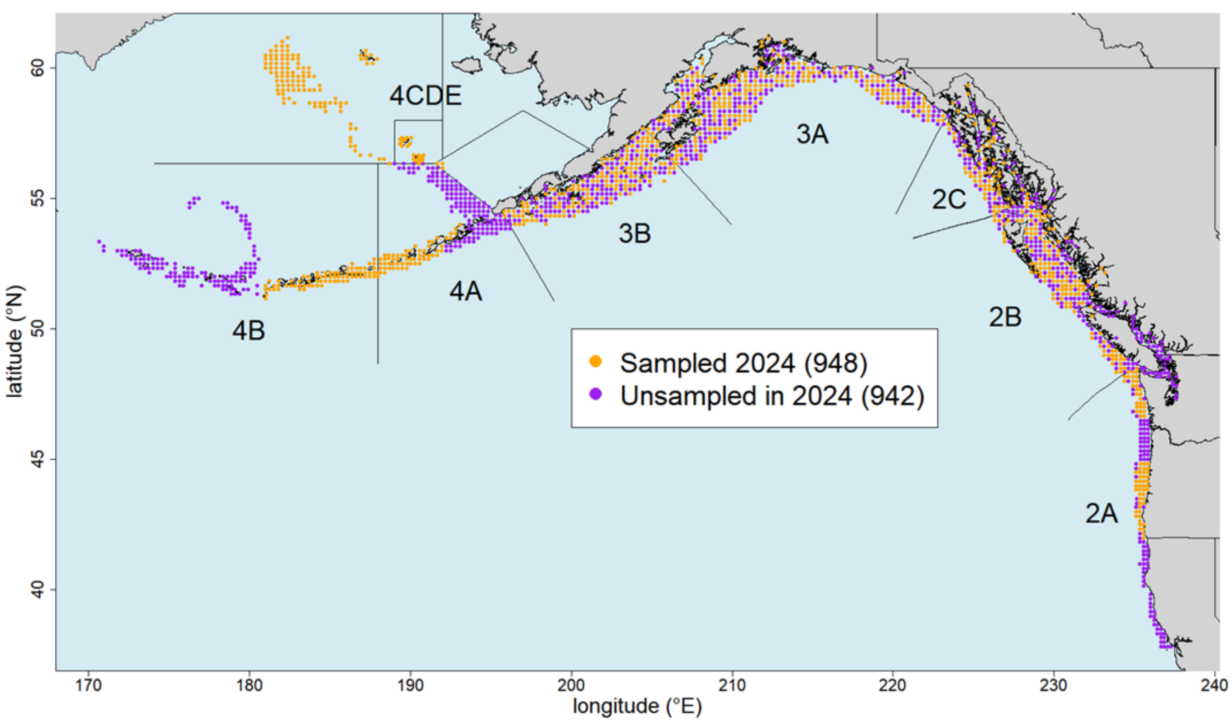

Figure 4. Proposed minimum FISS design in 2024 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

5. PACIFIC HALIBUT STOCK ASSESSMENT: 2021

18. The SRB **NOTED** paper IPHC-2021-SRB018-06, which provided a response to requests made during SRB016 and SRB017 (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R) and to provide an update of the 2021 assessment development.

19. The SRB **NOTED** paper IPHC-2021-SRB018-06, which provided a response to requests made during SRB016 and SRB017 (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R) and to provide an update of the 2021 assessment development.

20. The SRB **NOTED** that the 2021 stock assessment will be an update, including extending the time-series' for standard data sources (fishing mortality estimates, FISS index and age compositions, commercial fishery CPUE and age compositions, weight-at-age, etc.) and adding an additional year (2020) of sex-specific fishery age compositions based on genetic assays.

21. The SRB **NOTED** the evaluation of the logistic-normal likelihood in comparison with the Dirichlet-multinomial and multinomial, and was supportive of the IPHC Secretariat suggestion for a studentship in this area of research.

22. The SRB **NOTED** that the updated data weighting for 2020 was similar to that from the 2019 full assessment analysis and **AGREED** that the assessment should continue to update the data weighting, for both updates and full assessments, and to report the historical changes in data weightings.

23. The SRB **AGREED** that the choice of software and the research focus for further development of the stock assessment are dependent on both the MSE development and the Commission's pending adoption of a formal Management Procedure.

24. The SRB **REQUESTED** an analysis of annual surplus production and the fraction of that production harvested.

25. The SRB **NOTED** the explicit research priorities linked to critical sources of stock assessment uncertainty in the three categories of: data collection and processing, biological inputs, and fishery yield.

26. The SRB **ACKNOWLEDGED** and welcomed the explanation on how these topics linked to the work in other research areas as well as a guide to direct future research presented in IPHC-2021-SRB018-10.

6. MANAGEMENT STRATEGY EVALUATION: UPDATE

6.1 A summary of the MSE outcomes to date

27. The SRB **NOTED** paper IPHC-2021-SRB018-07 which provided the SRB with an update of the IPHC Management Strategy Evaluation (MSE) and an evaluation of management procedures for coastwide scale and distributing the TCEY to IPHC Regulatory Areas, as well as a response to requests made during SRB016 and SRB017 (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R) and potential topics for a program of work.

28. The SRB **NOTED** that integrating the various scientific areas and activities within the IPHC has been an on ongoing challenge, which is understandable to some degree as the main focus has been annual stock assessments and MSE development. In the past, the SRB has, therefore, strongly recommended that IPHC complete an initial round of MSE development that ends in clear recommendations for a harvest strategy without getting too bogged down in details of the operating models. The strong support and teamwork put into the MSE could now be bearing fruit, so we congratulate the Secretariat for that.

29. The SRB **NOTED** that there are many performance metrics reported from the MSE simulations and there are alternative ways to summarize them.

30. The SRB **REQUESTED** that the IPHC Secretariat present a revised system diagram of the MSE, showing components of variability and their implementation within MSE.

31. The SRB **AGREED** that Exceptional Circumstances (EC) should be defined around empirical, directly observable quantities to ensure transparency. ECs are meant to define unambiguous boundaries for acceptable system behaviour regardless of perspective (i.e. modeller, Commissioner, stakeholder).
32. The SRB **REQUESTED** that the Secretariat review potential indicators for use in defining ECs.
33. The SRB **AGREED** that the MSE is a useful tool to prioritize research topics with respect to their potential to improve management performance.
34. The SRB **URGED** continued development of the MSE over the next 5-year Plan to ready the MSE for providing such research prioritisation advice.
35. The SRB **NOTED** that the tasks in the MSE Program of Work collectively represent more work than can be accomplished in the next two years.
36. The SRB **REQUESTED** that the IPHC Secretariat prioritize tasks for the MSE Program of Work that lead to adoption of a well-defined management procedure, taking into account interdependencies among tasks and presenting tasks as linked sets.

7. BIOLOGICAL AND ECOSYSTEM SCIENCES RESEARCH

7.1 IPHC-5-year biological and ecosystem science research plan

37. The SRB **NOTED** paper IPHC-2021-SRB018-08 which provided the SRB with an update on current progress on research projects conducted and planned within the IPHC's five-year research plan (2017-21).
38. The SRB **NOTED** that good progress has been made by the IPHC Secretariat working in Stock Assessment (SA), Management Strategy Evaluation (MSE), and Biological and Ecosystem Sciences Research groups to better justify and focus Biological Science research program objectives and projects on SA and MSE needs. The appendices I, II, III, IV, and VI (in the paper) represent substantial improvements over materials presented previously. Likewise, Materials presented in SA meeting briefing document IPHC-2021-SRB018-06 and MSE briefing document IPHC-2021-SRB018-07 communicated needs that were consistent with information provided in the aforementioned Appendices.
39. The SRB **REQUESTED** that the IPHC Secretariat focus future reproductive biology studies on the development of updated regulatory area-specific maturity ogives (schedules of percent maturity by age).
40. The SRB **REQUESTED** that the IPHC Secretariat provide information on the age distribution of all females collected to characterize reproductive development throughout the annual cycle in order to refine efforts to identify potential skip-spawning females.
41. The SRB **REQUESTED** that planned studies on fecundity assessment are prioritized and that the sampling design be developed in coordination with the SA to ensure that the results are as informative as possible for assessment purposes. Effective sample stratification along age, weight and length gradients that maximise the contrast in the effect of these variables will be key to precise estimates of fecundity. Oocyte diameter in contrast may be a important covariate to provide but cannot be used in stratification. The primary goal of the fecundity research should be to estimate the exponent of the fecundity vs. weight relationship for incorporation in the SA.
42. The SRB **NOTED** that growth marker genes identified in transcriptomic profiling studies can be informative in future genome scans. However, the SRB **REQUESTED** that the Secretariat explicitly describe how the gene regions identified as 'over' or 'under' expressed would be used. For example, research has yet to determine mechanisms for transcriptional differences other than there is over- or under-representation of mRNA transcripts associated with different treatment groups (e.g. warm vs. cool water) from a heterogeneous set of individuals collected from a single location. The Secretariat has not yet established that results can be generalized to other regions in the species range. Neither has the transcriptional patterns been generalized to individuals of different size/age. These questions should be investigated.

43. The SRB **REQUESTED** that the Secretariat use these gene regions and align sequences to the whole genome sequence data. Specifically, the Secretariat should investigate whether there is sequence variability within gene coding regions or in regions around gene coding regions that may be transcriptional modifiers (e.g. promoters). If genetic variation exists in or near these genes, these variable base pair position(s) (i.e. single nucleotide polymorphisms or SNPs) should be incorporated in other aspects of the Secretariat research; for example for research activities under the Migration and Population Dynamics Research area.

44. The SRB **REQUESTED** that the analysis of seasonal patterns in gonad development be explicitly tied to the development/improvement of the maturity ogive (the vector of proportion mature at age that SA requires).

45. The SRB **NOTED** with respect to the discard mortality study that the injury profile information should be combined with the electronic tag survival data in a conditional logic framework to estimate fishery-level discard mortality.

7.2 Progress on ongoing research projects

46. The SRB **NOTED** the progress on ongoing research projects contemplated within the IPHC's five-year research plan (2017-21) involving:

    a) **Migration and Distribution**. Studies are aimed at further understanding reproductive migration and identification of spawning times and locations as well as larval and juvenile dispersal.

    b) **Reproduction**. Studies are aimed at providing information on the sex ratio of the commercial catch and to improve current estimates of maturity.

    c) **Growth and Physiological Condition**. Studies are aimed at describing the role of some of the factors responsible for the observed changes in size-at-age and to provide tools for measuring growth and physiological condition in Pacific halibut.

    d) **Discard Mortality Rates (DMRs) and Survival**. Studies are aimed at providing updated estimates of DMRs in both the longline and the trawl fisheries.

    e) **Genetics and Genomics**. Studies are aimed at describing the genetic structure of the Pacific halibut population and at providing the means to investigate rapid adaptive changes in response to fishery-dependent and fishery-independent influences.

47. The SRB **NOTED** that progress had been made to complete research in each of the five main research areas (Migration and Distribution, Reproduction, Growth and Physiological Condition, Discard Mortality rates (DMRs) and Survival), and Genetics and Genomics. Indeed, during the intersessional period, a number of manuscripts had been drafted and published in the peer review literature. The SRB views peer review and publication in the scientific literature as a fundamental indicator of acceptance of the Secretariat's research agenda and a prerequisite to incorporation into the IPHC SA and MSE programs.

8. PACIFIC HALIBUT FISHERY ECONOMICS UPDATE

48. The SRB **NOTED** paper IPHC-2021-SRB018-09 which provided an update on the IPHC economic study, including progress on developing the economic impact assessment model, state of the collection of primary economic data from Pacific halibut dependent sectors, and most recent results on regional and community economic impacts.

49. **NOTING** the considerable effort that has gone into the development of the economic model, especially given the challenging circumstance under which the project began, the SRB **AGREED** that an economic impacts study provides considerable value and leverage to stakeholders in establishing the importance of the Pacific halibut resource and fisheries to their respective communities, both locally, regionally, and internationally.

50. The SRB **NOTED** improving the accuracy of the economic impact assessment of the Pacific halibut resource depends on broader stakeholders' active participation in developing the necessary data for analysis and **ENCOURAGED** additional outreach activities.
51. The SRB **NOTED** that an external peer review of the economic study would be useful given the lack of economics expertise on the SRB and the importance of having a robust, well-vetted economic impact analysis.
52. The SRB **NOTED** that, without a clearer understanding of the Commissions purpose for future use of this work, it is difficult to provide guidance on prioritising model development (e.g. improve spatial resolution, incorporate dynamic / predictive processes, adding more detail on subsistence and recreational fisheries, including uncertainty in the assessment). The SRB therefore **REQUESTED** specific guidance and clarification from the Commission on the objectives and intended use of this study.
53. The SRB **AGREED** that there is potential value in introducing socioeconomic performance metrics to the MSE framework, though there may be alternative methods to accomplish this specific task.

9. INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH (2021-26)

54. The SRB **NOTED** paper IPHC-2021-SRB018-10 which provided the SRB with the current draft of the new IPHC 5-year program of integrated science and research (the Plan).
55. The SRB **NOTED** and appreciates that the Plan prioritises integration across the core research areas, which has been a recurring recommendation of the SRB.
56. The SRB **AGREED** to be available intersessionally to provide feedback and advice as the plan continues to develop.
57. The SRB **REQUESTED** that the forward-looking document on future integrated science and research priorities (IPHC-2021-SRB018-10) incorporate the following elements:
    a) Previous research priorities of stock assessment;
    b) How the Biological Division of the IPHC prioritized their research agenda in the previous 5-year plan to produce data to meet stock assessment needs;
    c) Introspective assessment of the success of the previous 5-year plan;
    d) Changing/New needs for stock assessment and MSE;
    e) Direction of new 5-year plan to continue unfinished objectives of the previous 5-yr plan and justification for goals and objectives of the proposed 5-year plan.
58. The SRB **REQUESTED** that Measures of Success (sub-section 5 of IPHC-2021-SRB018-10) be cast in metrics of quantifiable improvements to MSE and SA performance, particularly subsections 5.1 and 5.2.
59. The SRB **REQUESTED** that the Secretariat provide explicit statements of the direction of external funding grant requests and the justification based on MSE and SA needs. For example:
    a) What is the IPHC contributing to the Biological and Ecosystem Science Branch budget?
    b) What is needed in terms of additional resources and personnel and in which areas to support the proposed direction stated in the next 5-year plan?
    c) What are the grant priorities, what are the targeted granting agencies, who will be tasked to write the grants, what intellectual resources are needed to be successful (i.e. research agency or academic partners with desired technical and/or analytical skills)?
    d) Where could the SA and MSE analytical staff provide analytical support to the Biological Sciences section?

10. Review of the draft and adoption of the report of the 18th Session of the IPHC Scientific Review Board (SRB018)

60. The report of the 18th Session of the IPHC Scientific Review Board (IPHC-2021-SRB018-R) was **ADOPTED** on 17 June 2021, including the consolidated set of recommendations and/or requests arising from SRB018, provided at Appendix IV.

APPENDIX I
LIST OF PARTICIPANTS FOR THE 18TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

SRB Members

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APPENDIX II
AGENDA FOR THE 18TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

Date: 15-17 June 2021
Location: Electronic Meeting
Venue: Adobe Connect
Time: 12:00-17:00 (15th), 09:00-17:00 (16-17th)
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 17th Session of the SRB (SRB017) (D. Wilson)

3.3. Outcomes of the 97th Session of the IPHC Annual Meeting (AM097) (D. Wilson)

3.4. Observer updates (Science Advisors)

4. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS)

4.1. 2022-24 FISS design evaluation (R. Webster)

5. PACIFIC HALIBUT STOCK ASSESSMENT: 2021

5.1. Modelling updates (I. Stewart)

6. MANAGEMENT STRATEGY EVALUATION: UPDATE

6.1. A summary of the MSE outcomes to date (A. Hicks)

6.2. IPHC Secretariat MSE Program of Work (2021-23) (A. Hicks)

7. BIOLOGICAL AND ECOSYSTEM SCIENCES RESEARCH

7.1. IPHC 5-Year biological and ecosystem science research plan (2017-21) (J. Planas)

7.2. Progress on ongoing research projects (J. Planas)

8. PACIFIC HALIBUT FISHERY ECONOMICS UPDATE

9. INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH (2021-26)

10. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 18TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

APPENDIX III
LIST OF DOCUMENTS FOR THE 18TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

Document	Title	Availability
IPHC-2021-SRB018-01	Agenda & Schedule for the 18th Session of the Scientific Review Board (SRB018)	✓ 29 Mar 2021
IPHC-2021-SRB018-02	List of Documents for the 18th Session of the Scientific Review Board (SRB018)	✓ 29 Mar 2021 ✓ 15 May 2021 ✓ 15 June 2021
IPHC-2021-SRB018-03	Update on the actions arising from the 17th Session of the SRB (SRB017) (IPHC Secretariat)	✓ 11 May 2021
IPHC-2021-SRB018-04	Outcomes of the 97th Session of the IPHC Annual Meeting (AM097) (D. Wilson)	✓ 10 May 2021
IPHC-2021-SRB018-05 Rev_1	2022-24 FISS Design evaluation (R. Webster)	✓ 15 May 2021 ✓ 15 June 2021
IPHC-2021-SRB018-06	2021 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: Development (I. Stewart & A. Hicks)	✓ 10 May 2021
IPHC-2021-SRB018-07	An update on the IPHC Management Strategy Evaluation (MSE) process for SRB018 (A. Hicks & I. Stewart)	✓ 11 May 2021
IPHC-2021-SRB018-08	Report on current and future biological and ecosystem science research activities (J. Planas)	✓ 12 May 2021
IPHC-2021-SRB018-09	Pacific Halibut Multiregional Economic Impact Assessment (PHMEIA): update for SRB018 (B. Hutniczak)	✓ 11 May 2021
IPHC-2021-SRB018-10	International Pacific Halibut Commission 5-Year program of integrated science and research (2021-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, B. Hutniczak)	✓ 14 May 2021
Information papers		
Nil to-date	Nil to-date	

APPENDIX IV

CONSOLIDATED SET OF RECOMMENDATIONS AND REQUESTS OF THE 18TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

RECOMMENDATIONS

(para. 4) ***NOTING*** *that the core purpose of the SRB018 is to review progress on the IPHC science program, and to provide guidance for the delivery of products to the SRB019 in September 2021, the SRB* ***RECALLED*** *that formal recommendations to the Commission would not be developed at the present meeting, but rather, these would be developed at the SRB019.*

REQUESTS

IPHC Fishery-independent setline survey (FISS): 2022-24 FISS design evaluation

SRB018–Req.1 (para. 13) The SRB **REQUESTED** plots by survey area of WPUE vs. depth from both FISS and commercial fisheries to help understand if there is part of the Pacific halibut stock in deeper waters not covered by the FISS.

SRB018–Req.2 (para. 14) The SRB **REQUESTED** that the IPHC Secretariat conduct a preliminary comparison, to be presented at SRB020, between male, female, and sex-aggregated analysis of the FISS data using the spatial-temporal model.

SRB018–Req.3 (para. 15) The SRB **REQUESTED** that the shiny-tool to investigate data and model outputs for the FISS be made available to the SRB by SRB019.

Pacific halibut stock assessment: 2021

SRB018–Req.4 (para. 24) The SRB **REQUESTED** an analysis of annual surplus production and the fraction of that production harvested.

Management Strategy Evaluation: update

SRB018–Req.5 (para. 30) The SRB **REQUESTED** that the IPHC Secretariat present a revised system diagram of the MSE, showing components of variability and their implementation within MSE.

SRB018–Req.6 (para. 32) The SRB **REQUESTED** that the Secretariat review potential indicators for use in defining ECs.

SRB018–Req.7 (para. 36) The SRB **REQUESTED** that the IPHC Secretariat prioritize tasks for the MSE Program of Work that lead to adoption of a well-defined management procedure, taking into account interdependencies among tasks and presenting tasks as linked sets.

Biological and ecosystem sciences research

SRB018–Req.8 (para. 39) The SRB **REQUESTED** that the IPHC Secretariat focus future reproductive biology studies on the development of updated regulatory area-specific maturity ogives (schedules of percent maturity by age).

SRB018–Req.9 (para. 40) The SRB **REQUESTED** that the IPHC Secretariat provide information on the age distribution of all females collected to characterize reproductive development throughout the annual cycle in order to refine efforts to identify potential skip-spawning females.

SRB018–Req.10 (para. 41) The SRB **REQUESTED** that planned studies on fecundity assessment are prioritized and that the sampling design be developed in coordination with the SA to ensure that the results are as informative as possible for assessment purposes. Effective sample stratification along age, weight and length gradients that maximise the contrast in the effect of these variables will be key to precise estimates of fecundity. Oocyte diameter in contrast may be a important covariate to provide but cannot be used in stratification. The primary goal of the fecundity research should be to estimate the exponent of the fecundity vs. weight relationship for incorporation in the SA.

SRB018–Req.11 (para. 42) The SRB **NOTED** that growth marker genes identified in transcriptomic profiling studies can be informative in future genome scans. However, the SRB **REQUESTED** that the Secretariat explicitly describe how the gene regions identified as 'over' or 'under' expressed would be used. For example, research has yet to determine mechanisms for transcriptional differences other than there is over- or under-representation of mRNA transcripts associated with different treatment groups (e.g. warm vs. cool water) from a heterogeneous set of individuals collected from a single location. The Secretariat has not yet established that results can be generalized to other regions in the species range. Neither has the transcriptional patterns been generalized to individuals of different size/age. These questions should be investigated.

SRB018–Req.12 (para. 43) The SRB **REQUESTED** that the Secretariat use these gene regions and align sequences to the whole genome sequence data. Specifically, the Secretariat should investigate whether there is sequence variability within gene coding regions or in regions around gene coding regions that may be transcriptional modifiers (e.g. promoters). If genetic variation exists in or near these genes, these variable base pair position(s) (i.e. single nucleotide polymorphisms or SNPs) should be incorporated in other aspects of the Secretariat research; for example for research activities under the Migration and Population Dynamics Research area.

SRB018–Req.13 (para. 44) The SRB **REQUESTED** that the analysis of seasonal patterns in gonad development be explicitly tied to the development/improvement of the maturity ogive (the vector of proportion mature at age that SA requires).

Pacific halibut fishery economics update

SRB018–Req.14 (para. 52) The SRB **NOTED** that, without a clearer understanding of the Commissions purpose for future use of this work, it is difficult to provide guidance on prioritising model development (e.g. improve spatial resolution, incorporate dynamic / predictive processes, adding more detail on subsistence and recreational fisheries, including uncertainty in the assessment). The SRB therefore **REQUESTED** specific guidance and clarification from the Commission on the objectives and intended use of this study.

International Pacific Halibut Commission 5-year program of integrated science and research (2021-26)

SRB018–Req.15 (para. 57) The SRB **REQUESTED** that the forward-looking document on future integrated science and research priorities (IPHC-2021-SRB018-10) incorporate the following elements:

f) Previous research priorities of stock assessment;

g) How the Biological Division of the IPHC prioritized their research agenda in the previous 5-year plan to produce data to meet stock assessment needs;

h) Introspective assessment of the success of the previous 5-year plan;

i) Changing/New needs for stock assessment and MSE;

j) Direction of new 5-year plan to continue unfinished objectives of the previous 5-yr plan and justification for goals and objectives of the proposed 5-year plan.

SRB018–Req.16 (para. 58) The SRB **REQUESTED** that Measures of Success (sub-section 5 of IPHC-2021-SRB018-10) be cast in metrics of quantifiable improvements to MSE and SA performance, particularly subsections 5.1 and 5.2.

SRB018–Req.17 (para. 59) The SRB **REQUESTED** that the Secretariat provide explicit statements of the direction of external funding grant requests and the justification based on MSE and SA needs. For example:

e) What is the IPHC contributing to the Biological and Ecosystem Science Branch budget?

f) What is needed in terms of additional resources and personnel and in which areas to support the proposed direction stated in the next 5-year plan?

g) What are the grant priorities, what are the targeted granting agencies, who will be tasked to write the grants, what intellectual resources are needed to be successful (i.e. research agency or academic partners with desired technical and/or analytical skills)?

h) Where could the SA and MSE analytical staff provide analytical support to the Biological Sciences section?

<u>PROVISIONAL</u>: AGENDA & SCHEDULE FOR THE 18th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

Date: 15-17 June 2021
Location: Electronic Meeting
Venue: Adobe Connect
Time: 12:00-17:00 (15th), 09:00-17:00 (16-17th)
Chairperson: Dr Sean Cox (Simon Fraser University)
Vice-Chairperson: Nil

1. OPENING OF THE SESSION

2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

- *IPHC-2021-SRB018-01: Agenda & Schedule for the 18th Session of the Scientific Review Board (SRB018)*
- *IPHC-2021-SRB018-02: List of Documents for the 18th Session of the Scientific Review Board (SRB018)*

3. IPHC PROCESS

3.1. SRB annual workflow (D. Wilson)

3.2. Update on the actions arising from the 17th Session of the SRB (SRB017) (D. Wilson)
- *IPHC-2021-SRB018-03: Update on the actions arising from the 17th Session of the SRB (SRB017) (IPHC Secretariat)*

3.3. Outcomes of the 97th Session of the IPHC Annual Meeting (AM097) (D. Wilson)
- *IPHC-2021-SRB018-04: Outcomes of the 97th Session of the IPHC Annual Meeting (AM097) (D. Wilson)*

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

4. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS)

4.1. 2022-24 FISS design evaluation (R. Webster)
- *IPHC-2021-SRB018-05: 2022-24 FISS Design evaluation (R. Webster)*

5. PACIFIC HALIBUT STOCK ASSESSMENT: 2021

5.1. Modelling updates (I. Stewart)
- *IPHC-2021-SRB018-06: 2021 Pacific halibut (<u>Hippoglossus</u> <u>stenolepis</u>) stock assessment: Development (I. Stewart & A. Hicks)*

6. MANAGEMENT STRATEGY EVALUATION: UPDATE

- *IPHC-2021-SRB017-07: An update on the IPHC Management Strategy Evaluation (MSE) process for SRB018 (A. Hicks & I. Stewart)*

6.1. A summary of the MSE outcomes to date (A. Hicks)

6.2. IPHC Secretariat MSE Program of Work (2021-23) (A. Hicks)

7. BIOLOGICAL AND ECOSYSTEM SCIENCES RESEARCH

- *IPHC-2021-SRB018-08: Report on current and future biological research activities (J. Planas)*

7.1. IPHC 5-Year biological and ecosystem science research plan (2017-21) (J. Planas)
7.2. Progress on ongoing research projects (J. Planas)

8. PACIFIC HALIBUT FISHERY ECONOMICS UPDATE

- *IPHC-2021-SRB018-09: Pacific Halibut Multiregional Economic Impact Assessment (PHMEIA): summary of progress (B. Hutniczak)*

9. INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH (2021-26)

- *IPHC-2021-SRB018-10: International Pacific Halibut Commission 5-Year program of integrated science and research (2021-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, B. Hutniczak, & L. Erikson)*

10. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 18TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

PROVISIONAL: SCHEDULE FOR THE 18th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

Tuesday, 15 June 2021

Time	Agenda item	Lead
12:00-12:30	Adobe Connect - Participants encouraged to call in and test connection early	
12:30-12:45	1. OPENING OF THE SESSION 2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION	S. Cox & D. Wilson
12:45-13:30	3. IPHC PROCESS 3.1 SRB annual workflow (D. Wilson) 3.2 Update on the actions arising from the 17th Session of the SRB (SRB017) 3.3 Outcomes of the 97th Session of the IPHC Annual Meeting (AM097) 3.4 Observer updates (e.g. Science Advisors)	D. Wilson
13:30-14:45	4. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS) 4.1 2022-24 FISS design evaluation	R. Webster
14:45-15:30	5. PACIFIC HALIBUT STOCK ASSESSMENT: 2021 5.1 Modelling updates	I. Stewart
15:30-15:45	Break	
15:45-16:30	5. PACIFIC HALIBUT STOCK ASSESSMENT: 2020 (cont.)	I. Stewart
16:30-17:00	SRB drafting session	SRB members

Wednesday, 16 June 2021

Time	Agenda item	Lead
09:00-10:00	Review of Day 1 and discussion of SRB Recommendations from Day 1	Chairperson
10:00-10:30	6. MANAGEMENT STRATEGY EVALUATION: UPDATE 6.1 A summary of the MSE outcomes to date 6.2 IPHC Secretariat MSE Program of Work (2021-23)	A. Hicks

10:30-10:45	Break	
10:45-11:45	6. (Cont.) MANAGEMENT STRATEGY EVALUATION: UPDATE	A. Hicks
11:45-12:30	7. BIOLOGICAL AND ECOSYSTEM SCIENCES RESEARCH 7.1 IPHC 5-Year biological and ecosystem science research plan (2017-21) 7.2 Progress on ongoing research projects	J. Planas
12:30-13:30	Lunch	
13:30-14:30	7. BIOLOGICAL AND ECOSYSTEM SCIENCES REARCH (Cont.)	
14:40-15:30	8. PACIFIC HALIBUT FISHERY ECONOMICS UPDATE	B. Hutniczak
15:30-15:45	Break	
15:45-17:00	SRB drafting session	SRB members
Thursday, 17 June 2021		
Time	**Agenda item**	**Lead**
09:00-10:00	Review of Day 2 and discussion of SRB Recommendations from Day 2	Chairperson
10:00-12:30	9. INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH (2021-26)	D. Wilson et al.
12:30-13:30	Lunch	
13:30-14:30	SRB drafting session	SRB members
14:30-17:00	10. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 18th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)	S. Cox

LIST OF DOCUMENTS FOR THE 18th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB018)

Document	Title	Availability
IPHC-2021-SRB018-01	Agenda & Schedule for the 18th Session of the Scientific Review Board (SRB018)	✓ 29 Mar 2021
IPHC-2021-SRB018-02	List of Documents for the 18th Session of the Scientific Review Board (SRB018)	✓ 29 Mar 2021 ✓ 15 May 2021 ✓ 15 June 2021
IPHC-2021-SRB018-03	Update on the actions arising from the 17th Session of the SRB (SRB017) (IPHC Secretariat)	✓ 11 May 2021
IPHC-2021-SRB018-04	Outcomes of the 97th Session of the IPHC Annual Meeting (AM097) (D. Wilson)	✓ 10 May 2021
IPHC-2021-SRB018-05 Rev_1	2022-24 FISS Design evaluation (R. Webster)	✓ 15 May 2021 ✓ 15 June 2021
IPHC-2021-SRB018-06	2021 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: Development (I. Stewart & A. Hicks)	✓ 10 May 2021
IPHC-2021-SRB018-07	An update on the IPHC Management Strategy Evaluation (MSE) process for SRB018 (A. Hicks & I. Stewart)	✓ 11 May 2021
IPHC-2021-SRB018-08	Report on current and future biological and ecosystem science research activities (J. Planas)	✓ 12 May 2021
IPHC-2021-SRB018-09	Pacific Halibut Multiregional Economic Impact Assessment (PHMEIA): update for SRB018 (B. Hutniczak)	✓ 11 May 2021
IPHC-2021-SRB018-10	International Pacific Halibut Commission 5-Year program of integrated science and research (2021-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, B. Hutniczak, & L. Erikson)	✓ 14 May 2021
Information papers		
Nil to-date	Nil to-date	

UPDATE ON THE ACTIONS ARISING FROM THE 17TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB017)

PREPARED BY: IPHC SECRETARIAT (11 MAY 2021)

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 SRB017.

BACKGROUND

At the SRB017, the members recommended/requested a series of actions to be taken by the IPHC Secretariat, as detailed in the SRB017 meeting report (IPHC-2020-SRB017-R) available from the IPHC website, and as provided in Appendix A.

DISCUSSION

During the 18th Session of the SRB (SRB018), efforts will be made to ensure that any recommendations/requests for action are carefully constructed so that each contains the following elements:

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

RECOMMENDATION/S

That the SRB:

1) **NOTE** paper IPHC-2021-SRB018-03, 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 (SRB017).
2) **AGREE** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB018.

APPENDICES

Appendix A: Update on actions arising from the 17th Session of the IPHC Scientific Review Board (SRB017)

APPENDIX A
Update on actions arising from the 17th Session of the IPHC Scientific Review Board (SRB017)

RECOMMENDATIONS

Action No.	Description	Update
SRB017–Rec.01 (para. 14)	***IPHC Fishery-independent setline survey (FISS)*** The SRB **RECOMMENDED** that the Commission endorse the final 2021 FISS design as proposed by IPHC Secretariat, and provided at Appendix IVa.	**Completed**: Endorsed at SS09: IPHC-2020-ID016 (para. 8)
SRB017–Rec.02 (para. 31)	***Biological and ecosystem science program research updates*** **NOTING** the improved presentation of the research integration plan, the SRB **RECOMMENDED** that the research planning table shown in the meeting presentation for paper IPHC-2020-SRB017-08, be improved by adding clear prioritization of biological research needs for addressing uncertainties in the stock assessment and MSE programs. Ideally, this would be in the form of ranked biological uncertainties/parameters for the stock assessment and MSE operating model along with an explanation for deviations from this ranked list.	**Completed**: See papers IPHC-2021-SRB018-10 and 08
SRB017–Rec.03 (para. 49)	***Genetics and Genomics*** **NOTING** IPHC Secretariat responses to SRB016-Req. 15 that requested additional methodological detail pertaining to ongoing genomics research, the SRB **RECOMMENDED** that the IPHC Secretariat work with collectors to develop a series of benchmark summary statistics that characterize the quality of the Pacific halibut genome developed.	**Completed**: See paper IPHC-2021-SRB018-08
SRB017–Rec.04 (para. 53)	***Research integration*** The SRB **RECOMMENDED** that the IPHC Secretariat incorporate prioritization of research activities, as well as the timeline of available research outputs as inputs into the stock assessment and MSE processes.	**Completed**: See paper IPHC-2021-SRB018-10
SRB017–Rec.05 (para. 54)	The SRB **RECOMMENDED** that the IPHC Secretariat identify those research areas with uncertainty and indicate research questions that would require the SRB to provide input and/or decision in future documentation and presentations provided to the SRB.	**Completed**: See papers IPHC-2021-SRB018-10 and 08

Action No.	Description	Update
SRB017–Rec.06 (para. 57)	***Management Strategy Evaluation*** The SRB **NOTED** three options for estimation error are available and currently the option of simulating estimation is the most appropriate option to evaluate results in 2020, but **RECOMMENDED** continuing work to incorporate actual estimation models, as in the third option, because that method would best mimic the current assessment process.	**Pending**: See paper IPHC-2021-SRB018-07, Section 3.1.5 for a detailed description of the ongoing investigations of a suitable estimation model.
SRB017–Rec.07 (para. 59)	The SRB **RECOMMENDED** using the current MSE results to compare and contrast management procedures incorporating scale and distribution elements, but **NOTED** that, current results are conditional on some parameters and processes that remain uncertain. The uncertainty in applying the untested current approach potentially creates greater risk than adopting a repeatable management procedure that has been simulation tested under a wide range of uncertainties.	**Completed**: See paper IPHC-2021-SRB018-07, Section 3.1.6 stating that this was communicated to the Commission.
SRB017–Rec.08 (para. 60)	The SRB **RECOMMENDED** that Exceptional Circumstances be defined to determine whether monitoring information has potentially departed from their expected distributions generated by the MSE. Declaration of Exceptional Circumstances may warrant re-opening and revising the operating models and testing procedures used to justify a particular management procedure.	**Pending**: See paper IPHC-2021-SRB018-07, Section 3.1.7 for a listing of topics for exceptional circumstances that will be discussed with the Commission in the near future.

REQUESTS

Action No.	Description	Update
SRB017–Req.01 (para. 16)	***IPHC Fishery-independent setline survey (FISS)*** The SRB **REQUESTED** clarification of the FISS design workflow and timeline to make it clear that when FISS design proposals are presented to the SRB, the current year's FISS data will not be available, and therefore evaluation of design proposals for the subsequent three years will be based on past years' data only.	**Completed**: See paper IPHC-2021-SRB018-05
SRB017–Req.02 (para. 17)	The SRB **REQUESTED** that at SRB018, the IPHC Secretariat present information on changes in space-time model parameters and output over time:	**Completed**:

Action No.	Description	Update
	a) covariate parameter estimates over several years should be provided in order to assess their sensitivity to the addition of each year's new data; b) comparison maps of estimates of WPUE or NPUE at each FISS station for the same calendar year based on models fitted in different years to determine how station estimates are affected by the addition of new data; c) estimates of the relative contributions of covariates vs. spatio-temporal interpolations in predictions at unsampled locations.	See paper IPHC-2021-SRB018-05 and accompanying presentation
SRB017–Req.03 (para. 18)	The SRB **REQUESTED** that the IPHC Secretariat present at SRB018, a review of the methods used for adjusting WPUE and NPUE indices for the effects of hook competition in the FISS, given the SRB's interest in the following: a) the potential benefits of further analysis and/or hook timer experiments to better inform bait mortality rates used in FISS hook competition adjustments; b) an evaluation of hook competition incorporated into the space-time model to account for potential spatio-temporal patterns in hook competition and linking the hook competition adjustment to covariates of competitor (e.g. dogfish) abundance; c) a quantitative evaluation of the assumptions that the same hook competition adjustment factor can be applied to both NPUE and WPUE, as well as uniformly across regions, because the biomass to numbers (i.e. the mean weight) apparently changes over time.	**Pending**: To be presented at SRB019
SRB017–Req.04 (para. 21)	***Pacific halibut stock assessment: 2020*** The SRB **REQUESTED** that the IPHC Secretariat continue to update data weighting on an annual basis, even for updated stock assessments (such as 2020), in order to maintain internal model consistency and to best reflect changes in existing and new data as they arise.	**Completed**: See paper IPHC-2021-SRB018-06
SRB017–Req.05	The SRB **REQUESTED** that the IPHC Secretariat first investigate the consequences of implementing a logistic-normal likelihood for composition data	**Pending**:

Action No.	Description	Update
(para. 23)	assuming no correlation structure. This would provide an initial estimate of the benefits of self-weighting fairly quickly compared to developing a full age/sex correlated version.	See paper IPHC-2021-SRB018-06
SRB017–Req.06 (para. 24)	The SRB **REQUESTED** that the IPHC Secretariat continue to evaluate whether the Stock Synthesis modelling framework is the most efficient for Commission needs, and to coordinate future development with the MSE framework as features and technical needs evolve together for the two efforts.	**Completed**: See paper IPHC-2021-SRB018-06
SRB017–Req.07 (para. 33)	***Biological and ecosystem science program research updates*** The SRB **REQUESTED** that the IPHC Secretariat further develop planning for the remainder of the current 5-year planning period and to revise and submit a comparable synthesis planning document for review at SRB018. In terms of the current research activities and research outcomes, further detail is needed in several areas, including: a) further detail for (i) specific research outcomes, (ii) specific relevance for stock assessment relevance, (iii) specific relevance for MSE (see Section 8.1 for examples); b) prioritize research activities and research outcomes.	**Completed**: See paper IPHC-2021-SRB018-08
SRB017–Req.08 (para. 34)	**NOTING** that a time line was presented by the IPHC Secretariat that provided information on likely periods in future years when research outcomes would be available for use by the Secretariat, the SRB **REQUESTED** further clarification on funding and staffing needs required to meet self-imposed deadlines.	**Completed**: See paper IPHC-2021-SRB018-08
SRB017–Req.09 (para. 37)	The SRB **REQUESTED** that the IPHC Secretariat include explicit statements describing how research activities and research outcomes for each of the five IPHC research areas have relevance to stock assessment and the MSE in all future SRB meeting briefing documents beginning with SRB018.	**Completed**: See papers IPHC-2021-SRB018-10 and 08, as well as 06 and 07.
SRB017–Req.10 (para. 43)	***Reproduction*** The SRB **REQUESTED** that the Secretariat should clarify how skip-spawning research contributes to stock	**Completed**: See papers IPHC-2021-SRB018-06 and 08

Action No.	Description	Update
	assessment and MSE functions. In particular, future research should develop and present: i. models for forecasting or estimating skip-spawning for Pacific halibut taking into account the timing of the sample collection, size / age and potentially condition factor of females; ii. estimates of the potential impact of skip-spawning scenarios on management procedure performance; iii. clear plans for analyses of histological data, including incorporation of age variation and locational variation; iv. details of experimental and sampling designs, as well as expected analyses for "measures of fecundity"	
SRB017–Req.11 (para. 44)	***Growth and Physiological Condition*** The SRB **NOTED** ongoing studies aimed at describing the role of some of the factors responsible for the observed changes in size-at-age and to provide tools for measuring growth and physiological condition in Pacific halibut. Studies in this research area would benefit from greater integration with the genomics area. The SRB **REQUESTED** that the Secretariat provide a plan for integration of research outcomes in this research area with outcomes in the genetics and genomics research area.	**Completed**: See paper IPHC-2021-SRB018-10
SRB017–Req.12 (para. 47)	***Discard Mortality Rates (DMRs) and Survival*** The SRB **REQUESTED** that IPHC Secretariat provide the grant proposal funding the DMR work, and provide a more detailed presentation at SRB018.	**Completed**: See paper IPHC-2021-SRB018-08
SRB017–Req.13 (para. 51)	***Genetics and Genomics*** **NOTING** SRB016-Req. 18 was addressed and that the Pacific halibut genome has been annotated, the SRB **REQUESTED** that the IPHC Secretariat prepare a research plan for describing and justifying how the knowledge (and all the resources expended in getting it) of the genome will be used to inform SA and MSE information needs (i.e. as per above request to further elaborate the research plan for this research area). This will likely require some form of interaction (e.g. collaborations, workshops) with outside researchers and/or agencies.	**Completed**: See papers IPHC-2021-SRB018-10 and 08

Action No.	Description	Update
SRB017–Req.14 (para. 61)	***Management Strategy Evaluation*** The SRB **REQUESTED** that the IPHC Secretariat include plotting function in the MSE Explorer to visualize among-Regulatory Area trade-offs in various yield statistics.	**Completed**: See paper IPHC-2021-SRB018-07 and the MSE Explorer webpage

INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC-2021-SRB018-04

OUTCOMES OF THE 97TH SESSION OF THE IPHC ANNUAL MEETING (AM097)

PREPARED BY: IPHC SECRETARIAT (D. WILSON, 10 MAY 2021)

PURPOSE

To provide the SRB with the outcomes of the 97th Session of the IPHC Annual Meeting (AM097) relevant to the mandate of the SRB.

