INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC–2020–MSAB016–00

# 16th Session of the IPHC Management Strategy Advisory Board (MSAB016) – *Compendium of meeting documents*

19 – 22 October 2020, Courtenay, BC, Canada

**DISTRIBUTION:** IPHC WEBSITE
**LAST UPDATE:** 10 NOVEMBER 2020

**BIBLIOGRAPHIC ENTRY**
IPHC 2020. 16th Session of the IPHC Management Strategy Advisory Board (MSAB016) - Compendium of meeting documents. Int. Pac. Halibut Comm.

INTERNATIONAL PACIFIC
HALIBUT COMMISSION

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

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

Contact details:

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

# Report of the 16th Session of the IPHC Management Strategy Advisory Board (MSAB016)

Meeting held electronically, 19-22 October 2020

**Commissioners**

| Canada | United States of America |
|---|---|
| Paul Ryall | Chris Oliver |
| Neil Davis | Robert Alverson |
| Peter DeGreef | Richard Yamada |

**Executive Director**

David T. Wilson, Ph.D.

**DISTRIBUTION:**
Participants in the Session
Members of the Commission
IPHC Secretariat

**BIBLIOGRAPHIC ENTRY**
IPHC 2020. Report of the 16th Session of the IPHC Management Strategy Advisory Board (MSAB016). Meeting held electronically, 19-22 October 2020.
*IPHC–2020–MSAB016–R, 25 pp.*

INTERNATIONAL PACIFIC HALIBUT COMMISSION

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

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

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

Contact details:

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

## ACRONYMS

| | |
|---|---|
| AK | Alaska |
| AM | Annual Meeting |
| ADFG | Alaska Department of Fish & Game |
| CDN | Canada/Canadian |
| CPUE | Catch-per-unit-effort |
| DFO | Fisheries and Oceans Canada |
| IPHC | International Pacific Halibut Commission |
| Mlbs | Millions of pounds |
| MP | Management Procedure |
| MSAB | Management Strategy Advisory Board |
| MSE | Management Strategy Evaluation |
| NWIFC | Northwest Indian Fisheries Commission |
| OM | Operating Model |
| SRB | Scientific Review Board |
| SPR | Spawning Potential Ratio |
| SS | Special Session |
| TCEY | Total Constant Exploitation Yield |
| U26 | Under 26 inches |
| USA | United States of America |
| WPUE | Weight-per-unit-effort |

## 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.

## TABLE OF CONTENTS


REPORT OF THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)..............1

TABLE OF CONTENTS....4

EXECUTIVE SUMMARY....5

1. OPENING OF THE SESSION....6

2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION....6

3. IPHC PROCESS....6
   - 3.1 *MSAB Membership*....6
   - 3.2 *Update on the actions arising from the 15th Session of the MSAB (MSAB015)*....6
   - 3.3 *Review of the outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017)*....7
   - 3.4 *Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and the 6th Special Session of the IPHC (SS06)*....7

4. A REVIEW OF MANAGEMENT PROCEDURES TO DETERMINE THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) BY IPHC REGULATORY AREAS FOR PACIFIC HALIBUT FISHERIES....7
   - 4.1 *Management procedures for coastwide scale*....7
   - 4.2 *Management procedures for distributing the TCEY*....7

5. A FRAMEWORK TO INVESTIGATE FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES....9
   - 5.1 *Multi-area operating model*....9
   - 5.2 *Framework to investigate distributing the TCEY among IPHC Regulatory Areas*....9

6. RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES....10
   - 6.1 *Performance metrics for evaluation*....10
   - 6.2 *Results from the closed-loop simulations*....10

7. MSAB PROGRAM OF WORK....12
   - 7.1 *MSAB Program of Work (2020-21)*....12

8. OTHER BUSINESS....13

9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 15TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB015)....13

APPENDIX I LIST OF PARTICIPANTS FOR THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)....14

APPENDIX II AGENDA FOR THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)....16

APPENDIX III LIST OF DOCUMENTS FOR THE 16TH SESSION OF THE MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)....18

APPENDIX IV MSAB MEMBERSHIP....19

APPENDIX V PROPOSED MANAGEMENT PROCEDURES FROM IPHC-2020-MSAB015-R....21

APPENDIX VI PRIMARY OBJECTIVES AND PERFORMANCE METRICS....22

APPENDIX VII RANKINGS OF MANAGEMENT PROCEDURES AGAINST MEASURABLE OUTCOMES....23

APPENDIX VIII RANKINGS OF MANAGEMENT PROCEDURES AGAINST GENERAL OBJECTIVES....24

APPENDIX IX CONSOLIDATED SET OF RECOMMENDATIONS AND REQUESTS OF THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)....25

## EXECUTIVE SUMMARY

The 16th Session of the International Pacific Halibut Commission (IPHC) Management Strategy Advisory Board (MSAB016) was held in an electronic format (remote participation), from 19-22 October 2020. The MSAB consists of 24 board members, 21 of which attended the Session from the two (2) Contracting Parties. A total of 5 individuals attended the Session as Observers. In addition, one (1) IPHC Commissioner was in attendance, Mr Peter DeGreef (Canada). The list of participants is provided at Appendix I.