BACKGROUND

The agenda of the Commission's Annual Meeting (AM097) included several agenda items relevant to the SRB:

5. STOCK STATUS OF PACIFIC HALIBUT (2020) & HARVEST DECISION TABLE (2021)
   - 5.1 IPHC Fishery-Independent Setline Survey (FISS) (2020) (L. Erikson)
   - 5.2 Space-time modelling of survey data and FISS designs for 2021-23 (R. Webster)
   - 5.3 Stock Assessment: Data overview and stock assessment (2020), and harvest decision table (2021) (I. Stewart)
   - 5.4 Pacific halibut mortality projections using the IPHC mortality projection tool (2021) (I. Stewart)
   - 5.5 Size limit review (I. Stewart)

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

7. REPORT OF THE 21st SESSION OF THE IPHC RESEARCH ADVISORY BOARD (RAB020) (J. Planas)

8. REPORTS OF THE IPHC SCIENTIFIC REVIEW BOARD (S. Cox)

9. MANAGEMENT STRATEGY EVALUATION
   - 9.1 IPHC Management Strategy Evaluation: update (A. Hicks)
   - 9.2 Reports of the IPHC Management Strategy Advisory Board (A. Kaiser, R. Baker)

6. STOCK STATUS OF PACIFIC HALIBUT (2019) & HARVEST DECISION TABLE (2020)
   6.1 IPHC Fishery-Independent Setline Survey (FISS) design and implementation in 2019
   6.2 Space-time modelling of IPHC Fishery-Independent Setline Survey (FISS) data
   6.3 Stock Assessment: Independent peer review of the Pacific halibut stock assessment
   6.4 Stock Assessment: Data overview and stock assessment (2019), and harvest decision table (2020)
   6.5 Pacific halibut mortality projections using the IPHC mortality projection tool

7. IPHC 5-YEAR RESEARCH PROGRAM
   7.1 IPHC 5-year Biological & Ecosystem Science Research Plan: update

8. REPORT OF THE 20TH SESSION OF THE IPHC RESEARCH ADVISORY BOARD (RAB020)

9. REPORTS OF THE 14th AND 15TH SESSIONS OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB014; SRB015)

10. MANAGEMENT STRATEGY EVALUATION
   10.1 IPHC Management Strategy Evaluation: update
   10.2 Reports of the 13th and 14th Sessions of the IPHC Management Strategy Advisory Board (MSAB013; MSAB014)

DISCUSSION

During the course of the 97th Session of the IPHC Annual Meeting (AM097) 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-2021-SRB018-04 which details the outcomes of the 97th Session of the IPHC Annual Meeting (AM097) relevant to the mandate of the SRB.

APPENDICES

Appendix A: Excerpts from the 97th Session of the IPHC Annual Meeting (AM097) Report (IPHC-2021-AM097-R).

APPENDIX A
Excerpt from the 97th Session of the IPHC Annual Meeting (AM097) Report (IPHC-2021-AM097-R)

RECOMMENDATIONS

Nil.

REQUESTS

Management Strategy Evaluation

*AM097–Req.02 (para. 70) The Commission **REQUESTED** that the IPHC Secretariat consider and develop a draft MSE Program of Work for review by the Commission. The MSE Program of Work should describe technical versus policy-oriented issues, linkages between/among specific work products, and sequencing considerations between/among items. The MSE Program of Work should describe the resources required to complete items.*

Pacific halibut fishery economics update

*AM097–Req.04 (para. 94) The Commission **REQUESTED** that the IPHC Secretariat develop and distribute a Media Release on the Fishery economic project and the associated economic survey for industry to complete.*

2022-24 FISS design evaluation

PREPARED BY: IPHC SECRETARIAT (R. A. WEBSTER; 15 MAY, 15 JUNE 2021)

PURPOSE

To present the proposed designs for the IPHC's Fishery-Independent Setline Survey (FISS) for the 2022-24 period, and an evaluation of those designs, for review by the Scientific Review Board.

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) trawl survey (Webster et al. 2020).

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 within 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 fishing longline gear in shallower waters.) A second expansion in IPHC Regulatory Area 2A was completed in 2013, with a pilot California survey between latitudes of 40-42°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) 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 2022-24. Note that in the Bering Sea, the full FISS design does not provide complete spatial coverage, and FISS data are augmented with calibrated data from National Marine Fisheries Service (NMFS) and Alaska Department of Fish and Game (ADFG) trawl surveys (stations can vary by year – 2019 designs are shown in Figure 1). Both of these supplementary surveys are conducted approximately annually.

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 of 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 were recently published in a peer-review journal (Webster et al. 2020). Similar geostatistical models are now routinely used to standardise 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 R.

FISS design objectives

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 a rationalised 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. Potential considerations that could add to or modify the design are logistics and cost (secondary design layer), and FISS removals (impact on the stock), data collection assistance for other agencies, and IPHC policies (tertiary design layer). These priorities are outlined in Table 1.

Table 1. Prioritization of FISS objectives and corresponding design layers.

Priority	Objective	Design Layer
Primary	Sample Pacific halibut for stock assessment and stock distribution estimation	Minimum sampling requirements in terms of: • Station distribution • Station count • Skates per station
Secondary	Long term revenue neutrality	Logistics and cost: operational feasibility and cost/revenue neutrality
Tertiary	Minimize removals, and assist others where feasible on a cost-recovery basis.	Removals: minimize impact on the stock while meeting primary priority Assist: assist others to collect data on a cost-recovery basis IPHC policies: ad-hoc decisions of the Commission regarding the FISS design

Review process

Since completion of the FISS expansions, a review process has been developed for annual FISS designs created according the above objectives:

- The Secretariat presents design proposals to the SRB for three subsequent years at the June meeting (recognizing that data from the current summer FISS will not be available for analysis prior to the September SRB meeting).
- The first review of design proposals by Commissioners will occur at the September work meeting, revised if necessary based on June SRB input;
- Presentation of proposed designs for 'endorsement' occurs at the November Interim Meeting;
- Ad-Hoc modifications possible at the Annual Meeting to the design for the current year (due to unforeseen issues arising);
- Endorsed design for current year modified for cost and logistical reasons prior to summer implementation in FISS (February-April).

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

Note that while the review process examines designs for the next three years, revisions to designs for the second and third years are possible during subsequent review periods. Having design proposals available for three years instead of the next year only assists the IPHC with medium-term planning of the FISS, and allows reviewers (SRB, IPHC Commissioners) and stakeholders to more clearly see the planning process for sampling the entire FISS footprint over multiple years. Extending the proposed designs beyond three years was not considered worthwhile, as we expect further evaluation undertaken following collection of data during the one to three-year time period to influence design choices for subsequent years.

PROPOSED DESIGNS FOR 2022-24

The designs proposed for 2022-24 (Figures 2 to 4) use efficient subarea sampling in IPHC Regulatory Areas 2A, 4A and 4B, and incorporate a randomized subsampling of FISS stations in IPHC Regulatory Areas 2B, 2C, 3A and 3B (except for the near-zero catch rate inside waters around Vancouver Island), with a sampling rate chosen to keep the sample size close to 1000 stations in an average year. This was also used to generate the designs originally proposed for 2020 (but modified as a result of the impact of COVID19 and cost considerations), and for those proposed and approved for 2021. In 2020, designs for 2022-23 were also approved subject to revision. We are proposing one change from that 2022 design, bringing forward by one year (from 2023 to 2022) the sampling of the central and western subareas of IPHC Regulatory Area 4B to reduce the risk of bias in estimates from that area. Thus we propose that:

- In 2022 the lower-density western and central subareas of IPHC Regulatory Area 4B in sampled, followed by the higher-density eastern subarea in 2023-24
- The higher-density western subarea of IPHC Regulatory Area 4A be sampled in all three years, with the medium-density northern shelf edge subarea added in 2023 only
- The highest-density waters of IPHC Regulatory 2A in northern Washington and central/southern Oregon are proposed for sampling in each year of the 2022-24 period
- The near-zero density waters of the Salish Sea in IPHC Regulatory 2B are not proposed for sampling in 2022-24

Following this three-year period, it is expected that the remaining subareas will be included during the subsequent 3-5 years. These include the southeastern subarea of IPHC Regulatory 4A, and lower-density waters of IPHC Regulatory 2A (see below).

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

While the proposed designs continue to rely on randomised subsampling of stations within the core IPHC Regulatory Areas (2B, 2C, 3A and 3B) and logistically efficient subarea designs elsewhere, other designs have been considered and remain as options. A discussion of these, adapted from previous reports, is in Appendix A.

FISS DESIGN EVALUATION

Precision targets

In order to maintain the quality of the estimates used for the assessment, and for estimating stock distribution, the IPHC Secretariat has set a target range of less than 15% for the coefficient of variation (CV) of mean O32 and all sizes WPUE for all IPHC Regulatory Areas. We also established precision targets of IPHC Biological Regions and a coastwide target (IPHC-2020-AM096-07), but achievement of the Regulatory Area targets is expected to ensure that targets for the larger units will also be met.

Reducing the potential for bias

In IPHC Regulatory Areas in which stations are not subsampled randomly (IPHC Regulatory Areas 2A, 4A and 4B in the 2022-24 proposals), sampling a subset of the full data frame in any area or region brings with it the potential for bias. This is due to trends in the unsurveyed portion of a management unit (Regulatory Area or Region) potentially differing from those in the surveyed portion. To reduce the potential for bias, we also looked at how frequently part of an area or region ("subarea") should be surveyed in order to reduce the likelihood of appreciable bias. For this, we proposed a threshold of a 10% absolute change in biomass percentage: how quickly can a subarea's percent of the biomass of a Regulatory Area change by at least 10% (e.g., from 15 to 25% of the area's biomass)? By sampling each subarea frequently enough to reduce the chance of its percentage changing by more than 10% between successive surveys of the subarea, we minimize the potential for appreciable bias in the Regulatory Area's index.

We examined the effect of subsampling the FISS stations for a management unit on precision as follows:

- Where a randomised design is not used, identify logistically efficient subareas within each management unit and select priorities for future sampling
- Generate simulated data for all FISS stations based on the output from the most recent space-time modelling
- Fit space-time models to the observed data series augmented with 1 to 3 additional years of simulated data, where the design over those three years reflects the sampling priorities identified above
- Project precision estimates and quantify bias potential for comparison against threshold

Table 2 shows projected CVs following completion of the proposed 2022-24 FISS designs. With these designs, we are projected to maintain CVs within the target range. Estimates from the terminal year are most informative for management decisions, but they also typically have the largest CVs (all else being equal). The final column in Table 2 shows the CV projections immediately following the 2022 FISS, which are also within the target range.

The projected CV for 2024 for IPHC Regulatory Area 2A is close to exceeding the target, and in future revisions of the 2024 design, we may wish to consider adding stations from southern Washington/northern Oregon, and northern California to the design ("subarea 2" for this Regulatory Area). While historical data show this subarea to be highly stable over time in terms of its biomass proportion, by 2024 it will have been five years since any part of it was last sampled, and with no other lower-density subareas planned for sampling that year in IPHC Regulatory Areas 4A and 4B, this may be a logistically feasible year for fishing those stations. Should estimated CVs increase more rapidly than projected, future designs would be revised accordingly.

Table 2. Projected CVs (%) for 2021-24 for O32 WPUE estimated after completion of the proposed 2022-24 FISS designs, and (final column) after completion of the proposed 2022 FISS design only.

Reg. Area	2021	2022	2023	2024	2022 (Estimated in 2022)
2A	13	13	14	15	14
4A	10	9	9	10	10
4B	10	12	10	12	14

For maintaining low bias, we looked at estimates of historical changes in the proportion of biomass in each subarea, and used that to guide the sampling frequency in future designs. Thus subareas that have historically had rapid changes in biomass proportion need to be sampled most frequently, and those that are relatively stable can be sampled less frequently. For example, if a subarea's % of its Regulatory Area's biomass changed by no more than 8% over 1-2 years but by up to 12% over three years, we should sample it at least every three years based on the 10% criterion discussed above.

Based on estimates from the historical times series (1993-2020) of O32 WPUE, the proposed designs for 2022-24 would be expected to maintain low bias by ensuring that it is unlikely that biomass proportions for all subareas change by more than 10% since they were previously sampled (Table 3).

Table 3. Maximum expected changes (%) in biomass proportion since previous sampling of subareas that are unsampled in a given year, based on estimated the 1993-2020 time series.

Reg. Area	2021	2022	2023	2024
2A	8	9	9	9
4A	8	10	6	6
4B	10	9	8	10

Post-sampling evaluation for 2020

The evaluation of precision of proposed designs above is based on using simulated sample data generated under the fitted space-time model for future years. If observed data are more (or less) variable than those generated under the model, actual estimates of precision may differ from those projected from models making use of the generated data. Table 4 compares the estimates of the CV for mean O32 WPUE for the implemented 2020 design based on using simulated data for 2020 and estimated from fitting the models including observed 2020 data. The projected CVs based on simulated data are essentially the same as those estimated when observed data are used for 2020 for the four IPHC Regulatory Areas sampled in 2020.

Table 4. Comparison of projected and estimated CVs (%) for 2020 by IPHC Regulatory Area. Note that FISS sampling in 2020 did not include Areas 2A, 4A, 4B or 4CDE due to unplanned survey reductions, therefore projected and estimated CVs are identical.

Regulatory Area	2020 projected CV (%)	2020 estimated CV (%)
2A		22
2B	6	6
2C	6	5
3A	4	4
3B	10	10
4A		25
4B		25
4CDE		12

CONSIDERATION OF COST

Ideally, the FISS design would be based only on scientific needs. However, some Regulatory Areas are consistently more expensive to sample than others, so for these the efficient subarea designs were developed. The purpose of factoring in cost was to provide a statistically efficient and logistically feasible design for consideration by the Commission. During the Interim and Annual Meetings and subsequent discussions, cost, logistics and tertiary considerations (Table 1) are also factored in developing the final design for implementation in the current year. It is anticipated that under most circumstances, cost considerations can be addressed by adding stations to the minimum design proposed in this report (2020 was an exceptional case). In particular, the FISS is funded by sales of captured fish and is intended to have long-term revenue neutrality, meaning that any design must also be evaluated in terms of the following factors:

- Expected catch of Pacific halibut
- Expected Pacific halibut sale price
- Charter vessel costs, including relative costs per skate and per station
- Bait costs
- IPHC Secretariat administrative costs

Balancing these factors may result in modifications to the design such as increasing sampling effort in high-density regions and decreasing effort in low density regions. At present, with stocks near historic lows and extremely low prices for fish sales, the current funding model may require that some low-density habitat be omitted from the design entirely (as occurred in 2020). This will have implications for data quality, particularly if such reductions in effort relative to proposed designs continue over multiple years. Note that this did not occur in the 2021 design, as it was sufficient to include additional stations in core IPHC Regulatory Areas to generate a revenue-neutral coastwide design.

PARAMETER STABILITY AND THE IMPACT OF ADDING NEW DATA

At SRB017, the Scientific Review Board requested information on the stability of space-time model parameter estimates as new data are introduced each year into the modelling. Our model assumes a semi-parametric (or delta) model specifying separate, but spatially linked, processes for zero and non-zero data (see Appendix B, and Webster et al. 2020). The following parameters are estimated directly in the model and provided automatically as model output in R-INLA:

- τ_g : precision parameter of gamma-distributed non-zero WPUE or NPUE process
- τ_u : precision parameter of random walk for depth relationship for probability of zero
- τ_v : precision parameter of random walk for depth relationship with non-zero WPUE or NPUE
- τ_Y : precision parameter of random walk for year relationship (average temporal trend; non-zeros only)
- θ_1 , θ_2 : parameters governing spatial dependence model
- ρ : temporal correlation parameter
- β_ε : scalar parameter linking non-zero and zero error processes

In practice, the model is typically interpreted through transformed versions of several of these parameters, i.e., variance (inverse of precision, e.g. $\sigma_g^2 = 1/\tau_g$) or standard deviation, and spatial variance and range (transformations of θ_1 and θ_2: see Appendix B) are often used to help understand the processes. However, as stability in the transformed parameter estimates follows from stability in the parameter estimates provided in the model output, it is sufficient (and simpler) to present the values from the model output in order to understand the effect of new data on the model.

The values in Table 5 show high stability in all parameters except when significant changes occur to the input data, in particular when FISS expansions occurred. When new data were added through the FISS expansion program, this included data from deep and shallow stations for the first time, improving our understanding of the relationship between density and depth. This improved understanding was reflected in increases in precision parameters for the non-zero random walk process (τ_u) in particular in IPHC Regulatory Areas 2C and 3A, and the probability of zero process (τ_v) in IPHC Regulatory Areas 2B, 2C and 3A. Note that IPHC Regulatory Area 2C in particular has very few zero values, and the precision parameter for the depth relationship varies much more among years than for other areas as the addition of any new zeros can be quite influential. However, given how unlikely a zero is in this area, this model component is unimportant for final WPUE estimates relative to the non-zero process. We also note that the precision parameter of the temporal trend random walk (τ_Y) increased in these areas following the FISS expansions, reflecting a general reduction in uncertainty when unsurveyed habitat was sampled for the first time.

Other aspects of the SRB017 request will be discussed as part of the presentation at SRB018.

Table 5. Posterior means of space-time model parameters by IPHC Regulatory Area and year. Orange shading highlights years with expanded surveys, and green shading indicates years in which new covariates were added (see footnotes).

Reg. Area	Year	τ_g	τ_u	τ_v	τ_Y	θ_1	θ_2	ρ	β_ε
2A	2017	1.4	0.27	2.2	14	-7.9	5.8	0.90	0.55
	2018	1.4	0.34	2.2	31	-7.6	5.6	0.91	0.55
	2019	1.4	0.34	2.2	29	-7.7	5.7	0.91	0.55
	2020	1.4	0.34	2.2	30	-7.7	5.7	0.91	0.55
2B	2017	1.5	0.18	9.4	1.5	-7.5	5.8	0.93	0.46
	2018	1.7	0.29	8.0	3.0	-7.5	5.4	0.96	0.43
	2019[1]	1.7	0.30	7.2	2.7	-7.7	5.8	0.95	0.46
	2020[2]	1.7	0.24	6.9	2.9	-7.7	5.8	0.95	0.47
2C	2017	2.8	0.11	1.3	2	-8.9	6.6	0.96	0.43
	2018	2.8	0.61	2.1	10	-8.9	6.6	0.96	0.41
	2019[2]	2.8	0.50	2.2	12	-8.9	6.6	0.96	0.42
	2020	2.8	0.22	2.3	13	-8.8	6.5	0.96	0.42
3A	2017	1.9	0.14	0.9	4.4	-7.5	5.6	0.96	0.50
	2018	1.9	0.15	0.8	4.1	-7.3	5.5	0.96	0.53
	2019	1.9	0.20	10.6	5.0	-7.3	5.4	0.96	0.50
	2020	1.9	0.22	10.5	4.6	-7.3	5.4	0.96	0.50
3B	2017	2.4	0.16	1.2		-6.7	4.9	0.95	0.59
	2018	2.3	0.14	1.2		-6.7	4.9	0.95	0.58
	2019	2.3	0.16	1.1		-6.8	4.9	0.95	0.56
	2020	2.3	0.12	1.1		-6.7	4.9	0.95	0.57
4A	2017	1.6	0.14	2.4	4.4	-7.8	5.7	0.95	0.42
	2018	1.6	0.16	2.5	4.2	-7.8	5.7	0.95	0.43
	2019[3]	1.6	0.12	2.3	3.7	-7.8	5.6	0.95	0.37
	2020	1.6	0.12	2.3	3.7	-7.8	5.6	0.95	0.37
4B	2017	1.9	0.16	6.2	3.0	-8.1	5.8	0.90	0.41
	2018	1.9	0.15	6.8	2.9	-8.0	5.9	0.90	0.39
	2019	1.9	0.17	6.9	2.8	-8.0	5.8	0.91	0.38
	2020	1.9	0.17	6.9	2.8	-8.0	5.8	0.91	0.38
4CDE	2017	1.4	0.13	2.2		-6.8	5.1	0.90	0.49
	2018	1.4	0.14	2.2		-6.8	5.1	0.90	0.50
	2019	1.4	0.15	2.3		-6.8	5.1	0.90	0.49
	2020	1.5	0.15	2.3		-6.8	5.1	0.90	0.49

1. Binary covariate for low-density Salish Sea (sampled 2018 only in 2B) added to model.
2. Data from snap gear experiments included, along with covariates for difference between snap and fixed gear.
3. Revision of effectiveness criteria for whale depredation had greatest impact on IPHC Regulatory 4A, leading to removal of data from several sets that were fished just once in deeper waters.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2021-SRB018-05 that provides background on and a discussion of the IPHC fishery-independent setline survey design proposals for the 2022-24 period;
2) **ENDORSE** the final 2022 FISS design as presented in Figure 2, and
3) Provisionally **ENDORSE** the 2023-24 designs (Figures 3 and 4), recognizing that these will be reviewed again at subsequent SRB meetings.

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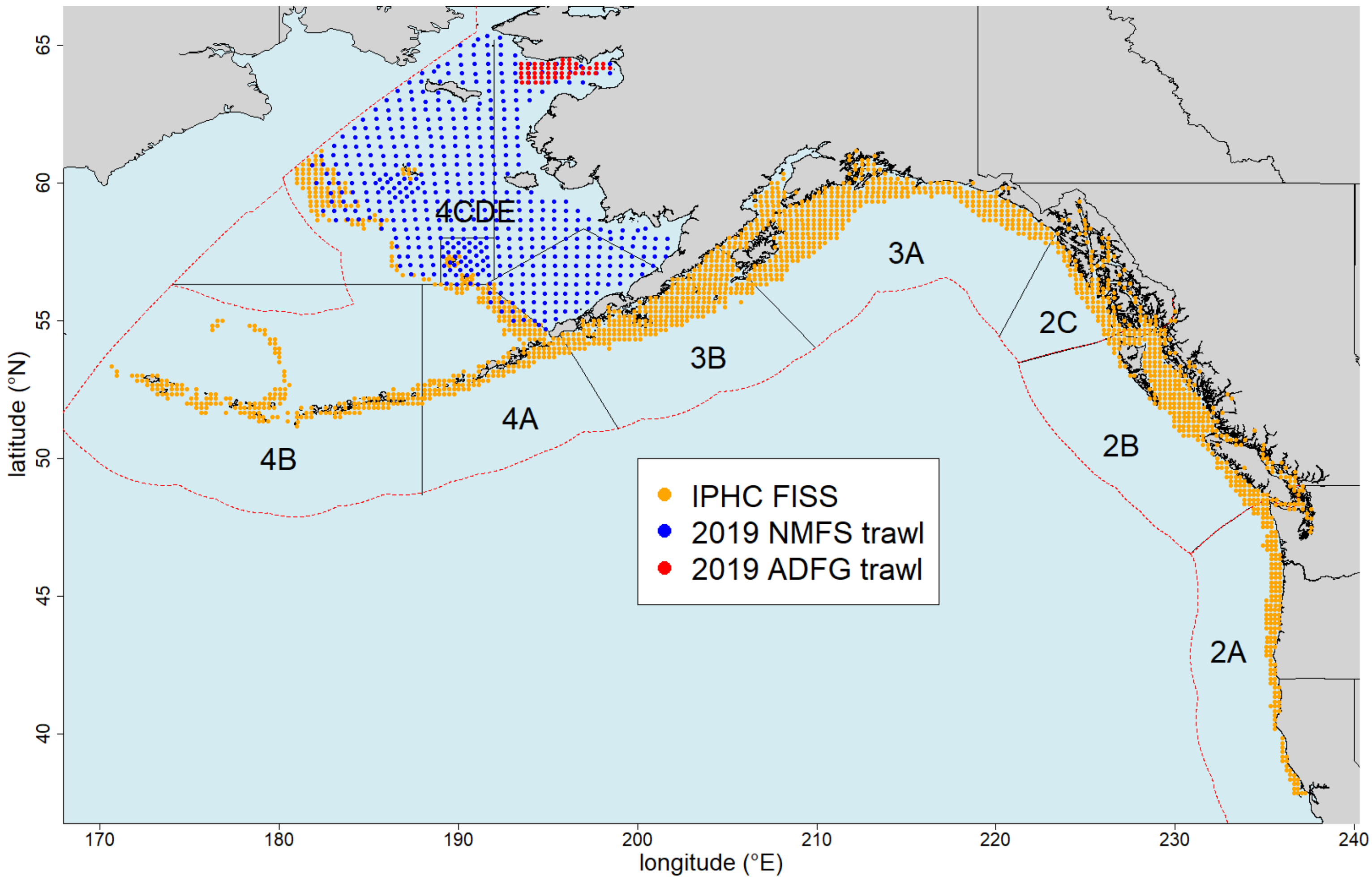

Figure 1. Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs, and other colours representing trawl stations from 2019 NMFS and ADFG surveys used to provide complementary data for Bering Sea modelling.

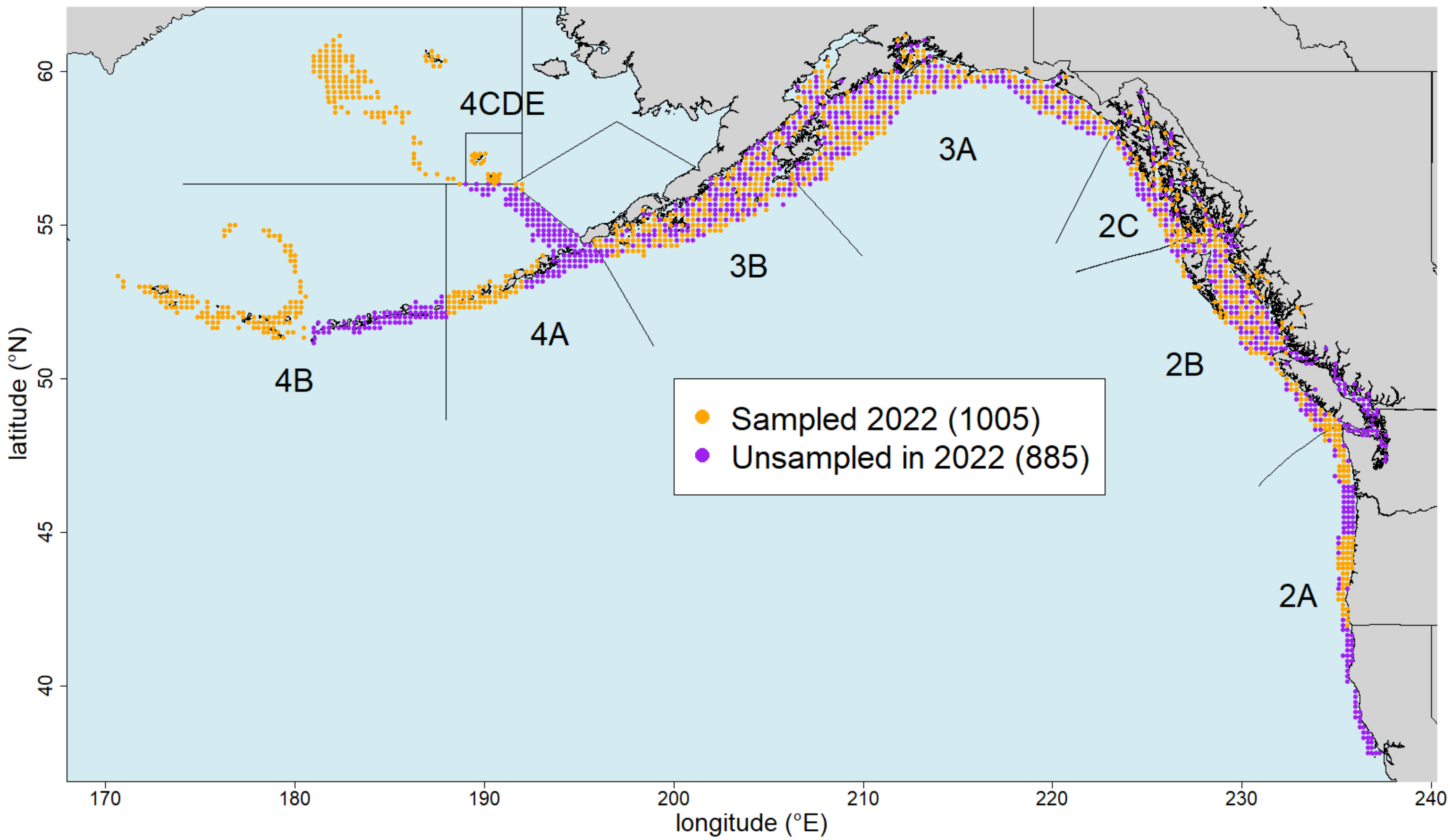

Figure 2. Proposed minimum FISS design in 2022 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

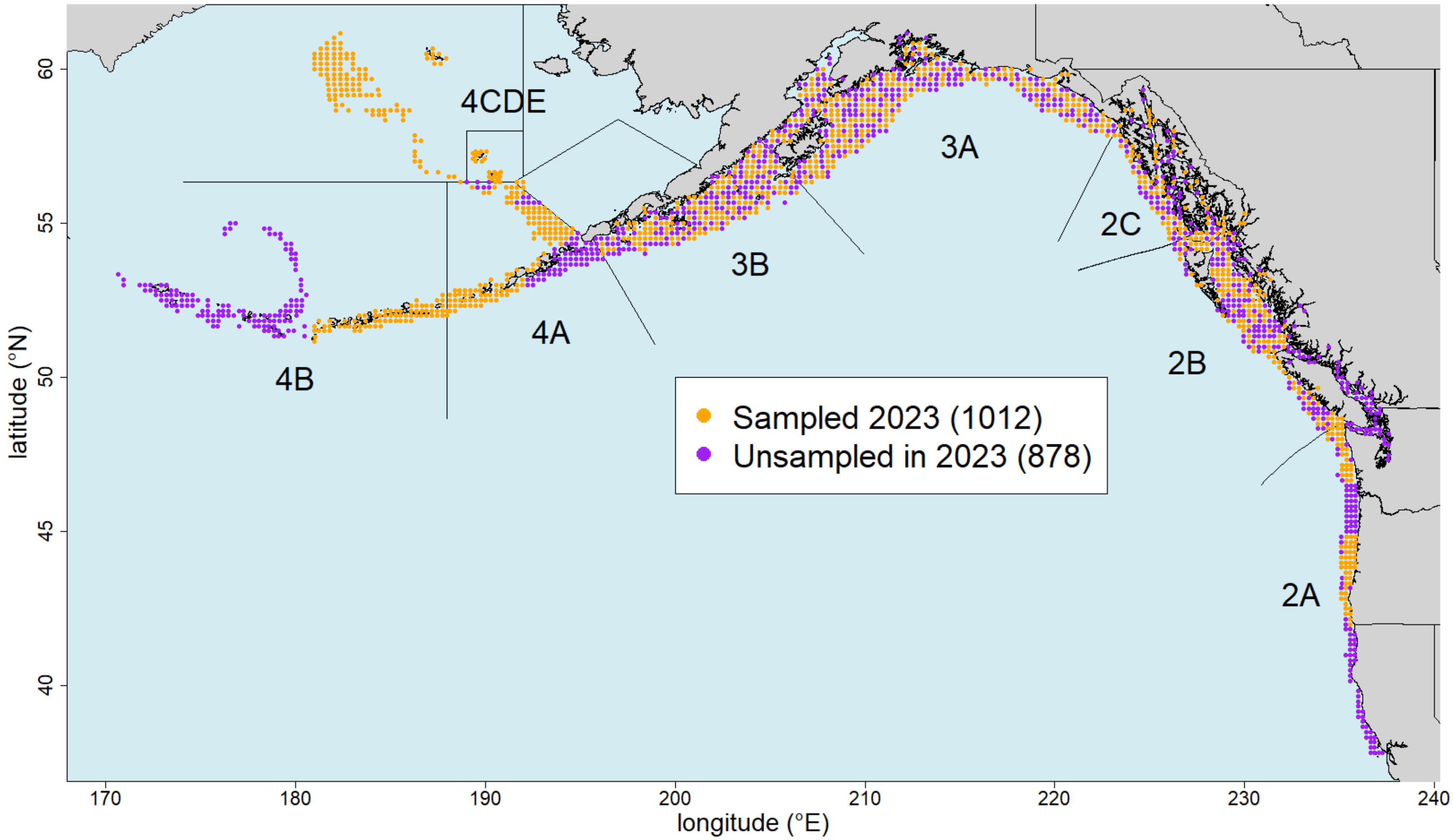

Figure 3. Proposed minimum FISS design in 2023 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

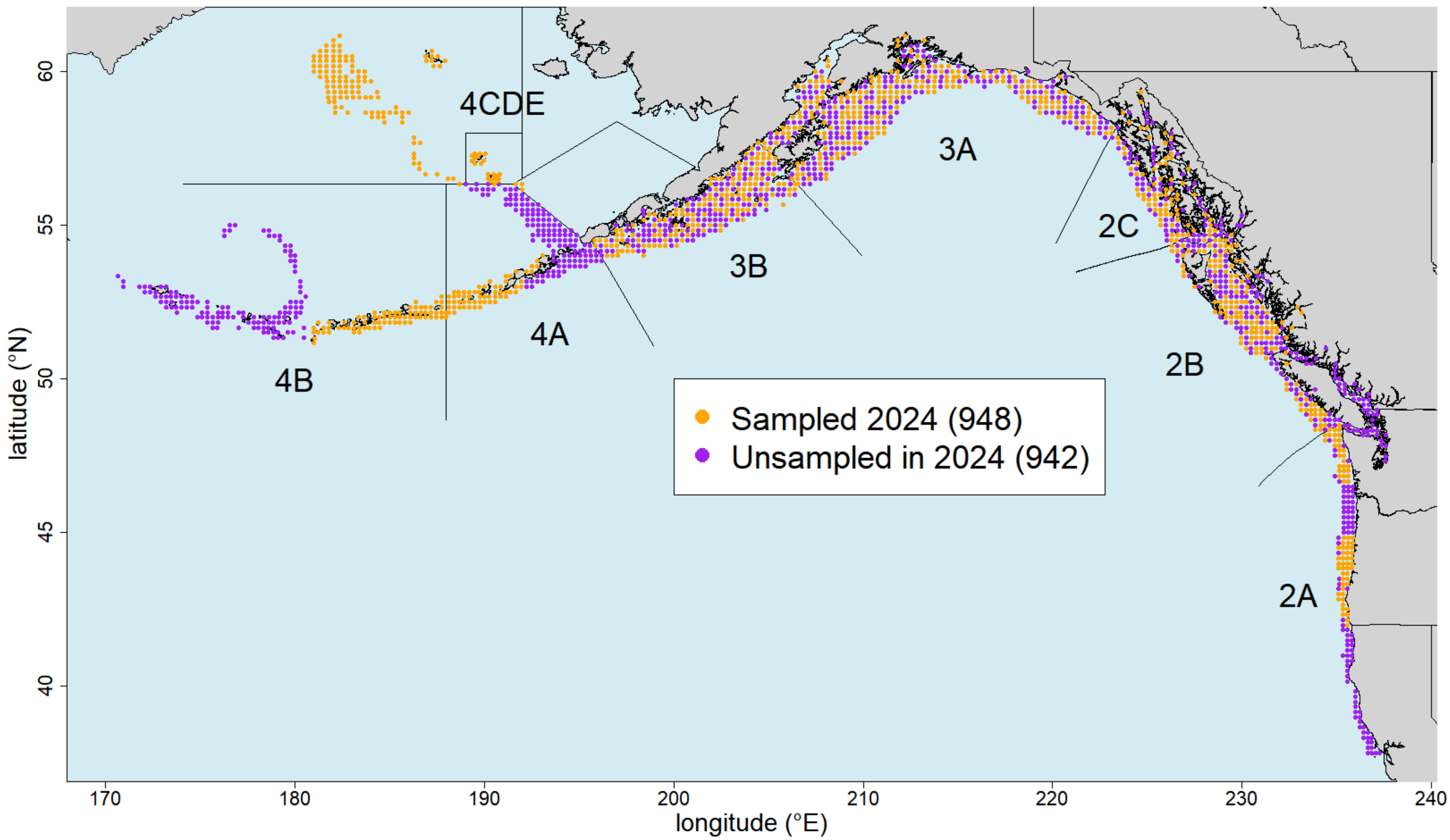

Figure 4. Proposed minimum FISS design in 2024 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

Appendix A

Sampling design options

The historical sampling, combined with FISS expansions from 2014-2019, established a full sampling design of 1890 stations from California to the Bering Sea shelf edge on a 10 nmi grid from depths of 10 – 400 ftm (Figure 1). Future annual FISS designs will comprise a selection of stations from this frame. Sample design options available for consideration in developing such designs include the following:

- Full sampling of the 1890 station design (Figure 1).
- Completely randomized sampling of stations within each IPHC Regulatory Area
- Randomized cluster sampling, in which clusters of stations are selected that comprise (where possible) 3-4 stations to make an operationally efficient fishing day.
- Subarea sampling, in which IPHC Regulatory Areas are divided into non-overlapping subareas, and all stations within a selection of these are sampled to allow for more efficient vessel activity on each sampling trip.

The latter two options above are examples that meet primary (statistical) sampling objectives, but also include a consideration of logistics and cost. For designs that use random sampling, the resulting estimates (eg, WPUE, NPUE indices) are unbiased. Designs based on sampling subareas require an evaluation of the potential for bias.

From a scientific perspective, more information is always better; however, sampling the full grid (Figure 1) is unnecessary as the precision target for the index can be maintained with substantial subsampling. While a fully randomized subsampling design (or a randomized cluster subsampling design) with sufficient sample size will still meet scientific needs, in several IPHC Regulatory Areas where Pacific halibut are concentrated in a subset of the available habitat, such a design can be inefficient. For this reason, we considered the subarea design, in which effort is focused in most years on habitat with highest density (which generally contributes most to the overall variance), while sampling other habitat with sufficient frequency to maintain low bias.

'Core' areas vs ends of the stock distribution
In considering potential FISS designs, it is helpful to make a distinction between the 'core' IPHC Regulatory Areas 2B, 2B, 3A and 3B, and the areas at the southern and northern ends of the stock's North America range, IPHC Regulatory Areas 2A, 4A, 4B and 4CDE. The former has generally high density throughout, while the latter have relatively high density limited to distinct subareas within each IPHC Regulatory Area. In other words, Pacific halibut distribution tends to become more heterogeneous ('patchy') toward the ends of the species range in the IPHC Convention Area. These areas are also much more logistically challenging to sample and generally produce lower catch rates. For these end areas, a fully randomised design would be inefficient, both logistically and statistically, as it would require effort where little is needed for estimation with low variance, while the frequently narrow bathymetric habitat area would result in a sparse randomised design with high vessel running time between selected stations. Provided the sampling rate is sufficient, a randomised design is generally more practical in the

core areas, and it also avoids concerns about bias that could arise from a subarea design that omits subareas with relatively high density.

Appendix B

Spatio-temporal model description

The IPHC's spatio-temporal model for FISS data is built around a semiparametric model (also known as a delta model) in which the probability of catching zero fish and the distribution of non-zero catches are modelled as connected spatio-temporal processes. Let $w(\boldsymbol{s},t)$ be the observed weight-per-unit-effort (WPUE) value at location $\boldsymbol{s}$ (a vector of coordinates) in year t, where $\boldsymbol{s}$ represents the spatial locations of the fished survey stations, taking values $\boldsymbol{s}_1, \ldots, \boldsymbol{s}_n$ (vectors of coordinates) and $t = t_1, \ldots, t_T$. In our model, each $\boldsymbol{s}_i \in S^2$, the set of points on the surface of a sphere. Data from the FISS contain observations of zero WPUE, due to stations in low-density areas catching no Pacific halibut. Two new variables are defined, $x(\boldsymbol{s},t)$ for presence or absence of Pacific halibut in the catch, and $y(\boldsymbol{s},t)$ for the WPUE value when Pacific halibut are present:

$$x(\boldsymbol{s},t) = \begin{cases} 0 & w(\boldsymbol{s},t) = 0 \\ 1 & w(\boldsymbol{s},t) > 0 \end{cases}$$

$$y(\boldsymbol{s},t) = \begin{cases} NA & w(\boldsymbol{s},t) = 0 \\ w(\boldsymbol{s},t) & w(\boldsymbol{s},t) > 0 \end{cases}$$

The NA indicates that $y(\boldsymbol{s},t)$ is a random variable that can only take non-zero values, and is therefore undefined when $w(\boldsymbol{s},t) = 0$. The variable $x(\boldsymbol{s},t)$ has a Bernoulli distribution, $x(\boldsymbol{s},t) \sim \text{Bern}(p(\boldsymbol{s},t))$, while a gamma distribution is used for the $y(\boldsymbol{s},t)$, $y(\boldsymbol{s},t) \sim \text{gamma}(a(\boldsymbol{s},t), b(\boldsymbol{s},t))$, which has mean $\mu(\boldsymbol{s},t) = a(\boldsymbol{s},t)/b(\boldsymbol{s},t)$. Only the gamma mean is allowed to vary: the variance, $\sigma_g^2 = a(\boldsymbol{s},t)/b^2(\boldsymbol{s},t)$, is assumed invariant over space and time. Note that $\sigma_g^2 = 1/\tau_g$, i.e., the gamma variance is the inverse of the precision parameter listed in Table 5.

Next let the $\varepsilon(\boldsymbol{s},t)$ be a Gaussian Field (GF) which is shared by both component random variables in the following way:

$$u(\boldsymbol{s},t) = \text{logit}\left(p(\boldsymbol{s},t)\right) = f_x\left(\boldsymbol{\beta}_x, \mathbf{z}(\boldsymbol{s},t)\right) + \varepsilon(\boldsymbol{s},t)$$

$$v(\boldsymbol{s},t) = \log\left(\mu(\boldsymbol{s},t)\right) = f_y\left(\boldsymbol{\beta}_y, \mathbf{z}(\boldsymbol{s},t)\right) + \beta_\varepsilon \varepsilon(\boldsymbol{s},t)$$

The parameter β_ε is a scaling parameter on the shared random effect, and appears in Table 5. Environmental covariates are introduced into each model component through f_x and f_y, functions of a spatially and temporally indexed covariate data matrix, $\mathbf{z}$, and covariate vectors $\boldsymbol{\beta}_x$ and $\boldsymbol{\beta}_y$.

Temporal dependence is introduced through a simple autoregressive model of order 1 (AR(1)), as described in Cameletti et al. (2013), as follows,

$$\varepsilon(\mathbf{s},t) = \rho\varepsilon(\mathbf{s},t-1) + \eta(\mathbf{s},t)$$

where ρ denotes the temporal correlation parameter and $|\rho| < 1$. For a given year, t, the spatial random field (SRF), $\eta(\boldsymbol{s}, t)$, is assumed to be a GF with mean zero and covariance matrix **Σ**. We assume a stationary Matérn model (Cressie, 1993) for the spatial covariance model, which specifies how the dependence between observations at two locations decreases with increasing distance. The two key parameters for this model are the spatial variance parameter, σ_η^2, and the spatial scale parameter, κ. The latter is related to the spatial range parameter, r, which for our model is defined in R-INLA as $r = \sqrt{8}/\kappa$ and is the distance (in radians) at which the spatial correlation is approximately 0.13 (and thus can be considered "small"). However, R-INLA instead directly estimates and outputs transformed versions of these parameters, θ_1 and θ_2, where:

$$\sigma_\eta^2 = \frac{1}{4\pi e^{2(\theta_1+\theta_2)}}$$

$$\kappa = e^{\theta_2}$$

Posterior means for θ_1 and θ_2 are shown in Table 5.