The following are a subset of the complete recommendations/requests for action from the MSAB016, which are provided in full at Appendix IX.

### *RECOMMENDATIONS*

MSAB016-Rec.1 (para. 35) The MSAB **RECOMMENDED** that the performance metrics related to the current primary objectives (Appendix VI) be considered when evaluating MPs.

MSAB016-Rec.2 (para. 53) The MSAB **RECOMMENDED** the following MPs for analysis and consideration in 2021:

a) MP-J in combination with a fixed TCEY of 1.65 Mlbs in Regulatory Area 2A, as in paragraph 97 b) of IPHC-2020-AM096-R, with total mortality rebalanced among remaining U.S.A. IPHC Regulatory Areas to maintain a constant SPR;

b) MP-J in combination with a minimum TCEY of 1.65 Mlbs in Regulatory Area 2A which allows the TCEY to exceed 1.65 in IPHC Regulatory Area 2A with total mortality rebalanced among remaining U.S.A. IPHC Regulatory Areas to maintain a constant SPR.

(para. 47) The MSAB **ENDORSED** Tier 1 MPs, that were ranked highest in the MSE results using the tools available, for consideration. These MPs are MP-D, MP-H, MP-I, MP-J, MP-K as specified in Appendix V.

## 1. OPENING OF THE SESSION

1. The 16th Session of the International Pacific Halibut Commission (IPHC) Management Strategy Advisory Board (MSAB016) was held in an electronic format (remote participation), from 19-22 October 2020. The MSAB consists of 24 board members, 21 of which attended the Session from the two (2) Contracting Parties. A total of 5 individuals attended the Session as Observers. In addition, one (1) IPHC Commissioner was in attendance, Mr Peter DeGreef (Canada). The list of participants is provided at Appendix I.

2. The MSAB **NOTED** that no apologies were received by the IPHC Secretariat and/or the Co-Chairpersons from absent board members (Appendix I).

3. The MSAB **RECALLED** that the primary role of the MSAB is to advise the Commission on the Management Strategy Evaluation (MSE) process. To meet this advisory role, the Commission has articulated the following specific objectives for the MSAB, as described in Appendix V, para. 2 of the IPHC Rules of Procedure (2020):

   a) *define clear measurable objectives and performance measures for the fishery;*

   b) *define candidate management strategies, which include aspects of the fishery that can be managed (e.g. regulatory requirements);*

   c) *advise the IPHC Secretariat about plausible scenarios for investigation, which include aspects of the fishery that cannot be managed by the IPHC (e.g. environmental conditions and removals under the management authority of a domestic management agency);*

   d) *Gather and clearly articulate the interests and concerns of constituents and incorporate them into the MSAB's discussions;*

   e) *encourage and allow members to test tentative ideas and exploratory suggestions without prejudice to future discussions;*

   f) *represent information, views, and outcomes of the MSAB discussions to external parties accurately and appropriately;*

   g) *encourage the understanding and support of their constituencies for the MSAB process and for consensus positions developed by MSAB.*

4. **NOTING** paragraph 3, the MSAB **RECALLED** that the Management Strategy Evaluation process is a stakeholder informed, scientifically driven process.

## 2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

5. The MSAB **ADOPTED** the Agenda as provided at Appendix II. The documents provided to the MSAB016 are listed at Appendix III.

## 3. IPHC PROCESS

### *3.1 MSAB Membership*

6. The MSAB **NOTED** paper IPHC-2020-MSAB016-03 which provided the current membership list and term expirations for the MSAB. The current full membership list is provided at Appendix IV.

### *3.2 Update on the actions arising from the 15th Session of the MSAB (MSAB015)*

7. The MSAB **NOTED** paper IPHC-2020-MSAB016-04 which provided the MSAB with an opportunity to consider the progress made during the inter-sessional period in relation to the recommendations and requests of the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015).

8. The MSAB **AGREED** to consider and revise as necessary, the actions arising from the MSAB015, and for these to be combined with any new actions arising from the MSAB016.

### *3.3 Review of the outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017)*

9. The MSAB **NOTED** paper IPHC-2020-MSAB016-05 which provided the outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) relevant to the mandate of the MSAB, which were provided for reference.

### *3.4 Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and the 6th Special Session of the IPHC (SS06)*

10. The MSAB **NOTED** paper IPHC-2020-MSAB016-06 which detailed the outcomes of the 96th Session of the IPHC Annual Meeting (AM096), and the 6th Special Session of the IPHC (SS06), relevant to the mandate of the MSAB.

11. The MSAB **RECALLED** the two (2) inter-sessional decisions relevant to the MSAB from the Commission as follows:

    IPHC-2020-ID001: *The Commission RECOMMENDED that the primary coastwide and area-specific objectives outlined in Table 1 of Appendix A be used for evaluating MSE results conditional on future consideration of the objectives;*

    IPHC-2020-ID002: *The Commission RECOMMENDED a reference SPR fishing intensity of 43% with a 30:20 control rule be used as an updated interim harvest policy consistent with MSE results pending delivery of the final MSE results at AM097, noting the additional components intended to apply for a period of 2020 to 2022 as defined in IPHC-2020-AM096-R paragraphs 97 b, c, d, and e. Specifically, these additional components are allocations to 2A and 2B, accounting for some impacts of U26 non-directed discard mortality, and the use of a rolling three-year average for projecting non-directed fishery discard mortality.*

## 4. A REVIEW OF MANAGEMENT PROCEDURES TO DETERMINE THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) BY IPHC REGULATORY AREAS FOR PACIFIC HALIBUT FISHERIES

12. The MSAB **NOTED** paper IPHC-2020-MSAB016-07 which provided an update on management procedures (MPs) related to distributing the TCEY for use in the MSE process.

### *4.1 Management procedures for coastwide scale*

13. The MSAB **RECALLED** paragraph IPHC-2020-ID002 as noted in paragraph 11 above and **NOTED** that an SPR of 43% was justified from results based on the coastwide MSE, and is subject to further evaluation using the multi-region MSE.

14. The MSAB **NOTED** that coastwide scale is determined from a procedural SPR that is modified based on stock status to determine the coastwide fishing intensity and total mortality.

### *4.2 Management procedures for distributing the TCEY*

15. The MSAB **RECALLED** that eleven MPs were identified by the MSAB for evaluation at MSAB016, as listed in Appendix V.

16. The MSAB **NOTED** that descriptions of the eleven management procedures identified by the MSAB at MSAB015 (Appendix V) are in IPHC-2020-MSAB016-INF03.

17. The MSAB **RECALLED** paragraph 97 a) and b) of IPHC 2020-AM096-R:

    IPHC-2020-AM096-R, para 97: "*The Commission ADOPTED:*

    *a) a coastwide mortality limit (TCEY) of 36.6 million pounds; and*

    *b) a fixed TCEY for IPHC Regulatory Area 2A of 1.65 million pounds is intended to apply for a period from 2019-2022, subject to any substantive conservation concerns;*"

18. The MSAB **NOTED** that the fixed TCEY of 1.65 Mlbs for IPHC Regulatory Area 2A was used in MP15-A through MP15-E following paragraph 97 b) of IPHC-2020-AM096-R, although the intent of the proposed MP was to implement a minimum TCEY of 1.65 Mlbs that may increase for evaluation in the MSE process.

19. The MSAB **RECALLED** paragraphs 55, 57, and 58 from IPHC-2019-MSAB014-R:

*IPHC-2019-MSAB014-R, para 55. The MSAB REQUESTED that a number of elements in distribution management procedures be included for evaluation at MSAB015:*

a) *A coastwide constraint using a slow-up, fast-down approach with a maximum change in the TCEY of 15%;*

b) *evaluating different relative harvest rates across IPHC Regulatory Areas or Biological Regions;*

c) *distributing the TCEY directly to IPHC Regulatory Area;*

d) *A fixed shares concept for all or some IPHC Regulatory Areas, Biological Regions, or Management Zones with options to distribute the TCEY to the areas without a fixed share. The determination of these shares may be fixed or varying over time; and*

e) *A maximum fishing intensity defined by an SPR of 36% to act as a buffer when distributing the TCEY to IPHC Regulatory Areas.*

*IPHC-2019-MSAB014-R, para 57. The MSAB NOTED additional elements for distribution procedures to consider as sensitivities when developing management procedures for evaluation at MSAB015 as follows:*

a) *a constraint applied to the TCEY for each IPHC Regulatory Area using a slow-up, fast-down approach with a maximum change in the TCEY of 15%;*

b) *using O32 estimates of stock distribution or "all sizes" estimates of stock distribution from the modelled survey results;*

c) *evaluating different relative harvest rates across IPHC Regulatory Areas or Biological Regions (e.g. harvest rates for Biological Region 2, IPHC Regulatory Areas 2A and/or 4CDE);*

d) *calculating shares across Biological Regions, Management Zones, or IPHC Regulatory Areas using approaches that blend multiple sources of information (e.g., using historical TCEYs and stock distribution results for all IPHC Regulatory Area, a 5-year window of estimated stock distribution, etc.);*

e) *the importance the order of applying elements in the distribution procedure when limiting the maximum SPR (i.e. using a buffer).*