The relationships with depth were included in the models, and specified using a random walk (of order 1) as data exploration showed that they did not follow an obvious parametric form. Depth from 0 to 732 (400 ftm) is first discretised into d equally-spaced levels, with the change due to depth from level i to i+1 modelled as a zero-mean Gaussian process. Thus, for the zero (u) and non-zero (v) processes respectively, we have

$$\Delta u_i = u_i - u_{i+1} \sim N(0, \sigma_u^2)$$

$$\Delta v_i = v_i - v_{i+1} \sim N(0, \sigma_v^2)$$

Likewise, a temporal trend in the non-zero component was also included in the model as a random walk (of order 1) in order to improve prediction in unsampled areas (so that in the absence of data, predictions track the same trend as sampled regions rather than drift toward the long-term mean). The variance parameter associated with this random walk (with increments of one year) was σ_Y^2. All three random walk parameters are represented by their reciprocals, the precision parameters τ_u, τ_v and τ_Y, in Table 5.

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2021 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: Development

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 10 MAY 2021)

PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with a response to requests made during SRB016 and SRB017 (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R) and to provide the Commission with an update of the 2021 assessment development.

INTRODUCTION

In 2019, a full stock assessment (Stewart and Hicks 2020a) with external (Stokes 2019) and SRB reviews (SRB014, SRB015) was conducted. The 2020 stock assessment (Stewart and Hicks 2021) represented an update to data sources (Stewart and Webster 2021) without structural changes to the modelling. The input data files are archived each year on the stock assessment page of the IPHC's website, along with the full assessment and data overview documents. Assessment material from 2015 onward is available at that location. A summary of the 2020 assessment results (Stewart et al. 2021b) was posted to the IPHC's 97th Annual Meeting page.

For 2021, the Secretariat plans to conduct a second updated stock assessment, consistent with the schedule for conducting a full assessment and review approximately every three (3) years. Standard data sources, for which the time-series is extended and the recent years are updated annually (where needed), are expected to remain unchanged. Commercial fishery sex-ratio-at-age data from the 2020 fishery are anticipated to be available and included in preliminary models presented at SRB019, 21-23 September 2021. These sex ratios will extend the time-series, based on genetic analysis of (now) routinely collected fin-clips during standard port sampling procedures, to four years: 2017-2020. Evaluation of the necessity and estimability of time-varying selectivity for male Pacific halibut relative to females will likely be investigated in the next full assessment depending on the level of temporal variability observed in the data.

The 2021 updated stock assessment again comprises an ensemble of four equally weighted models: two long time-series models, reconstructing historical dynamics back to the beginning of the modern fishery, and two short time-series models incorporating data from 1992 to the present, a time-period for which estimates of all sources of mortality and survey indices are available for all regions. Consistent with recent analyses, management quantities represent the median of the integrated model ensemble, explicitly accounting for the uncertainty within and among models. This uncertainty forms the basis for the annual Harvest Decision Table, reporting the estimated probability for a series of management and conservation metrics under different levels of future fishery yield.

TIME-SERIES AND SOFTWARE UPDATES

In order to provide comparability between these results and all subsequent steps working toward the final 2021 stock assessment (the annual bridging analysis), this evaluation began with the final 2020 models. First, each of the four assessment models was extended by one year, including projected 2021 mortality from all sources based on the mortality limits set during AM097 (IPHC 2021). This does not affect the historical time-series' estimates, but allows for a stepwise evaluation of the effect of adding data and other making any other changes to the model prior to the final version used for management.

Next, the stock synthesis software was updated to the most recent non-beta version available, 3.30.16.02 (Methot Jr et al. 2020). The changes from the version used for the 2020 stock assessment (3.30.15.09) were unimportant to the Pacific halibut stock assessment (the results were identical to the final 2020 assessment), but maintaining a current version (when possible and efficient) reduces the likelihood of compatibility issues with plotting and other software and reduces the cumulative transitional burden (which was substantial for the 2019 stock assessment) when future changes are added. A 22% increase in model run-time was noted, despite no new features added relevant to the halibut assessment. In addition, for the two Areas-As-Fleets (AAF) models, temporary files were written during estimation unless memory buffers were increased at the command line. Although neither of these differences is prohibitive for routine use of this platform, they do illustrate one cost of using a generalized tool.

COMMISSION AND SRB REQUESTS AND RESULTS

During 2020 there were a number of assessment-related analyses requested by the Commission (e.g. evaluation of the commerical fishery minimum size limit; Stewart et al. 2021a); however, there were no requests made at AM097 specifically relating to the 2021 annual stock assessment. This likely reflects the shift in Commission focus toward the results of the IPHC's Management Strategy Evaluation (MSE), and the upcoming need for an agreed Management Procedure (MP) for setting the 2023 mortality limits. The current interim MP, in place since 2019, was intended to apply through the 2022 mortality limits (AM098).

In 2020, the SRB made the following assessment requests during SRB016 and SRB017:

1) SRB016 (para. 21):

   "The SRB AGREED that data weighting approaches, including alternative error distributions (e.g. self-weighting), should be evaluated further in the context of the next full stock assessment, and should strive to make use of the best methods available, noting that there are a range of approaches in use for similar stock assessments. In particular, the SRB REQUESTED that the IPHC Secretariat investigate the feasibility of a logisticnormal distribution to incorporate correlated errors in age composition data (see Francis, R.I.C.C. 2014. Replacing the multinomial in stock assessment models: A first step. Fisheries Research 151: 70–84). This change may be technically challenging given the current assessment software, as well as having sexed age composition data, and could nontrivially affect the stock assessment estimates of biomass and recruitment. Therefore, the SRB does not expect new results until at least SRB018 in June 2021."

2) SRB017 (para. 21):

   "The SRB REQUESTED that the IPHC Secretariat continue to update data weighting on an annual basis, even for updated stock assessments (such as 2020), in order to maintain internal model consistency and to best reflect changes in existing and new data as they arise."

3) SRB017 (para. 23):

   "The SRB REQUESTED that the IPHC Secretariat first investigate the consequences of implementing a logistic-normal likelihood for composition data assuming no correlation structure. This would provide an initial estimate of the benefits of self-weighting fairly quickly compared to developing a full age/sex correlated version."

4) SRB017 (para. 24):

"The SRB REQUESTED that the IPHC Secretariat continue to evaluate whether the Stock Synthesis modelling framework is the most efficient for Commission needs, and to coordinate future development with the MSE framework as features and technical needs evolve together for the two efforts."

Request 1 – Logistic-normal likelihood feasibility

Data weighting in fisheries stock assessment models is used to create internal consistency between input and output error distribution assumptions and results as well as address conflicts among data sources. A CAPAM (Center for the Advancement of Population Assessment Methodology) workshop on data weighting was attended by IPHC Secretariat staff 19-23 October 2015 (See full special issue of Fisheries Research; Maunder et al. 2017). Although a wide range of analyses and approaches were presented and discussed, no clear consensus on a single approach for weighting compositional data was reached. Many methods remain in common use, including nominal sample sizes based on fish, samples or trips, the harmonic mean (McAllister and Ianelli 1997), the average age (Francis 2011; Francis 2017), and others, including the Dirichlet-multinomial (Thorson et al. 2017; Xu et al. 2020).

The Secretariat has investigated several options for an improved likelihood for use with sex-specific age composition data. For SRB016 (IPHC-2020-SRB016-07), the Secretariat focused on the Dirichlet-multinomial, and four issues were identified that made its use non-optimal for the Pacific halibut stock assessment (and likely many other assessments). These issues were:

1) Increased weighting of small samples as the estimated variance in the composition data gets large.

2) The parameterization is not self-weighting near the nominal sample size as the estimated parameter goes to a bound and requires fixing at a static value to avoid potential estimation problems.

3) The approach produced standardized residuals that were inconsistent with the likelihood assumption (far more than 2.5% > 1.96).

4) The Dirichlet-multinomial does not allow for the correlation structure known to exist among proportions-at-age (or length).

For SRB017 (IPHC-2020-SRB017-07), the Secretariat staff reviewed the recent literature on error distributions for compositional data, with a particular focus on the logistic-normal (LM). Francis (2014) introduces several likelihood function options for compositional data and provides discussion of each with relative shortcomings and advantages. He found clear theoretical support for the logistic-normal because: 1) it is self-weighting (not requiring an iterative approach), 2) his suggested parameterization can maintain the relative annual input sample sizes in the likelihood, and 3) it allows for estimated correlations among bins. His analysis did not include fitting assessment models to data, but instead relied on comparing the likelihood of previous assessment model fits to compositional data.

Other authors have both investigated and implemented versions of the logistic-normal. Cadigan (2016) used the multiplicative logistic-normal in a state-space model for Atlantic cod. His example was relatively simple compared to Pacific halibut: he had sexes-aggregated data, did not retain the annual sample sizes, and did not include correlations among the proportions, instead estimating a single variance parameter for all proportions that was then adjusted using *ad hoc* scaling of the youngest (age-2) and oldest (age-8+) bins. Schnute and Richards (1995) used what they called the 'multivariate logistic', which appears to be equivalent to the logistic-normal later described by Schnute and Haigh (2007). These authors also did not include sex-specific compositional data or include a provision to weight the variance by the observed sample size in each year. Finally, Albertsen et al. (2017) compared a range of compositional models (among other structuring choices, including comparing numbers-at-age with proportions-at-age), including the Dirichlet and logistic-normal, and finding that the latter performed better on their data sets. They considered both the additive and multiplicative versions of the logistic-normal. They used an AR(1) approach to correlation among age bins but again did not have sex-specific information.

In previous Secretariat investigations of the LN, the issue of the treatment of the nominal sample size as a maximum was not considered, but is very important to the simultaneous tuning of process and observation error. The LN relies on an estimated variance parameter (σ) to determine the overall weighting of the compositional data. This parameter may be multiplied by some function of the input sample size (*n*) in each year (*y*) to retain the inter-annual variability created by the sampling intensity, as well as the variability inherent in the compositional data for each data set. This seemingly reasonable approach increases the weight as the sample size increases, but less so at very large sample sizes relative to the mean ($\bar{n}$):

$$\sigma_y = \sigma \left({}^{\bar{n}}/_{n_y} \right)^{0.5}$$

The Pacific halibut models are allowing for process error in selectivity (via time-varying selectivity parameters) that is iterated along with sample sizes determining the compositional data weighting. This process has been found to be robust, but requires some constraint to achieve convergence. Starting from a small value for the input σ for each fleet and parameter combination where temporal variability was allowed, process error is increased until the tuned value is consistent with the degree of variability observed among the deviations (SE^2_{devs}) and the average uncertainty of the deviations themselves ${\bar{\sigma}_{dev}}^2$. This approach is very close to that outlined by Thompson and Lauth (2012) and is consistent with the preferred method for tuning this and other types of process error (such as recruitment deviations) in stock synthesis (Methot and Taylor 2011; Methot et al. 2019):

$$\sigma_{tuned} \sim \sqrt{SE^2_{devs} + {\bar{\sigma}_{dev}}^2}$$

After the initial tuning of the process error, the input sample sizes (inversely related to the observation error for the composition data) are then reduced, where needed, via the Francis approach. Critically, the input sample sizes at this step are not increased beyond the nominal values, thus they are treated as defining a 'minimum variance' for the age composition data. Nominal inputs represent the number of survey sets and fishery trips (and not the number of individual fish measured, which would be much larger). Previous investigation by the Secretariat across many assessment models has found that exceeding the nominal sample sizes during iterative tuning can lead to cases where models will fit one or more data sources to the exclusion of other data sets and/or lead to dramatically increased estimates or process error as the weighting and process error increase together.

For the LN, it is not clear how the concept of nominal sample sizes as a maximum could be mapped into any of the currently available parameterizations. This represents an important shortcoming when comparing likelihood options (Table 1), particularly relevant to the Pacific halibut assessment models that was not identified in previous evaluations.

Identification of the best error distribution for fitting to age composition data remains an open question in stock assessment. All currently available approaches have moderate to substantial shortcomings, either in the treatment of correlations among age categories (and between sexes), the need for iteration during fitting, the ability to use information on heterogeneity in annual sample size, the ability to limit and estimate the effective sample size, or combinations of all these. The Secretariat continues to recommend that a graduate student project or other collaboration is likely to be the best path forward to derive and test a candidate logistic-normal or other likelihood implementation that meets all of the needs of the current Pacific halibut stock assessment. Even with a candidate logistic-normal formulation, it may take longer than a year for it to be implemented and tested in stock synthesis.

Table 1. Comparison of desirable properties of several candidate likelihoods for use with sex-specific age composition data. Inspired by table 2 in Francis (2014).

Likelihood property	Multinomial	Dirichlet-multinomial	Logistic-normal
Self-weighting (no iteration)	No	Yes	Yes
Includes correlations among ages	No	No	Possibly
Includes annual sample size variation	Yes	Yes	Yes
Maintains relative sample sizes (scale independent)	Yes	No	Yes
Allows for zeros	Yes	Yes	No
Provides internally consistent residuals	Yes	No	Unknown
Includes nominal maximum sample size	Yes	Yes	No
Currently available in stock synthesis	Yes	Yes	No

Recommendation 2 – update data weighting

One of the outcomes from the review of the full 2019 stock assessment was the recommendation to update the data-weighting each year and to track how that weighting changes over time. Data weighting was therefore updated for the final 2020 stock assessment. There were relatively small changes to all components relative to the weighting in the final 2019 stock assessment (Table 2). A minor increase in the fixed sample size was applied to the recreational sex-specific age composition data in the AAF long model. Recreational data have been down-weighted substantially in all recent assessments to allow estimation of selectivity, but minimize the effects of these data on other model estimates (Stewart and Hicks 2019). Preliminary model runs after adding the sex-specific recreational data (new to the 2020 assessment) indicated that the additional parameters describing the male selectivity offset showed occasional poor convergence under the previous weighting; therefore, the sample sizes were increased slightly until selectivity parameters showed better estimation behavior. This had no appreciable effect on management-relevant model outputs such as spawning biomass. In the long-term, it would be preferable to have recreational sampling for age information from all components within the coastwide recreational fishery such that the data could be considered representative and weighting treated naturally along with all other data sets. However, at this time it appears unlikely that sampling in recreational fisheries outside of IPHC Regulatory Area 3A will routinely include otoliths. Attempts to use length data to infer age distributions for recreational data have been hampered by the lack of reliable IPHC Regulatory Area-specific annual age-length keys for small/young Pacific halibut outside of the Bering Sea.

Table 2. Comparison of data weighting implied by the Francis method (iterated average input sample sizes) for age composition data from the final 2019 and 2020 assessments. Historical assessments did not use sex-specific commercial (2018 and earlier) or recreational (2019 and earlier) information.

	2019 Assessment	2020 Assessment	Change from 2019
Coastwide short			
Directed commercial fishery	38	43	5
Directed discards[1]	9	9	0
Non-directed discards[1]	5	5	0
Recreational[1]	5	5	0
FISS	263	264	1
Coastwide long			0
Directed commercial fishery	136	140	4
Directed discards[1]	6	6	0
Non-directed discards[1]	2.5	2.5	0
Recreational[1]	2.5	2.5	0
FISS	65	63	-2
AAF short			0
Region 2 directed commercial fishery[2]	538	531	-7
Region 3 directed commercial fishery[2]	278	273	-5
Region 4 directed commercial fishery[2]	26	24	-2
Region 4B directed commercial fishery[2]	22	22	0
Directed discards[1]	6	6	0
Non-directed discards[1]	5	5	0
Recreational[1]	5	5	0
Region 2 FISS	7	10	3
Region 3 FISS	22	18	-4
Region 4 FISS	88	83	-5
Region 4B FISS	42	43	1
AAF long			0
Region 2 directed commercial fishery[2]	271	272	1
Region 3 directed commercial fishery[2]	167	166	-1
Region 4 directed commercial fishery[2]	30	29	-1
Region 4B directed commercial fishery[2]	22	22	0
Directed discards[1]	6	6	0
Non-directed discards[1]	2.5	2.5	0
Recreational[1,3]	5	7.5	2.5
Region 2 FISS	8	6	-2
Region 3 FISS	15	8	-7
Region 4 FISS	97	86	-11
Region 4B FISS	54	54	0

[1]Inputs downweighted, and not iteratively reweighted (Stewart and Hicks 2019).
[2]Sample size equal to maximum (input based on number of samples).
[3]Sample size increased slightly to allow estimation of male selectivity offsets based on sex-specific age composition data available for the 2020 analysis.

Request 3 – Logistic-normal likelihood without correlation structure

Based on the evaluation described for Request 1 (above) the Secretariat has not yet investigated a logistic-normal likelihood without explicit correlation structure.

Recommendation 4 – continue to evaluate stock synthesis for IPHC needs

The IPHC has relied on a variety of model platforms for implementing its stock assessment, many of which have been developed specifically for Pacific halibut (e.g., Clark and Hare 2006; Deriso et al. 1985; Quinn et al. 1990). From 2012 to 2014, the IPHC transitioned from a single stock assessment model to an ensemble of models including alternative structural assumptions. At the same time, the software platform was also transitioned from the previous halibut-specific model implemented directly in ADMB to models using stock synthesis (Methot and Wetzel 2013a; Methot and Wetzel 2013b). This transition was made in order to speed the evaluation of a wide range of alternative models, facilitate quantitative summary of multiple models, reduce the potential for undiagnosed coding errors, and provide for more tranparent review.

The benefits of using a generalized platform for the Pacific halibut stock assessment come with costs, which include lack of some parameterizations that might be desirable, delayed development of new approaches, and in some cases run times that are inflated due to unused model features. These pros and cons have been discussed previously by the SRB and were noted in the 2019 external review (Stokes 2019).

The source code for stock synthesis was publicly released on 2 March 2021. A GitHub repository is now available, containing the source code, which will allow for easier investigation of specific details of currently implemented features and testing of custom additions for potential submission to the official platform. It also fosters a formal tracking and response framework for new features. These changes represent an important improvement in accessibility, particularly for organizations like the IPHC. However, the code itself remains extensive and highly challenging to modify in meaningful ways. It is not clear to what degree the IPHC may be able to actually develop new additions to the code, or whether direct access will likely foster improved communication with the development team.

Although stock synthesis currently meets the assessment modelling needs for the IPHC, several features would be useful for further development of our assessment models. These include implementation of random effects for time-varying processes (e.g., recruitment and selectivity), more flexible movement and tagging parameterizations, and alternative likelihoods such as the logistic-normal. Looking farther forward, during 2020 and 2021 the beginnings of a 'next generation' stock assessment that would succeed stock synthesis were made. Called the "NOAA's fisheries integrated modelling system" this effort is intended to reconcile the various models used in different areas of the U.S. It will be important for the IPHC to remain involved in this effort, as it did with the recent CAPAM workshop (Hoyle et al. 2020), along with other non-NOAA Fisheries organizations.

The MSE operating model (largely based on the structure of the current stock assesment, but programmed independently) has and will continue to refine the Secretariat's understanding of key biological processes and technical modelling needs that may feed back to the stock assessment. Additionally, the MSE framework will be useful for testing the stock assessment behavior under various assumptions through simulation. Ultimately, the choice of a medium- to long-term assessment platform may depend on the type of MP selected by the Commission. The current compressed 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 MSE, adoption of a management procedure by the IPHC and strategic planning for the stock assessment modelling platform should be considered together and the long-term focus should be on selecting the most efficient tools to meet management needs as they continue to evolve.

INTEGRATION WITH RESEARCH PLANNING

In response to previous SRB requests to better integrate research planning with stock assessment and MSE priorities, a ranking system has been developed that includes separate and explicit (but not necessarily different) priorities for the research supporting the stock assessment and the MSE (see IPHC-2021-SRB018-10). The stock assessment priorities have been subdivided into three categories: Assessment data collection and processing, biological inputs, and fishery yield. It is important to note that ongoing monitoring, including the annual FISS and port sampling programs is not considered research and is therefore not included in this list despite the critical importance of these collections.

Within the three assessment categories, the following topics have been identified as top priorities in order to focus attention on their importance for the stock assessment and management of Pacific halibut. A brief narrative is provided here to supplement the information provided in the 5-year research plan and to highlight the specific use of products from these studies in the stock assessment.

<u>Assessment data collection and processing</u>:

1) *Commercial fishery sex-ratio-at-age via genetics and development of methods to estimate historical sex-ratios-at-age*

   Commercial fishery sex-ratio information has been found to be closely correlated with the absolute scale of the population estimates in the stock assessment, and has been identified as the greatest source of uncertainty since 2013. With only three years (2017-2019) of commercial sex-ratio-at-age information available for the 2020 stock assessment, the annual genetic assay of fin clips sampled from the landings remain critically important. When the time series grows longer, it may be advantageous to determine the ideal frequency at which these assays need to be conducted. Development of approaches to use archived otoliths, scales or other samples to derive historical estimates could provide valuable information on earlier time-periods (with differing fishery and biological properties), and therefore potentially reconcile some of the considerable historical uncertainty in the present stock assessment.

2) *Whale depredation accounting and tools for avoidance*

   Whale depredation currently represents a source of unobserved and unaccounted-for mortality in the assessment and management of Pacific halibut. A logbook program has been phased in over the last several years, in order to record whale interactions observed by commercial fishermen. While this program may allow for future estimation of depredation mortality (e.g., perhaps following the approach of Peterson and Hanselman 2017), such estimates will likely come with considerable uncertainty. Reduction of depredation mortality through improved fishery avoidance and/or catch protection would be a preferable extension and/or solution to basic estimation. As such, research to provide the fishery with tools to reduce depredation is considered a closely-related high priority.

Biological inputs:

1) *Maturity, skip-spawning and fecundity*

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

2) *Stock structure of IPHC Regulatory Area 4B relative to the rest of the convention area*

The current stock assessment and management of Pacific halibut assume that IPHC Regulatory Area 4B is functionally connected with the rest of the stock, i.e., that recruitment from other areas can support harvest in Area 4B and that biomass in Area 4B can produce recruits that may contribute to other Areas. Tagging (Webster et al. 2013) and genetic (Drinan et al. 2016) analyses have indicated the potential for Area 4B to be demographically isolated. An alternative to current assessment and management structure would be to treat Area 4B separately from the rest of the coast. This would not likely have a large effect on the coastwide stock assessment as Area 4B represents only approximately 5% of the surveyed stock (Stewart et al. 2021b). However, it would imply that the specific mortality limits for Area 4B could be very important to local dynamics and should be separated from stock-wide trends. Therefore, information on the stock structure for Area 4B has been identified as a top priority.

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

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

Fishery yield:

1) *Biological interactions with fishing gear*

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

2) *Guidelines for reducing discard mortality*

   Much is already known about methods to reduce discard mortality, in non-directed fisheries as well as the directed commercial and recreational sectors. Promotion and adoption of best handling practices could reduce discard mortality and lead to greater retained yield.

Looking forward, the IPHC has recently considered adding close-kin genetics (e.g., Bravington et al. 2016) to its ongoing research program. Close-kin genetics can potentially provide estimates of the absolute scale of the spawning output from the Pacific halibut population. This type of information can be fit directly in the stock assessment, and if estimated with a reasonable amount of precision, even a single data point could substantially reduce the uncertainty in the scale of total population estimates. Data collection of genetic samples from 100% of the sampled commercial landings has been in place since 2017 (as part of the sex-ratio monitoring) and routine comprehensive genetic sampling of FISS catch will begin in 2021. The analysis to produce reproductive output estimates from close-kin genetics is both complex and expensive, and it could take several years for this project to get fully underway.

2021 FISHING AND FISS

During 2020, observed mortality was below the Commission limits for nearly all fisheries coastwide. The Commission also had to rely on a reduced FISS design reflecting the unique challenges to both the value of the catch as well as the logistics of conducting normal operations. This led to an assessment with slightly greater uncertainty (both quantified and unquantified) than in recent years, but also a reduced level of fishing intensity relative to that projected based on the adopted mortality limits.

Unlike the reduced design in 2020, the planned 2021 FISS will include sampling in all IPHC Regulatory Areas. In addition, a NOAA Fisheries trawl survey is anticipated for the eastern and northern Bering Sea in 2021, which should provide for a very robust modelled survey index in IPHC Area 4CDE.

As of the middle of May, it appears unlikely that the reduced actual mortality that occurred in 2020 relative to projections will persist again in 2021. Most fisheries appear to be achieving more normal operations this year, and there are indications of somewhat better prices. Of note, the Commission adopted a later season ending date for 2021 (7 December rather than 15 November). This may lead to a greater proportion of the landings remaining at the time the assessment data is finalized (31 October), and therefore additional uncertainty in the actual mortality. However, this challenge has always been present to some degree as almost all sectors must be projected to the end of the calendar year. These projections are always replaced with actual estimates in the following stock assessment and therefore are likely to have a minimal effect on the overall results.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2021-SRB018-06 which provides a response to requests from SRB016 and SRB017, and an update on model development for 2021.
b) **REQUEST** any further analyses to be provided at SRB019, September 2021.

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An update on the IPHC Management Strategy Evaluation (MSE) process for SRB018

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PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with an update of the International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) and an evaluation of management procedures for coastwide scale and distributing the TCEY to IPHC Regulatory Areas, as well as a response to requests made during SRB016 and SRB017 (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R) and potential topics for a program of work.

1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) has completed an evaluation of management procedures (MPs) relative to the coastwide scale and distribution of the Total Constant Exploitation Yield (TCEY) to IPHC Regulatory Areas for the Pacific halibut fishery using a recently developed framework. The TCEY is the mortality limit composed of mortality from all sources except under-26-inch (66.0 cm, U26) non-directed commercial discard mortality, and is determined by the Commission at each Annual Meeting for each IPHC Regulatory Area. The current interim management procedure (MP) is shown in Figure 1.

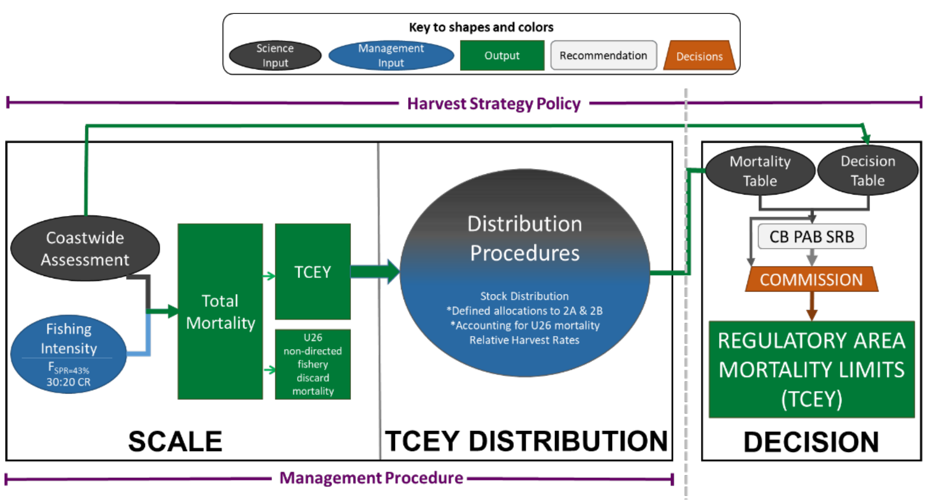

Figure 1. Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC CIRCULAR 2020-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are three-year interim agreements to 2022. The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

The development of this MSE framework aimed to support the scientific, forecast-driven evaluation of the trade-offs between fisheries management scenarios. The MSE framework with a multi-area operating model (OM) and three options for examining estimation error is described in Hicks et al. (2020) with technical details available from the IPHC MSE website (to be posted soon after publication of this document). Descriptions of the MPs being evaluated are presented in Hicks et al. (2021). Simulation results are presented in Hicks et al. (2021) and summarized in this document. Lastly, potential topics for a future program of work, incorporating past SRB and Commission requests, are provided.

2 SIMULATION RESULTS

Eleven MPs were recommended at MSAB015 to be simulation tested using the MSE framework (Table 1) and results were presented to the Commission at the 97th Session of the IPHC Annual Meeting (AM097). For brevity, results related to primary objectives (see Appendix I of Hicks et al. (2021)) from only one implementation of estimation error (simulated) are reported here to compare across Spawning Potential Ratio (SPR) values and MPs, and some figures and tables only present results using an SPR of 43%. Simulations with alternative estimation error methods and additional SPR values are available on the interactive MSE Explorer website.

Figure 2 shows coastwide performance metrics linked to the primary coastwide objectives. The relative spawning biomass (RSB) is similar across all management procedures, but varies with SPR. All MPs are less than the 5% tolerance for RSB dropping below 20% SPR, and the median RSB resulting from an SPR of 40% is slightly less than 36%. The probability of being below 36% is slightly less for MP-A compared to all other MPs (three to four percentage points excluding MP-D). The Average Annual Variability in the TCEY (AAV) was higher for MP-A as well, especially at lower SPR values, because MP-A was the only MP without an annual constraint of 15% on the TCEY. For the same reason, the probability that the Annual Change (AC) was greater than 15% in three or more years (AC3) was greater than zero for MP-A and zero for all other MPs, except MP-D which allowed the coastwide TCEY to increase in order to accommodate agreements in 2A and 2B. Short-term median TCEY was between 30 and 50 Mlbs (13,600 and 22,700 t) for all MPs and SPR values, with larger values for lower SPR values (higher fishing intensity) and slight variations between MPs. The difference in the short-term median TCEY was less than 2.5 Mlbs (1,100 t) between MPs for an SPR of 43%.

Short-term performance metrics for the TCEY in each IPHC Regulatory Area are shown in Figure 3 (and Tables 6-8 in Hicks et al. (2021)). MPs F–K show decreased TCEY in 2A and MPs E and G–K show decreased TCEY in 2B along with increased TCEY in all other IPHC Regulatory Areas because the current agreements from 2A and 2B, or national shares for 2B, are not included in those MPs. The TCEY increased in 3B, 4A, and 4B with the increased relative harvest rate included in MP-H and MP-K, while it decreased in other IPHC Regulatory Areas. MP-J, which uses a 5-year average of stock distribution, shows similar TCEY values as MP-G, but with lower AAV for most IPHC Regulatory Areas. Stability related performance metric differences are evident at the IPHC Regulatory Area level with MP-J, even though its stability was not much different than that of MP-G at the coastwide level (e.g. median AAV). Additional performance metrics presented in the MSE Explorer may assist in the evaluation of the MPs.

Table 1: A comparison of management procedures (MPs) showing the elements included in defined MPs. See Appendix II and Appendix III of Hicks et al (2021) for additional details of the MPs.

Element	MP-A	MP-B	MP-C	MP-D	MP-E	MP-F	MP-G	MP-H	MP-I	MP-J	MP-K
Maximum coastwide TCEY change of 15%											
Maximum Fishing Intensity buffer (SPR=36%)											
O32 stock distribution											
O32 stock distribution (5-year moving average)											
All sizes stock distribution											
Fixed distribution updated in 5th year from O32 stock distribution											
Relative harvest rates of 1.0 for 2-3A, and 0.75 for 3B-4											
Relative harvest rates of 1.0 for 2-3, 4A, 4CDE, and 0.75 for 4B											
Relative harvest rates by Region: R2=1, R3=1, R4=0.75, R4B=0.75											
1.65 Mlbs fixed TCEY in 2A											
Formula percentage for 2B											
National shares (2B=20%)											

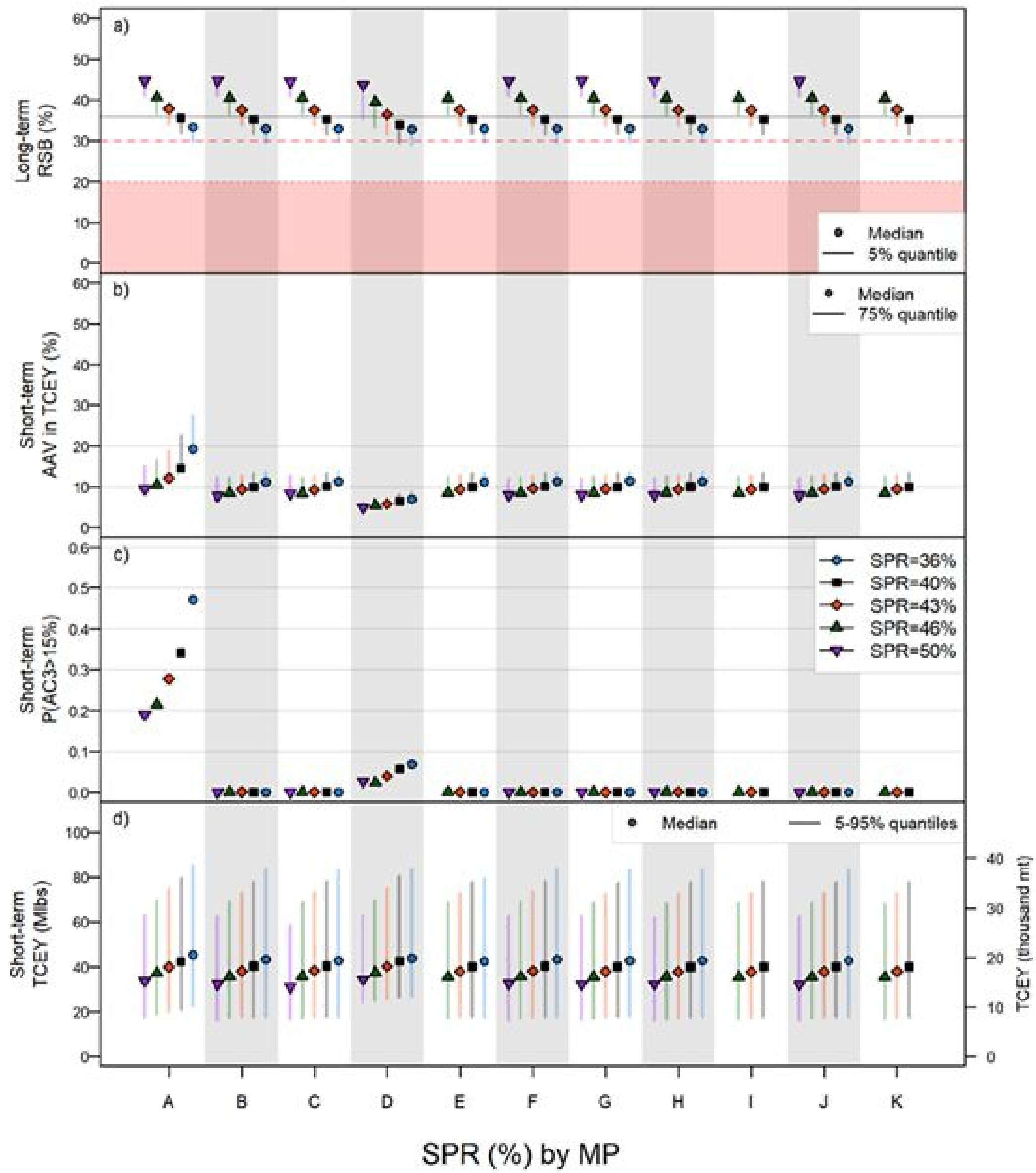

Figure 2. Coastwide performance metrics for MPs A through K using simulated estimation error with SPR values of 40%, 43%, and 46% for all and 36% and 50% for some. The relative spawning biomass and the limit (20%), trigger (30%) and target (36%) are shown in a). The AAV for TCEY is shown in b). The probability that the annual change exceeds 15% in 3 or more years is shown in c). The median TCEY along with 5th and 95th quantiles are shown in d)

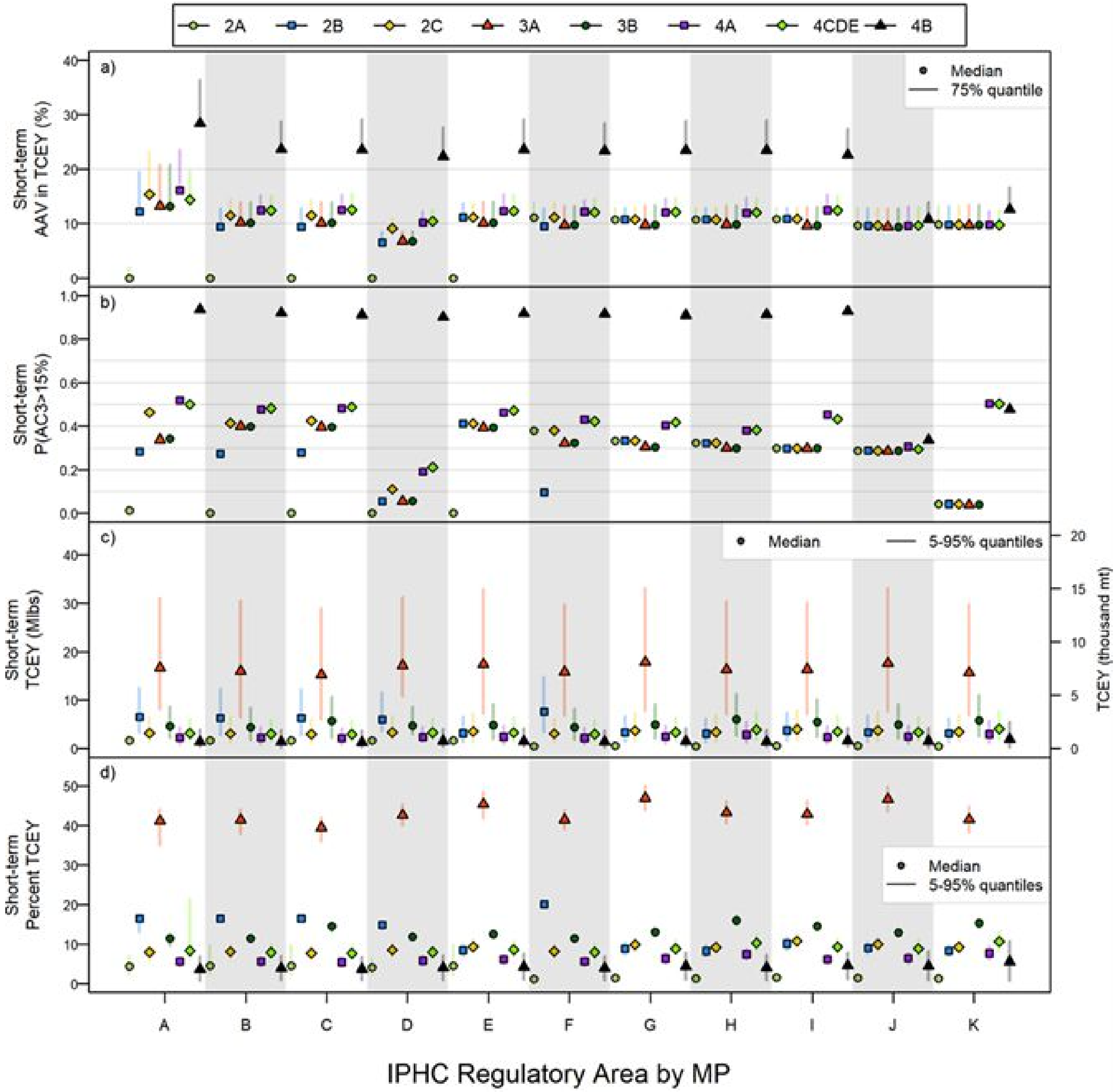

Figure 3. Performance metrics by IPHC Regulatory Areas for MPs A through K using simulated estimation error with an SPR value of 43%. The AAV for TCEY is shown in a). The probability that the annual change exceeds 15% in 3 or more years is shown in b). The median TCEY with 5th and 95th quantiles is shown in c). The median percentage of the TCEY in each IPHC Regulatory Area is shown in d).

Overall, the eleven MPs differ slightly at the coastwide level but showed some important differences at the IPHC Regulatory Area level. Trade-offs between IPHC Regulatory Areas are an important consideration when evaluating the MSE results. Ranking the performance metrics across management procedures and then averaging groups of ranks (e.g. over IPHC Regulatory Areas) can assist in identifying MPs that perform best overall.

The Biological Sustainability objectives have a tolerance defined making it possible to determine if each objective is met by a management procedure. All management procedures met the Biological Sustainability objectives, except for the objective to maintain a minimum percentage of female spawning biomass above 2% in IPHC Regulatory Area 4B with a tolerance of 0.05 (Table 2). This distribution of the projected percentage of spawning biomass in Biological Region 4B is less than 2% with a probability of 0.19 with no fishing mortality (Figure 4). This probability is slightly less with fishing mortality (Table 2) because the spawning biomass is less variable with fishing. The fact that this objective is not met without fishing or when applying any management procedure suggests two things: 1) the objective should be revisited and/or 2) the operating model is possibly mischaracterizing the population in Biological Region 4B, and thus the proportion of the population in this Biological Region.

The operating model was conditioned to the observed stock distribution and the predicted range of historical stock distribution from the operating model for Biological Region 4B is wider than the confidence intervals for the observed stock distribution (Figure 8 in IPHC-2020-MSAB016-08). Biological Region 4B is a unique region in the IPHC convention area, possibly with an effectively separate stock (genetic research is ongoing to better understand the connectivity of 4B with the rest of the stock), and the operating model may not be completely capturing the stock dynamics in that area. Additionally, with mostly out-migration from 4B and little recruitment distributed to that area, large increases in spawning biomass in the other Biological Regions may result in Biological Region 4B containing a small percentage of the spawning biomass even though the absolute spawning biomass is at a high level. Regardless, the spawning biomass simulated in the OM persists in that Biological Region. In addition to revisiting the assumptions in the OM, it may be prudent to revisit the regional spawning biomass objective.

The ranking of short-term performance metrics for the Fishery Sustainability objectives are shown in Table 3, Table 4, Table 5, and Table 6. Higher ranks generally occurred for MPs D, I, J, and K, although not necessarily for IPHC Regulatory Areas 2A and 2B when compared to MPs where agreements for those areas are in place. The general objectives were averaged over IPHC Regulatory Areas to produce a summary of ranks as shown in Table 7. This summary shows that MPs D and J generally have higher ranks for stability and yield objectives specific to IPHC Regulatory Areas, although better stability at the IPHC Regulatory Area level does not imply stability at the coastwide level. Further summary of the ranks to general objectives are shown in Table 8, with better average performance for MPs D, I, J, and K, in general.