*IPHC-2019-MSAB014-R, para 58. The MSAB NOTED additional elements for distribution procedures to consider when developing management procedures for evaluation at MSAB016 as follows:*

a) *a constraint applied to the TCEY for each IPHC Regulatory Area using a slow-up, fast-down approach;*

b) *a constraint applied to the TCEY for each IPHC Regulatory Area implementing a maximum change in the TCEY of 15%;*

c) *a maximum fishing intensity defined by an SPR of 40% to act as a buffer when distributing the TCEY to IPHC Regulatory Areas;*

d) *adjusting relative harvest rates to reflect current stock productivity (note that this will be explored before MSAB015);*

e) *using trends in fishery CPUE to adjust allocation percentages by IPHC Regulatory Area (note that this will be explored before MSAB015);*

f) *additional approaches to first distribute the TCEY to Biological Region or Management Zone.*

20. The MSAB **NOTED** that results from additional MPs are available for informational purposes and comparison to the eleven MPs identified by the MSAB at MSAB015 (Appendix V) that incorporate other elements of interest.

## 5. A FRAMEWORK TO INVESTIGATE FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES

21. The MSAB **NOTED** paper IPHC-2020-MSAB016-08 which provided an update on Management Strategy Evaluation (MSE) activities relating to the definition and development of a framework to evaluate MPs for distributing the TCEY.

22. The MSAB **ACKNOWLEDGED** the significant effort of the IPHC Secretariat to develop and implement the MSE framework for simulation of MPs related to coastwide scale and distribution of the TCEY.

### *5.1 Multi-area operating model*

23. The MSAB **NOTED** that a multi-area OM capable of modelling movement between four Biological Regions with thirty-three fisheries was used in the MSE framework.

### *5.2 Framework to investigate distributing the TCEY among IPHC Regulatory Areas*

24. The MSAB **AGREED** that the simulation of domestic allocation mimicked the domestic catch-sharing agreements to the extent possible, but may not reflect realised allocations at low TCEYs.

25. The MSAB **NOTED** various categories of implementation variability: 1) departures from the MP due to the decision-making process (i.e. the adopted mortality limit), and 2) differences in the realized fishing mortality (not due to estimation error) from the adopted mortality limit (as modelled in the operating model). Furthermore, estimated fishing mortality may differ from realised fishing mortality due to uncertainty in reported landings and other sources of fishing mortality, which would be used by the estimation model.

26. The MSAB **RECALLED** paragraph 59 of IPHC-2020-SRB017-R:

> IPHC-2020-SRB017-R, 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.*"

27. The MSAB **AGREED** that the MSE framework is useful to test the eleven MPs from MSAB015 (Appendix V) and that the following are some of the parameters and processes that remain uncertain and are a priority to be further developed:

a) implementation variability including decision-making variability, realized fishing mortality (some of which is currently implemented), and catch estimation uncertainty;

b) movement parameterization including uncertainty and time-varying properties;

c) recruitment distribution including uncertainty and time-varying properties;

d) estimated O32 stock distribution in IPHC Regulatory Areas, which is partly due to the proportion of biomass in each IPHC Regulatory Area within a Biological Region defined as a static value over time determined from the last 10 years of estimated stock distribution, as well as other assumptions in the OM;

e) determination of size structure (e.g. O32 biomass), which should be linked to variable size-at-age over time.

28. The MSAB **RECALLED** paragraph 37 from IPHC-2020-MSAB014-R:

> (para. 37) "*The MSAB **AGREED** to an objective to conserve spatial population structure that is defined as a minimum proportion of the spawning biomass in each Biological Region as 5% in Region 2, 33% in Region 3, 10% in Region 4, and 2% in Region 4B. These proportions were proposed by the IPHC Secretariat after qualitatively investigating the modelled survey proportion of O32 stock distribution in each Biological Region since 1993 and may be updated following further review.*"

29. The MSAB **NOTED** the simulated percentage of spawning biomass in IPHC Regulatory Area 4B is less than 2% in more than 5% of the simulations in the long-term with zero fishing mortality, which is a result of the OM specifications rather than an effect of an MP.

30. The MSAB **NOTED** that there is research currently being conducted by the IPHC Secretariat investigating movement, stock structure, and other pertinent topics for future MSE, noted in IPHC-2020-IM096-10. This research will be useful for addressing the points in paragraphs 25 and 27.

31. The MSAB **AGREED** that sensitivity analyses exploring alternative hypotheses about connectivity between all Biological Regions in addition hypotheses of other aspects of population dynamics would help to evaluate the robustness of MPs.

32. **NOTING** paragraph 29, the MSAB **AGREED** that sensitivity analyses exploring alternative hypotheses about connectivity between Biological Region 4B and other areas, including outside of the IPHC Convention Area, in addition to hypotheses of other aspects of population dynamics in Biological Region 4B would help to evaluate the robustness of MPs.