Table 2. Long-term performance metrics for biological sustainability objectives for MPs A through K with an SPR value of 43% using simulated estimation error. Red shading indicates that the current defined objective is not met, and green shading indicates that the objective is met. Values in the cells are the calculated probabilities.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain a coastwide female SB above a biomass limit reference point 95% of the time	$P(SB < SB_{Lim})$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=2} < 5\%)$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=3} < 33\%)$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=4} < 10\%)$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintain a minimum proportion of female SB	$P(\%SB_{R=4B} < 2\%)$	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.15	0.16	0.16	0.18

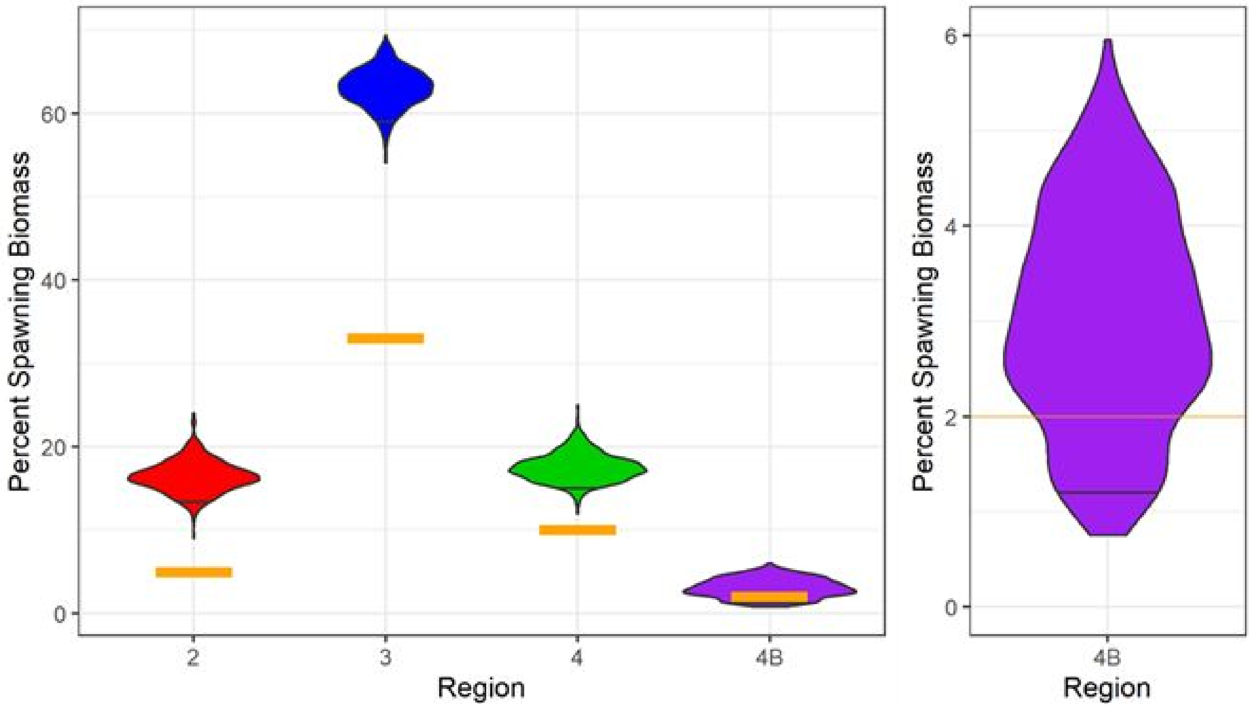

Figure 4. Distribution of the percentage of spawning biomass in each Biological Region after 60 years of projections with no fishing mortality. The right panel is zoomed in on Biological Region 4B. A horizontal line shows the 5% quantile in each plot. Primary objectives are to maintain the female spawning biomass above 5%, 33%, 10%, and 2% for Biological Regions 2, 3, 4, and 4B, respectively. These limits are shown in orange horizontal lines.

Table 3. Long-term performance metrics for fishery objective 2.1 for MPs A through K with an SPR value of 43% using simulated estimation error. The ranks are determined by how close the long-term probability is to 0.5 after rounding to two decimal places. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain the coastwide female SB above a target at least 50% of the time	$P(SB < SB_{36\%})$	11	4	4	1	4	4	4	2	2	4	4

Table 4. Short-term performance metrics for fishery stability objectives for MPs A through K with an SPR value of 43% using simulated estimation error. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures. Ranks were determined after rounding probabilities (i.e. P(AC_3>15%)) to two decimals and percentages (i.e. AAV) to one decimal.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Limit TCEY AC	P(AC_3 > 15%)	11	1	1	10	1	1	1	1	1	1	1
Limit TCEY AAV	Median AAV TCEY	11	3	2	1	3	8	8	3	3	8	3
Limit AC in Reg Areas TCEY	P(AC_3 2A > 15%)	5	1	1	1	1	11	10	9	8	7	6
	P(AC_3 2B > 15%)	5	4	5	2	11	3	10	9	8	7	1
	P(AC_3 2C > 15%)	11	8	10	2	8	7	6	5	4	3	1
	P(AC_3 3A > 15%)	8	10	10	2	9	7	6	4	4	3	1
	P(AC_3 3B > 15%)	8	10	10	2	9	7	4	4	4	3	1
	P(AC_3 4A > 15%)	11	8	8	1	7	5	4	3	6	2	10
	P(AC_3 4CDE > 15%)	10	8	9	1	7	4	4	3	6	2	10
	P(AC_3 4B > 15%)	11	7	4	3	7	7	4	4	10	1	2
Limit AAV in Reg Areas TCEY	Median AAV 2A	1	1	1	1	1	11	9	8	9	6	7
	Median AAV 2B	11	2	2	1	10	4	7	7	7	5	6
	Median AAV 2C	11	9	9	1	7	8	4	4	4	2	3
	Median AAV 3A	11	10	8	1	8	3	6	7	3	2	3
	Median AAV 3B	11	10	8	1	8	3	6	7	3	2	3
	Median AAV 4A	11	8	8	3	7	6	5	4	8	1	2
	Median AAV 4CDE	11	8	10	3	7	5	5	4	8	1	2
	Median AAV 4B	11	10	8	3	8	5	6	6	4	1	2

Table 5. Short-term performance metrics for fishery yield objectives related to the TCEY for MPs A through K with an SPR value of 43% using simulated estimation error. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures. Ranks were determined after rounding to the nearest one million pounds.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Optimize TCEY	Median TCEY	1	3	3	1	3	3	3	3	3	3	3
Maintain minimum TCEY by Reg Areas	Median Min 2A	1	1	1	1	1	6	6	6	6	6	6
	Median Min 2B	5	2	2	2	8	1	8	8	6	6	8
	Median Min 2C	8	8	8	1	1	8	1	1	1	1	1
	Median Min 3A	11	5	10	1	2	5	2	5	5	2	5
	Median Min 3B	9	9	2	2	2	9	2	1	2	2	2
	Median Min 4A	11	1	1	1	1	1	1	1	1	1	1
	Median Min 4CDE	5	5	5	5	5	5	5	1	1	1	1
	Median Min 4B	1	1	1	1	1	1	1	1	1	1	1
Optimize Reg Areas TCEY	Median TCEY 2A	1	1	1	1	1	9	6	9	6	6	9
	Median TCEY 2B	2	3	3	3	7	1	7	7	6	7	7
	Median TCEY 2C	5	5	5	5	1	5	1	5	1	1	5
	Median TCEY 3A	3	6	11	3	3	6	1	6	6	1	6
	Median TCEY 3B	5	10	1	5	5	10	5	1	1	5	1
	Median TCEY 4A	3	3	3	3	3	3	3	1	3	3	1
	Median TCEY 4CDE	4	4	4	4	4	4	4	1	1	4	1
	Median TCEY 4B	6	6	6	1	6	6	1	6	1	1	1

Table 6. Short-term performance metrics for fishery yield objectives related to the percentage of TCEY in each IPHC Regulatory Area for MPs A through K with an SPR value of 43% using simulated estimation error. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures. Ranks were determined after rounding to two decimals

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain minimum % TCEY by Reg Areas	Median Min % 2A	5	1	1	4	1	11	8	10	6	6	8
	Median Min % 2B	3	2	3	5	10	1	8	11	6	7	9
	Median Min % 2C	10	8	10	7	5	8	3	6	1	2	4
	Median Min % 3A	10	9	11	5	3	8	2	4	5	1	7
	Median Min % 3B	11	9	3	8	7	9	6	1	4	5	2
	Median Min % 4A	10	8	11	7	5	8	4	2	5	3	1
	Median Min % 4CDE	8	8	11	7	6	8	5	2	4	3	1
	Median Min % 4B	11	8	10	6	5	8	3	7	3	2	1
Optimize TCEY percentage among Reg Areas	Median % TCEY 2A	4	1	1	5	1	11	7	9	6	7	9
	Median % TCEY 2B	3	2	3	5	9	1	8	10	6	7	10
	Median % TCEY 2C	10	9	11	7	4	8	3	5	1	2	5
	Median % TCEY 3A	10	9	11	6	3	7	1	4	5	2	7
	Median % TCEY 3B	11	9	3	8	7	9	5	1	4	6	2
	Median % TCEY 4A	10	8	11	7	5	8	3	2	5	3	1
	Median % TCEY 4CDE	7	8	11	8	6	8	4	2	3	4	1
	Median % TCEY 4B	11	8	10	6	5	8	4	6	2	3	1

Table 7. Ranks for the target biomass, fishery yield, and stability short-term performance metrics for MPs A–K with an SPR value of 43% averaged with equal weighting over IPHC Regulatory Areas for those that are reported by IPHC Regulatory Areas (Tables 13–15). Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
Maintain the coastwide female SB above a target	$P(SB < SB_{36\%})$	11	4	4	1	4	4	4	2	2	4	4
Limit AC in coastwide TCEY	$P(AC_3 > 15\%)$	11	1	1	10	1	1	1	1	1	1	1
Limit AAV in coastwide TCEY	Median AAV TCEY	11	3	2	1	3	8	8	3	3	8	3
Optimize average coastwide TCEY	Median TCEY	9.75	7.25	6.75	1.75	7	5.62	6	5.88	5.75	2.5	3.5
Limit AC in Reg Areas TCEY	$P(AC_3 > 15\%)$ Reg Areas	8.62	7	7.12	1.75	7.38	6.38	6	5.12	6.25	3.5	4
Limit AAV in Reg Areas TCEY	Median AAV TCEY Reg Areas	1	3	3	1	3	3	3	3	3	3	3
Optimize Reg Areas TCEY	Median TCEY Reg Areas	8.5	6.62	7.5	6.12	5.25	7.62	4.88	5.38	4.25	3.62	4.12
Optimize TCEY % among Reg Areas	Median % TCEY Reg Areas	6.38	4	3.75	1.75	2.62	4.5	3.25	3	2.88	2.5	3.12
Maintain minimum TCEY by Reg Areas	Median Min(TCEY) Reg Areas	3.62	4.75	4.25	3.12	3.75	5.5	3.5	4.5	3.12	3.5	3.88
Maintain minimum % TCEY by Reg Areas	Median Min(% TCEY) Reg Areas	8.25	6.75	7.62	6.5	5	7.5	4.38	4.88	4	4.25	4.5

SB: Spawning Biomass; AC: Annual Change; AAV: Average Annual Variability; Regulatory Areas: IPHC Regulatory Areas; TCEY: Total mortality minus under 26" (U26) non-directed commercial discard mortality.

Table 8. Ranks for the target biomass, fishery yield, and stability short-term performance metrics for MPs A–K with an SPR value of 43% averaged with equal weighting over IPHC Regulatory Areas for those that are reported by IPHC Regulatory Areas (Tables 13–15) and equally over objectives within each general category. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures.

Objective	Performance Metric	A	B	C	D	E	F	G	H	I	J	K
2.1 Maintain the coastwide female SB above a target	$P(SB < SB_{Targ})$	11	4	4	1	4	4	4	2	2	4	4
2.2 Limit catch variability	Limit annual change	10.09	4.56	4.22	3.62	4.59	5.25	5.25	3.75	4	3.75	2.88
2.3 Provide directed fishing yield	Optimize TCEY and maintain minimum TCEY in Regulatory Areas	5.55	5.02	5.22	3.7	3.92	5.62	3.8	4.15	3.45	3.37	3.72

2.1 A closer look at the best performing management procedures

The best performing management procedures, based on the rankings of management procedures when using an SPR value of 43% (Table 3 to Table 8), were MP-D and MP-J. These management procedures generally had better stability ranks for IPHC Regulatory Areas and comparable fishery yield ranks when compared to other management procedures. MP-I was not included in this comparison because there is some concern that different relative harvest rates are highly dependent on migration assumptions, thus robust testing should include additional migration scenarios. MP-K performed well according to these performance metrics, but there is a potential for a change in the TCEY every fifth year to be large, which warrants further evaluation.

MP-D and MP-J are different in two ways. MP-D accommodates the agreements for IPHC Regulatory Areas 2A and 2B by allowing for the fishing intensity to be exceeded (i.e. lowering the SPR to 36% if necessary). Both MPs use O32 stock distribution to distribute the TCEY to IPHC Regulatory Areas, but MP-J uses a moving five-year average of the O32 stock distribution whereas MP-D uses the estimates from the previous year.

We define three ways to report SPR. First, the procedural SPR is the SPR defined by the harvest rule, such as 43%. The applied SPR is the SPR that is actually used to determine mortality limits and differs from the procedural SPR because it may be modified by the control rule (e.g. when the stock status is less than 30%) or by the adjustment in MP-D. The determination of stock status depends on the estimation model, which is dependent on the data, thus the applied SPR is a product of the entire management procedure and subject to uncertainty. Likewise, the determination of the maximum fishing intensity to accommodate the agreements in MP-D depends on the estimated parameters and stock size from the estimation model, thus is also subject to uncertainty. Thirdly, the realized SPR additionally accounts for the implementation of the fishery and changes in the population (i.e. the operating model processes). For example, the total mortality realized from the fisheries may not equal the mortality limit determined from the applied SPR, thus the realized SPR will differ. Overall, the procedural, applied, and realized SPRs will differ from each other due to the control rule, estimation error, and implementation variability.

Adjusting the fishing intensity to accommodate agreements within IPHC Regulatory Areas results in a variable applied SPR value that has a chance of exceeding the procedural SPR. The average realized SPR for the long-term is plotted in Figure 5 for MP-D and MP-J for different procedural SPR values. The two MPs show similar median average realized SPR values at lower fishing intensities, which are nearly the same as the procedural SPR because the simulated estimation error is unbiased and stock status is not often estimated to be less than 30% (where the control rule reduces fishing intensity). At higher fishing intensities, like an SPR of 40%, the median average realized SPR is more (i.e. lower fishing intensity) than the procedural SPR because it is affected by the control rule. This occurs because the stock status is more often estimated to be lower than 30%, thus the control rule increases the SPR (i.e. lowers the fishing intensity) from the procedural SPR. However, the control rule does not lower the procedural SPR (i.e. increase fishing intensity). This asymmetry results in a skewed distribution of realized SPR, especially with higher fishing intensities that result in lower stock status.

Allowing the procedural SPR to be modified in MP-D, the realized SPR is greater more often than in MP-J because the accommodation of agreements may reduce the applied SPR (increase fishing intensity) and act in opposition of the control rule. The average realized SPR does not reach the minimum SPR of 36% because 1) the asymmetry of the control rule, higher fishing intensities have a greater chance of meeting the agreements in 2A and 2B, 2) this is a realized SPR subject to estimation error, and 3) it is an average of a ten-year period.

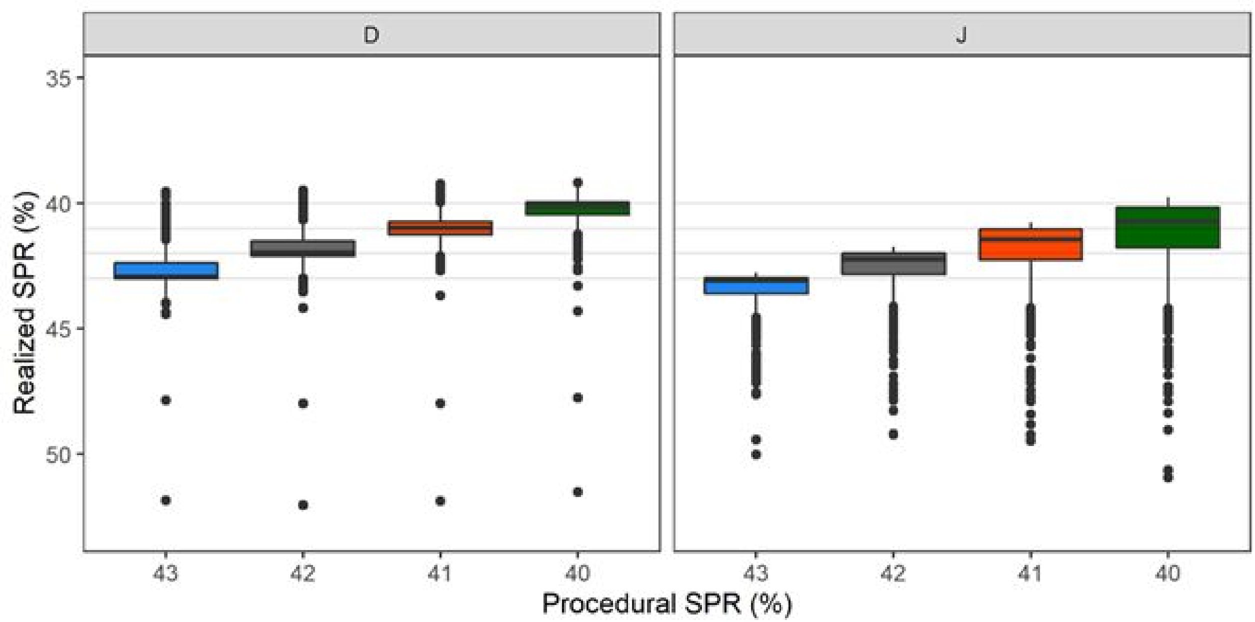

Figure 5. The average realized SPR over the long-term period for combinations of SPR values from 40-43% with MP-D and MP-J. The box outlines the 25th and 75th percentiles and the median is plotted as a horizontal line). Horizontal grid lines are shown for 40%, 41%, 42%, and 43% for reference. Sixteen simulations resulted in average SPR values for MP-D that were less than 20%, which are not plotted. Note that both axes are reversed to indicate increasing fishing intensity with decreasing SPR values.

Coastwide performance metrics differ between MP-D and MP-J in important ways (Figure 6). The long-term average RSB is slightly less in MP-D for the same SPR, and the probability of the stock status being lower than 20% is higher, although still less than 5%. The AAV is less for MP-D. The probability of the annual change being greater than 15% in three or more years of a ten-year period is near 5% for MP-D, and is zero for MP-J (as defined by the constraint). Therefore, the annual change in TCEY is never more than 15% in MP-J but is on average higher in MP-J (likely near 15% most of the time). The median TCEY is slightly greater for MP-D, for a given SPR, and is at lower values more often for MP-J.

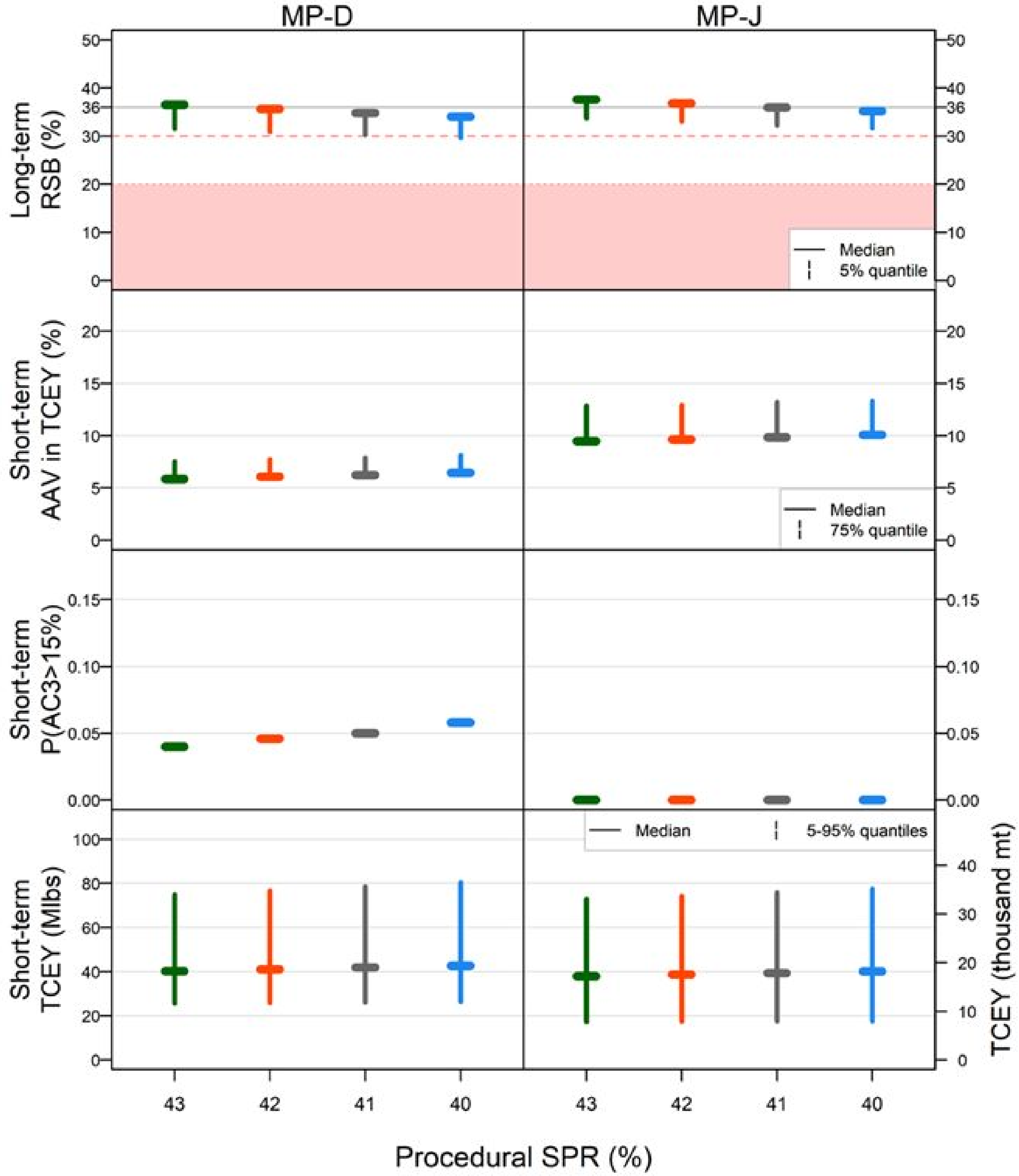

Figure 6. Coastwide performance metrics for SPR values ranging from 40 to 43% using MP-D and MP-J. The median value is shown as a horizontal line and quantiles are shown with vertical lines. Light gray horizontal lines are drawn for reference.

It is useful to compare MP-D and MP-J at distinct but different procedural SPR values that make them more similar. For MP-D, a procedural SPR near 42% would maintain the stock equally above and below the target RSB of 36%, while for MP-J, a procedural SPR near 41% would satisfy that objective. The stability metrics are still different between the two procedures at these two SPR values, with MP-D having a lower AAV but a higher probability of exceeding a 15% annual change in the TCEY. The median TCEYs for the two procedures are more similar, but MP-D shows TCEYs less than 20 Mlbs (~9,100 mt) much less often. They both have a similar chance of experiencing high TCEYs near 80 Mlbs (~36,300 mt).

Overall, at the coastwide level, both MPs meet the coastwide biological sustainability objectives, but MP-D has a slightly higher risk of experiencing low stock status because the fishing intensity may increase to accommodate the agreements, which results in a slightly higher TCEY (Figure 6). The change in the annual TCEY has different patterns between the two MPs because the accommodation of the agreements in MP-D is not subject to the constraint and the maximum fishing intensity is not affected by the control rule, in this implementation. Furthermore, other performance metrics show that a change in the TCEY that is greater than 15% is more often associated with an increase (about eleven times more often).

The results are not as straight-forward when examining the short-term fishery sustainability performance metrics for IPHC Regulatory Areas (Figure 7). The stability performance metrics converge to similar values across all IPHC Regulatory Areas with MP-J. IPHC Regulatory Areas 2A and 2B lose stability because MP-J does not have the agreements for those areas and IPHC Regulatory Area 4B gains a considerable amount of stability with MP-J due to the averaging of the estimated stock distribution. The AAV is similar for other IPHC Regulatory Areas, but the probability that the TCEY changes by more than 15% in three or more years increases for all IPHC Regulatory Areas except 4B. The long-term results for stability metrics show improved stability with MP-J for more IPHC Regulatory Areas, especially 4A, 4B, and 4CDE (Figure 8).

The TCEY tends to be lower in IPHC Regulatory Areas 2A and 2B for MP-J, as expected without the agreement, and increases in all other IPHC Regulatory Areas (Figure 7). The increased TCEY that results from the agreements for the two IPHC Regulatory Areas in MP-D is spread across the remaining six areas in MP-J, although 2C and 3A have the largest increases. Long-term results show a similar pattern as short-term results.

These two MPs highlight the trade-offs present in distributing the TCEY to IPHC Regulatory Areas. Allocating TCEY to 2A and 2B, even when allowing for an increase in the fishing intensity, improves the stability for most areas in the short-term but has a different effect in the long-term (Figure 8). IPHC Regulatory Areas 4A, 4B, and 4CDE show the most improvement in stability in MP-J with little change in the median TCEY, while IPHC Regulatory Areas 2C and 3A show the largest increases in median TCEY in MP-J with little improvement to stability. These long-term insights are not related to the current primary objectives but highlight the differences between short-term and long-term effects.

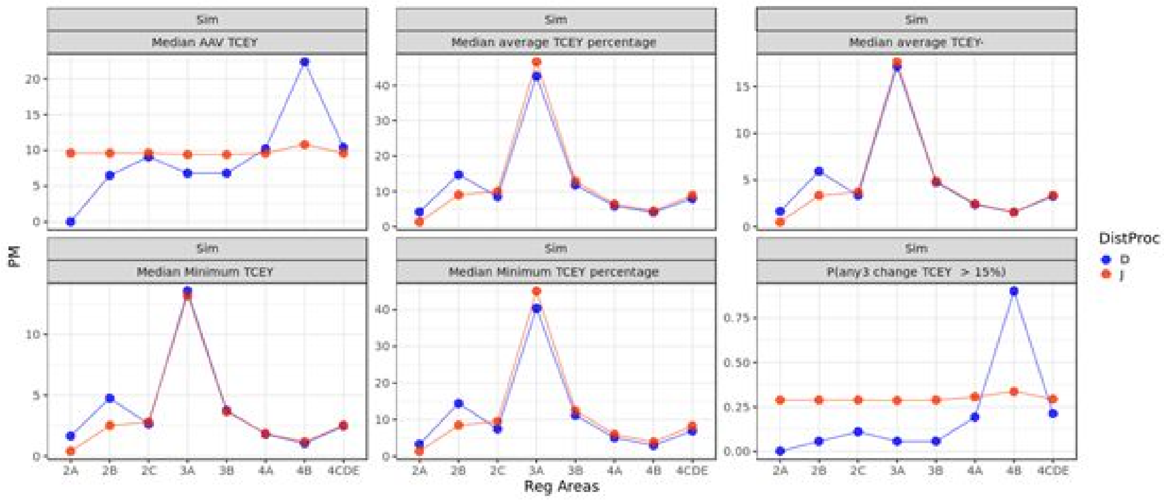

Figure 7. Short-term fishery sustainability performance metrics for IPHC Regulatory Areas using an SPR of 43% with MP-D (blue) and MP-J (red).

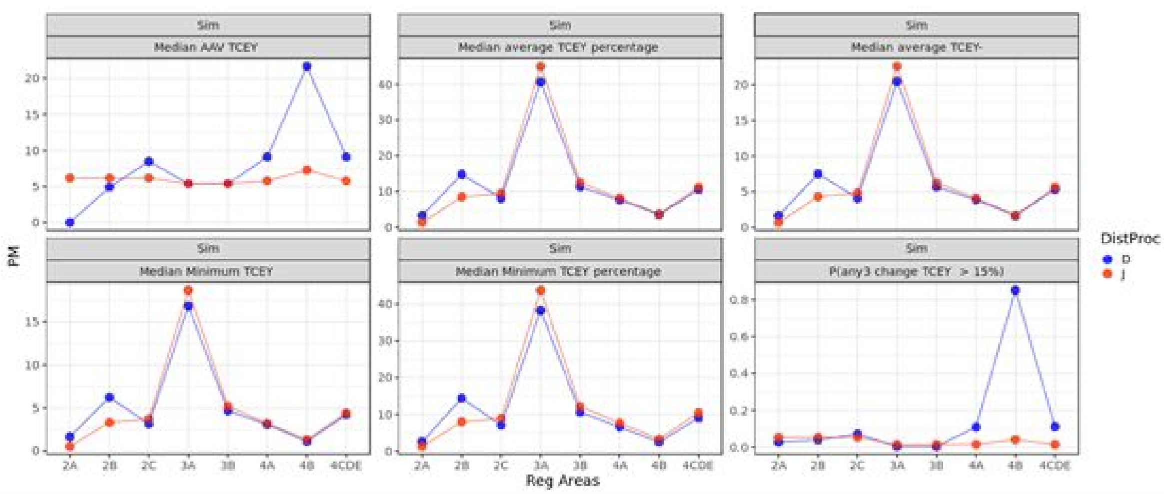

Figure 8. Long-term fishery sustainability performance metrics for IPHC Regulatory Areas using an SPR of 43% with MP-D (blue) and MP-J (red).

Overall, MP-D has a higher risk to the stock because the fishing intensity is allowed to increase without being affected by a control rule, although the performance metrics do not show a risk level beyond the tolerance defined in the primary objectives. The control rule helps to avoid low stock sizes and is very affective at maintaining the stock status above the limit reference point of 20%. A potential improvement to the concept of a maximum fishing intensity in MP-D would be to define a control rule on the minimum SPR as well such that increases in fishing intensity are suppressed when the stock size is low. Some potential methods are to 1) not accommodate the agreements when the stock status is below the trigger, 2) accommodate the agreements but not increase the fishing intensity when the stock status is below the trigger, or 3) increase the minimum SPR (i.e. reduce the maximum fishing intensity) when the stock status is less than the trigger as is done with the procedural SPR. Furthermore, elements of MP-D and MP-J can be combined such as averaging the estimated stock distribution or incorporating agreements for one IPHC Regulatory Area (e.g., paragraph 53 of IPHC-2020-MSAB016-R). These modified management procedures are not available for evaluation at this time.

3 POTENTIAL TOPICS FOR AN IPHC SECRETARIAT MSE PROGRAM OF WORK IN 2021-2022

MSE is a process that can develop over many iterations to investigate different aspects of a harvest strategy with the goals of identifying robust management procedures as well as understanding the dynamics of Pacific halibut. It is also a process that needs monitoring and adjustments to make sure that management procedures are performing adequately. Therefore, the MSE work for Pacific halibut will be ongoing as new objectives are defined, more complex models are built, new management procedures are defined, results are updated, and defined exceptional circumstances are observed.

3.1 Recent Commission and SRB recommendations and requests

The Commission had one request and one agreement at the 97th session of the IPHC Annual Meeting that was related to the MSE work (IPHC-2021-AM097-R).

> **AM097, para. 70.** *The Commission REQUESTED that the IPHC Secretariat consider and develop a draft MSE Program of Work for review by the Commission. The MSE Program of Work should describe technical versus policy oriented issues, linkages between/among specific work products, and sequencing considerations between/among items. The MSE Program of Work should describe the resources required to complete items.*
>
> **AM097, para.** ***71.*** *The Commission AGREED to meet intersessionally to review the draft MSE program of work for the IPHC Secretariat and provide direction on the prioritisation of tasks over the next 1-2 years, as well as the role of the MSAB in contributing to those tasks.*

Furthermore, the Commission noted many topics in the report for AM097 (IPHC-2021-AM097-R) that may be investigated with the MSE framework. These included investigating size limits and relative harvest rates among IPHC Regulatory Areas. A draft program of work is currently in development and the Secretariat is waiting to confirm a date for a meeting to review the draft with the Commission.

In 2020 the SRB made the following MSE-related recommendations and requests at the 16th and 17th sessions of the IPHC Scientific Review Board (SRB016 and SRB017).

3.1.1 SRB016, para. 26. *The SRB REQUESTED that the IPHC Secretariat carefully (i.e. narrowly) scope the MSE work for 2020 to questions that are reasonably determined given the rapid expansion of uncertainties in a more complex model. The MSE timelines for delivery is short; therefore, results will need to be presented conditional on some parameters and processes remaining highly uncertain. For example, processes that remain highly uncertain be collected in a "reference grid" of plausible scenarios and a "robustness grid" of processes that currently lack evidence based on historical data***.**

The IPHC Secretariat presented results from eleven MPs that were focused on the primary objectives defined by the Commission. The uncertainty and narrow scope of the operating model was communicated and affected the consideration of some MPs. For example MP-I was interpreted cautiously because the effects of changing relative harvest rates among IPHC Regulatory Area are likely dependent on migration assumptions. Development of a range of OMs representing uncertainty in various processes is currently underway.

3.1.2 SRB016, para. 27. *The SRB NOTED that stochasticity in Pacific halibut productivity is driven substantially by extrinsic factors (i.e. processes independent of Pacific halibut population size, structure, distribution, etc.). While the current approach is reasonable at this early stage of operating model development, the SRB REQUESTED that the IPHC Secretariat investigate intrinsic drivers (e.g. compensatory and depensatory effect) for at least some of these processes. Further integration of the IPHC's biological and ecosystem sciences research plan into the MSE operating model development could be used to sensitivity-test such scenarios. Given the existing MSE timelines, however, more complex operating models could be delayed until SRB018 in June 2021***.**

The development of the operating model is influenced by the outcomes of ongoing research and the research plan developed by the Biological and Ecosystem Sciences Branch (BESB). Currently, the operating model is in development to incorporate additional processes and the Secretariat is awaiting further direction from the Commission.

3.1.3 SRB016, para. 28. *The SRB NOTED autocorrelation structure in projected Pacific halibut weight-at-age in the spatial operating model. While such a structure adequately captures the smoothness of historical patterns, it is not clear whether it captures the correlation structure among ages. Therefore, the SRB REQUESTED that a multivariate normal distribution be investigated (for SRB018 June 2021) for weight-at-age deviations in which these are correlated among ages. This would involve fitting a multivariate time-series model instead of the ARIMA. Other forms of growth deviations (e.g. cohort-dependence) could also be used to better represent changes in weight-at-age over time.*

Improved methods to simulate weight-at-age will continue to be investigated with a particular focus on correlation among ages.

3.1.4 SRB016, para. 29. *The SRB NOTED that the operating model includes decision-making variability or implementation uncertainty. This is an important addition to the MSE because, while some management procedures may perform reasonably well if fully implemented, large inter-annual adjustments could be made in practice in response to anticipated economic and social disruptions to the fishery. Thus, the SRB REQUESTED further investigation of decision-making variability, including empirical analysis of the relationship between recommended and implemented harvest levels.*

We define implementation variability as the variation in the applied, realized, and perceived total mortality as compared to the total mortality determined from the application of the management procedure. These three types of implementation variability are all important to simulate for Pacific halibut and are described here.

1. **Decision-making variability** is the difference between the mortality limits determined from the MP and the mortality limits set by the Commission. With the decision-making step in the harvest strategy policy occurring after the management procedure, this is an important source of variability to simulate. However, it is difficult to determine the amount of variability, and a brief look at past outcomes is described below.
2. **Realized variability** is the difference between the mortality limits set by the Commission and the actual mortality caused by fishing. In recent years, the total mortality for Pacific halibut is typically slightly less than the total mortality limit, although for some fisheries it is above and others below. Work is currently being done to further characterize this mortality.
3. **Perceived variability** is the difference from the realized mortality that is a result of estimating the mortality rather than knowing the actual fishing mortality (e.g., for fisheries with uncertain discard mortality rates, and/or low levels of observer coverage). This has been highlighted as a source of variation that is important to the MSAB because some fisheries may have more uncertainty in the determination of their mortality. This type of variability will be implemented in the framework in the future.

Recent MSE simulations have included realized variability for a few of the fisheries. We describe the work being done to examine decision-making variability below.

The harvest policy has been evolving since 2013 as a result of a new stock assessment paradigm introduced in 2013 and the influence of the MSE results. Three important changes are noted here that influence the interpretation of decision-making variability. First, new assessments were completed at the end of 2012 (Stewart et al. 2012) and the end of 2013 (Stewart & Martell 2013) that addressed past retrospective patterns, introduced an ensemble of models, and presented decision tables to assist the Commission. Second, the Commission moved to making decisions on the TCEY in 2018 rather than the FCEY (para 30 in IPHC-2017-AM093-R). Lastly, the MSE investigations resulted in a move to an SPR-based harvest policy approach in 2018 with a reference SPR of 46% set initially based on an average of the SPR values from mortality limit decisions over the previous three years (para 29 in IPHC-2017-AM093-R).

The 2012 stock assessment re-examined the data and modelling and eliminated the large retrospective issues present in assessments prior to 2012. This resulted in a change in the outlook of the stock and a reduction in the mortality limits based on the management procedure at that time compared to prior years. The Commission was hesitant to make a large change in one single year given this new paradigm, thus took a moderate approach in 2013 and moved toward the new mortality limits, but did not adopt the full reductions. Therefore, the examination of decision-making variability begins with the decisions in 2014.

The Commission also moved to a new MP in 2018 that replaced the prior procedure called the “blue line” with an SPR-based approach that accounts for the mortality of all sizes and from all sources. There was little difference to the methods to provide advice to the Commission (e.g. presentation of a decision table) but it did allow for the Commission to move to setting TCEY limits rather than FCEY (historically representing the directed commercial fishery landings only, but adjusted over time to include other components based on IPHC Regulatory Area-specific catch agreements), bringing consistency across all IPHC Regulatory Areas.

Another result of the MSE work was to change the reference fishing intensity from $F_{SPR=46\%}$ to $F_{SPR=43\%}$ in 2020 for application in 2021. The Commission’s harvest strategy policy may be updated in the near future as additional MSE work is completed.

Decision-making variability was investigated by comparing the Commission’s mortality since 2014 with the mortality limits from the MP at that time (Figure 9). The coastwide TCEY has been set 9 to 20% higher than the MP TCEY, except in 2019 when it was 3.5% lower and in 2021 when it was the same.

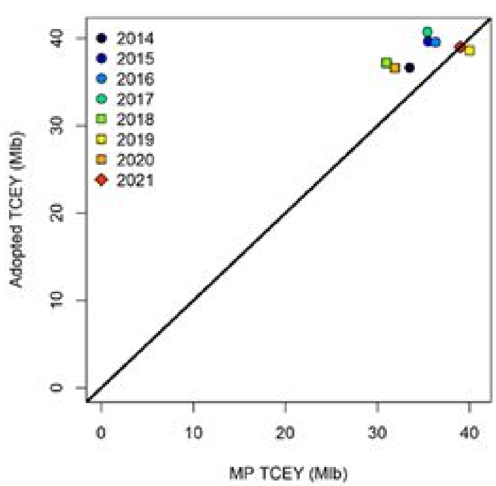

Figure 9. Comparison of adopted coastwide TCEY mortality limits for 2014-2021. Circles represent the years using the “blue line” MP, squares are years using an $F_{SPR=46\%}$ reference fishing intensity, and the diamond for 2021 is when $F_{SPR=43\%}$ was the reference fishing intensity. The diagonal line is the 1:1 line for comparison.

Examining each IPHC Regulatory Area highlights some area-specific trends (Figure 10). Many mortality limits were set higher than the MP mortality limits, but in some IPHC Regulatory Areas, such as 4A, the mortality limits were often near or less than the MP mortality limits. IPHC Regulatory Areas 2A and 2B show good correspondence in recent years, which is a result of interim agreements put in place as part of the current MP.

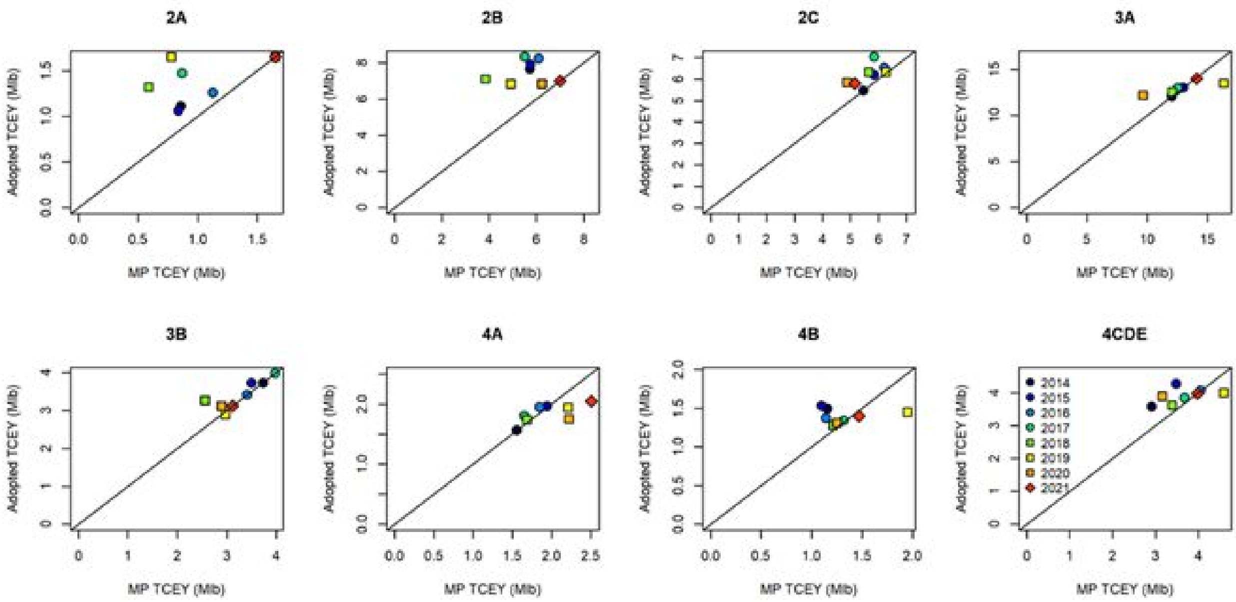

Figure 10. Adopted TCEYs plotted against the MP TCEYs for each IPHC Regulatory Area and years 2014–2021. Circles represent the years using the "blue line" MP, squares are years using an $F_{SPR=46\%}$ reference fishing intensity, and the diamond for 2021 is when $F_{SPR=43\%}$ was the reference fishing intensity. The diagonal line is the 1:1 line for comparison.

These investigations provide insight into past decision-making variability, but it is uncertain how this variability may change in the future, especially with changes in the MP. Looking at the level of risk the Commission is willing to accept (using probabilities from the decision table) shows that the decisions since 2014 have mostly shown a slightly greater acceptance of risk for metrics that are three years in the future and for a declining spawning biomass in the next year (Figure 11). However, when the risk that the spawning biomass may fall below 30% increases, the decisions appear to be closer to the MP.

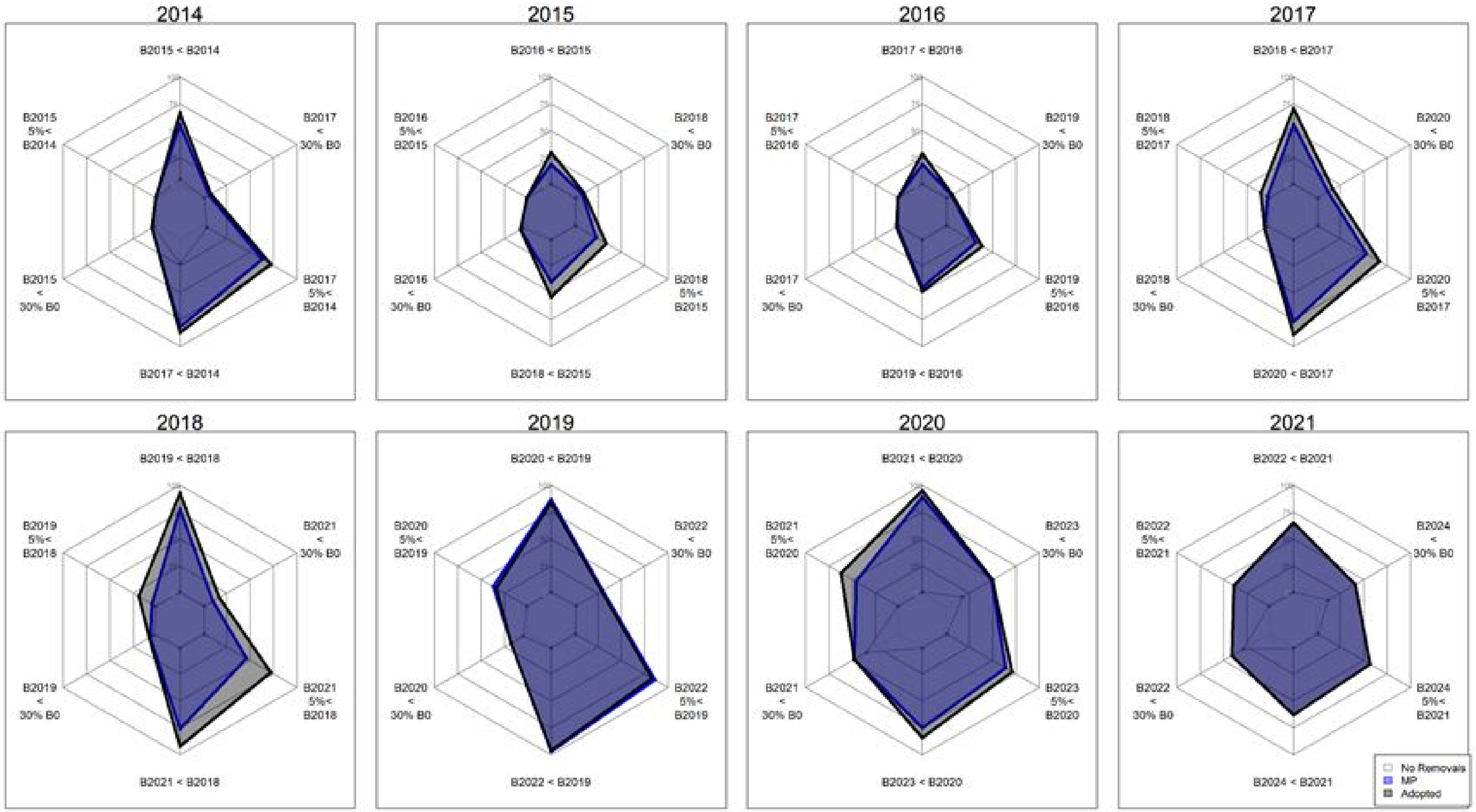

Figure 11. Radar plots comparing the risk levels from the decision table for the options “no removals” (thin line and points in center), the MP at that time (blue), and the adopted mortality limits (think line and gray) in each year from 2014–2021.

3.1.5 **SRB017, para. 57.** *The SRB NOTED three options for estimation error are available and currently the option of simulating estimation is the most appropriate option to evaluate results in 2020, but RECOMMENDED continuing work to incorporate actual estimation models, as in the third option, because that method would best mimic the current assessment process.*

A considerable amount of work was done to implement an estimation model that would mimic the behavior of the ensemble stock assessment. This method is preferred by the IPHC Secretariat, but some concern with simulated patterns of estimated stock abundance in the simulations led to the decision to focus on results obtained by simulating estimation error.

The development of an estimation model for simulation focused on reducing the running time, maintaining acceptable performance when compared to the ensemble stock assessment, the data requirements for an estimation model, and the deadlines imposed for delivery of results. Using stock synthesis, simplified versions of the short and long coastwide assessment models were tested to determine their performance and run times. The amount of data fitted by the models was reduced, some historical parameters were fixed at previous estimates to focus on near-term prediction, and convergence criteria were slightly reduced. These simplifications greatly decreased the run time (i.e. time to estimate the parameters without a hessian). Initially, there was a bias in stock status and fishing intensity when averaging the estimates from the two simplified models even when fixing the survey catchability at 1 and using an absolute index (Figure 12). The biases appeared to be occurring in the simplified short coastwide model because results from the simplified long coastwide model were more similar to the OM (Figure 13).

The Secretariat will continue to work on implementing an estimation module in the MSE framework that is representative of the ensemble stock assessment. It is important to mimic the ensemble assessment because multiple estimation models may offer a great stability in predictions when new data are added (Stewart and Hicks 2018). However, the halibut example used by Stewart and Hicks (2018) showed high correlations among the models in the ensemble, thus a single estimation model in the MSE simulations may suffice.

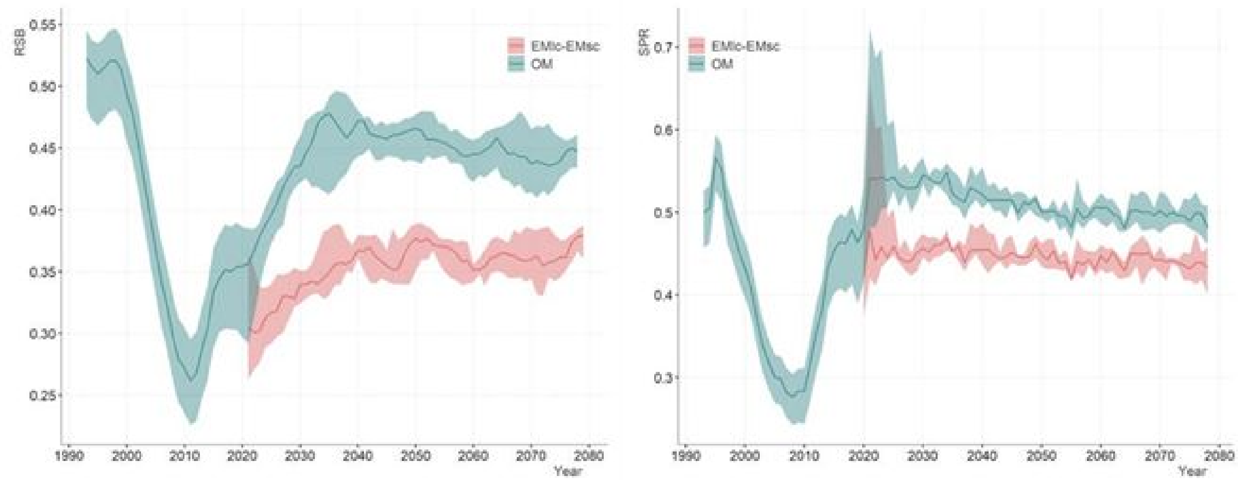

Figure 12. Results from ten simulated trajectories to examine the performance of a simplified ensemble estimation model (red) with the OM (green). Relative spawning biomass (RSB) is shown on the left and spawning potential ratio (SPR) is shown on the right for a simulated period of 60 years.

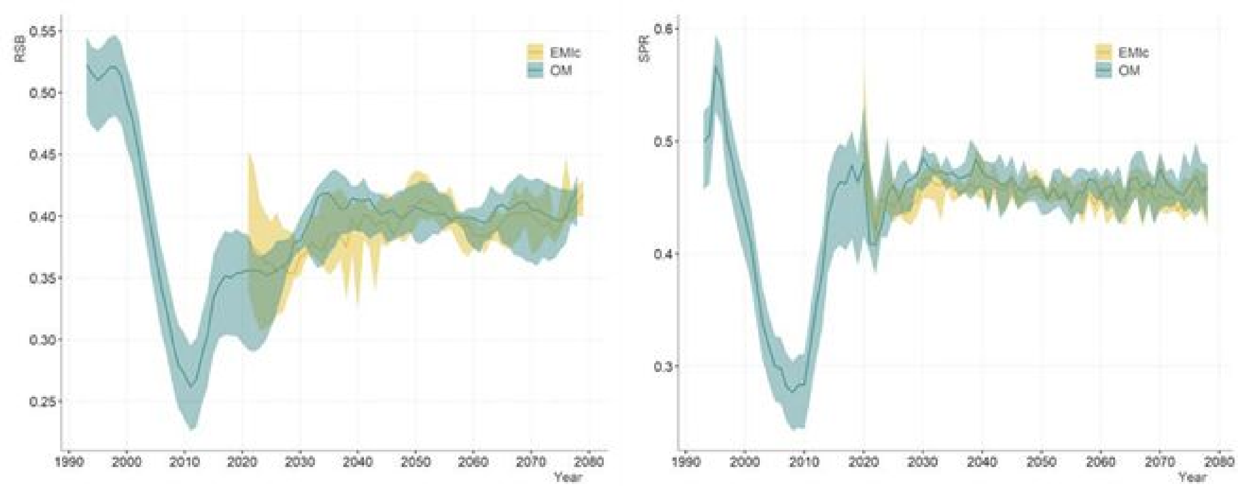

Figure 13. Results from ten simulated trajectories to examine the performance of the simplified long coastwide estimation model (yellow) with the OM (green). Relative spawning biomass (RSB) is shown on the left and spawning potential ratio (SPR) is shown on the right for a simulated period of 60 years.

3.1.6 SRB017, para. 59. *The SRB RECOMMENDED using the current MSE results to compare and contrast management procedures incorporating scale and distribution elements, but NOTED that, current results are conditional on some parameters and processes that remain uncertain. The uncertainty in applying the untested current approach potentially creates greater risk than adopting a repeatable management procedure that has been simulation tested under a wide range of uncertainties.*

This recommendation was communicated to the Commission as described under SRB016 request from paragraph 26 (Section 3.1.1 above).

3.1.7 SRB017, para. 60. *The SRB RECOMMENDED that Exceptional Circumstances be defined to determine whether monitoring information has potentially departed from their expected distributions generated by the MSE. Declaration of Exceptional Circumstances may warrant re-opening and revising the operating models and testing procedures used to justify a particular management procedure***.**

This is a topic that the Secretariat looks forward to discussing with the Commission at the intersessional meeting to discuss the MSE Program of Work and with the Management Strategy Advisory Board at a future meeting for feedback and recommendations. Some potential topics for exceptional circumstances include

1. Stock distribution
2. TCEY (coastwide and reg Area)
3. Assessment decision table probabilities
4. Changes in data collection (port sampling or survey)
5. Changes in fisheries (particularly bycatch)

3.1.8 SRB017, para. 61. *The SRB REQUESTED that the IPHC Secretariat include plotting function in the MSE Explorer to visualize among-Regulatory Area trade-offs in various yield statistics.*

The IPHC Secretariat updated the trade-offs page of the MSE Explorer and added a page showing trade-offs between IPHC Regulatory Areas. The latter page was often referenced and proved useful to examine the trade-offs that were important to many stakeholders.

3.2 Integration with Research Planning

In response to previous SRB requests to better integrate research planning with stock assessment and MSE priorities, a ranking system has been developed that includes separate and explicit (but not necessarily different) priorities for the research supporting the stock assessment and the MSE (see IPHC-2021-SRB018-10). MSE priorities have been subdivided into two categories: 1) biological parameterisation and validation of movement estimates, and 2) fishery parameterisation. Within these two categories, the following topics have been identified as top priorities.

3.2.1 Biological and population parameterisation

1. *Distribution of life stages and stock connectivity*

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

   This research includes examining larval and juvenile distribution which is a main source of uncertainty in the OM that is currently not fully incorporated. Outcomes will assist with conditioning the OM, verify patterns from the OM, and provide information to develop reasonable sensitivity scenarios to test the robustness of MPs. The recent work by Sadorus et al. (2021) is an example of the research that will benefit the development of the OM.

   Also included in this number one priority is stock structure research, especially with regard to IPHC Regulatory Area 4B. As noted above in the simulation results, the spawning biomass in IPHC Regulatory Area 4B showed a small percentage of the coastwide spawning biomass in the conditioned OM with and without fishing mortality (Figure 4). The dynamics of this IPHC Regulatory Area are not fully understood and it is useful to continue research on the connectivity of IPHC Regulatory Area 4B with other IPHC Regulatory Areas.

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

2. *Spatial spawning patterns and connectivity between spawning populations*

   An important parameter that can influence simulation outcomes is the distribution of recruitment across Biological Regions. Continued research in this area will improve the OM and provide justification for parameterising temporal variability. Research includes assigning individuals to spawning areas and establishing temporal and spatial spawning patterns. Outcomes may also provide information on recruitment strength and the relationship with environmental factors.

3. *Understanding growth variation*

   Changes in the average weight-at-age of Pacific halibut is one of the major drivers of changes in biomass over time and is an important consideration for many fish populations (Stawitz & Essington 2019). The OM currently simulates temporal changes in weight-at-age via a random autocorrelated process which is unrelated to population size or environmental factors. Ongoing research in drivers related to growth in Pacific halibut will help to improve the simulation of weight-at-age and satisfy the SRB request in paragraph 26 of IPHC-2020-SRB016-R (see Section 3.1.1).

3.2.2 Fishery parameterization

1. The specifications of fisheries and their parameterizations involved consultation with Pacific halibut stakeholders but some aspects of those parameterizations benefit from targeted research. One specific example is knowledge of discarding and discard mortality rates in directed and non-directed fisheries. Discard mortality can be a significant source of fishing mortality in some IPHC Regulatory Areas and appropriately modelling that mortality will provide a more robust evaluation of MPs. Current research includes DMRs in the directed longline fishery and in directed recreational fisheries.

3.3 Potential general categories for a program of work

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

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

The IPHC Secretariat will be meeting with the Commission to discuss and prioritize specific tasks within these categories. Part of that discussion will be the relationships between tasks, such as the development of migration scenarios to fully understand the long-term effects of size limits, and the time commitment with a recently reduced MSE Team.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2021-SRB018-07 which provides a response to requests from SRB016 and SRB017, and an update on model development for 2021.

b) **REQUEST** any further analyses to be provided at SRB019, September 2021.

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Report on Current and Future Biological and Ecosystem Science Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, 12 MAY 2021)

PURPOSE

To provide the Scientific Review Board with a description of progress on IPHC's five-year Biological and Ecosystem Science Research Plan (2017-21).

BACKGROUND

The primary biological and ecological research activities at IPHC that follow Commission objectives are identified and described in the IPHC Five-Year Biological and Ecosystem Science Research Plan (2017-21). These activities are integrated with stock assessment and the management strategy evaluation processes (Appendix I) and are summarized in five main areas, as follows:

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

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

SRB RECOMMENDATIONS AND REQUESTS

The SRB issued the following recommendations and requests in their report of SRB017 (IPHC-2020-SRB017-R):

Recommendation 1 (SRB017-Rec.02 (para. 31))

> ***"**the SRB **RECOMMENDED** that the research planning table shown in the meeting presentation for paper IPHC-2020-SRB017-08, be improved by adding clear prioritization of biological research needs for addressing uncertainties in the stock assessment and MSE programs. Ideally, this would be in the form of ranked biological uncertainties/parameters for the stock assessment and MSE operating model along with an explanation for deviations from this ranked list"*

The Secretariat has produced a ranked list of biological uncertainties and parameters for stock assessment (Appendix II) and the management strategy evaluation process (Appendix III) and their links to research activities and outcomes derived from the five-year research plan. Based on this information, the Secretariat has prioritized the biological research needs for addressing uncertainties in the stock assessment and MSE programs (Appendix IV).

Recommendation 2 (SRB017-Rec.03 (para. 49))

***"**the SRB **RECOMMENDED** that the IPHC Secretariat work with collectors to develop a series of benchmark summary statistics that characterize the quality of the Pacific halibut genome developed."*

The Secretariat completed in 2020 the first chromosome-level assembly of the Pacific halibut genome (https://www.ncbi.nlm.nih.gov/assembly/GCF_013339905.1) and was annotated by the NCBI Eukaryotic Genome Annotation Pipeline (NCBI Hippoglossus stenolepis Annotation Release 100; https://www.ncbi.nlm.nih.gov/genome/annotation_euk/Hippoglossus_stenolepis/100/). The summary statistics of the genome assembly are provided in Table 2 of this report.

*Recommendation 3 (*SRB017–Rec.04 (para. 53))

***"**The SRB **RECOMMENDED** that the IPHC Secretariat incorporate prioritization of research activities, as well as the timeline of available research outputs as inputs into the stock assessment and MSE processes."*

The IPHC Secretariat has prioritized the biological research needs for addressing uncertainties in the stock assessment and MSE programs (Appendix IV) and has produced a timeline of research outputs and their use as inputs into the stock assessment and MSE processes (please see document IPHC-2021-SRB018-10).

*Recommendation 4 (*SRB017–Rec.04 (para. 53))

***"**The SRB **RECOMMENDED** that the IPHC Secretariat identify those research areas with uncertainty and indicate research questions that would require the SRB to provide input and/or decision in future documentation and presentations provided to the SRB."*

The Secretariat has identified the following research questions related to research areas with uncertainty that would require guidance and input from the SRB:

1. Genetics and Genomics Research Area. Research questions:
    - 1.1. Review proposed development of a genetic marker panel (GT-seq) for downstream applications (e.g. individual population assignments).
    - 1.2. Review proposed population assignment methods to inform on distribution with particular emphasis in IPHC Regulatory Area 4B.

   1.3. Discuss potential interest and fishery sample collection designs for planning future coastwide assessment of stock composition with the use of a genetic marker panel.
   1.4. Discuss potential interest and study design considerations for planning future close-kin mark recapture studies to provide estimates of population size, connectivity, fecundity, etc.
2. Reproduction Area. Research questions:
   2.1. Review information presented on skip-spawning in Pacific halibut and discuss the scope and planning of research suggested in this area.
   2.2. Discuss ovarian sample collection designs to assess maturity and fecundity at temporal and spatial scales.
   2.3. Discuss strategies to scale maturity and fecundity information at the population level.
   2.4. Discuss need for long-term monitoring of maturity and fecundity.

*Request 1 (*SRB017–Req.07 (para. 33))

"*The SRB* ***REQUESTED*** *that the IPHC Secretariat further develop planning for the remainder of the current 5-year planning period and to revise and submit a comparable synthesis planning document for review at SRB018. In terms of the current research activities and research outcomes, further detail is needed in several areas, including:*

a) further detail for (i) specific research outcomes, (ii) specific relevance for stock assessment relevance, (iii) specific relevance for MSE (see Section 8.1 for examples);

b) prioritize research activities and research outcomes.."

The IPHC Secretariat has provided a description of the planned research activities contemplated for the remainder of the current 5-year Biological and Ecosystem Science Research Plan (2017-2021) in this document (page 18).

*Request 2 (*SRB017–Req.08 (para. 34))

"*The SRB* ***REQUESTED*** *that further clarification on funding and staffing needs required to meet self-imposed deadlines"*

The Secretariat has provided information on staffing and funding availability in relation to the estimated timeline of research outputs presented in SRB017 (please see document IPHC-2021-SRB018-10).

*Request 3 (*SRB017–Req.10 (para. 43))

> ***"****The SRB* ***REQUESTED*** *that the IPHC should clarify how skip-spawning research contributes to stock assessment and MSE functions. In particular, future research should develop and present:*
>
> *i. models for forecasting or estimating skip-spawning for Pacific halibut taking into account the timing of the sample collection, size / age and potentially condition factor of females;*
>
> *ii. estimates of the potential impact of skip-spawning scenarios on management procedure performance;*
>
> *iii. clear plans for analyses of histological data, including incorporation of age variation and locational variation;*
>
> *iv. details of experimental and sampling designs, as well as expected analyses for "measures of fecundity"."*

The IPHC Secretariat has provided a description of the relevance of research on skip-spawning for stock assessment and MSE in this document as well as in document IPHC-2021-SRB018-08. The IPHC Secretariat is assessing the scope and planning of research suggested in this area and guidance and input from the SRB is needed in order to fulfill this request.

*Request 4 (*SRB017–Req.11 (para. 44))

> ***"****The SRB* ***REQUESTED*** *that the IPHC Secretariat provide a plan for integration of research outcomes in this research area with outcomes in the genetics and genomics research area*"
>
> The SRB request to integrate growth research conducted by the IPHC Secretariat with genomics research is under consideration due to research prioritization, staffing and funding reasons and will be addressed in SRB018.

*Request 5 (*SRB017–Req.12 (para. 47))

> ***"****The SRB* ***REQUESTED*** *that the IPHC Secretariat provide the grant proposal funding the DMR work, and provide a more detailed presentation at SRB018"*
>
> The IPHC Secretariat will kindly provide the project narratives of grant proposals awarded to IPHC by the National Fish and Wildlife Foundation and North Pacific Research Board that provide funding for this work. In addition, a detailed presentation on this project will be provided at SRB018

*Request 6 (*SRB017–Req.13 (para. 51))

"*The SRB* ***REQUESTED*** *that the IPHC Secretariat prepare a research plan for describing and justifying how the knowledge (and all the resources expended in getting it) of the genome will be used to inform SA and MSE information needs (i.e. as per above request to further elaborate the research plan for this research area). This will likely require some form of interaction (e.g. collaborations, workshops) with outside researchers and/or agencies"*

The Pacific halibut genome represents a valuable and necessary resource to pursue population genomics studies that are aimed at defining population structure, identifying genetic baselines, assigning individuals to populations, identifying regions of the genome responsible for key biological traits, etc. The research activities that the IPHC Secretariat is planning to conduct regarding population genomics of Pacific halibut and that are relevant for stock assessment and MSE are concentrated on (1) establishing population structure, as the results may lead to revisit whether a single or separate stock assessment should be conducted in different IPHC regulatory areas, and (2) assigning individuals to source populations in order to derive stock composition and connectivity information, given that spatial dynamics are a major source of uncertainty in the stock assessment. Details of the initial planning and execution of these research activities are provided in this document and also in the form of a grant proposal that the IPHC Secretariat is preparing on these topics in collaboration with outside researchers and that would benefit from guidance and input from the SRB.

UPDATE ON PROGRESS ON THE MAIN RESEARCH ACTIVITIES

1. Migration and Distribution.

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

   1.1. Larval distribution and connectivity between the Gulf of Alaska and Bering Sea.
   Principal Investigator: Lauri Sadorus (M.Sc.)

   Knowledge of the dispersal of Pacific halibut larvae and subsequent migration of young juveniles has remained elusive because traditional tagging methods are not effective on these life stages due to the small size of the animals. This larval connectivity project, in cooperation with NOAA EcoFOCI, used two recently developed modeling approaches to estimate dispersal and migration pathways of larval and young juvenile Pacific halibut in order to better understand the connectivity of populations both within and between the Gulf of Alaska and Bering Sea. The results of this study have been published in the journal *Fisheries Oceanography* (Sadorus et al., 2021).

1.2. Wire tagging of U32 Pacific halibut.
Principal Investigator: Joan Forsberg (B.Sc.)

The patterns of movement of Pacific halibut among IPHC Regulatory Areas have important implications for management of the Pacific halibut fishery. The IPHC Secretariat has undertaken a long-term study of the migratory behavior of Pacific halibut through the use of externally visible tags (wire tags) on captured and released fish that must be retrieved and returned by workers in the fishing industry. In 2015, with the goal of gaining additional insight into movement and growth of young Pacific halibut (less than 32 inches [82 cm]; U32), the IPHC began wire-tagging small Pacific halibut encountered on the National Marine Fisheries Service (NMFS) groundfish trawl survey and, beginning in 2016, on the IPHC fishery-independent setline survey (FISS). In 2020, 465 Pacific halibut were tagged and released on the IPHC FISS but no tagging was conducted in the NMFS groundfish trawl surveys because of its cancellation due to COVID-19. Therefore, a total of 3,577 U32 Pacific halibut have been wire tagged and released on the IPHC FISS and 96 of those have been recovered to date. In the NMFS groundfish trawl surveys through 2019, a total of 6,536 tags have been released and, to date, 69 tags have been recovered.

2. Reproduction.

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

2.1. Sex ratio of the commercial landings.
Principal Investigator: Anna Simeon (M.Sc.)

The IPHC Secretariat has completed the processing of genetic samples from the 2017, 2018 and 2019 aged commercial landings. Given that additional years of commercial catch sex-ratio information are likely to further inform selectivity parameters and cumulatively reduce uncertainty in future estimates of stock size, the IPHC Secretariat is currently processing genetic samples from the 2020 age commercial landings.

The IPHC Secretariat is continuing work towards providing sex ratio information in years previous to 2017 through the use of genotyping techniques using historical otolith samples. Initial tests conducted by the IPHC Secretariat have not been conclusive regarding the ability to extract sufficient amounts of quality DNA from clean archived otoliths. Further work in this area was postponed until work can be resumed in the IPHC laboratory.

2.2. Maturity assessment.
Principal Investigator: Josep Planas (Ph.D.)

Recent sensitivity analyses have shown the importance of changes in spawning output due to skip spawning and/or changes in maturity schedules for stock assessment (Stewart and Hicks, 2018). Information of these key reproductive parameters provides direct input to stock assessment. For example, information on fecundity-at-age and –at-size could be used to replace spawning biomass with egg output as the metric of reproductive capability in the stock assessment and management reference points. This information highlights the need for a better understanding of factors influencing reproductive biology and success of Pacific halibut. In order to fill existing knowledge gaps related to the reproductive biology of female Pacific halibut, research efforts are devoted to characterize female maturity in this species. Specific objectives of current studies include: 1) histological assessment of the temporal progression of female developmental stages and reproductive phases throughout an entire reproductive cycle; 2) investigation of skip-spawning in females; and 3) fecundity estimations.

2.2.1. Histological assessment of the temporal progression of female developmental stages and reproductive phases throughout an entire reproductive cycle.

Sample collection. Biological samples (gonads, blood, pituitary, otolith, fat content) from female Pacific halibut were collected at monthly intervals throughout an entire calendar year, from September 2017 until August 2018. At each month, 30 females > 90 cm in fork length were collected to select for mature females, as females of this size range have a greater than 0.5 probability of being mature (Clarke et al., 1999). Pacific halibut were captured by a contracted longline commercial fishing vessel in the Portlock region in the central Gulf of Alaska, historically known to contain major spawning grounds (St. Pierre, 1984), in order to attempt collecting fish from a single spawning population of Pacific halibut at various stages during their reproductive cycle. Length (fork length) and weight (round weight) measures were recorded. Blood samples were drawn from the caudal vein with the use of heparinized hypodermic needles and syringes, centrifuged at 1,500 x g for 30 min and plasma samples were frozen and kept at -20C. Somatic fat content was estimated using a Distell Fish Fatmeter (Model FM 692, Fauldhouse West Lothian, Scotland) by taking two readings from an area located midway between the lateral arch and the dorsal fin insertion on the non-pigmented side of the fish and applying the average to a fat calibration curve developed for Pacific halibut to derive percent fat content values. Ovaries and liver were excised and weighed to calculate the gonadosomatic index (GSI; ovary weight/round weight x 100) and hepatosomatic index (HSI; liver weight/round weight x 100). Two small ovarian fragments were dissected per ovary and one fragment was fixed in buffered formalin for histological analysis and stored at room temperature and the other fragment was placed in pre-labeled 2 ml screw-cap microcentrifuge tubes containing 1 ml of RNAlater and kept frozen at -20C. Pituitary glands were also collected into RNAlater-prefilled microcentrifuge tubes and kept frozen at -20C.

All sampled Pacific halibut were assigned one of the four maturity stages for females (immature, maturing, ripe and resting) that are currently applied in IPHC's FISS for maturity assessment based on visual/macroscopic criteria of the gonads. Photographic images of the gonads were also taken in order to validate the visual assignment.

Histological analyses and developmental stage or reproductive phase classification criteria. Ovarian tissue samples (360 in total) were processed for histology by an independent laboratory (Histology Consultation Services, Everson, Washington, USA) where two series of four micrometer (µm) thick Paraffin sections, separated by approximately 500 µm, were mounted on two slides and stained with hematoxylin and eosin. Slides were examined visually with a compound microscope (1x – 100x magnification) and ovarian follicle developmental stages were assigned as described in Fish et al. (2020). In brief, the oocyte developmental stages described for Pacific halibut corresponded to Primary Growth (PG): one nucleolus (PGon), perinuclear (PGpn), cortical alveolar (PGca); Secondary Growth: primary-, secondary-, and tertiary-vitellogenesis (Vtg1, Vtg2, Vtg3): and Oocyte Maturation: germinal vesicle migration (GVM), and periovulatory (PO) (Fish et al., 2020). As shown in this previous study, female developmental stages were assigned on the basis of the most advanced oocyte stage present in the ovarian sections examined. Furthermore, female reproductive phases were determined by comparing female developmental stages with histological indications of past spawning events (e.g. presence of post-ovulatory follicles, atretic follicles, blood vessels, etc.) and assigned as immature, developing, spawning capable, regressing or regenerating according to Brown Peterson et al. (2011).

Results. The temporal analysis of female developmental stages showed a clear progression in reproductive development, with females in early vitellogenesis (Vtg1) predominantly from March until June, progressing to mid vitellogenesis during July and August and to late vitellogenesis from September to December (Fish et al., in preparation; figures provided separately). Females at the GVM stage appeared in low numbers in November and December and increased to almost 50% in January. Females at the PO stage were found only in January and February, coinciding with the period when females with the post-ovulatory follicles (i.e. evidence of spawning) were found. Therefore, these results clearly reflect the group-synchronous oocyte developmental reproductive strategy of Pacific halibut and confirm that the peak period of spawning takes place in January and February. Analysis of the temporal changes in female reproductive phase shows that spawning capable females are detected as early as August and that they are prevalent until December, coinciding with the temporal progression of females in the late vitellogenic (Vtg3) developmental stage. These results indicate that the transition between mid and late vitellogenesis (Vtg2 to Vtg3) marks the beginning of the spawning capable reproductive phase, that for stock assessment purposes, contains females that are considered mature. Importantly, the detection of spawning capable females in July-August is conducive to conducting routine histological assessments of female maturity during the IPHC's FISS sample collection, as these are conducted between June and late August.

For all examined females, data on average oocyte diameter, GSI, HSI, Fulton's K, age and fat content was expressed by month of collection, by female developmental stage and by female reproductive phase. Significant positive correlations (Pearson, $p < 0.05$) were observed between oocyte diameter and GSI and also between Fulton's K and HIS, likely a reflection of ovarian development and the important role of the liver in lipid storage.

Current activities. Preparation of a manuscript for publication describing temporal progression of reproductive development in female Pacific halibut and relationship of reproductive development with physiological condition indicators is in progress (Fish et al., in preparation).

2.2.2. Investigation of skip-spawning in females.

Sample collection and methodology. Histological samples described in 2.2.1 were examined for the possible presence of skip spawning females (i.e. mature females that do not produce gametes in a given reproductive cycle), as described in Rideout et al (2005). Search for potential skip spawning females was focused on the period during the reproductive cycle when females initiate the progression of oocyte development towards oocyte maturation and spawning. This period, as indicated in section 2.2.1, begins with the transition between Vtg2 and Vtg3 developmental stages that marks the beginning of the spawning capable reproductive phase starting in August. Only females collected between the months of August and February (i.e. the end of the spawning period) and that were classified at a developmental stage less advanced than Vtg2 were examined. The presence of the following features characteristic of skip spawning females (Rideout et al., 2005) were recorded in the examined females: degenerating ovarian follicles, blood vessels, enlarged extracellular matrix, muscle bundles and thick ovarian wall (if present in the histological sections).

Results. During the spawning capable phase (August to February), eight females were classified at the CA developmental stage (one collected in November and seven in December) and one at the PGpn developmental stage (Table 2). During these two months, all remaining females were classified at the Vtg3 or GVM developmental stages. The female at the PGpn developmental stage that was collected in December was 9 years old, showed tightly compacted ovaries with no signs of degeneration and was, therefore, classified as immature (average age at 50% maturity is estimated to be 11.6 years; Stewart and Webster, 2021). All other females at the CA stage ranged in age from 10 until 15 years and all showed presence of reabsorbing follicles, with various degrees of muscle bundle presence and blood vessels. With the available histological evidence it is difficult to distinguish between immature females that initiated their first reproductive cycle and failed to progress and mature females (i.e. previous spawners) that are true skip spawners.

Current activities. Examine biological measures of potential skip spawners and compare them with those of maturing females to try to establish if age, length, weight, condition or fat content could explain the ovarian developmental delay in these females. Blood and pituitary samples from these fish could be examined for potential differences in endocrine reproductive markers (e.g. plasma steroid hormone levels and pituitary mRNA expression levels of FSH and LH).

Table 1. Biological measures and developmental stage and reproductive phase classification of Pacific halibut females showing delayed ovarian development during the spawning capable phase.

Month	Female #	Weight (kg)	Length (cm)	Age (years)	Oocyte diameter (microns)	Gonadosomatic index (%)	Hepatosomatic index (%)	Fat content (%)	Developmental stage	Reproductive phase
Nov	27	14.73	108	15	394.33	0.71	0.64	2.22	CA	Regenerating
Dec	4	19.08	114	11	348.74	0.43	0.80	1.66	CA	Regenerating
Dec	5	24.13	124	15	328.57	0.51	0.90	1.90	CA	Regenerating
Dec	20	9.56	91	12	316.45	0.46	1.15	1.78	CA	Regenerating
Dec	23	20.72	120	14	336.67	0.47	0.92	2.74	CA	Regenerating
Dec	24	22.81	122	11	418.48	0.49	1.29	2.32	CA	Regenerating
Dec	26	19.65	119	10	438.52	0.55	0.89	1.66	CA	Regenerating
Dec	27	18.91	117	12	354.43	0.51	0.67	1.69	CA	Regenerating
Dec	25	8.85	90	9	221.90	0.52	0.88	1.21	PGpn	Immature

2.2.3. Fecundity estimations in Pacific halibut. The IPHC Secretariat is conducting a review of existing literature of described methods for fecundity measures in fish species with determinate fecundity, such as the Pacific halibut. In addition, contacts with experts in the field are also being pursued. Plans for collecting a small number of Pacific halibut ovaries in the field (FISS) for testing existing methodologies are currently in preparation (please see section on future research activities).

3. Growth.
Principal Investigator: Josep Planas (Ph.D.)

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.

3.1. Identification and validation of physiological markers for somatic growth. The IPHC Secretariat has recently completed a study funded by the North Pacific Research Board (Project No. 1704) that involved the combination of transcriptomic and proteomic approaches for the identification of physiological markers for somatic growth. This study resulted in the identification of 23 markers in skeletal muscle that were indicative of growth suppression and 10 markers in skeletal muscle that were indicative of growth stimulation. These markers represented genes and proteins that changed both their mRNA expression levels and abundance levels in skeletal muscle, respectively, in parallel with changes in the growth rate of Pacific halibut. From these, three markers showed patterns of expression and abundance that mirrored the change in growth rate: Asparagine synthetase, Ornithine carbamoyltransferase (both involved in amino acid and protein synthesis) and ubiquitin carboxyl-terminal hydrolase (involved in muscle contraction and development). A manuscript describing the procedures and results of this study is in preparation (Planas et al., in preparation).

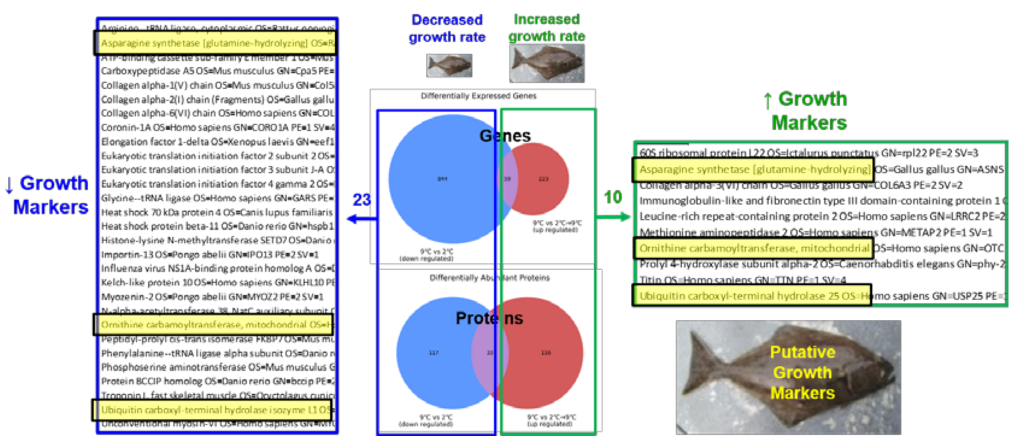

Figure 1. Identification of physiological growth markers. Markers on the left (blue box) and on the right (green box) correspond to markers that change both at the level of mRNA expression and protein abundance with decreased and increased growth rates, respectively. Markers highlighted in yellow correspond to markers that mirror changes in growth rate, irrespective of the direction of the change.

3.2. Application of molecular growth markers for evaluating growth patterns in the Pacific halibut population. The IPHC Secretariat has developed molecular assays to measure the mRNA expression levels by real time qPCR of growth markers identified in 3.1. These markers will be used to test the hypothesis that size differences among fish of the same age may be reflected by differences in the mRNA expression levels of growth markers and, therefore, validate the use of molecular growth markers to inform on growth patterns of Pacific halibut (please see section on future research activities).

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

Information on all Pacific halibut removals is integrated by the IPHC Secretariat, providing annual estimates of total mortality from all sources for its stock assessment. Bycatch and wastage of Pacific halibut, as defined by the incidental catch of fish in non-target fisheries and by the mortality that occurs in the directed fishery (i.e. fish discarded for sublegal size or for 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 parametization (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.
Principal Investigator: Claude Dykstra (B.Sc.)

A manuscript describing discard mortality rate estimations in the directed longline fishery has been finalized and is being prepared for submission to the Journal of North American Fishery Management (Loher et al., in preparation). Additional updates on modeling analyses of potential relationships between individual physiological characteristics, environmental conditions and handling practices, as well as on the ability of electronic monitoring systems to capture release methods and individual lengths of captured fish, will be provided at SRB019.

4.2. Estimation of discard mortality rates in the charter recreational sector.
Principal Investigator: Claude Dykstra (B.Sc.)

The IPHC Secretariat is conducting a research project to better characterize the nature of charter recreational fisheries with the ultimate goal of better understanding discard practices relative to that which is employed in the directed longline fishery. This project has received funding from the National Fish and Wildlife Foundation and the North Pacific Research Board (Appendix V) and the project narratives of both projects are provided. The experimental field components of this research project will take place in Sitka, Alaska (IPHC Regulatory Area 2C) from 21-27 May 2021, and in Seward, Alaska (IPHC Regulatory Area 3A) from 11-16 June 2021, with methods and analyses detailed in the project narratives provided. In brief, Pacific halibut will be captured with the use of 12/0 and 16/0 circle hooks that best capture the gear currently used in this fishery and fish sizes will be targeted to cover the Pacific halibut size distribution recorded by ADFG on an annual basis. All injuries will be documented, along with length, weight, somatic fat measurements (using the Distell Fatmeter), and a blood sample (for measuring the levels of physiological stress indicators in plasma) for each fish, before they are tagged and released. Environmental information on temperature (bottom/surface) and time (fight time, time on deck) will also be tracked. Eighty (80) Pacific halibut of Excellent release viability will be fitted with a satellite pop-up archival tag (sPAT – Wildlife Computers) for near term survival estimation in IPHC Regulatory Area 3A.

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

5.1. Population genomics.
Principal Investigator: Andy Jasonowicz (M.Sc.)

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

5.1.1. Determine the genetic structure of the Pacific halibut population in the Convention Area. Understanding population structure is imperative for sound management and conservation of natural resources (Hauser and Carvalho 2008). Pacific halibut in Canadian and USA waters are managed by the IPHC as a single coastwide unit stock since 2006 (Stewart and Martell 2014). The rationale behind this management approach is based on our current knowledge of the highly migratory nature of Pacific halibut as assessed by tagging studies (Webster et al. 2013) and of past analyses of genetic population structure that failed to demonstrate significant differentiation in the northeastern Pacific Ocean population of Pacific halibut by allozyme (Grant et al. 1984) and small-scale microsatellite analyses (Bentzen et al. 1998; Nielsen et al. 2010). However, more recent studies have reported slight genetic population structure on the basis of genetic analysis conducted with larger sets of microsatellites suggesting that Pacific halibut captured in IPHC Regulatory Area 4B may be genetically distinct from other areas (Drinan et al., 2016). These findings of subtle genetic structure in the Aleutian Island chain area are attributed to limited movement of adults and exchange of larvae between this area and the rest of the stock due to the presence of oceanographic barriers to larval and adult dispersal (i.e. Amchitka Pass) that could represent barriers to gene flow. Unfortunately, genetic studies suggesting subtle genetic structure (Drinan et al. 2016) were conducted using a relatively limited set of microsatellite markers and, importantly, using genetic samples collected in the summer (i.e. non-spawning season) that may not be representative of the local spawning population.