33. The MSAB **AGREED** that the strength of the model is to rank MPs against one another, and is likely less informative of specific predictions for metrics such as the TCEY in a particular IPHC Regulatory Area. For example, predictions of O32 stock distribution departed from the observations in recent years and did not fully cover the range or patterns over time of past observations. Similarly, the OM did not encompass the full range of possible variability from many components, and thus some performance metrics may not be completely characterized (e.g. yield stability).

## 6. RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES

### *6.1 Performance metrics for evaluation*

34. The MSAB **NOTED** paper IPHC-2020-MSAB015-09 Rev_1 which provided results for the evaluation of MPs for distributing the TCEY in the form of performance metrics related to the current primary objectives.

35. The MSAB **RECOMMENDED** that the performance metrics related to the current primary objectives (Appendix VI) be considered when evaluating MPs.

### *6.2 Results from the closed-loop simulations*

36. The MSAB **NOTED** that results and the online tool called *MSE Explorer* is archived on the IPHC MSE webpage and includes all performance metrics and statistics of interest displayed in tables and various plots.

37. The MSAB **NOTED** that the IPHC Fishery-Independent Setline Survey (FISS) is currently the best scientific method for estimating stock distribution among Biological Regions and IPHC Regulatory Areas.

38. The MSAB **AGREED** that the use of FISS-derived distribution for distribution of the TCEY in an MP is a management decision.

39. The MSAB **RECALLED** IPHC-2020-MSAB015-R, para. 39:

IPHC-2020-MSAB015-R, para. 39: "*The MSAB **NOTED** potential categories of elements for MPs (alone or in combination) includes:*

a) *Modelled survey estimates (e.g. relative biomass estimates by Biological Region, IPHC Regulatory Areas or other scale, O32 WPUE, trend in O32 WPUE, etc.);*

b) *Fishery dependent data (e.g. trend in CPUE by Biological Region, IPHC Regulatory Area or other scale);*

c) *Other tools (e.g. relative harvest rate, percentage allocation to an IPHC Regulatory Areas, proportion of adopted TCEY, fixed allocations, minimum TCEY, etc.).*"

40. The MSAB **AGREED** that when developing MPs for evaluation, distribution of the TCEY to IPHC Regulatory Areas can have several components, that range from purely scientific, to describe the stock distribution and shifts in harvest rates due to differences in productivity, to policy driven, that modify the distribution based on additional considerations.

41. The MSAB **AGREED** that all eleven MPs evaluated met the current primary biological sustainability objectives and resulted in similar coastwide TCEYs on average for an SPR of 43% with a 30:20 control rule, notwithstanding objective 1.1 for IPHC Regulatory Area 4B, as described in paragraph 29.

42. The MSAB has evaluated MPs for distributing TCEYs as part of the scientifically driven MSE process and **AGREED** that MPs with components that are data-driven and/or policy-driven all satisfied biological sustainability objectives 1.1 and 2.1, notwithstanding objective 1.1 for IPHC Regulatory Area 4B, as described in paragraph 29.

43. The MSAB **NOTED** two summary ranking tables of MP performance metrics in Appendix VII and Appendix VIII. Appendix VIII describes the overall performance of MPs relative to each other within the general objective and Appendix VII describes rankings within measurable objectives (objectives are listed in Appendix VI).

44. The MSAB **NOTED** that an intent of MSE is to rank the performance of MPs relative to each other against defined objectives. However, there are many methods to determine quantitative rankings between the MPs, included weighting performance metrics when averaging. The preliminary ranking method used in the current evaluation may exaggerate differences between management procedures. Therefore, when considering these tables, the results (i.e. specific performance metrics) should be considered along with these summary ranking tables. The rank values do not indicate the magnitude of the difference in performance metrics between MPs.

45. The MSAB **AGREED** to categorize the eleven MPs into three ranked performance tiers.

46. The MSAB **NOTED** Tier 1 contained MPs that generally maintained the spawning biomass closer to the defined target (objective 2.1), limited catch variability for multiple IPHC Regulatory Areas (objective 2.2), and provided higher yield in multiple IPHC Regulatory Areas relative to Tier 2 and Tier 3. The following MPs are classified as Tier 1:

a) MP-D: ranked 1st in maintaining spawning biomass near the biomass target, ranked 2nd to limit catch variability, and 3rd in providing yield, relative to all eleven MPs. This MP incorporated flexibility in the determination of the total mortality limit to allow for the current interim agreements for IPHC Regulatory Areas 2A and 2B without reducing the TCEY in other IPHC Regulatory Areas within the defined buffer for fishing intensity, which resulted in higher and more stable mortality limits in IPHC Regulatory Areas in Alaska waters.

b) MP-H: tied 2nd in rank for maintaining spawning biomass near the biomass target, tied for 3rd to limit catch variability, and 7th in providing yield, relative to all eleven MPs. This MP increased relative harvest rates in IPHC Regulatory Areas 3B, 4A, and 4CDE relative to other MPs evaluated, which may be supported by recent analysis of productivity. However, it is uncertain if this MP is robust to alternative assumptions about movement, recruitment distribution, and productivity.

c) MP-I: tied 2nd in rank for maintaining spawning biomass near the biomass target, 4th in rank to limit catch variability, and 2nd in providing yield, relative to all eleven MPs. This MP uses all-sizes estimated stock distribution to distribute the TCEY among IPHC Regulatory Areas. There is uncertainty of how robust this MP is to assumptions in the OM to determine the proportion of O32 fish, which likely applies to all evaluated MPs.

d) MP-J: tied 4th in rank for maintaining spawning biomass near the biomass target, tied 3rd in rank to limit catch variability, and was 1st in providing yield, relative to all eleven MPs. A rolling five-year average of estimated O32 stock distribution for stock distribution among IPHC Regulatory Areas accomplished stability for the TCEY coastwide and within IPHC Regulatory Areas.

e) MP-K: tied 4th in rank for maintaining spawning biomass near the biomass target, 1st for limiting catch variability, and was 2nd in providing yield, relative to all eleven MPs. This MP uses a fixed proportion changing every fifth year to distribute the TCEY determined by averaging the previous five years of estimated stock distribution to achieve stability in mortality limits. However, there were concerns that the current performance metrics do not indicate the amount of change in yield or catch variability that may occur every fifth year, which may be undesirably high.

47. The MSAB **ENDORSED** Tier 1 MPs, that were ranked highest in the MSE results using the tools available, for consideration. These MPs are MP-D, MP-H, MP-I, MP-J, MP-K as specified in Appendix V.

48. The MSAB **NOTED** Tier 2 contained MPs that were all ranked lower in limiting catch variability relative to Tier 1. The MPs contained in this Tier are MP-B, C, E, F, G. Most were ranked lower for providing yield summarizing performance metrics across all IPHC Regulatory Areas, except MP-E and MP-G.

49. The MSAB **NOTED** Tier 3 contained MP-A, which ranked lowest for maintaining spawning biomass near the biomass target, limiting catch variability, and providing yield.

50. The MSAB **NOTED** that trade-offs exist between IPHC Regulatory Areas and objectives specific to each IPHC Regulatory Area, not specifically stated as a primary objective, are not met across all IPHC Regulatory Areas by any single MP evaluated. However, modifying some elements of Tier 1 MPs may better meet those unstated objectives, as specified in Section 7.1.

## 7. MSAB PROGRAM OF WORK

51. The MSAB **NOTED** paper IPHC-2020-MSAB015-10 which provided an update on the MSE Program of Work (2020-21), given current Commission directives.

### *7.1 MSAB Program of Work (2020-21)*

52. The MSAB **NOTED** the fixed delivery date of January 2021 for the MSE results to the Commission, including Scale and Distribution components of the MP, for potential adoption by the Commission and subsequent implementation.

53. The MSAB **RECOMMENDED** the following MPs for analysis and consideration in 2021:

    a) MP-J in combination with a fixed TCEY of 1.65 Mlbs in Regulatory Area 2A, as in paragraph 97 b) of IPHC-2020-AM096-R, with total mortality rebalanced among remaining U.S.A. IPHC Regulatory Areas to maintain a constant SPR;

    b) MP-J in combination with a minimum TCEY of 1.65 Mlbs in Regulatory Area 2A which allows the TCEY to exceed 1.65 in IPHC Regulatory Area 2A with total mortality rebalanced among remaining U.S.A. IPHC Regulatory Areas to maintain a constant SPR.

54. The MSAB **AGREED** that MPs for evaluation, especially those with alternative relative harvest rates such as in MP-H, be evaluated against alternative hypotheses of migration, recruitment distribution, and productivity.

55. The MSAB **NOTED** paragraph 89 of IPHC-2020-AM096-R:

    IPHC-2020-AM096-R, para. 89: "*The Commission REQUESTED the MSAB to confirm the proposed topics of work beyond the 2021 deliverables in time for the Interim Meeting (IM096), including work to investigate and provide advice on approaches for accounting for the impacts of bycatch in one Regulatory Area on harvesting opportunities in other Regulatory Areas.*"

56. The MSAB **AGREED** to incorporate additional MPs and analyses into the Program of Work following recommendations from the 97th Session of the IPHC Annual Meeting.

57. The MSAB **AGREED** that proposed topics of work beyond the 2021 deliverables include revisiting objectives, MPs, specifications of the MSE framework and operating model, improving estimation models and data generation (e.g. uncertainty), outreach and communication tools, as well as recommendations from the 2020 peer review of the MSE. Some examples include those items described in paragraphs 30 and 31.

58. The MSAB **REQUESTED** that an MSAB meeting be scheduled to discuss a Program of Work for 2021 and beyond.

## 8. OTHER BUSINESS

59. Nil

## 9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 15TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB015)

60. The report of the 16th Session of the IPHC Management Strategy Advisory Board (IPHC-2020-MSAB016–R) was **ADOPTED** on 22 October 2020, including the consolidated set of recommendations and/or requests arising from MSAB016, provided at Appendix IX.