With the collection of winter (i.e. spawning season) genetic samples in the Aleutian Islands by the IPHC in early 2020, the IPHC has initiated efforts to re-examine population genetic structure using low-coverage whole-genome resequencing (lcWGR) (Therkildsen and Palumbi 2017; Clucas et al. 2019). Previous sample collections made during the spawning season will be used to investigate spatial and temporal patterns of population structure. The inclusion of temporal replicates will enable the investigation of variability of these patterns of time, ensuring confidence in the results (Waples, 1998). The available samples correspond to the following geographic areas and dates of collection:

- British Columbia (Haida Gwaii; 1999, 2004, 2007)
- Central Gulf of Alaska (Portlock region; 1999, 2004, 2007, 2018)
- Bering Sea (Pribilof Canyon; 2004, 2007)
- Central Aleutian Islands (Adak; 2007, 2020)
- Western Aleutian Islands (Attu; 2020)

DNA has been extracted and purified from these samples, sequencing libraries have been constructed, and we are now generating DNA sequence data. Qiagen DNeasy Blood & Tissue Kits (Qiagen, Valencia, California, USA) were used to extract and purify genomic DNA from a total of 50 samples per collection (600 total). Dual-indexed Illumina sequencing libraries were prepared for each sample using Illumina's Tagment DNA TDE1 Enzyme ran Buffer Kit (Illumina, San Diego, California, USA) according to previously published protocols (Therkildsen and Palumbi 2017). In September of 2020, an initial sequencing run of 36 samples was conducted using the Illumina HiSeq 4000 (2x150 bp paired end reads) platform by the Novogene Corporation (Novogene, Sacramento, CA, USA). This sequencing run was carried out to ensure that the library preparation methods worked and to begin working on a bioinformatics pipeline for processing the raw sequence data, which was done as follows. FastQC (v11.9) (Andrews et al. 2015) was used to assess the quality of the raw sequence reads. Illumina adapter sequences were removed using trimmomatic (v0.39) (Bolger et al. 2014). The trimmed reads were then mapped to the Pacific halibut reference genome (NCBI RefSeq Accession: GCF_013339905.1) using the minimap2 aligner (v2.17) (Li 2018) with the genomic short-read mapping presets. Samtools (v1.12) (Li et al. 2009) was used to filter alignments based on mapping quality scores, retaining those alignments with a score >= 20. Polymerase chain reaction (PCR) and optical duplicates were filtered out using picard (v2.25.2) ("Picard toolkit" 2019) with a pixel distance of 2500 specified. Overlapping ends of each aligned read pair were clipped using the clipOverlap tool in bamUtil (v1.0.14) (Jun et al. 2015). Lastly local realignment around insertion/deletion elements was performed using GATK (v3.8) (Van der Auwera and O'Connor 2020). Single nucleotide polymorphisms (SNPs) were identified and genotype likelihoods were estimated using the GATK model implemented in ANGSD (v0.934) (Korneliussen et al. 2014). SNPs were retained if they had a global minor allele frequency of 0.05, p-value of 1e-6 or less for a site being variable, and present in at least 80% of the individuals.

An average of 26.5 million (range = 21.8 - 42.9 million) raw sequencing reads per sample were obtained from this sequencing run. The alignment of the reads to the Pacific halibut genome and quality filtering steps resulted in an average of 60% (range = 54% - 69%) of the raw reads being retained per sample and used for SNP calling. Individual genomic coverages for the quality filtered alignments were on average 3.2x (range = 2.6x – 5x). A total of 5,051,577 SNPs were identified using this preliminary dataset.

A second sequencing run of 250 samples was submitted to the Novogene Corporation in early 2021 for sequencing on the Illumina NovaSeq 6000 platform using an S4 flowcell (2x150 bp paired end reads). This data has been received and the run yielded an average of 24.7 million (range = 10.7 – 47.2 million) sequence reads per sample. Currently, the IPHC secretariat is working on setting up a cloud-computing environment in Micorsoft Azure for the bioinformatic processing of this data.

To date, 285 out of the 600 samples have been submitted for DNA sequencing. After sequencing is completed for all samples, measures of genetic differentiation (FST) will be estimated among the sample collections to examine levels of divergence between them and test for patterns of isolation by distance. The software ngsAdmix (Skotte et al. 2013), will be used to infer the number of genetic clusters across the range of Pacific halibut without making a priori assumptions about sample origin. This program also attempts to estimate the ancestry of individual fish and therefore will be useful in the identification of potential migrants. Additionally, outlier tests will also be used to scan the genome for SNPs showing signals of divergent selection. These SNPs showing potential signatures of selection may offer more power to resolve population structure in highly migratory marine fish (Grewe et al. 2015; Anderson et al. 2019). We will compare the results of multiple methods of SNP outlier detection, in particular both FST based methods (eg. OutFLANK (Whitlock and Lotterhos 2015), tess3r (Caye et al. 2016)) and PCA based methods (PCAngsd (Meisner and Albrechtsen 2018)) will be used. Furthermore, SNPs showing signals of selection may be functionally relevant and linked to local adaptations. Transcriptomic resources developed by the IPHC Secretariat have been used by NCBI to annotate the Pacific halibut genome (https://www.ncbi.nlm.nih.gov/genome/annotation_euk/Hippoglossus_stenolepis/100/) which will be necessary for interpreting the functional significance of SNPs identified in this study.

5.2 Generation of genomic resources.

Principal Investigator: Josep Planas (Ph.D.)

The IPHC Secretariat has conducted studies aimed at generating genomic resources for Pacific halibut that are instrumental for a more in-depth understanding the genetic make-up of the species: a reference genome and a comprehensive collection of expressed sequence tags (ESTs). The generated genomic resources will greatly assist current studies on the genetic structure of the Pacific halibut population, on the application of genetic signatures for assigning individuals to spawning populations and for a thorough characterization of regions of the genome or genes responsible for important traits of the species.

5.2.1 Pacific halibut genome sequencing. The Pacific halibut genome represents a valuable and necessary resource to conduct population genomics studies that are aimed at defining population structure, identifying genetic baselines, assigning individuals to populations, identifying regions of the genome responsible for key biological traits, etc. The research activities that the IPHC Secretariat is planning to conduct regarding population genomics of Pacific halibut and that are relevant for stock assessment and MSE are concentrated on (1) establishing population structure, as the results may lead to revisit whether a single or separate stock assessment should be conducted in different IPHC regulatory areas, and (2) assigning individuals to source populations in order to derive stock composition and connectivity information, given that spatial dynamics are a major source of uncertainty in the stock assessment (Appendix II and Appendix III). Details of the initial planning and execution of these research activities are provided in this document and also in the form of a grant proposal that the IPHC Secretariat is preparing on these topics in collaboration with outside researchers and that would benefit from guidance and input from the

SRB. The IPHC Secretariat completed the first draft sequence of the Pacific halibut genome in collaboration with the French National Institute for Agricultural Research (INRA, Rennes, France). The Pacific halibut genome has a size of 594 Mb and contains 24 chromosome-size scaffolds covering 98.6% of the complete assembly with a N50 scaffold length of 25 Mb at a coverage of 91x. The Pacific halibut whole genome sequence has been deposited at DDBJ/ENA/GenBank under the accession JABBIT000000000 and the chromosome-level assembly is available in https://www.ncbi.nlm.nih.gov/assembly/GCF_013339905.1. In addition, the Pacific halibut genome was also annotated by NCBI and is available as NCBI Hippoglossus stenolepis Annotation Release 100 (https://www.ncbi.nlm.nih.gov/genome/annotation_euk/Hippoglossus_stenolepis/100/). The Pacific halibut genome assembly statistics and assembly completeness are shown in Table 2.

Table 2. Pacific halibut genome assembly statistics and assembly completeness.

		Complete assembly	**Chromosomes only**
Assembly metrics	Number of scaffolds	120	24
	Total size of scaffolds	594,269,479	585,884,243
	Longest scaffold	32,413,955	32,413,955
	Shortest scaffold	4,965	11,318,318
	Mean scaffold size	4,952,246	24,411,843
	Median scaffold size	13,681	24,662,186
	N50 scaffold length	24,986,857	24,986,857
	L50 scaffold count	11	11
	% of assembly in chromosomes	-	98.6 %
	% of assembly in unanchored scaffolds	-	1.4 %
Assembly completeness	Complete BUSCOs (C)	4,472 (97.6%)	
	C and single-copy BUSCOs	4,345 (94.8%)	
	C and duplicated BUSCOs	127 (2.8%)	
	Fragmented BUSCOs	33 (0.7%)	
	Missing BUSCOs	79 1.7%)	

5.2.2 Transcriptome sequencing. The IPHC Secretariat has completed transcriptome (i.e. RNA) sequencing of a wide variety of tissues (12) in Pacific halibut including white and red skeletal muscle, liver, heart, ovary, testis, head kidney, brain, gill, pituitary, spleen and retina. The raw sequence data have been deposited in NCBI's Sequence Read Archive (SRA) under the bioproject number PRJNA634339 (https://www.ncbi.nlm.nih.gov/bioproject/PRJNA634339) and with SRA accession numbers SAMN14989915 - SAMN14989926. As previously described, the transcript assemblies for each tissue were annotated using the Trinotate pipeline. TransDecoder (v5.5.0) was used to identify open reading frames longer than 100 codons and used to predict likely protein coding sequences. Transcripts and predicted proteins were queried against the Swiss-Prot database using BLASTx and BLASTp, respectively, and annotated. Importantly, raw sequence data were provided to NCBI for the annotation of the Pacific halibut genome (https://www.ncbi.nlm.nih.gov/genome/annotation_euk/Hippoglossus_stenolepis/100/).

External Funding and Publication Generation throughout the Five-Year IPHC Biological and Ecosystem Science Research Plan (2017-2021)

In relation to the research areas and research activities contemplated in the Five-Year IPHC Biological and Ecosystem Science Research Plan (2017-2021), the external research grants awarded to the IPHC and the peer-reviewed journal publications resulting from research activities (published, submitted to a peer-reviewed journal and in preparation) are indicated in Appendix VI.

Remaining Research Areas Contemplated in the Five-Year IPHC Biological and Ecosystem Science Research Plan (2017-2021):

The following research activities are planned to be conducted prior to the finalization of the current 5-year Research Plan (2017-2021):

1. Migration and Distribution. Continuation of the wire tagging efforts of U32 Pacific halibut will take place in the FISS in 2021.

2. Reproduction.
    - 2.1. Sex-ratio information. Processing of fin clips from the 2020 commercial samples for DNA extraction and genotyping for sex will begin in the summer of 2021. In addition, efforts to attempt to purify DNA from archived otoliths will be resumed during the summer of 2021.
    - 2.2. Maturity assessment.
        - 2.2.1. Skip-spawning. Information on histological and biological characteristics of females with delayed ovarian development during the spawning capable reproductive phase will be contrasted with field observations (maturity classification and imaging).

2.2.2. Fecundity determinations. Current methods for fecundity determinations will be assessed and selected based on accuracy and feasibility for Pacific halibut field collections. Ovaries from three females that are classified as maturing (stage 2) will be collected in FISS for testing selected fecundity assessment methods in the Fall of 2021.

3. Growth. Following the identification of growth markers, as described in Planas et al. (in preparation), the IPHC Secretariat is planning on testing a set of real time qPCR-validated gene markers (alpha actin, asparagine synthetase, fast muscle myosin heavy chain, myosin regulatory light chain 2, ornithine carbamoyltransferase, fructose-2,6-bisphosphatase) on skeletal muscle samples from juvenile Pacific halibut collected in the field. These muscle samples correspond to a total of 30 age-matched individuals (4 years-old) of different sizes and will prove useful to test the hypothesis that size differences in age-match individuals are reflected by differences in the mRNA expression levels of growth marker genes, as assessed by real time qPCR. The muscle samples that will be processed correspond to three size categories of juvenile Pacific halibut: 30-36 cm (N=10), 44 cm (N=10) and 53-61 cm (N=10) in fork length.

4. Discard Mortality and Survival Assessment. Work contemplated in this area involves the field experimental component of the study on mortality rates and survival assessment of Pacific halibut discarded by the recreational fishery. This work is described in detail in the provided project narratives of the grants awarded from the National Fish and Wildlife Foundation and the North Pacific Research Board to conduct this work. This project will cease in 2021.

5. Genetics and Genomics. Planned research activities in this research area involve the completion of library construction and low coverage whole genome resequencing for the totality of 600 individual samples from Pacific halibut collected during the spawning season in order to establish the genetic structure and identify genetic baselines according to protocols presented at SRB017. The objectives, management implications, description of available sample collections and methodology are detailed in the Update on Progress on the Main Research Activities (Section 5) in the present document and in the provided project narrative of a grant proposal that the IPHC Secretariat is preparing for submission to a funding agency and that is requesting review from the SRB.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2020-SRB018-08 which provides a response to requests from SRB017, and a report on current and future research activities contemplated within the IPHC Five-Year Biological and Ecosystem Science Research Plan (2017-2021).
b) **REQUEST** any further analyses to be provided at SRB019, September 2021.

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APPENDIX I

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

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

APPENDIX II

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

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

APPENDIX III

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

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

APPENDIX IV

Potential prioritization of proposed research activities (next period)

Research areas	Research activities	Research outcomes	Relevance for stock assessment	Relevance for MSE	Specific analysis input	SA Rank	MSE Rank	Research priorization
Reproduction	Sex ratio of current commercial landings	Sex ratio-at-age	Scale biomass and fishing intensity		Annual sex-ratio at age for the commercial fishery fit by the stock assessment	1. Assessment data collection and processing		1
	Historical sex ratios based on archived otolith DNA analyses	Historical sex ratio-at-age						1
Mortality and survival assessment	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	2. Assessment data collection and processing		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		3
	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			3
	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			3
	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			3
Genetics and genomics	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	4
	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		5
Migration	Larval and juvenile connectivity studies	Improved understanding of larval and juvenile distribution	Improve estimates of productivity	Improve parametization of the Operating Model	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	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	6
	Discard mortality rate estimate: recreational fishery				Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits			6
	Best handling and release practices	Guidelines for reducing discard mortality			May reduce discard mortality, thereby increasing available yield for directed fisheries	2. Fishery yield		7
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	8
		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			8
		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			8

APPENDIX V
Summary of current awarded research grants

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**National Fish & Wildlife Foundation**	Improving the characterization of discard mortality of Pacific halibut in the recreational fisheries (NFWF No. 61484)	IPHC Dr J. Planas and Mr Claude Dykstra	Alaska Pacific University, U of A Fairbanks, charter industry	$98,902	Bycatch estimates	1 April 2019 – 30 June 2021
2	**North Pacific Research Board**	Pacific halibut discard mortality rates (NPRB No. 2009)	IPHC Dr. J. Planas	Alaska Pacific University,	$210,502	Bycatch estimates	1 January 2021 – 31 March 2022
Total awarded ($)					**$309,404**		

APPENDIX VI

Funding and publications resulting from research activities conducted during the 5-yr research plan (2017-2021)

Research areas	Research activities	Project participants	2017				2018				2019				2020				2021				Publications
Migration	Larval connectivity	AFSC-Seattle (lead), IPHC (Sadorus, Webster, Planas)														Ms prep	Ms submission		**Pub**				**Sadorus et al. 2021a**
Migration	Adult and juvenile migration	IPHC (Loher, Sadorus, Dykstra, Forsberg, 2017 IPHC Intern, Planas)																Ms prep	Ms sub				Loher et al. 2021a (in review)
Migration	Migration	IPHC																Ms prep	Ms sub				Carpi et al. 2021 (in review)
Migration	Environmental variabiliy and distribution	IPHC (Sadorus, Webster), UW																Ms prep	Ms sub				Sadorus et al. 2021b (in review)
Reproduction	Sex ratio of current commercial landings	IPHC (Simeon, Planas, Stewart)																				Ms prep	Stewart et al. 2022 (expected)
Reproduction	Sex-marking program	IPHC (Loher, Simeon, Erikson, Planas)																	Ms prep				Loher et al., 2021b (expected)
Reproduction	Reproductive assessment	IPHC (lead, Planas), APU													Ms prep	Ms submission		**Pub**					**Fish et al., 2020**
Reproduction	Reproductive assessment	IPHC (lead, Planas), APU																	Ms prep				Fish et al., 2021 (expected)
Reproduction	Reproductive assessment	IPHC (lead, Simeon, 2019 IPHC Intern, Planas)																			Ms prep		Simeon et al., 2022 (expected)
Reproduction	Field maturity classification	IPHC (lead, Planas), APU																		Ms prep			Fish et al., 2022 (expected)
Growth	Identification of growth markers	IPHC (lead, Simeon, Rudy, Planas), AFSC-Newport				NPRB 1704 Funding												Ms prep					Planas et al., 2021 (expected)
Growth	Direct temperature effects on growth	IPHC (lead, Simeon, Rudy, Planas), AFSC-Newport																					
Growth	Stress effects on growth	IPHC (lead, Simeon, Rudy, Planas), AFSC-Newport																				Ms prep	Hurst et al., 2022 (expected)
Growth	Growth pattern evaluation	IPHC (Simeon, Planas)																					2022 (expected)
Mortality and survival assessment	Trawl DMRs	AFSC (lead), IPHC (Loher)							Ms prep	Ms sub	**Pub**												**Rose et al., 2019**
Mortality and survival assessment	Longline DMRs	IPHC (lead, Dykstra, Loher, Stewart, Hicks, Planas), APU			Saltonstall-Kennedy NOAA Funding												Ms prep	Ms sub	**Pub**				**Kroska et al. 2021**
Mortality and survival assessment	Longline DMRs																**Pub**						**van Helmond et al. 2020**
Mortality and survival assessment	Longline DMRs																		Ms prep				Loher et al., 2021c (expected)
Mortality and survival assessment	Longline DMRs																					Ms prep	Dykstra et al., 2022 (expected)
Mortality and survival assessment	Recreational DMRs	IPHC (lead, Dykstra, Stewart, Hicks, Planas), APU									NFWF Funding												Dykstra et al., 2022 (expected)
Mortality and survival assessment	Recreational DMRs																		NPRB 2009 Funding				
Mortality and survival assessment	Pacific halibut trawl avoidance	PSMFC (lead), IPHC (Dykstra Simeon, Rudy, Planas)							BREP Funding								Ms prep	Ms sub	**Pub**				**Lomeli et al., 2021**
Genetics and Genomics	Genome sequencing	IPHC (lead, Jasonowicz, Simeon, Planas), INRA-France																	Ms prep				Jasonowicz et al., 2021 (expected)
Genetics and Genomics	Transcriptomic resources	IPHC (Jasonowicz, Simeon, Planas)																	Ms prep				Jasonowicz et al., 2022 (expected)
Genetics and Genomics	Population structure	IPHC (Jasonowicz, Planas)																					Jasonowicz et al., 2022 (expected)

Pub (in bold): publication in peer-reviewed journal

Ms sub: manuscript submitted to peer-reviewed journal (in review)

Ms prep: manuscript in preparation for submission to peer -reviewed journal

Pacific Halibut Multiregional Economic Impact Assessment (PHMEIA): update for SRB018

PREPARED BY: IPHC SECRETARIAT (B. HUTNICZAK; 11 MAY 2021)

PURPOSE

To provide an update on the International Pacific Halibut Commission (IPHC) economic study, including progress on developing the economic impact assessment model, state of the collection of primary economic data from Pacific halibut dependent sectors, and most recent results on regional and community economic impacts.

BACKGROUND

Under the Convention, the IPHC's mandate is *optimum* management of the Pacific halibut resource, which necessarily includes an economic dimension. Fisheries economics is an active field of research around the world in support of fisheries policy and management. Adding the economic expertise to the IPHC Secretariat, the IPHC has become the first regional fishery management organization (RFMO) in the world to do so.

The goal of the IPHC economic study is to provide stakeholders with an accurate and all-sectors-encompassing assessment of the economic impact of the Pacific halibut resource in Canada and the United States of America. The intention of this update is to inform on the project's progress.

The economic effects of changes to harvest levels can be far-reaching. Fisheries management policies that alter catch limits have a direct impact on commercial harvesters, but at the same time, there is a ripple effect through the economy. Industries that supply commercial fishing vessels with inputs, generally referred to as *backward-linked industries*, rely on this demand when making decisions related to their production levels and expenditure patterns. For example, vessels making more fishing trips purchase more fuel and leave more money in a local grocery store that supplies crew members' provisions. More vessel activity means more business to vessel repair and maintenance sector or gear suppliers. An increase in landings also brings more employment opportunities, and, as a result, more income from wages is in circulation. When spending their incomes, local households support local economic activity that is indispensable to coastal communities' prosperity.

Changes in the domestic fisheries output, unless fully substituted by imports, are also associated with production adjustments by industries relying on the supply of fish, such as seafood processors. Similarly to the directly affected sector, any change in production by the *forward-linked industry* has a similar ripple effect on its suppliers. The complete path of landed fish, from the hook to the plate, also includes seafood wholesalers and retailers, and, in the case of highly-prized fish such as Pacific halibut, services. Traditionally, the vast majority of Pacific halibut is consumed at white-tablecloth restaurants. Any adjustment in gross revenue generated by these industries resulting from a change in the supply of directly affected fish is further magnifying the economic impact of management decisions altering harvest levels.

Similar effects are attributed to the recreational fishing sector. By running their businesses, charter operators generate demand for fuel, bait fish, boat equipment, and fishing trip provisions. They also create employment opportunities and provide incomes that can be spent locally, supporting various local businesses. What is more, anglers themselves contribute to the economy by creating demand for goods and services related to their fishing trips. A number of sectors support tourism relaying on the Pacific halibut fishing, both guided and unguided. These include lodging, local retailers, or restaurants.

Besides shaping a complex combination of local effects, the industries' interlinked nature is generating cross-regional impacts. Economic benefits from the primary area of the resource extraction are leaked when inputs are imported, when wages earned by nonresidents are spent outside the place of employment, or when earnings from quota holdings flow to nonresident beneficial owners. At the same time, the inflow of economic benefits to the local economies from outside is occurring when products are exported or local businesses are bringing tourism cash to the region.

Understanding the multiregional impacts of changes to fisheries sectors is now more important than ever considering how globalized it is becoming. Fish harvested on the other side of the globe can be easily found on the shelf or on the menu in the United States or Canada, competing with domestically produced seafood. The United States and Canada imported seafood worth over USD 28.8 billion (CAD 37.4 billion) in 2018 (Statistics Canada, 2020a; US Census, 2020). On the production side, the origin of inputs to any sector is increasingly distant, implying a gradual shift of economic activity supported by fisheries and seafood industries abroad. While generally cost-effective, such high exposure to international markets makes seafood accessibility fragile to perturbations, as shown by the covid-19 outbreak (OECD, 2020). Fisheries are also at the forefront of exposure to the accelerating impacts of climate change. A rapid increase of the water temperature of the coast of Alaska, termed *the blob*, is affecting fisheries (Cheung and Frölicher, 2020) and may have a profound impact on Pacific halibut distribution. Thus analyzing the sector in a broader context is crucial.

A good grasp of the multiregional impacts is also fundamental to correctly assess the impacts the resource such as Pacific halibut has on communities. Some of the local communities particularly rely on fishing-related economic activities. A good understanding of localized effects is pivotal to policymakers that are often concerned about community impacts, particularly in terms of impact on employment opportunities and households' welfare. Fisheries policies have a long history of disproportionally hurting smaller communities, often because potential adverse effects were not sufficiently assessed. For example, in a system based on transferable quotas, small remote fishing communities are more likely to sell their quota. What follows is a disproportional economic impact on the spatial scale. Loss of fisheries opportunities in small indigenous communities can be an unintended consequence of quota systems (Carothers, Lew, and Sepez 2010; Szymkowiak, Kasperski, and Lew 2019).

Update on the model development

Economic impacts are typically estimated with the use of an input-output (IO) model. The traditional IO model is used to investigate how changes in final demand affect economic variables such as output, income and employment or contribution to the region's gross domestic product (GDP). This is known as impact analysis. With an adjustment for the shock type, the model can also demonstrate the magnitude of changes in supply-constrained industries such as total allowable catch (TAC) constrained fisheries. Adopting a multiregional approach, the model accommodates the cross-regional trade. The IO model can also be extended to the so-called social accounting matrix (SAM). Adopting SAM, the calculated effects account for labor commuting patterns and residency of beneficial owners of production factors, and as a result, the flow of earnings between regions.

The Pacific halibut multiregional economic impact assessment (PHMEIA) model is a multiregional SAM model describing economic interdependencies between sectors and regions developed to assess the economic contribution of Pacific halibut resource to the economy of the United States and Canada. The adopted methodology is an extension from the multiregional SAM model for Southwest Alaska developed by Seung, Waters, and Taylor (2019) and draws on a few decades' worth of experience in developing IO models with applications to fisheries (for review of relevant literature, please refer to the economic study section on the IPHC website, subsection *Review of economic impact assessment models focused on the fisheries sector*).

The PHMEIA model accounts for three economic impact (EI) components. The **direct EIs** reflect the changes realized by the direct Pacific halibut resource stock users (fishers, charter business owners). The **indirect EIs** are the result of business-to-business transactions indirectly caused by direct the EIs. The indirect EIs provide an estimate of the changes related to expenditures on goods and services used in the production process of the directly impacted industries. In the context of the PHMEIA, this includes an impact on upstream economic activities associated with supplying intermediate inputs to the direct users of the Pacific halibut resource stock. Finally, the **induced EIs** result from increased personal income caused by the direct and indirect effects. In the context of the PHMEIA, this includes economic activity generated by households spending earnings that rely on the Pacific halibut resource.

The model reflects the interdependencies between eleven major sectors and two Pacific halibut-specific sectors. These include the Pacific halibut fishing sector, as well as the forward-linked Pacific halibut processing sector.[1] In addition, the extended model (referred here as PHMEIA-r) introduces to the SAM also the Alaskan saltwater charter sector that is disaggregated from the services-providing industry.[2] The list of industries considered in the PHMEIA and PHMEIA-r models, as well as the primary commodities they produce, is available in **Table 1**.

The model accounts for interregional spillovers. These represent economic stimulus in the regions other than the one in which the exogenous change is considered. This allows accommodation of increasing economic interdependence of regions and nations. The model considers three primary Pacific halibut producing regions, as well as residual regions to account for cross-boundary effects of fishing in the Pacific Northwest:

- Alaska (AK)
- US West Coast (WC – including WA, OR and CA)

[1] As noted by Steinback and Thunberg (2006), there is a number of seafood substitutes available to buyers. Thus including impacts beyond processors and wholesalers in the SAM framework could be misleading considering that it is unlikely that supply shortage would result in a noticeable change in retail level gross revenues. Alternative approaches to assess these effects are beyond the scope of the project at this time. Data limitations preclude the inclusion of wholesale buyers from the assessment of forward-linked effects.

[2] The inclusion of the British Columbia and US West Coast charter sector is underway, pending data collection.

- British Columbia (BC)
- Rest of the United States (RUS)
- Rest of Canada (ROC)
- Rest of the world (ROW)[3]

By accounting for the economic linkages among these six regions, the study shows the importance of multiregional approaches to measuring economic impacts more accurately. This is particularly important in the context of shared resources and joint management, such as the case of collective management of Pacific halibut by the IPHC. The economic metrics derived from the PHMEIA model range from total economic impact on output along the value chain to impacts on employment and incomes, as well as contribution to the GDP and households' prosperity.

The model adopts a recently published multiregional generalized RAS (MRGRAS) updating technique (Temursho, Oosterhaven and Cardenete, 2020) to develop an up-to-date model that can incorporate partial information on its components while continuing to conform to the predefined balanced structure. This technique can make the multiregional model consistent with aggregated national data[4] and include up-to-date estimates from a limited number of focus sectors. For more details on the methodological approach, please refer to the article *Method for efficient updating of regional supply and use tables* (*Journal of Economic Structures*, In Review) and economic study section on the IPHC website (subsection Methodological annex).

The current version of the model is based primarily on secondary data sources.[5] As such, the results are conditional on the adopted assumptions for the components for which data were not available. In order to improve the accuracy of the assessment, the IPHC intends to increasingly rely on the primary economic data collected directly from members of Pacific halibut dependent sectors (see *Identification of available data sources and primary data collection*), applying the so-called partial-survey method (Miller and Blair 2009, pp. 303). **The subsequent revisions of the model incorporating IPHC-collected data will bring a better characterization of the Pacific halibut sectors' economic impact**.

The model is operational and available for 2014, 2016, 2018, and 2019. For more details on the SAM application to the assessment of the impact of the Pacific halibut resource on the economies of Canada and the United States, please refer to the economic study section on the IPHC website (subsection *PHMEIA model*).

[3] The ROW region in the model is considered exogenous. This implies that the trade relations with the ROW are unaffected by the changes to the Pacific halibut sectors considered in this project. While the full inclusion of the ROW component allows for assessment of impact outside Canada and the United States if trade with ROW was to be considered responsive to changes in Pacific halibut sector activity, this is not typically seen in the literature.

[4] For example, data from the National Economic Accounts (NEA). NEA data provide a comprehensive view of national production, consumption, investment, exports and imports, and income and saving. These statistics are best known by summary measures such as gross domestic product (GDP), corporate profits, personal income and spending, and personal savings.

[5] That is data collected by other parties, not the IPHC.

Table 1 Industries and commodities considered in the PHMEIA and PHMEIA-r models.

	Industry	Primary commodity produced
1	Pacific halibut fishing	Pacific halibut
2	Other fish and shellfish fishing	Other fish and shellfish(1)
3	Agriculture and natural resources (ANR)	Agriculture and natural resources
4	Construction	Construction
5	Utilities	Utilities
6	Pacific halibut processing	Seafood
7	Other fish and shellfish processing	Seafood
8	Food manufacturing (excluding seafood manufacturing)	Food (excluding seafood) (2)
9	Manufacturing (excluding food manufacturing)	Manufactured goods (excluding food)
10	Transport	Transport
11	Wholesale	Wholesale
12	Retail	Retail
13	Services (including public administration)	Services (including public administration)
14	Saltwater charter sector(3)	Saltwater fishing trips

Notes: (1)In the case of Canada, other fish and shellfish commodity includes, besides wild capture production, also aquaculture output produced by the aquaculture industry that is a part of the ANR industry. Other fish and shellfish processing industry in the USA component, on the other hand, draws more on the ANR commodity that includes aquaculture output. However, this misalignment between model components is not concerning as linking these is based on the trade of aggregated seafood commodity. (2)There is a slight misalignment between model components related to the allocation of beverage and tobacco manufacturing products that, in some cases, are considered non-durable goods and lumped with the food commodity. In the case of the USA component, this misalignment is corrected with the use of additional data available from the Annual Survey of Manufactures (ASM) (US Census, 2021b). No correction is performed for the ROW component, but the global production of beverage and tobacco products is considered of minor importance compared to other food commodities. (3)Saltwater charter sector extension included in PHMEIA-r model, currently applied only for Alaska. The Pacific halibut charter sector is assumed to account for 22.4% (2019) of the Alaskan saltwater charter sector. This is calculated as a share of Pacific halibut effort reported by Webster & Powers (2020) in total effort reported by the Marine Recreational Information Program (NOAA, 2021c).

Identification of available data sources and primary data collection

The current version of the model is built using a broad set of secondary data sources. These include region-specific commercial fishing outputs in terms of value (DFO, 2021; NOAA, 2021a), including detailed landing data from eLandings system for Alaska (ADFG, 2021a), wholesale value[6] (AgriService BC, 2018; COAR, 2021), employment and wages[7] (AK DLWD, 2020; Statistics Canada, 2021), out-of-state employment (Kreiger and Whitney, 2021), seafood trade (NOAA, 2020; Statistics Canada, 2020a). Lew & Lee (2019) report on costs, earnings, and employment in the Alaska saltwater sport fishing charter sector in 2017. Additional data are available on recreational harvest and participation in recreational angling (ADFG, 2020; RecFIN, 2020; Webster and Powers, 2020; NOAA, 2021c), subsistence and research harvest (IPHC, 2020a). More details on fisheries-related secondary data sources can be found in the economic study section on the IPHC website (subsection *Fisheries-related economic statistics*).

The social accounting matrix, even if built with the purpose of assessing a limited number of sectors (i.e., Pacific halibut dependent industries in this case), also requires input on supply and use by all industries in the economy, as well as supplementary data on household accounts to provide insight into

[6] Not available for the US West Coast (confirmed with NOAA NWFSC, personal communication).
[7] Not available for the US West Coast (confirmed with NOAA NWFSC, personal communication).

the demographics of the workforce that builds the market for supply and demand of labor and trade data to link model components. The following sources serve as a base for the up-to-date estimates (list not exhaustive):

- US Bureau of Economic Analysis (BEA) industry accounts supplemented by BEA Regional Data resources (BEA, 2020) - the USA model component
- United States Census Bureau's Annual Survey of Manufactures (ASM) (US Census, 2021b) – complementary statistics on manufacturing establishments
- Provincial-level supply and use tables published by Statistics Canada (Statistics Canada, 2020b) – the Canadian model component
- US Trade provided by the U.S. Census Bureau (US Census, 2020)
- Canadian International Merchandise Trade Database (Statistics Canada, 2020a)

More accuracy of the results can be achieved by incorporating into the model primary economic data collected directly from members of Pacific halibut-dependent sectors. An essential input to the SAM model is data on production structure (i.e., data on the distribution of revenue between profit and expenditure items). Currently, the model uses estimates from the species-based NOAA model for Alaska for 2014 (Seung, Waters and Taylor, 2019), as well as Pacific halibut sector estimates for the West Coast provided directly by the authors of the NOAA input-output model for the Pacific Coast fisheries (Leonard and Watson, 2011; Pacific halibut estimates not published). No equivalent detail model is available for British Columbia, although some partial statistics are derived from Edwards and Pinkerton (2020).[8]

A series of surveys to gather information from commercial fishers and processing plant operators has been announced at the AM96. To expand the model's scope, a survey aimed at charter business owners has been announced at the IM96. The web-based survey forms are available:

- Here, for Pacific halibut commercial harvesters;
- Here, for Pacific halibut processors;
- Here, for Pacific halibut charter business owners.

IPHC stakeholders are encouraged to fill the relevant survey form and contribute to the assessment of the importance of the Pacific halibut resource to the economy of Canada and the United States of America.

Primary data collection in the time of the crisis

Recent perturbations in the markets caused by covid-19 serve as an additional argument for considering the broader economic dimension of Pacific halibut's contribution to regional economies. The widespread closure of restaurants, the Pacific halibut's biggest customers, diminished the demand for fish, particularly high-quality fresh fish that fetch higher prices. Lower prices, down in 2020 by up to 30% compared with the previous year (Stremple, 2020; **Table 2**), caused a slow first half of the season

[8] Edwards and Pinkerton (2020) provide estimates of average operational and fixed costs. These are used to derive value added related to Pacific halibut fishing used in the model.

(Ess 2020). Less harvest activity has repercussions in the economy beyond the harvest sector as it affects also harvest sector suppliers and downstream industries that rely on its output. Outbreaks of covid-19 in fish processing plants (Estus, 2020; Krakow, 2020) also affect economic activity generated regionally by this directly related to the Pacific halibut supply sector. Moreover, seafood processors incur additional costs associated with protective gear, testing, and quarantine accommodations (Ross, 2020; Sapin and Fiorillo, 2020; Welch, 2020).

The pandemic turned out to be also a major impediment to successful primary data collection in 2020. The survey's announcement happened shortly before the covid-19 outbreak that shifted the focus of participants to the Pacific halibut fishery. An intensified effort to reach out to commercial vessel operators was made starting July when the IPHC fisheries data specialists (ports) distributed a paper version of the survey. To this date, however, too few responses have been received to make reliable estimates for full model calibration, and the Secretariat continues efforts to improve the response rate. Meanwhile, the survey results are used to inform the model on a number of parameters for which no other estimates are available (e.g., the workforce composition).

The preliminary survey results are available to all contributors and prospective participants for comparison with regional and local averages here:[9]

http://iphcecon.westus2.cloudapp.azure.com:3838/srApp/.

As a reminder, the participants to the Pacific halibut fisheries (commercial and charter sector) are encouraged to fill the form for 2020, but also retrospectively submit information for 2019. Responses are accepted on a rolling basis and used to update the results app periodically. The benefits of filling the survey for both years are as follows:

- Data for 2019, covering pre-covid-19 operations, can be considered a baseline suitable for drawing conclusions under normal circumstances and using for predictions.
- Data for 2020, covering an abnormal year of operations, can be used to assess losses incurred by the Pacific halibut sectors, but also sectors' resilience to unfavorable exogenous circumstances. If the project continues and data for 2021 are collected, the project could inform on the response to the crisis and undertake an analysis of the path to recovery.

[9] At this stage, the estimates are based on a limited sample and should not be considered necessarily reflective of the whole indicated sector. The main intention of sharing this app at this time is to demonstrate the potential of the survey to provide a comparison of a broad set of economic statistics across regions and years.

Table 2 Pacific halibut commercial landings by IPHC Regulatory Area – 2019 vs. 2020.

IPHC Regulatory Area	Value [USD] 2019	Price [USD] 2019	Value [USD] 2020	Price [USD] 2020
2A	5,015,314	3.64	NA	NA
2B	34,988,780	5.02	NA	NA
2C	17,305,677	5.67	12,547,601	4.32
3A	43,214,560	5.65	28,027,417	4.37
3B	8,410,477	5.46	6,130,597	4.19
4A	5,947,111	4.46	4,438,663	3.80
4B	4,079,609	4.41	3,229,892	3.67
4C	1,991,117	4.23	242,879	3.76
4D	4,452,681	4.49	5,162,180	3.94
4E	348,426	5.42	280,031	3.94
SUM AK (2C-4E)	85,749,658	5.35	60,059,259	4.21

Notes: NA – not available. Data for 2A based on (NOAA, 2021a), and data for 2B based on (DFO, 2021). Estimates for Alaska based on data from eLandings system (ADFG, 2021a), limited to harvest landed under IFQ and CDQ management program and reported sold. Value calculated based on average price per ticket and landings allocated based on ADFG grid converted to IPHC regulatory areas. For border areas, the first reported area was assigned.

Pacific halibut value along the supply chain

The complete path of landed fish, from the hook to the plate, includes, besides harvesters and processors, also seafood wholesalers and retailers, and in the case of highly-prized fish such as Pacific halibut, services when it is served in restaurants. Any change in gross revenue generated by these industries as a result of a change in the supply of directly affected fish is further magnifying the economic impact of management decisions altering harvest levels.

Isolating data on Pacific halibut wholesale and retail is challenging as no relevant statistics have been identified. However, it is important to note that there are many seafood substitutes available to buyers. Thus, including economic impacts beyond processors and wholesalers could be misleading when considering that it is unlikely that supply shortage would result in a noticeable change in retail level gross revenues (Steinback and Thunberg, 2006).

Recreational sector in the PHMEIA model – PHMEIA-r

There are two components to consider when attempting to assess the full scope of the Pacific halibut resource's economic impact occurring as a result of recreational fishing activities. The first is the contribution to the economy by the charter sector that provides service to anglers. These include services directly related to angling, for example, providing a boat, trip supplies and guides, but also not directly related, for example, hospitality services in case of fly-in lodges that specialize in serving customers interested in Pacific halibut fishing. The economic impact is generated by the sector's demand for inputs from other industries, including manufacturing, professional services (accounting, marketing, etc.) and demand for labor.

The second component is the contribution of anglers who create demand for goods and services related to their fishing trips. This includes expenses related to the travel that would otherwise not be incurred (e.g., auto rental, fuel cost, lodging, food, site access fees), as well as money spent on durable goods that are associated with recreational fishing activity, e.g., rods, tackle, outdoor gear, boat purchase, etc. This component applies to both guided and unguided recreational fishing. Assessment of anglers' contribution to the economy typically requires surveying private anglers on their fishing-related expenditures and fishing preferences.

The extended PHMEIA-r model introduces to the SAM the Alaskan saltwater charter sector.

Economic impact assessment of subsistence fishing

Previous research suggested that noncommercial or nonmarket-oriented fisheries contribution to national GDP is often grossly underestimated, particularly in developing countries (e.g., Zeller, Booth, and Pauly 2006). Subsistence fishing is also important in traditional economies, often built around indigenous communities. Wolfe and Walker (1987) found that there is a significant relationship between the percentage of the native population in the community and reliance on wildlife as a food source in Alaska. However, no comprehensive assessment of the economic contribution of the subsistence fisheries to the Pacific northwest is available. The only identified study, published in 2000 by Wolfe (2000), suggests that the replacement value of the wild food harvests in rural Alaska may be between 131.1 and 218.6 million dollars, but it does not distinguish between different resources and assumes equal replacement expense per lb. Aslaksen et al. (2008) proposed an updated estimate for 2008 based on the same volume, noting that transportation and food prices have risen significantly between 2000 and 2008, and USD 7 a pound is a more realistic replacement value. This gives the total value of USD 306 million, but the approach relies upon the existence of a like-for-like replacement food (in terms of taste and nutritional value), which is arguably difficult to accept in many cases (Haener *et al.*, 2001) and ignores the deep cultural and traditional context of the Pacific halibut in particular (Wolfe, 2002). A more recent study by Krieg, Holen, and Koster (2009) suggests that some communities may be particularly dependent on wildlife, consuming annually up to 899 lbs per person, but no monetary estimates are derived. Moreover, although previous research points to the presence of sharing and bartering behavior that occurs in many communities (Wolfe, 2002; Szymkowiak and Kasperski, 2020), the economic and cultural values of these networks have yet to be thoroughly explored.

Economic impact assessment results

This section summarizes the most recent outcomes of the PHMEIA and PHMEIA-r models. It is important to note that these are based on **the current version of the model incorporating primarily secondary data sources**. As such, **the results are conditional on the adopted assumptions for the components for which up-to-date data were not available** (summarized for Alaska in Appendix 1 Assumptions on the Pacific halibut sectors in Alaska) **and are subject to change**.

The current results incorporate the following changes in comparison to the results presented at the AM97:

- The model uses an updated set of data, and estimates are now available for 2019 (previously up to 2018);

- The report includes preliminary estimates of community effects – it incorporates county-level results for Alaska;
- The extended model (PHMEIA-r) provides preliminary estimates for the charter sector (limited to guided fishing in Alaska);
- The estimates fully incorporate described flows of earnings related to all Pacific halibut sectors (fishing, processing, and charter/Alaska only).

Economic impact of Pacific halibut commercial fishing

The model results suggest that Pacific halibut commercial fishing's total estimated impact in 2019 amounts to USD 194.2 mil. (CAD 257.7 mil.) in earnings[10] (including estimated USD 42.5 mil / CAD 56.4 mil in earnings in the Pacific halibut fishing sectors), USD 134.3 mil. (CAD 178.2 mil.) in compensation of employees (including estimated USD 26.6 mil / CAD 35.3 mil in wages in the Pacific halibut fishing sectors), 4,326 in jobs, USD 178.4 mil (CAD 236.7 mil.) in households income and over USD 665.2 mil. (CAD 882.6 mil.) in output. This is about 5.3 times the fishery output value of USD 126.4 mil.[11] (CAD 167.7 mil.) recorded for 2019 (DFO, 2021; NOAA, 2021a). The estimate is the total economic impact, the sum of the direct, indirect, and induced effects from changes to the Pacific halibut fishing sector, as well as indirect and induced effects associated with forward-linked industries (Pacific halibut processing sector).

Table 3 Estimated economic impact of Pacific halibut commercial sector in 2019.

	Value [mil. USD / mil. CAD]	Value per 1 USD of output
Value of landings	126.4 / 167.7	-
Economic impact – output	665.2 / 882.6	5.26
Economic impact – compensation of employees	134.3 / 178.2	1.06
Economic impact – earnings	194.2 / 257.7	1.54
Economic impact - employment	4326 jobs	34.22
Economic impact – households	178.4 / 236.7	1.41

The results suggest that the revenue generated by Pacific halibut at the harvest stage accounts for only a fraction of economic activity that would be forgone if the resource was not available to fishers in the pacific northwest. Besides supporting production by other industries, the sector also contributes to the GDP of Canada and the United States and has a considerable impact on employment in both countries. Understanding such a broad scope of impacts is essential for designing policies with desired effects depending on regulators' priorities.