## APPENDIX I
## LIST OF PARTICIPANTS FOR THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)

**Officers**

| Co-Chairperson (Canada) | Co-Chairperson (United States of America) |
|---|---|
| Mr Adam **Keizer**: adam.keizer@dfo-mpo.gc.ca | Dr Carey **McGilliard**: Carey.McGilliard@noaa.gov |

**MSAB Members**

| Canada | United States of America |
|---|---|
| Mr Chuck **Ashcroft**: chuckashcroft@telus.net | Ms Rachel **Baker**: rachel.baker@alaska.gov |
| Mr Robert **Hauknes**: robert_hauknes@hotmail.com | Mr Forrest **Braden**: forrest@seagoalaska.org |
| Ms Ann-Marie **Huang:** Ann-Marie.Huang@dfo-mpo.gc.ca | Ms Angel **Drobnica**: adrobnica@apicda.com |
| Mr Adam **Keizer**: adam.keizer@dfo-mpo.gc.ca | Mr Dan **Falvey**: myriadfisheries@gmail.com |
| Mr Jim **Lane**: jim.lane@nuuchahnulth.org | Mr James **Johnson**: JimJ@glacierfish.com |
| Mr Chris **Sporer**: chris.sporer@phma.ca | Mr Jeff **Kauffman**: jeff@spfishco.com |
| | Mr Tom **Marking**: tmmarking@gmail.com |
| | Mr Scott **Mazzone**: smazzone@quinault.org |
| | Dr Carey **McGilliard**: carey.McGilliard@noaa.gov |
| | Mr Glenn **Merrill**: glenn.merrill@noaa.gov |
| | Mr Per **Odegaard**: vanseeodegaard@hotmail.com |
| | Ms Peggy **Parker**: peggyparker616@gmail.com |
| | Mr Joe **Petersen**: jpetersen@nwifc.org |
| | Ms Maggie **Sommer**: maggie.sommer@state.or.us |
| | Ms Sarah **Webster**: sarah.webster@alaska.gov |
| | |
| | |
| **Absentees** | **Absentees** |
| Mr Angus **Grout**: rommel@telus.net | Mr Joseph **Morelli**: jmorelli@spcsales.com |
| Mr Brad **Mirau**: brad@aerotrading.ca | |

**Commissioners**

| Canada | United States of America |
|---|---|
| Mr Peter **DeGreef**: peterjdegreef@hotmail.com | |

**Observers**

| Canada | United States of America |
|---|---|
| | Lynn **Mattes** (NOAA) |
| | Alicia M **Miller** (NOAA) |
| | Whitney **Roberts** (WDFW) |
| | Joe **Kashevarof** (CBSFA) |
| | Will **Jaspar** (unknown affiliation) |

**IPHC Secretariat**

| Name | Position and email |
|---|---|
| Dr David **Wilson** | Executive Director, david.wilson@iphc.int |
| Dr Steven **Berukoff** | MSE Programmer, steven.berukoff@iphc.int |
| Dr Piera **Carpi** | MSE Researcher, piera.carpi@iphc.int |
| Ms Lara **Erikson** | Branch Manager, Fisheries Statistics and Services, lara.erikson@iphc.int |
| Dr Allan **Hicks** | Quantitative Scientist, allan.hicks@iphc.int |
| Dr Josep **Planas** | Branch Manager, Biological and Ecosystem Sciences, josep.planas@iphc.int |
| Dr Ian **Stewart** | Quantitative Scientist, ian.stewart@iphc.int |
| Mr Tom **Kong** | Fisheries Data Specialist, tom.kong@iphc.int |

## APPENDIX II
## AGENDA FOR THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)

**Date**: 19-22 October 2020
**Location**: Electronic
**Venue**: G-To-Meeting
**Time**: 09:00-17:00 PDT daily
**Co-Chairpersons**: Mr. Adam Keizer (Canada) and Dr. Carey McGilliard (U.S.A.)

**1. OPENING OF THE SESSION**

**2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION**

- *IPHC-2020-MSAB016-01: Agenda & Schedule for the 16th Session of the Management Strategy Advisory Board (MSAB016)*
- *IPHC-2020-MSAB016-02: List of Documents for the 16th Session of the Management Strategy Advisory Board (MSAB016)*

**3. IPHC PROCESS**

3.1. MSAB Membership (D. Wilson)
- *IPHC-2020-MSAB016-03: MSAB Membership (D. Wilson)*

3.2. Update on the actions arising from the 15th Session of the IPHC MSAB (MSAB015) (A. Hicks)
- *IPHC-2020-MSAB016-04: Update on the actions arising from the 15th Session of the MSAB (MSAB015) (A. Hicks)*