Moreover, the results suggest that incorporating Pacific halibut-specific outflows has a considerable impact on results. Error! Reference source not found. shows the estimates of economic impact on households in Alaska from the final model contrasted with estimates from the model that does not account for cross-regional flows of earnings. While 1 USD of Pacific halibut output in Alaska could generate USD 0.71 USD for Alaskan households, out-of-state employment, flows related to beneficial

[10] Earnings include both employee compensation and proprietors' income.
[11] For Alaska, the model only includes harvest landed under IFQ and CDQ management program that was marked as sold.

ownership of Pacific halibut fishing rights in Alaska (i.e. quota holdings) and corporate interests of processing sector entities cause this estimate to drop to USD 0.58.

Table 4 Effect of incorporating Pacific halibut specific outflows - impact on households per 1 USD of Pacific halibut output in Alaska (2019).

	Model with no Pacific halibut specific outflows	Model with Pacific halibut specific outflows
Households in Alaska	0.71	0.58
WC households	0.11	0.21
RUS households	0.41	0.42

Notes: Impacts on households in Canada omitted.

Community impacts in Alaska

Besides providing economic impact estimates for broadly-defined regions, the PHMEIA model results can inform the community impacts of the Pacific halibut resource throughout its range and highlight communities particularly dependent on fishing-related economic activities.

Based on the 2019 PHMEIA model, Pacific halibut commercial output in Alaska of USD 85.7 mil.[12] generated through Pacific halibut directed commercial fishing and directly forward-linked Pacific halibut processing about USD 28.2 mil of earnings, of which USD 19.8 mil. (70.2%) was retained in Alaska.[13]

The earnings were not evenly distributed (**Table 5**, **Figure 1**). The highest earnings are estimated for Kenai Peninsula, Kodiak Island and Petersburg counties. The most direct earnings per dollar landed are estimated for Ketchikan Gateway, Petersburg and Sitka countries, while the least for Aleutians East, Yakutat and Aleutians West counties. Low earnings per 1 USD of Pacific halibut landed in the county are a result of the outflow of earnings related to vessels' home base, vessels' ownership and quota ownership, processing locations and processing companies' ownership.

The last column of **Table 5** represents the distribution of the total economic impact of Pacific halibut industries on households in Alaska by county (USD 49.6 mil. in total for 2019). The remaining economic impact on households representing indirect and induced EIs is evaluated based on local exposure[14] to the region's Pacific halibut economic impact, using calculated multiplier effects. It is important to note that these estimates assume the use of imported commodities in the same proportions by each county and no cross-county trade in commodities,[15] which in turn implies that intra-Alaska indirect and induced economic effects retention within the county.

[12] Limited to harvest landed under IFQ and CDQ management program and reported sold.

[13] Community effects assessment is currently limited to Alaska. The feasibility of a similar assessment for other regions is currently under investigation. For example, Canadian quotas (L fishery), which are vessel-based, can be allocated based on vessel owner's residency, searchable in the Canadian Register of Vessels available through Transport Canada's Vessel Registration Query System.

[14] Local exposure assessed as a county's share in the total value of Pacific halibut landed in Alaska. Values were assigned to counties based on the registered homeport of the vessel landing Pacific halibut.

[15] This assumption implies that all commodities used in the production that are not imported from another state or country are sourced from the county where the production process occurs. This applies to all industries in the economy. For example, if the Pacific halibut fishing industry in Aleutians East county uses USD 1,000 of food commodity as an input to production and, on average, Alaska imports from other US states and abroad 30% of food commodity it uses for production,

The updated PHMEIA app translates these effects directly based on changes in harvest allocations by IPHC Regulatory Area using eLandings data that include the harvest location (PHMEIA app release 2.0).

Table 5 Economic impacts estimates for Alaskan counties - 2019.

County	Estimated earnings from Pacific halibut commercial sectors (fishing and processing)	Earning per 1 USD of Pacific halibut landed in the county	Change in % value of landings vs. % estimated earnings	Estimated economic impact of Pacific halibut commercial fishing on households(1)
Aleutians East	0.32	**0.067**	-	0.86
Aleutians West	1.45	**0.129**	-	4.35
Anchorage	0.53	NA	+	0.81
Bristol Bay	c	NA	+	c
Dillingham	c	c	c	c
Fairbanks North Star	c	NA	+	c
Haines	0.19	NA	+	0.39
Hoonah-Angoon	0.40	0.201	-	1.09
Juneau	1.65	0.237	+	5.13
Kenai Peninsula	**4.69**	0.182	-	**11.25**
Ketchikan Gateway	0.39	**0.502**	+	0.85
Kodiak Island	**3.23**	0.369	+	**8.31**
Lake and Peninsula	c	NA	c	c
Matanuska-Susitna	c	NA	+	c
Nome	0.22	0.288	+	0.52
Petersburg	**2.83**	**0.437**	+	**7.50**
Prince of Wales-Hyder	0.22	0.362	+	0.59
Sitka	1.04	**0.432**	+	2.48
Skagway	c	NA	+	c
Southeast Fairbanks	c	NA	+	c
Valdez-Cordova	0.82	0.175	-	2.04
Wrangell	0.56	0.223	-	1.19
Yakutat	0.67	**0.118**	-	1.54

Notes: Counties with no Pacific halibut landings or earnings from Pacific halibut sectors omitted. c – masked to preserve confidentiality; NA – not applicable (no landings reported for the given county). (1)Assumes intra-Alaska indirect and induced economic effects retention within the county, i.e. no cross-county trade in commodities.

the model assumes that USD 700 of food commodity demanded by the Pacific halibut fishing industry is sourced from within the Aleutians East county, not other Alaskan counties. The same rule is applied to the workforce. Available statistics suggest a considerable movement of workers between Alaskan counties (see summary in Appendix 3 Intra-Alaska workplace commuting flows summary). Further research on the impact of cross-county flow of commodities and wages on the presented results is recommended.

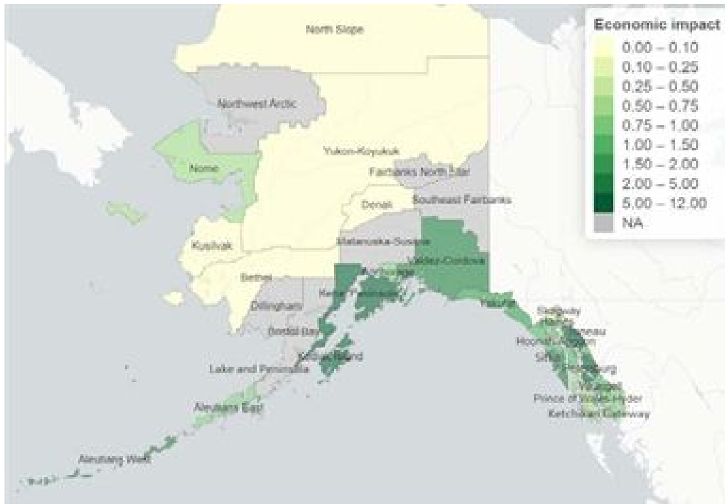

Figure 1 County-level economic impact estimates for Alaska – 2019.

Economic impact of Pacific halibut charter fishing in Alaska

Assuming that the economic impact of Pacific halibut charter fishing in Alaska is equivalent to estimating the total economic loss resulting from the saltwater charter sector therein shrinking by share of Pacific halibut effort in total effort (22.4% in 2019), the total economic impact of Pacific halibut charter sector in Alaska is assessed at USD 87.7 mil for 2019.

It is more meaningful, however, to analyze the Pacific halibut charter sector in terms of its contribution to households, particularly to local households. **Table 6** summarizes the results, also providing a comparison with the economic impact on households of commercial fishing in Alaska. Not surprisingly, the economic impact per 1 USD of output is higher for the commercial vs. the charter sector. The commercial sector is producing an intermediate input that is not only supporting suppliers to the harvesting sector, but also the forward-linked processing sector. However, the economic impact of 1 lbs of Pacific halibut removal counted against TAC in the stock assessment is 66% higher for the charter sector when compared with the commercial sector.

It should also be noted that this assessment accounts for only a fraction of the Pacific halibut contribution to the economy through recreational fishing. The analysis, at this time, does not account for the impact of anglers spending money on durable goods they use on the charter trips (e.g., fishing equipment) and expenditures by private anglers.

Table 6 Results for the Pacific halibut charter sector in Alaska and comparison with the commercial sector in Alaska (2019).

	Unit	Charter	Commercial
Economic impact on households	Total in mil. USD	27.08	105.45
Economic impact on households in Alaska	Total in mil. USD	14.2	49.56
Economic impact on households	USD per 1 USD of output	1.05	1.23
Economic impact on households in Alaska	USD per 1 USD of output	0.55	0.58
Economic impact on households	USD per 1 lb of removals	9.54	5.75
Economic impact on households in Alaska	USD per 1 lb of removals	5.01	2.70

Final remarks

The study's main contribution is the first consistent estimation of both backward and forward-linked effects of fisheries supply changes in a multiregional setup tracing the transmission of impacts internationally.[16] By linking multiple spatial components, the model offers a better understanding of the impacts of changes in shared stock supply.

The complexity of Pacific halibut supply-side restriction in the form of region-based allocations suggests the need for a tool enabling regulators to assess various combinations of TAC allocations. To address this, the results are complemented by an interactive web-based application allowing users to estimate and visualize joint effects based on custom changes simultaneously applied to all IPHC-managed Pacific halibut producing areas. The tool is available at:

http://iphcecon.westus2.cloudapp.azure.com:3838/ModelApp_azure/.

Release 2.0 of the tool (expected by May 20, 2021) accounts for the commercial sector and the charter sector in Alaska. Inclusion of the recreational component for other regions is underway. The updated version of the tool also translates changes in harvest allocations by IPHC Regulatory Area to county-level economic impact estimates for Alaska, informing on community impacts of changes to Pacific halibut regional allocations. See *Appendix 2 Harvest translated into landings by county* for example of the translation table.

The updated PHMIA model translating the changes in harvest allocations by IPHC Regulatory area directly to economic impact is also well adapted to use with the Pacific halibut management strategy evaluation (MSE) framework (IPHC, 2020b). Economic performance metrics presented alongside already developed biological/ecological performance metrics would bring the human dimension to the MSE framework, adding to the IPHC's portfolio of tools for assessing policy-oriented issues (as requested by the Commission, IPHC-2021-AM097-R, AM097-Req.02).

Lastly, while the quantitative analysis is conducted with respect to components that involve monetary transactions, Pacific halibut's value is also in its contribution to the diet through subsistence fisheries and importance to the traditional users of the resource. To native people, traditional fisheries constitute a vital aspect of local identity and a major factor in cohesion. One can also consider the Pacific halibut's

[16] While a study analyzing the impact of Pacific salmon fisheries on the economy of both the USA and Canada using the IO approach was identified (Gislason *et al.*, 2017), the models therein are disconnected and do not offer the consistency of an integrated multiregional model.

existence value as an iconic fish of the Pacific Northwest. While these elements are not quantified at this time, recognizing such an all-encompassing definition of the Pacific halibut resource contribution, the project echoes a broader call to include the human dimension into the research on the impact of management decisions, as well as changes in environmental or stock conditions.

OBJECTIVES

Table 7 summarizes the progress to date against the IPHC economic study objectives.

Table 7. The study objectives – summary of progress

Objective	Status*
Item 1: Survey of previous studies and existing information	**---**
Item 1.a: Literature review	**COMPLETED**
Item 1.b: Description of ongoing regular data collection programs	**COMPLETED**
Item 1.c: Collection of primary data – commercial sector survey	**IN PROGRESS**
Item 1.d: Collection of primary data – charter sector survey	**IN PROGRESS**
Item 2: Comprehensive qualitative structural description of the current economics of the Pacific halibut resource	**---**
Item 2.a: Description of the economics of the Pacific halibut commercial sector	**COMPLETED**
Item 2.b: Description of the economics of the Pacific halibut recreational sector	**COMPLETED**
Item 2.c: Description of the economics of other Pacific halibut sectors (bycatch, subsistence, ceremonial, research, non-directed)	**IN PROGRESS**
Item 3: Quantitative analysis of the economic impact of the directed Pacific halibut fishery	**---**
Item 3.a: Methodology – a model of the economy	**COMPLETED**
Item 3.b: Methodology – inclusion of the commercial sector in the SAM	**COMPLETED(1)**
Item 3.c: Methodology – inclusion of the recreational sector in the SAM	**COMPLETED(1)**
Item 3.d: Methodology – economic value of the subsistence use	**IN PROGRESS(2)**
Item 4: Account of the geography of the economic impact of the Pacific halibut sectors	**---**
Item 4.a: Visualization of region-specific economic impacts	**COMPLETED(1)**
Item 5: Analysis of the community impacts of the Pacific halibut fishery throughout its range, including all user groups	**---**
Item 5.a: Community impacts assessment of the Pacific halibut fishery	**COMPLETED(1)**
Item 6: Summary of the methodology and results of the IPHC study in comparison to other economic data and reports for the Pacific halibut resource, other regional fisheries, and comparable seafood industry sectors	**---**
Item 6.a: Putting results into perspective	**IN PROGRESS**

* All items marked as COMPLETED are subject to updates based on the direction of the project and evolution of the situation in the Pacific halibut fisheries. (1)Subject to changes based on the data collected through the IPHC Economic survey. (2)Subject of collaborative research proposal with NOAA Alaska Fisheries Science Center.

Suggested extensions beyond the 2-year time frame

Expanding the static SAM model to a computable general equilibrium model

Relaxing the assumption of fixed technical coefficients by specifying these coefficients econometrically as a function of relative prices of inputs is one of the most compelling extensions to the static IO or SAM models. Such models, generally referred to as computable general equilibrium (CGE) models, require however extensive research to develop credible functional relationships between prices and consumption that would guide economic agents' behavior in the model.

The CGE approach is a preferred way forward when expanding the model usability and considering applying it in conjunction with the Pacific halibut management strategy evaluation (IPHC, 2020b). The dynamic model is well suited to analyze the impact of a broad suite of policies or external factors that would affect the stock over time.

Improving the spatial granularity of the SAM model

Extending the community analysis beyond a simplified approach described in section *Community impacts in Alaska* to a full community level (or any other spatial scale) SAM-based model requires significant investment in identifying the economic relationships between different sectors or industries (including both seafood and non-seafood industries) within each broader-defined region, this including deriving estimates on intra-regional trade in commodities and flow of earnings. It is an appealing extension of the current model, but not a feasible avenue for the project with its current time frame.

Study of recreational demand

It is important to note that while it is reasonable to assume that changes in harvest limits have a relatively proportional impact on production by commercial fishers (unless these are dramatic and imply fleet restructure or a significant shift in prices), the effects on the recreational sector are not so straightforward.

A separate study estimating changes in saltwater recreational fishing participation as a response to the changing recreational harvest limits is necessary if the stakeholders are interested in assessing policy impact rather than snapshot economic impact. Such studies typically require surveying recreational fishers.

There is scope for collaboration here with the NOAA Alaska Fisheries Science Center, where there is ongoing work on estimating the marginal value of a Pacific halibut from the charter fishing sector in Alaska. If the project was to continue beyond two years, the IPHC could consider surveying recreational fishers. The charter owners who participated in the charter survey pilot implied willingness to help with, e.g., distributing a link to the IPHC survey inquiring about their customers' fishing preferences. How to reach private anglers partaking in unguided fishing was not researched at this time.

Assessment of the economic impact of other sources of Pacific halibut mortality

All-sectors-encompassing assessment of the economic impact of the Pacific halibut resource necessitates the development of a methodological approach for the remaining sources of Pacific halibut mortality, including subsistence fishing, bycatch, and research catch. Methods adopted for the commercial and charter sector are not adequate for this portion of the harvest.

RECOMMENDATIONS

That the SRB:

1) **NOTE** paper IPHC-2021-SRB018-09 which provides an update on the IPHC economic study, including progress on the development of the economic impact assessment model, state of the collection of primary economic data from Pacific halibut dependent sectors, and the most recent set of results on regional and community impacts;
2) **RECOMMEND** the use of the PHMEIA model results as supplementary performance metrics in the MSE framework;
3) **RECOMMEND** improvements to the PHMEIA and PHMEIA-r framework, including methodological approach and model assumptions.
4) **NOTE** that improving the accuracy of economic impact assessment of the Pacific halibut resource depends on broader stakeholders' active participation in developing the necessary data for analysis and **RECOMMEND** additional outreach activities.

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Appendix 1 *Assumptions on the Pacific halibut sectors in Alaska*

Workforce flows in the Pacific halibut commercial fishing sectors

The Alaska Department of Labor and Workforce Development (ADLWD) data suggest a considerable share, in a range of 61-68% (2014-2019), of out-of-state employment in the fisheries sector in Alaska (Kreiger and Whitney, 2021).[17] However, the preliminary results from the IPHC economic survey focused on the Pacific halibut fleet suggest more local employment in this part of the fishing sector. Consequently, the model assumes the following composition of the labor force (in terms of wages) in the Pacific halibut fishing sector: 78% Alaska residents, 20% residents of the US West Coast and 2% residents of other US states. Due to the currently low sample size, the adopted estimates on the cross-state flow of wages in the Pacific halibut fishing sector are subject to change.

The ADLWD also reports on the nonresident workers in the seafood processing sector, noting that this industry has had the highest number and percentage of nonresident workers every year since data collection began (Kreiger and Whitney, 2021). The latest available estimates for 2019 suggest that nonresidents constituted 68.3% of the workforce in terms of wages. The model adopts the same share to Pacific halibut processing, assuming there is no significant difference in the operations of processing plants depending on the species. The nonresident origin is assumed to follow the general trends reported by the Internal Revenue Service (IRS, 2020).

In the assessment of the county-level economic impacts, the resident workforce is allocated based on vessel homeport county, as reported by the Commercial Fisheries Entry Commission CFEC (CFEC, 2021b), and matched using vessels ADFG number.

Proprietor income flows in the Pacific halibut commercial fishing sectors

While the Pacific halibut commercial harvest limits are allocated between IPHC Regulatory areas and can be categorized according to landing location using logbook data, the economic analysis of the sector calls for tracing the monetary flows beyond the harvest and landing stage. Profits from Pacific halibut commercial fishing and processing can be spatially allocated based on a combination of various other parameters: (1) residence of the vessel owner, reported by the CFEC (2021); (2) residence of the quota owner, reported by the CFEC (2021a); (3) location of the harvest buyer, reported in the ADFG's Commercial Permit and License Holders Listing (ADFG, 2021b); (4) location of processing, including custom processing[18] if ordered; and (5) location of the processing company owner or business headquarters. The headquarters are assumed to be synonymous with the location of the final beneficiary of the processing profits.

According to 2020 data (details in **Table 8**), the county of landing matched the county of vessel owner residence for about 48.5% worth of harvest. When it comes to the residence of the permit owner, it matched the county of landing for 46.1% harvest value. Vessel homeport matched about 50.0% worth of landings. This suggests a considerable flow of benefits related to the harvest of Pacific halibut between Alaskan counties, as well as an outflow of the benefits from Alaska to other US states. The

[17] Historical reports are available at: https://live.laborstats.alaska.gov/reshire/reshist.cfm.

[18] Custom processing is when another entity is processing the fish on behalf of the buyer.

direction of the flow of benefits from the landing area to vessel owner residence, quota holder residence and vessel homeport location is depicted in **Figure 2**. Here, the inner circle represents the county where the fish was landed, and the outer circle represents the county where (1) the vessel owner resides, (2) where the quota owner resides, and (3) the vessel homeport is located. The width of the ring section represents the estimated value of landings.

Table 8 Cross-regional and cross-county flow of benefits related to residence of the vessel owner, the permit owner, and vessel homeport.

	Landing value	Value by the residence of the vessel owner	Change vs. landing value	Value by the residence of the quota holder	Change vs. landing value	Value by vessel homeport location[(1)]	Change vs. landing value
Aleutians East	5.69	0.62	-89.2%	0.67	-88.3%	1.23	-78.4%
Aleutians West	7.04	1.44	-79.6%	1.81	-74.3%	4.52	-35.9%
Anchorage	0	0.77	+	1.42	+	0.37	+
Bristol Bay	c	0	NA	0	NA	0	NA
Dillingham	0.05	0.06	25.7%	0.06	25.7%	0.06	25.7%
Fairbanks North Star	0	c	+	c	+	0	+
Haines	c	1.02	NA	0.72	NA	0.38	NA
Hoonah-Angoon	1.64	0.76	-53.7%	0.65	-60.6%	0.97	-40.9%
Juneau	5.81	2.96	-49.1%	2.87	-50.5%	6.04	4.0%
Kenai Peninsula	16.81	12.50	-25.6%	10.44	-37.9%	11.69	-30.5%
Ketchikan Gateway	0.82	0.81	-0.9%	0.89	9.3%	1.05	27.8%
Kodiak Island	6.29	6.97	10.7%	5.74	-8.8%	8.30	31.9%
Lake and Peninsula	0	c	+	c	+	c	+
Matanuska-Susitna	0	2.01	+	1.30	+	c	+
Nome	0.57	0.57	0.0%	0.57	0.0%	0.49	-13.8%
Petersburg	3.79	6.32	66.6%	6.58	73.5%	7.15	88.5%
Prince of Wales-Hyder	0.51	0.52	1.9%	0.55	7.8%	0.61	18.4%
Sitka	1.07	1.92	79.1%	1.79	67.7%	2.04	91.2%
Southeast Fairbanks	0	1.14	+	1.04	+	c	+
Skagway	c	0	NA	c	NA	0	NA
Valdez-Cordova	3.53	1.26	-64.2%	1.95	-44.9%	1.78	-49.6%
Wrangell	1.16	1.25	7.7%	1.15	-1.1%	1.10	-5.3%
Yakutat	3.68	1.95	-47.0%	1.83	-50.1%	1.61	-56.3%
WC	1.57	14.22	803.4%	14.33	810.7%	10.34	556.7%
RUS	0	0.96	+	3.60	+	0	+

Notes: c – confidential, represents less than three vessels; + represents a positive flow when the landing base was zero. [(1)]Vessel homeport was not identified for about USD 228,600 worth of landings.

(1) Landing area vs. vessel owner residence (2) Landing area vs. permit owner residence (3) Landing area vs. vessel homeport location

Figure 2 Direction of the flow of benefits from the landing area to (1) vessel owner residence, (2) quota holder residence, and (3) vessel homeport location.

The majority of the Pacific halibut buyers in 2020 were located in Alaska (97.8% in terms of value); 2.2% worth of harvest went to out-of-state buyers and could not be traced further. Within Alaska, 99.7% of buyers were shorebased processors. Processing typically occurs in the buyer's location. Only about 10.9% of the harvest in terms of landing value went through custom processing, of which 23.9% in the place different to the location of the buyer, typically right where it was landed (100%). The remaining harvest (i.e., not going through custom processing) matched the landing county for about 91.4% of landings in terms of value, with the remainder going through buying stations located at the landing location.

Following the flow of revenues further, about 58.9% worth of harvest purchased by shorebased processors was purchased by shorebased processors that listed as a point of contact a county other than the location of the processing facility. Assuming that the contact point location is associated with the business owner or business headquarters, this suggests substantial monetary flows related to profits from the processing. What is more, 96.3% of the above value can be traced to processors with headquarters on the US West Coast. Note that the share here was calculated based on the original landing value and does not account for variation in wholesale value dependent on the type of produced outputs.

Figure 3 depicts the flow of revenue from the harvest location to the processing profit beneficiary. Here, nods represent spatial aggregation:

- Blue – harvest by IPHC Regulatory Areas;
- Red – county of the landing site;
- Yellow – if ordered, county of the custom processing;
- Green – county of the reported buyer (location of the buying station not included in the figure);
- Purple – location of the Fisheries Business License holder (based on the contact address).

Ribbons represent flows in terms of the estimated value of landings (mil. USD) (i.e., landing value, not adjusted for value added through processing):

- Blue ribbons represent the flows from harvest grounds to landing sites in Alaska;
- Grey ribbons represent the flows between nodes that are located in the same Alaskan county;
- Orange ribbons represent the flows between nodes that are located in different counties;
- Red ribbons represent the flows out of Alaska.

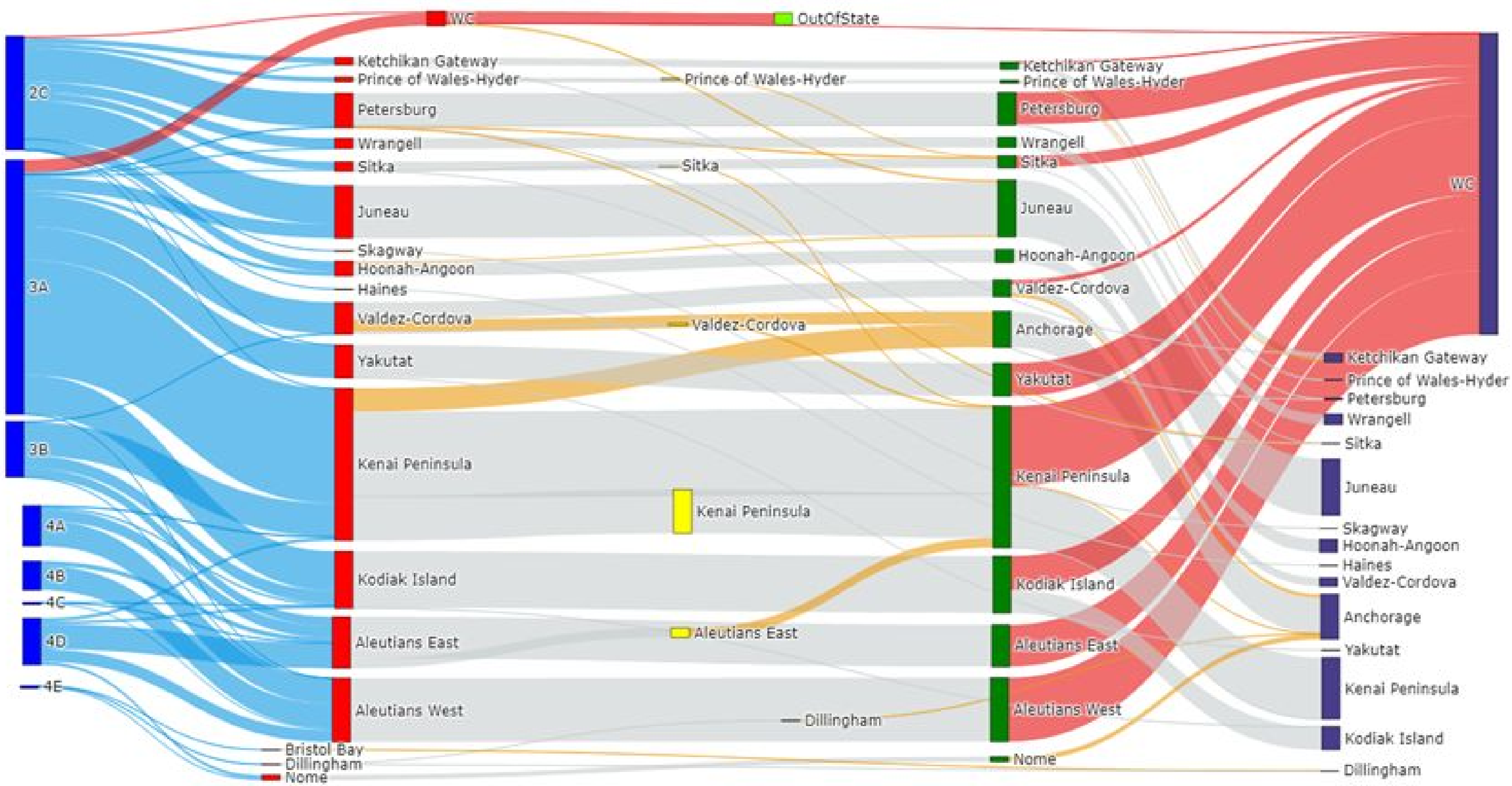


Figure 3 Flow of Pacific halibut harvest from harvest location to buyer's headquarters (2020).

Production structure of the Alaskan saltwater charter sector

Assuming no structural changes to the Alaskan saltwater charter sector from 2017 to 2019, using values reported in Lew & Lee (2019) adjusted for inflation[19] and effort changes (NOAA, 2021c), the model (PHMEIA-r) introduces to the SAM a new sector disaggregated from services with the production total of USD 115.2 mil. This includes USD 75.8 mil in operating costs and USD 16.3 mil in labor expenses. The distribution of the sector's expenditures is based on data reported by Seung & Lew (2017).

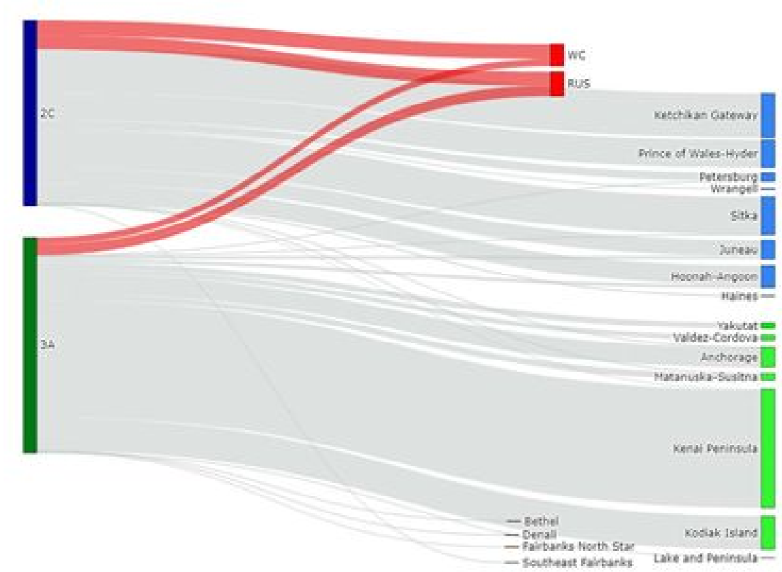
Pacific halibut charter sector is assumed to account for 22.4% (2019) of the Alaskan saltwater charter sector (USD 25.8 mil.). This is calculated as a share of Pacific halibut effort reported by Webster & Powers (2020) in total effort reported by the Marine Recreational Information Program (NOAA, 2021c).

Flows in the Alaskan Pacific halibut charter sector

NOAA (2021b) reports on ownership of Charter Halibut Permits (CHPs). The cross-regional flows related to proprietors' income were assessed using permit holder addresses and the number of endorsed anglers associated with each permit. These flows in 2020 are depicted in **Figure 4**. Outflows related to the workforce in the charter sector are set to 10% for the US West Coast, 40% for the rest of the USA, and 15% for the rest of the world, and are based on the IPHC economic survey responses.

The charter sector also assumes "export" of Pacific halibut fishing trips (i.e., offering services to nonresidents) based on out-of-state participation statistics (NOAA, 2021c) allocated between regions following estimates reported by Southwick Associates (2014).

[19] Using consumer price index, available here: https://data.bls.gov/cgi-bin/cpicalc.pl.



Note: Flows in terms of the number of endorsed anglers. Red ribbons represent outflows from Alaska. Source: NOAA (2021b).

Figure 4 Proprietors income flows for Alaska charter sector (2020).

Appendix 2 *Harvest translated into landings by county*

Table 9 Harvest (in terms of value) translated into landings by county (2020).

	2C	3A	3B	4A	4B	4C	4D	4E	SUM	Total USD
Aleutians East	0	0	1.7%	2.1%	0.9%	0.1%	4.6%	0	9.5%	5.7
Aleutians West	0	c	0.0%	4.7%	4.5%	0.3%	2.3%	0	11.7%	**7.0**
Bristol Bay	0	0	0	0	0	0	0	c	0.0%	c
Dillingham	0	0	0	0	0	0	0	0.1%	0.1%	0.1
Haines	c	0	0	0	0	0	0	0	0.0%	c
Hoonah-Angoon	1.9%	0.8%	0	0	0	0	0	0	2.7%	1.6
Juneau	**7.1%**	2.6%	0	0	0	0	0	0	9.7%	5.8
Kenai Peninsula	c	**21.1%**	**6.1%**	0.2%	0	0	0.6%	0	28.0%	**16.8**
Ketchikan Gateway	1.0%	0.4%	0	0	0	0	0	0	1.4%	0.8
Kodiak Island	0	**7.3%**	2.3%	0.4%	0	c	c	0	10.5%	**6.3**
Nome	0	0	0	0	0	0	0.6%	0.4%	0.9%	0.6
Petersburg	**6.1%**	0.2%	0	0	0	0	0	0	6.3%	3.8
Prince of Wales-Hyder	0.9%	0	0	0	0	0	0	0	0.9%	0.5
Sitka	1.5%	0.3%	0	0	0	0	0	0	1.8%	1.1
Skagway	c	0	0	0	0	0	0	0	0.0%	c
Valdez-Cordova	0	5.8%	c	0	0	0	0	0	5.8%	3.5
Wrangell	1.9%	c	0	0	0	0	0	0	1.9%	1.2
Yakutat	0.1%	6.1%	0	0	0	0	0	0	6.1%	3.7
West Coast	0.4%	2.3%	0	0	0	0	0	0	2.6%	1.6
SUM	**20.9%**	**46.7%**	10.1%	7.4%	5.4%	0.4%	8.1%	0.4%		60.1

Notes: c – confidential, represents less than 3 vessels. Numbers in grey do not sum to the total for the landing county/IPHC Regulatory Area due to confidentiality restrictions.

Appendix 3 *Intra-Alaska workplace commuting flows summary*

Table 10 Intra-Alaska workplace commuting flows summary (2019).

	Outflow to other AK countries	Inflow from other AK counties	Intra-Alaska net flow	Flow as % of total workforce	Nonlocal wages (private)	Nonresident wages (private)
Aleutians East	3	51	48	0.35%	11.4%	73.8%
Aleutians West	7	146	139	0.71%	10.4%	47.1%
Hoonah-Angoon	101	79	-22	-0.31%	19.6%	31.4%
Juneau	150	376	226	0.17%	10.7%	20.6%
Kenai Peninsula	1836	341	-1495	-0.83%	7.3%	13.2%
Ketchikan Gateway	63	156	93	0.17%	7.0%	18.8%
Kodiak Island	75	83	8	0.02%	8.0%	19.6%
Nome	16	105	89	0.34%	15.0%	14.4%
Petersburg	123	101	-22	-0.17%	8.6%	25.3%
Prince of Wales-Hyder	74	87	13	0.08%	5.7%	38.1%
Sitka	58	45	-13	-0.04%	6.8%	25.4%
Valdez-Cordova	92	662	570	1.46%	18.6%	28.0%
Wrangell	40	9	-31	-0.45%	10.1%	21.6%
Yakutat	7	11	4	0.18%	11.5%	32.9%

Notes: Columns 2-4 based on the American Community Survey, Residence County to Workplace County Commuting Flows for the United States and Puerto Rico Sorted by Residence Geography: 5-Year ACS, 2011-2015 (US Census, 2021a). Total workforce as reported in BEA table CAEMP25N. Nonlocal wages are wages earned by AK residents who commute for work to different county. Nonresident wages are wages earned by nonresidents, defined as persons not eligible for the Alaska Permanent Fund Dividend. Nonlocal and nonresident wages based on Kreiger & Whitney (2021). Table includes only countries with Pacific halibut landings typically over USD 100,000. (ADFG, 2021a).

INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH (2021-26)

PREPARED BY: IPHC SECRETARIAT (D. WILSON, J. PLANAS, I. STEWART, A. HICKS, B. HUTNICZAK, R. WEBSTER, & L. ERIKSON; 14 MAY 2021)

PURPOSE

To provide the SRB with the current draft of the new IPHC 5-year program of integrated science and research (2021-26)

BACKGROUND

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

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

An overarching goal of the IPHC 5-Year Program of Science and Research (2021-26) is therefore to promote integration and synergies among the various science and research activities of the IPHC Secretariat in order to improve our knowledge of key inputs into the Pacific halibut stock assessment, and Management Strategy Evaluation (MSE) processes.

DISCUSSION

The SRB is invited to review and provide additional guidance to assist the IPCH Secretariat finalise the draft plan provided at Appendix A.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2021-SRB018-10 which provides the current draft of the new IPHC 5-year program of integrated science and research (2021-26).

APPENDICES

Appendix A: DRAFT: IPHC 5-Year program of integrated science and research (2021-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, B. Hutniczak, & L. Erikson)

INTERNATIONAL PACIFIC HALIBUT COMMISSION

5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH

(July 2021- June 2026)

INTERNATIONAL PACIFIC
HALIBUT COMMISSION

Commissioners

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

Executive Director

David T. Wilson, Ph.D.

BIBLIOGRAPHIC ENTRY

IPHC 2021. International Pacific Halibut Commission 5-Year program of integrated science and research (2021-26). Seattle, WA, U.S.A. *IPHC–2021–5YPISR*, *XX pp.*

INTERNATIONAL PACIFIC HALIBUT COMMISSION

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ACRONYMS

<<<To be completed>>>

DEFINITIONS

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

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1. Introduction

The International Pacific Halibut Commission (IPHC) is an intergovernmental organization established by a Convention between Canada and the United States of America. The IPHC Convention was concluded in 1923 and entered into force that same year. The Convention has been revised several times since, to extend the Commission's authority and meet new conditions in the fishery. The most recent change occurred in 1979 and involved an amendment to the 1953 Halibut Convention. The amendment, termed a "protocol", was precipitated in 1976 by Canada and the United States of America extending their jurisdiction over fisheries resources to 200 miles. The 1979 Protocol along with the U.S. legislation that gave effect to the Protocol (Northern Pacific Halibut Act of 1982) has affected the way the fishery is conducted, and redefined the role of IPHC in the management of the fishery during the 1980s. Canada does not require specific enabling legislation to implement the protocol.

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

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

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

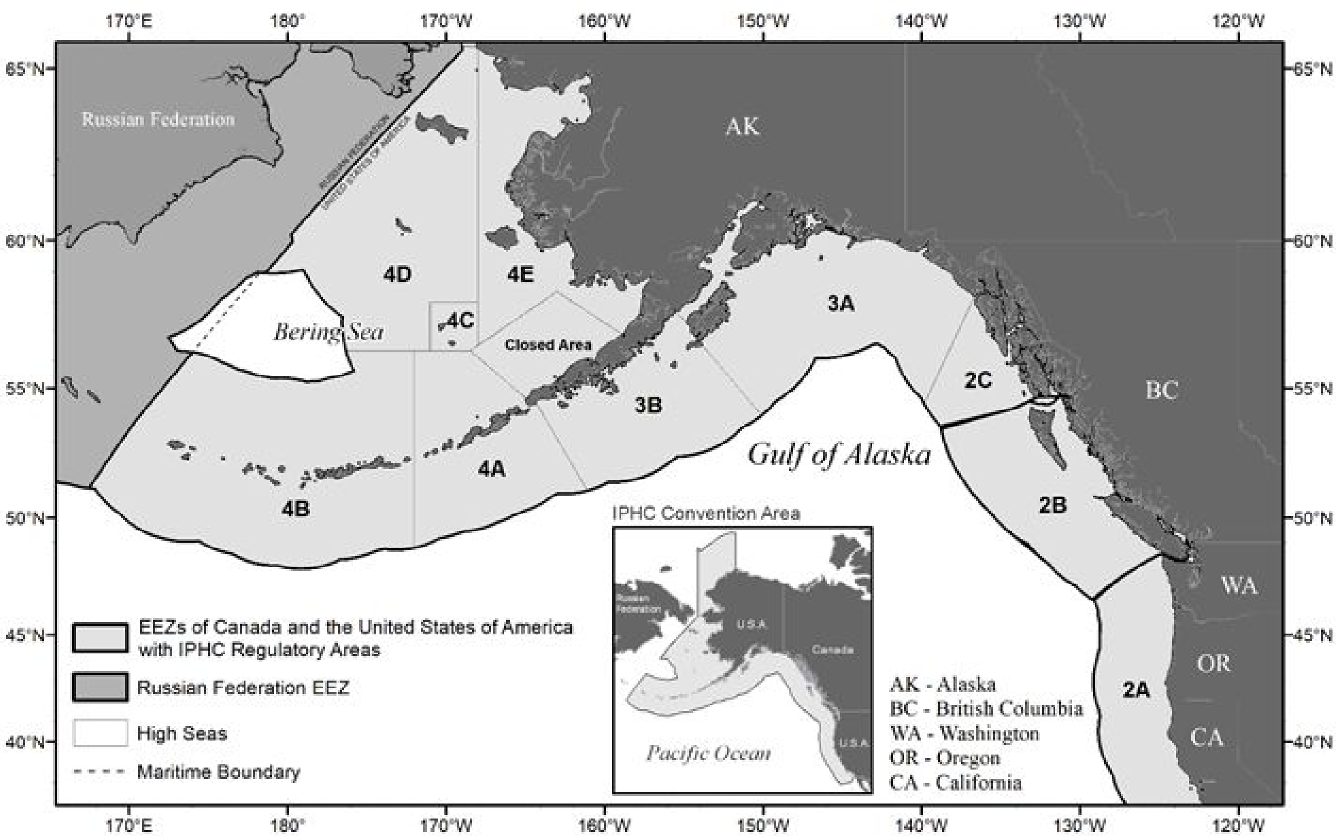

Figure 1. Map of the IPHC Convention Area (map insert) and IPHC Regulatory Areas.

2. *Science and Research objectives*

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

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

An **overarching goal** of the *IPHC 5-Year Program of Science and Research (2021-26)* is therefore to promote integration and synergies among the various science and research activities of the IPHC Secretariat in order to improve our knowledge of key inputs into the Pacific halibut stock assessment, and Management Strategy Evaluation (MSE) processes.

The science and research activities conducted by the IPHC Secretariat are directed towards fulfilling the following five (5) **objectives** within areas of data collection, biological and ecological research, stock assessment, MSE, and fisheries economics, with the overall aim of proving an integrated program of science and research (Fig 2):

1) **Fisheries data**: collect representative fishery dependent and fishery-independent data on the distribution and abundance of Pacific halibut through ongoing monitoring activities;
2) **Biology and Ecology**: identify and assess critical knowledge gaps in the biology and ecology of Pacific halibut within its known range, including the influence of environmental conditions on population and fishery dynamics;
3) **Stock assessment**: apply the resulting knowledge to reduce uncertainty in current stock assessment models and the stock management advice provided to the Commission;
4) **Management Strategy Evaluation (MSE)**: to provide inputs that inform the MSE process, which will evaluate the consequences of alternative management options, known as harvest strategies.
5) **Fishery economics**: to provide stakeholders with an accurate and all-sectors-encompassing assessment of the economic impact of the Pacific halibut resource in Canada and the United States of America.

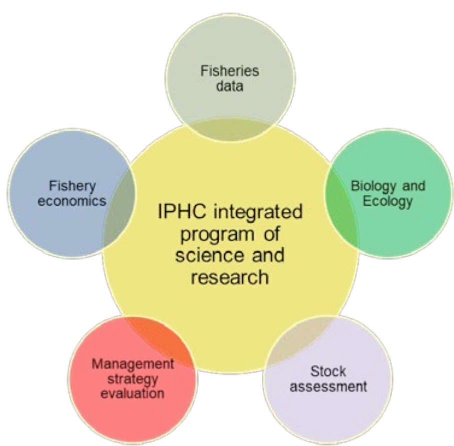

Figure 2. Core areas of the IPHC's integrated program of science and research.

3. *Strategy*

The IPHC Strategic Plan (2019-23) (the Plan) contains five (5) enduring strategic goals in executing our mission, including our overarching goal and associated science and research objectives. Although priorities and tasking will change over time in response to events and developments, the Plan provides a framework to standardise our approach when revising or setting new priorities and tasking. The Strategic goals as they apply to the science and research activities of the IPHC Secretariat, are operationalised through a multi-year tactical activity matrix (Appendix I) at the organisational and management unit (Branch) level (Fig. 3). The tactical activity matrix is described in the sections below, and has been developed based on the core needs of the Commission, in developing and implementing robust, scientifically-based management decisions on an annual, and multi-year level.

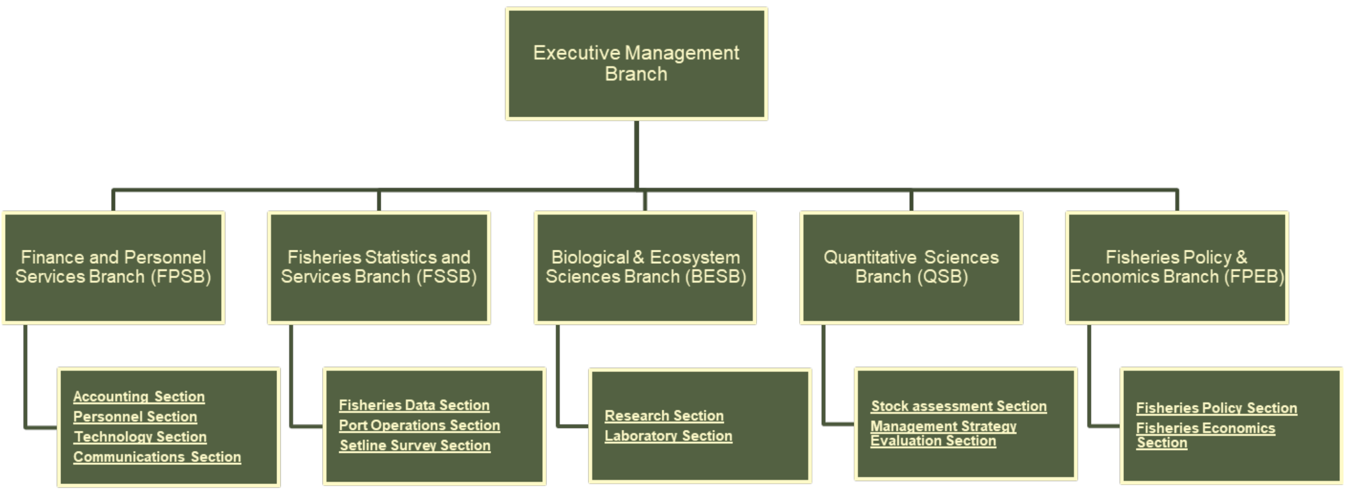

Figure 3. IPHC Secretariat organisation chart (May 2021).

4. *Core focal areas and activities*

The goals of the main activities of the *5-Year program of integrated science and research (2021-26)* are integrated across the organisation, involving regular monitoring (fisheries-dependent and –independent data collection), biological and ecological research, modelling (FISS and stock assessment), Management Strategy Evaluation (MSE), and fishery economic analysis, as outlined in the following sub-sections.

4.1 Fisheries data

Objective: Collect fishery-dependent and fishery-independent data on the distribution and abundance of Pacific halibut, as well as other key biological data, through ongoing monitoring activities.

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

- **Directed commercial fisheries data**: The IPHC Secretariat collects logbooks, otoliths, tissue samples, and associated sex-length-weight data from directed commercial landings coastwide (Fig. 4). A sampling rate is determined for each port by IPHC Regulatory Area. The applicable rate is calculated from the current year's mortality limits and estimated percentages of weight of fish landed, and estimated percentages of weight sampled in that port to allow for collection of the target number of biological samples by IPHC Regulatory Area. An example of the data collected and the methods used are provided in the annually updated directed commercial sampling manual (e.g. IPHC Directed Commercial Landings Sampling Manual 2021). Directed commercial fishery landings are recorded by the Federal and State agencies of each Contracting Party and summarized each year by the IPHC. Discard mortality for the directed commercial fishery is currently estimated using a combination of research survey (USA) and observer data (Canada).

- **Non-directed commercial discard mortality data**: The IPHC accounts for non-directed commercial discard mortality by IPHC Regulatory Area and sector. Non-directed commercial discard mortality estimates are provided by State and Federal agencies of each Contracting Party, and compiled annually for use in the stock assessment and other analysis. https://www.iphc.int/data/datatest/non-directed-commercial-discard-mortality-fisheries.
  Non-directed commercial discard mortality of Pacific halibut is estimated because not all fisheries have 100% monitoring and not all Pacific halibut that are discarded are assumed to die. The IPHC relies upon information supplied by observer programs run by Contracting Party agencies for non-directed commercial discard mortality estimates in most fisheries. Non-IPHC research survey information or other sources are used to generate estimates of non-directed commercial discard mortality in the few cases where fishery observations are unavailable. Trawl fisheries off Canada British Columbia are monitored and non-directed commercial discard mortality information is provided to IPHC by DFO. NOAA Fisheries operates observer programs off the USA West Coast and Alaska, which monitor the major groundfish fisheries. Data collected by those programs are used to estimate non-directed commercial discard mortality.

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

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

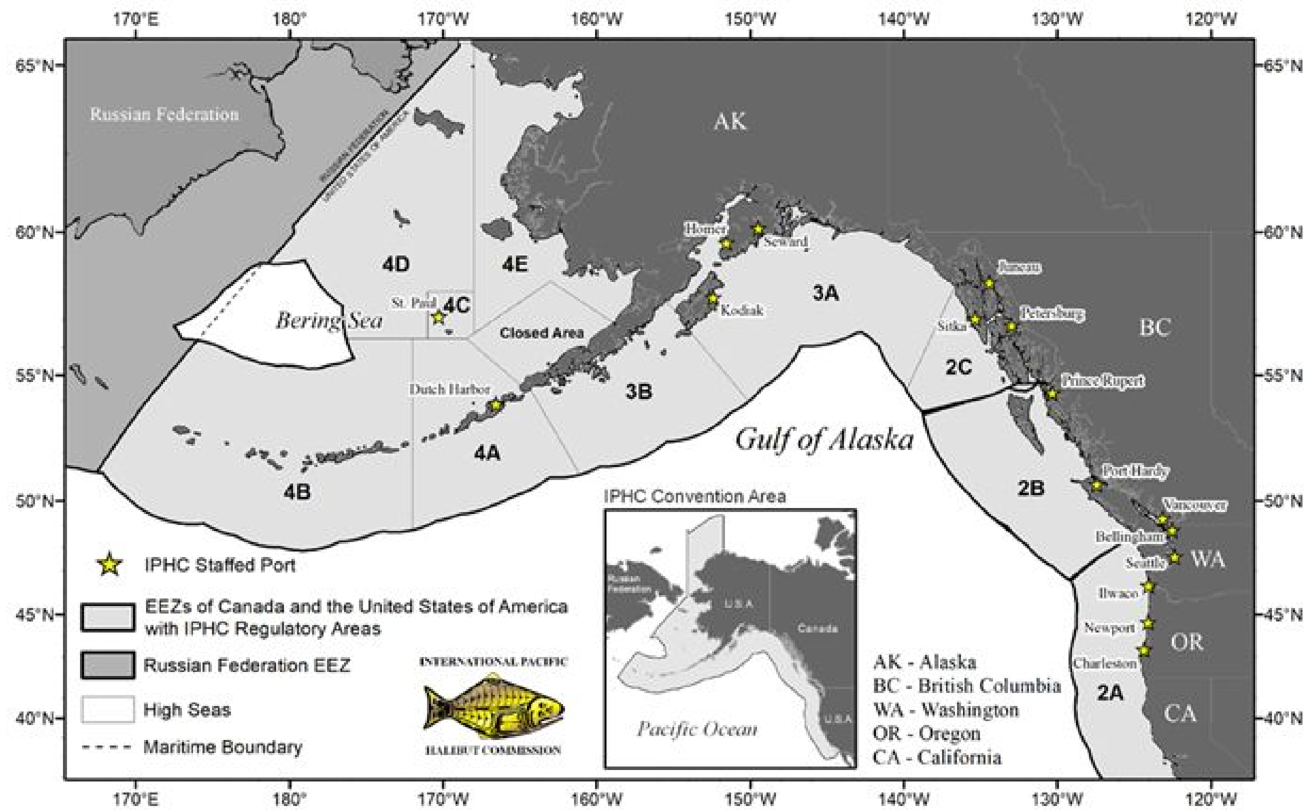

Figure 4. Ports where the IPHC samples directed commercial landings throughout the fishing period.

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

- **Fishery-independent setline survey (FISS)**: The IPHC Fishery-Independent Setline Survey (FISS) provides catch-rate information and biological data on Pacific halibut that are independent of the fishery. These data, collected using standardized methods, bait, and gear during the summer of each year, provide the primary index of population abundance used in the stock assessment. The FISS is restricted to the summer months, but encompasses nearly all of the commercial fishing grounds in the Pacific halibut fishery. The standard FISS grid totals 1,890 stations (Fig. 5). Biological data collected on the FISS (e.g. the length, weight, age, and sex composition of Pacific halibut) are used to monitor changes in biomass, growth, and mortality of the Pacific halibut population. In addition, records of non-target species caught during FISS operations provide insight into bait competition, and serve as an index of abundance over time, making them valuable to the potential management and avoidance of non-target species. An example of the data collected and the methods used are provided in the annually updated FISS sampling manual (e.g. IPHC FISS Sampling Manual 2021).

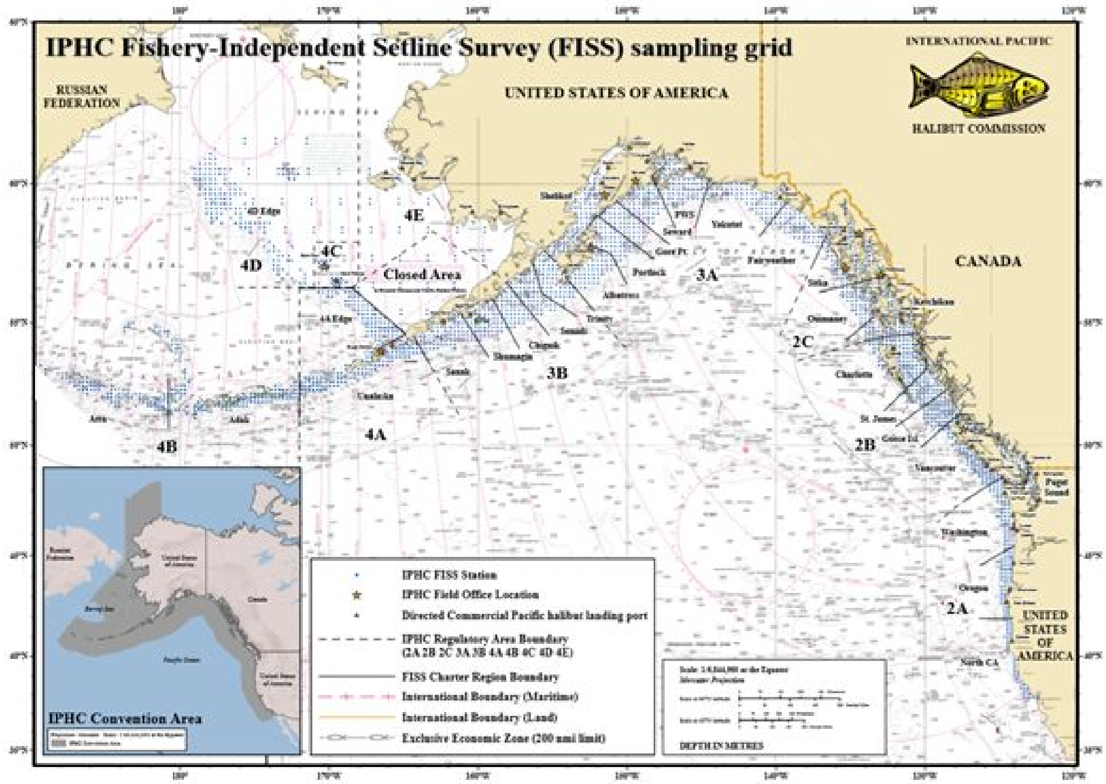

Figure 5. IPHC Fishery-Independent Setline Survey (FISS) with full sampling grid shown.

- **Fishery-independent Trawl Survey (FITS)**: Since 1996, the IPHC has participated annually in the NOAA Fisheries trawl surveys operating in the Bering Sea (Fig. 6) and Aleutian Islands/Gulf of Alaska (Fig. 7). The information collected from Pacific halibut caught on these surveys, together with data from the IPHC Fishery-Independent Setline Survey (FISS) and commercial Pacific halibut data, are used directly in estimating indices of abundance and in the stock assessment and to monitor population trends, growth/size, and to supplement understanding of recruitment, and age composition of young Pacific halibut.

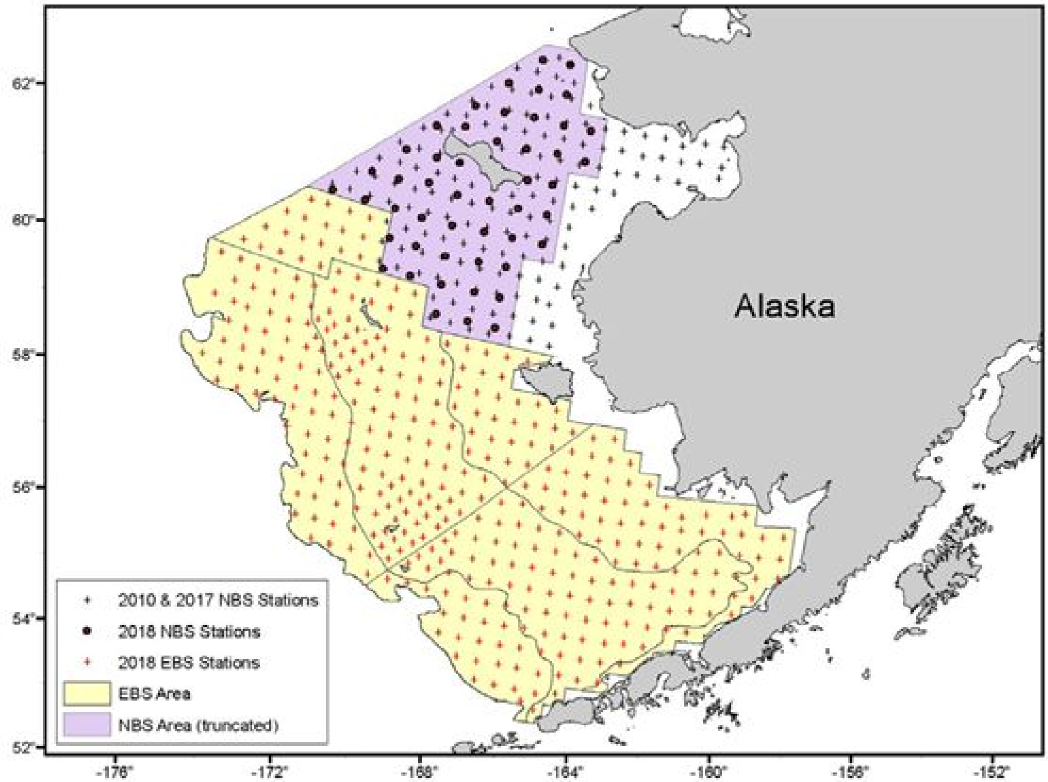

Figure 6. Sampling station design for the 2018 NOAA Bering Sea bottom trawl survey. Black dots are stations sampled in the 2018 "rapid-response" NBS trawl survey and black plus signs are stations sampled in the 2010 and 2017 standard NBS trawl surveys.

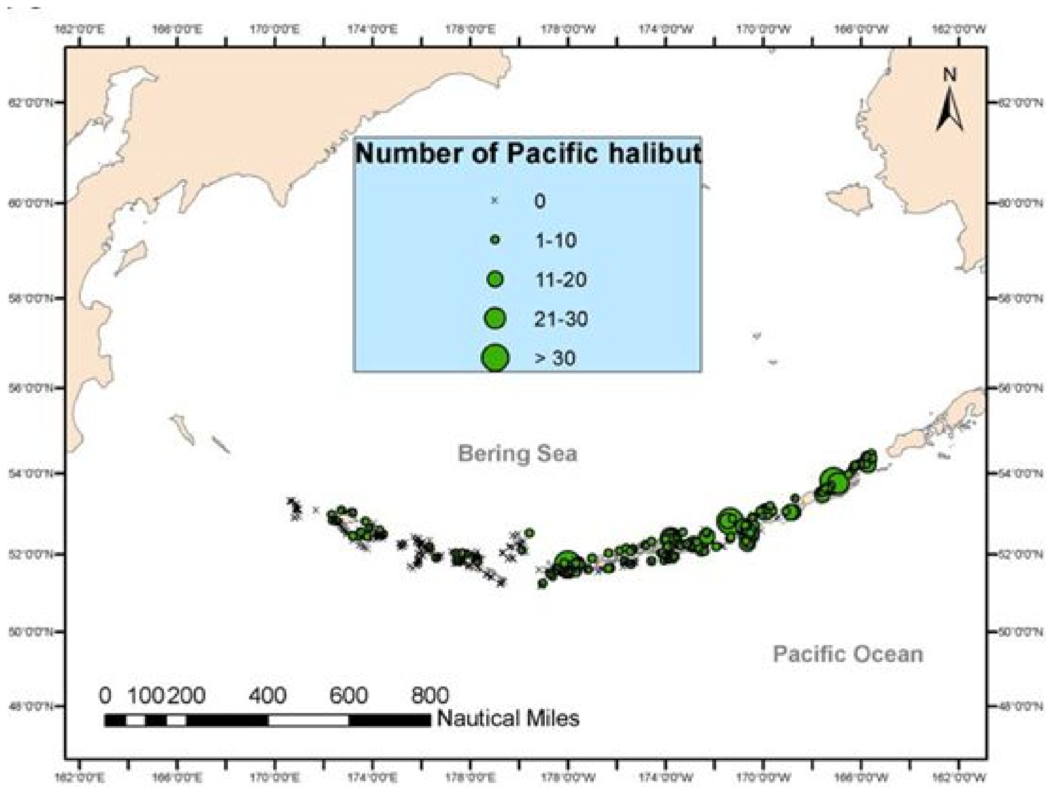

Figure 7a. Sampling stations and catch for the 2018 NOAA-Fisheries Aleutian Islands bottom trawl survey.

[2021 Map to be added]

Figure 7b. Sampling stations and catch for the yyyy NOAA-Fisheries Gulf of Alaska bottom trawl survey.

4.2 Biology and Ecology

Objective: Identify and assess critical knowledge gaps in the biology and ecology of Pacific halibut within its known range, including the influence of environmental conditions on population and fishery dynamics.

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

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

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

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

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

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

- Evaluate possible variation in somatic growth patterns in Pacific halibut as informed by physiological growth markers, physiological condition, energy content and dietary influences.

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

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

- Provide information on the types of fishing gear and fish handling practices used in the Pacific halibut recreational (charter) fishery as well as on the number and size composition of discarded Pacific halibut in this fishery.
- Establish best handling practices for reducing discard mortality of Pacific halibut in recreational fisheries.
- Investigate new methods for whale avoidance and/or deterrence for the reduction of Pacific halibut depredation by whales and for improved estimation of depredation mortality.
- Investigate physiological and behavioral responses of Pacific halibut to fishing gear in order to reduce Pacific halibut bycatch.

4.2.5 ***Climate Change Studies aimed …***

<<In development>>>

4.2.6 ***Fishing technology Studies aimed …***

<<In development>>>

4.3 Stock assessment

Objective: apply the resulting knowledge to reduce uncertainty in current stock assessment models and the stock management advice provided to the Commission.

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

The 2020 stock assessment relied on an ensemble of four population dynamics models to estimate the probability distributions describing the current stock size, trend, and demographics. The ensemble is designed to capture both uncertainty related to the data and stock dynamics (due to estimation) as well as uncertainty related to our understanding of the way in which the Pacific halibut stock functions and is best approximated by a statistical model (structural uncertainty).

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

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

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

It is important to note that ongoing monitoring, including the annual FISS and directed commercial landings sampling programs is not considered research and is therefore not included in this list despite the critical importance of these collections. These are prescribed in Section 4.1 above.

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

4.3.1 Assessment data collection and processing:

4.3.1.1 Commercial fishery sex-ratio-at-age via genetics and development of methods to estimate historical sex-ratios-at-age

Commercial fishery sex-ratio information has been found to be closely correlated with the absolute scale of the population estimates in the stock assessment, and has been identified as the greatest source of uncertainty since 2013. With only three years (2017-19) of commercial sex-ratio-at-age information available for the 2020 stock assessment, the annual genetic assay of fin clips sampled from the landings remains critically important. When the time series grows longer, it may be advantageous to determine the ideal frequency at which these assays need to be conducted. Development of approaches to use archived otoliths, scales or other samples to derive historical estimates could provide valuable information on earlier time-periods (with differing fishery and biological properties), and therefore potentially reconcile some of the considerable historical uncertainty in the present stock assessment.

4.3.1.2 Whale depredation accounting and tools for avoidance

Whale depredation currently represents a source of unobserved and unaccounted-for mortality in the assessment and management of Pacific halibut. A logbook program has been phased in over the last several years, in order to record whale interactions observed by commercial fishermen. While this program may allow for future estimation of depredation mortality, such estimates will likely come with considerable uncertainty. Reduction of depredation mortality through improved fishery avoidance and/or catch protection would be a preferable extension and/or solution to basic estimation. As such, research to provide the fishery with tools to reduce depredation is considered a closely-related high priority.

4.3.2 Biological inputs:

4.3.2.1 Maturity, skip-spawning and fecundity

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

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

The current stock assessment and management of Pacific halibut assume that IPHC Regulatory Area 4B is functionally connected with the rest of the stock, i.e., that recruitment from other areas can support harvest in Area 4B and that biomass in Area 4B can produce recruits that may contribute to other Areas. Tagging (Webster et al. 2013) and genetic (Drinan et al. 2016) analyses have indicated the potential for Area 4B to be demographically isolated. An alternative to current assessment and management structure would be to treat Area 4B separately from the rest of the coast. This would not likely have a large effect on the coastwide stock assessment as Area 4B represents only approximately 5% of the surveyed stock (Stewart et al. 2021b). However, it would imply that the specific mortality limits for Area 4B could be very important to local dynamics and should be separated from stock-wide trends. Therefore, information on the stock structure for Area 4B has been identified as a top priority.

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

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

4.3.3 Fishery yield:

4.3.3.1 Biological interactions with fishing gear

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

4.3.3.2 Guidelines for reducing discard mortality

Much is already known about methods to reduce discard mortality, in non-directed fisheries as well as the directed commercial and recreational sectors. Promotion and adoption of best handling practices could reduce discard mortality and lead to greater retained yield.

Looking forward, the IPHC has recently considered adding close-kin genetics (e.g. Bravington et al. 2016) to its ongoing research program. Close-kin mark-recapture can potentially provide estimates of the absolute scale of the spawning output from the Pacific halibut population. This type of information can be fit directly in the stock assessment, and if estimated with a reasonable amount of precision, even a single data point could substantially reduce the uncertainty in the scale of total population estimates. Data collection of genetic samples from 100% of the sampled commercial landings has been in place since 2017 (as part of the sex-ratio monitoring) and routine comprehensive genetic sampling of FISS catch will begin in 2021. The genetic analysis required to produce data allowing the estimation of reproductive output and other population parameters from close-kin mark-recapture modelling is both complex and expensive, and it could take several years for this project to get fully underway.

4.4 Management Strategy Evaluation (MSE)

Objective: to provide inputs that inform the MSE process, which will evaluate the consequences of alternative management options, known as harvest strategies.

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

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

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

The MSE process involves:

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

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

1. **Objectives**: The goals and objectives that are used in the evaluation.
2. **Management Procedures (MPs)**: Specific, well-defined management procedures that can be coded to produce simulated TCEYs for each IPHC Regulatory Area.
3. **Framework**: The specifications and computer code for the closed-loop simulations including the operating model and how it interacts with the MP.
4. **Evaluation**: The performance metrics and presentation of results. This includes how the performance metrics are evaluated (e.g. tables, figures, and rankings), presented to the Commission and its subsidiary bodies, and disseminated for outreach.

5. **Application**: Specifications of how a MP may be applied in practice and re-evaluated in the future, including responses to exceptional circumstances.

All of these categories provides inputs and outputs of the MSE process, but the Framework category benefits most from the integration of biological and ecosystem research because the operating model and the simulation of the monitoring program, the estimation model, and potential ecosystem effects are determined from this knowledge. MSE priorities for this important aspect have been subdivided into two categories: 1) biological parameterisation and 2) fishery parameterization. In detail, the following topics have been identified as top priorities.

4.4.1 Biological and population parameterization

4.4.1.1 Distribution of life stages and stock connectivity

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

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

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

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

4.4.1.2 Spatial spawning patterns and connectivity between spawning populations

An important parameter that can influence simulation outcomes is the distribution of recruitment across Biological Regions. Continued research in this area will improve the OM and provide justification for parameterising temporal variability. Research includes assigning individuals to spawning areas and establishing temporal and spatial spawning patterns. Outcomes may also provide information on recruitment strength and the relationship with environmental factors.

4.4.1.3 Understanding growth variation

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

4.4.2 Fishery parameterization

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

<<New Program of Work to be added here in summary form once the Commission reviews and approves at the next Special Session of the Commission: June 2021>>

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

4.5 Fishery economics

Objective: to provide stakeholders with an accurate and all-sectors-encompassing assessment of the economic impact of the Pacific halibut resource in Canada and the United States of America.

Under the Convention, the IPHC's mandate is optimum management of the Pacific halibut resource, which necessarily includes an economic dimension. Fisheries economics is an active field of research around the world in support of fisheries policy and management. Adding the economic expertise to the Secretariat, the IPHC has become the first regional fishery management organization (RFMO) in the world to do so.

The goal of the IPHC economic study is to provide stakeholders with an accurate and all-sectors-encompassing assessment of the economic impact of the Pacific halibut resource that includes the full scope of Pacific halibut's contribution to regional economies of Canada and the United States of America. The economic effects of changes to harvest policies can be far-reaching. Altered catch limits have an impact on the direct users of the stock (commercial harvesters, recreational anglers, subsistence fishers), but at the same time, there is a ripple effect through the economy. Fisheries operations create demand for inputs from other sectors while at the same time support industries further along the value chain that rely on the supply of fish, such as seafood processors. The viability of the Pacific halibut sectors is vital to the prosperity of fisheries-dependent households, having a considerable impact on coastal communities. The economic impacts are transmitted cross-regionally through business-to-business transactions (trade in commodities), labor commuting patterns, and the dissemination of profits along the value chain. There is also an inflow if economic benefits to the local economies from outside when non-residents partake in local leisure activities that would not attract the same number of visitors if not for the opportunity to catch this iconic fish of the Pacific Northwest. Pacific halibut's value is also in its contribution to the diet through subsistence fisheries and importance to the traditional users of the resource. To native people, traditional fisheries constitute a vital aspect of local identity and a major factor in cohesion.

Understanding such a broad scope of regional impacts is essential for designing policies with desired effects depending on regulators' priorities. The ability to trace the economic impacts cross-regionally is particularly important in the context of shared resources and joint management, such as the case of collective management of Pacific halibut by the IPHC. Moreover, the study informs on the community impacts of the Pacific halibut resource throughout its range, highlighting communities particularly dependent on economic activities that rely on Pacific halibut. A good understanding of the localized effects is pivotal to policymakers who are often concerned about community impacts, particularly in terms of impact on employment opportunities and households' welfare.

4.5.1 The priorities of the IPHC fisheries economics program can be subdivided into four categories:

4.5.1.1 Primary economic data collection

In order to accurately capture the economic impact of the Pacific halibut, the IPHC designed a series of surveys to gather information from the sectors relying on the Pacific halibut resource. The survey target groups are commercial fishers, processing plant operators, and charter business owners. The goal of the survey is to improve the understanding of each sector's production structure (i.e., data on the distribution of revenue between profit and expenditure items), profitability (including the viability of the sector depending on the stock condition), and distribution of earnings. The compiled survey data serves as an input to the economic impact assessment model.

4.5.1.2 Development of the Pacific halibut multiregional economic impact assessment (PHMEIA) model

PHMEIA model is a multiregional model based on a social accounting matrix (SAM) framework that describes the economic interdependencies between sectors and regions developed to assess the economic contribution of Pacific halibut resource to the economy of the United States and Canada. The model describes the within-region production structure of the Pacific halibut sectors (fishing, processing, charter). In addition, it accounts for interregional spillovers, which represent economic stimulus in the regions other than the one in which the harvest occurs. This is done by tracing Pacific halibut-dependent earnings from the landing stage to beneficial owners of the resource.

It is important to note that accurate characterization of the Pacific halibut sectors in the PHMIA model requires active participation of IPHC stakeholders, including commercial fishers, processing plant operators, and charter business owners in developing the necessary data for analysis.

4.5.1.3 Provide stakeholders with a user-friendly tool visualizing the spatial distribution of economic impacts

The complexity of Pacific halibut supply-side restriction in the form of region-based allocations suggests the need for a tool enabling regulators to assess various combinations of quota allocations easily. To address this, the results of the PHMEIA model are complemented by an interactive web-based application allowing users to estimate and visualize joint economic impacts based on custom changes simultaneously applied to all IPHC-managed Pacific halibut producing areas. In addition, the app highlights the spatial variation of the economic impacts and the importance of cross-regional flows in assessing the dependence of fishing communities on the Pacific halibut resource.

4.5.1.4 Provide input to the management strategy evaluation

The PHMIA model translating the changes in harvest allocations by IPHC regulatory area directly to economic impact by region is well adapted to use with the Pacific halibut management strategy evaluation (MSE) framework. Socio-economic performance metrics presented alongside already developed biological/ecological performance metrics bring the human dimension to the MSE framework, adding to the IPHC's portfolio of tools for assessing policy-oriented issues for the Pacific halibut throughout the Convention Area.

4.5.2 Looking forward, the following areas have been identified as priorities for the IPHC fisheries economics program.

4.5.2.1 Expanding the static SAM model to a computable general equilibrium model

Relaxing the assumption of fixed technical coefficients by specifying these coefficients econometrically as a function of relative prices of inputs is one of the most compelling extensions to the static SAM model. Such models, generally referred to as computable general equilibrium (CGE) models, require research to develop credible functional relationships between prices and consumption that would guide economic agents' behavior in the model. The CGE approach is a preferred way forward when expanding the model usability and applying it in conjunction with the Pacific halibut management strategy evaluation. In addition, the dynamic model is well suited to analyze the impact of a broad suite of policies or external factors that would affect the stock over time.

4.5.2.2 Improving the spatial granularity of the SAM model

Extending the community analysis beyond a simplified approach described in the IPHC-2021-SRB018-09 (section *Community impacts in Alaska*) to a full community level (or any other spatial scale) SAM-based model requires significant investment in identifying the economic relationships between different sectors or industries (including both seafood and non-seafood industries) within each broader-defined region, this including deriving estimates on intra-regional trade in commodities and flow of earnings. It is an appealing extension of the current model with a great potential for more accurate estimates of the community effects.

4.5.2.3 Study of recreational demand

It is important to note that while it is reasonable to assume that changes in harvest limits have a relatively proportional impact on production by commercial fishers (unless these are dramatic and imply fleet restructure or a significant shift in prices), the effects on the recreational sector are not so straightforward. A separate study estimating changes in saltwater recreational fishing participation as a response to the changing recreational harvest limits is necessary to assess policy impacts in the recreational sector rather than provide a snapshot economic impact. Such studies typically require surveying recreational fishers.

4.5.2.4 Study of demand for Pacific halibut products

Catches can be converted to revenues, but one has to determine what price to multiply harvests by. Since price fluctuates with harvest levels, pragmatic assessment of harvest limits changes needs to be supplemented with a model of demand for Pacific halibut. The demand-adjusted prices provide more economics-sound projections of gross revenues in the sector.

The demand model can also be used to estimate final consumer benefits from changing Pacific halibut harvests and prices (i.e., consumer surplus). In 2019, fresh Alaskan Pacific halibut fillets routinely sold for USD 24-28 a pound, and often more, downtown Seattle. Understanding the formation of the price paid by final consumers is an important step in assessing the contribution of Pacific halibut along the entire value chain, from the hook to the plate.

4.5.2.5 Assessment of the economic impact of other sources of Pacific halibut mortality

All-sectors-encompassing quantitative assessment of the economic impact of the Pacific halibut resource necessitates the development of a methodological approach for the remaining sources of Pacific halibut mortality, including subsistence fishing, bycatch, and research catch. Methods adopted for the commercial and charter sector are not adequate for this portion of the harvest.

4.5.2.6 Uncertainty in the PHMEIA model

The PHMEIA model results focus on the magnitude of the Pacific halibut contribution to the economy and its spatial distribution. To increase confidence in the PHMEIA results, the model needs to consider sources of input variations and the cumulative effect of interactions among them. The natural next step is to conduct sensitivity analysis to account for the uncertainties in the system. The current framework would benefit from proposing methods for calculating the range (confidence intervals) of impacts from input variations within a PHMEIA framework, explicitly accounting for multiple sources of input variations.

5. *Measures of Success*

The Secretariat's success in the implementing the *IPHC 5-Year Program of Integrated Science and Research (2021-26)* will be measured according to the following criteria:

5.1 Timely delivery of specified products

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

<<<In development>>>

- Fisheries Data
    - o
- Biology and Ecology
    - o
- Stock Assessment
    - o
- Management Strategy Evaluation
    - o
- Fishery Economics
    - o

5.2 Positive contributions from the Scientific Review Board (SRB) and the Research Advisory Board (RAB)

Periodic review of projects and associated deliverables by both the SRB and RAB as appropriate.

5.3 External research funding

At least 20% of the funds for this program to be sourced from external funding bodies on an annual basis.

<<<In development>>>

- Fisheries Data
    - o
- Biology and Ecology
    - o
- Stock Assessment
    - o
- Management Strategy Evaluation
    - o
- Fishery Economics

5.4 Peer-reviewed journal publication

Publication of research outcomes from activities contemplated in this program in peer-reviewed literature. Each sub-project shall be published in a timely manner.

<<<In development>>>

- Fisheries Data
    - o

- Biology and Ecology
    - o
- Stock Assessment
    - o
- Management Strategy Evaluation
    - o
- Fishery Economics

6. *Future Strategic Science and Research Activities*

Along with the implementation of the medium- and long-term activities contemplated in this *IPHC 5-Year Program of Integrated Science and Research (2021-26)*, the IPHC Secretariat shall strive to:

1) Establish world-leading programs in fisheries research, particularly on genomics and genetics.
2) Establish new collaborative agreements and interactions with research agencies and academic institutions.
3) Promote the international involvement of the IPHC by continued and new participation in international scientific organizations and by leading international science and research collaborations.
4) Incorporation of talented students and early researchers in research activities contemplated.

<<<In development>>>

- Fisheries Data
    - o
- Biology and Ecology
    - o
- Stock Assessment
    - o
- Management Strategy Evaluation
    - o
- Fishery Economics
    - o

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APPENDICES

Appendix I: Integration of science and research activities

Appendix II: Proposed schedule of outputs

Appendix III: Proposed schedule with funding and staffing indicators

APPENDIX I

Integration of science and research activities

(in development: Fisheries Data, Fishery Economics to be added)

Research areas	Research activities	Research outcomes	Relevance for stock assessment	Specific analysis input in stock assessment (SA)	SA Rank	Relevance for MSE	MSE Rank
Migration and Population Dynamics	Larval and juvenile connectivity and early life history 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	Improve parametization of the Operating Model	1. Biological parameterization and validation of movement estimates. 2. Biological parameterization and validation of recruitment distribution
	Population structure	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	2. Biological input		
	Adult migration and 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		
	Close-kin mark-recapture studies	Genomic analysis of population size and connectivity		Population size estimates to fit in the stock assessment			
	Seascape genomics	Identification of adaptive loci, decipher genomic basis of adaptation and detect genomic responses to environmental change		Will be used to define management targets for minimum spawning biomass by Biological Region			
	Genome-wide association analyses	Understand the genetic basis of phenotypic variation, including size-at-age, age-at-maturity, spawning timing, etc.		May help to delineate between effects due to fishing and those due to environment, thereby informing appropriate management response			
Reproduction	Histological maturity assessment	Updated maturity schedule	Scale biomass and reference point estimates	Will be included in the stock assessment, replacing the current schedule last updated in 2006	1. Biological input	Improve simulation of spawning biomass in the Operating Model	
	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			
	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			
	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			
	Sex ratio of current commercial landings	Sex ratio-at-age	Scale biomass and fishing intensity	Annual sex-ratio at age for the commercial fishery fit by the stock assessment	1. Assessment data collection and processing		
	Historical sex ratios based on archived otolith DNA analyses	Historical sex ratio-at-age		Annual sex-ratio at age for the commercial fishery fit by the stock assessment			
	Recruitment strength and variability	Establishment of temporal and spatial maturity and spawning patterns	Improve stock-recruitment curve for more precise assessment	May be used to provide a weighted spawning biomass calculation and or inform targets for minimum spawning biomass by Biological Region		Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model	2. Biological parameterization and validation of recruitment variability and distribution
Growth	Evaluation of somatic growth variation as a driver for changes in size-at-age	Validation of physiological markers for growth pattern evaluation	Scale stock productivity and reference point estimates	May inform yield-per-recruit and other spatial evaluations of productivity that support mortality limit-setting		Improve simulation of variability and allow for scenarios investigating climate change	3. Biological parameterization and validation for growth projections
		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			
		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			
Mortality and survival assessment	Discard mortality rate estimate: recreational fishery	Experimentally-derived DMR	Improve estimates of unobserved mortality	Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits		Improve estimates of stock productivity	1. Fishery parameterization
	Best handling practices: recreational fishery	Guidelines for reducing discard mortality		May reduce discard mortality, thereby increasing available yield for directed fisheries	2. Fishery yield		
	Whale depredation accounting and tools for avoidance	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	2. Assessment data collection and processing		
	Biological interactions with fishing gear	Physiological and behavioral responses to fishing gear	Reduce incidental mortality	May increase yield available to directed fisheries	1. Fishery yield		

APPENDIX II

Proposed schedule of outputs

(in development: Yet to incorporate elements outside BESB)

Research areas	Research activities	2021		2022				2023				2024				2025				2026	
Migration and Population Dynamics	Larval and juvenile connectivity and early life history studies	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Population structure	■	■	■	■																
	Adult migration and distribution	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Close-kin mark-recapture studies				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Seascape genomics					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Genome-wide association analyses						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Reproduction	Histological maturity assessment	■	■	■	■	■	■	■													
	Examination of potential skip spawning	■	■	■	■	■	■	■													
	Fecundity assessment	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Examination of accuracy of current field macroscopic maturity classification	■	■	■	■																
	Sex ratio of current commercial landings	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Historical sex ratios based on archived otolith DNA analyses	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Recruitment strength and variability	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Growth	Application of physiological markers for growth pattern evaluation	■	■																		
	Environmental influences on growth patterns					■	■	■	■	■	■	■	■	■	■	■	■				
	Dietary influences on growth patterns and physiological condition					■	■	■	■	■	■	■	■	■	■	■	■				
Mortality and survival assessment	Discard mortality rate estimate: recreational fishery	■	■																		
	Best handling practices: recreational fishery	■	■	■	■																
	Whale depredation accounting and tools for avoidance			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Biological interactions with fishing gear			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

APPENDIX III

Proposed schedule of funding and staffing indicators

(in development: Yet to incorporate elements outside BESB)

Research areas	Research activities	Required FTEs/Year	IPHC FTEs/Year	2021	2022	2023	2024	2025	2026	IPHC Funds	Grant Funds
Migration and Population Dynamics	Larval and juvenile connectivity and early life history studies	0.45	0.45		RS (0.25 FTE)		RB2 (0.2 FTE)			Yes	No
	Population structure	1	1	RB1						Yes	Proposed
	Adult migration and distribution	1								Yes	Proposed
	Close-kin mark-recapture studies	1	0							No	Planning
	Seascape genomics	1	0							No	Planning
	Genome-wide association analyses	1	0							No	Planning
Reproduction	Histological maturity assessment	0.75	0							Yes	No
	Examination of potential skip spawning	0.25	0							Yes	No
	Fecundity assessment	0.5	0.25			RS				Yes	No
	Examination of accuracy of current field macroscopic maturity classification	0.25								Yes	No
	Sex ratio of current commercial landings	0.5	0.75	LT						Yes	No
	Historical sex ratios based on archived otolith DNA analyses	0.5								Yes	No
	Recruitment strength and variability	0.5	0							Yes	Planning
Growth	Application of physiological markers for growth pattern evaluation	0.25	0.25	LT						Yes	No
	Environmental influences on growth patterns	0.5	0.5			RS				No	Planning
	Dietary influences on growth patterns and physiological condition	0.5	0.2			RB2				No	Planning
Mortality and survival assessment	Discard mortality rate estimate: recreational fishery	0.5	1			RB 3				No	Yes
	Best handling practices: recreational fishery	0.5								No	Yes
	Whale depredation accounting and tools for avoidance	0.5								No	Pending
	Biological interactions with fishing gear	0.5								No	Pending

Current IPHC staff (Total 4.4 FTEs):

RS: Research Scientist (PhD). Full time permanent position (100% research; 1 FTE)

RB1: Research Biologist 1 (Geneticist; MSc). Full time temporary position (until April 2022; 1 FTE). 55% of salary requested in grant application.

RB2: Research Biologist 2 (Early Life History; MSc). Full time permanent position (40% research; 0.4 FTE)

RB3: Research Biologist 3 (DMR; MSc candidate). Full time permanent position (100% research; 1 FTE)

LT: Laboratory Technician (MSc). Full time temporary position (100% research; 1 FTE)