3.3. Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) (D. Wilson)
- *IPHC-2020-MSAB016-05: Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) (D. Wilson)*

3.4. Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and the 6th Special Session of the IPHC (SS06) (D. Wilson & A. Hicks)
- *IPHC-2020-MSAB016-06: Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and the 6th Special Session of the IPHC (SS06) (D. Wilson & A. Hicks)*

**4. A REVIEW OF MANAGEMENT PROCEDURES TO DETERMINE THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) BY IPHC REGULATORY AREAS FOR PACIFIC HALIBUT FISHERIES**

- *IPHC-2020-MSAB016-07: Potential management procedures to determine the total constant exploitation yield (TCEY) by IPHC Regulatory Areas for Pacific halibut fisheries (P. Carpi, A. Hicks, I. Stewart)*

4.1. Management procedures for coastwide scale (A. Hicks)

4.2. Management procedures for distributing the TCEY (P. Carpi)

**5. A FRAMEWORK TO INVESTIGATE FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES**

- *IPHC-2020-MSAB016-08: Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries. (A. Hicks, P. Carpi, S. Berukoff & I. Stewart)*

5.1. Multi-area operating model (A. Hicks)

5.2. Framework to investigate distributing the TCEY among IPHC Regulatory Areas (P. Carpi)

**6. RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES**

- *IPHC-2020-MSAB016-09 Rev_1: Results investigating fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries (A. Hicks, P. Carpi, I. Stewart & S. Berukoff)*

6.1. Performance metrics for evaluation (P. Carpi)

6.2. Results from the closed-loop simulations (A. Hicks)

**7. MSE PROGRAM OF WORK**

- *IPHC-2020-MSAB016-10: IPHC Secretariat program of work for MSAB related activities in 2020–21 (A. Hicks, P. Carpi, S. Berukoff)*

7.1. MSAB program of work (2020-21) (A. Hicks)

**8. OTHER BUSINESS**

**9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)**

## APPENDIX III
## LIST OF DOCUMENTS FOR THE 16TH SESSION OF THE MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)

| Document | Title | Availability |
|---|---|---|
| IPHC-2020-MSAB016-01 | Agenda & Schedule for the 16th Session of the IPHC Management Strategy Advisory Board (MSAB016) | ✓ 21 Jul 2020<br>✓ 28 Jul 2020<br>✓ 18 Oct 2020 |
| IPHC-2020-MSAB016-02 | List of Documents for the 16th Session of the IPHC Management Strategy Advisory Board (MSAB016) | ✓ 28 Jul 2020<br>✓ 19 Sep 2020<br>✓ 19 Oct 2020 |
| IPHC-2020-MSAB016-03 | MSAB Membership (D. Wilson) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-04 | Update on the actions arising from the 15th Session of the MSAB (MSAB015) (A. Hicks) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-05 | Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) (D. Wilson) | ✓ 25 Sep 2020 |
| IPHC-2020-MSAB016-06 | Outcomes of the 96th Session of the IPHC Annual meeting (AM096) and the 6th Special Session of the IPHC (SS06) (D. Wilson & A. Hicks) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-07 | Potential management procedures to determine the total constant exploitation yield (TCEY) by IPHC Regulatory Areas for Pacific halibut fisheries (P. Carpi, A. Hicks, I. Stewart) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-08 | Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries. (A. Hicks, P. Carpi, S. Berukoff & I. Stewart) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-09 Rev_1 | Results investigating fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries (A. Hicks, P.Carpi, I. Stewart & S. Berukoff) | ✓ 19 Sep 2020<br>✓ 09 Oct 2020 |
| IPHC-2020-MSAB016-10 | IPHC Secretariat program of work for MSAB related activities in 2020-21 (A. Hicks, P. Carpi & S. Berukoff) | ✓ 19 Sep 2020 |
| ***Information papers*** | | |
| IPHC-2020-MSAB016-INF01 | Technical details of the IPHC MSE framework (A. Hicks, P. Carpi, S. Berukoff) | ✓ 18 Oct 2020 |
| IPHC-2020-MSAB016-INF02 | Independent peer review of the 2020 IPHC Management Strategy Evaluation process (T. Branch) | ✓ 25 Sep 2020 |
| IPHC-2020-MSAB016-INF03 | Description of management procedures proposed from MSAB015 (A. Hicks & P. Carpi) | ✓ 19 Oct 2020 |

## APPENDIX IV
## MSAB MEMBERSHIP
(*as of 19 September 2020*)

| Membership category | Member | Canada | U.S.A. | Current Term commencement | Current Term expiration |
|---|---|---|---|---|---|
| **Commercial harvesters (6-8)** | | | | | |
| **1** | Sporer, Chris | CDN Commercial | | 09-May-17 | 08-May-21 |
| **2** | Hauknes, Robert | CDN Commercial | | 09-May-17 | 08-May-21 |
| **3** | Grout, Angus | CDN Commercial | | 03-Dec-19 | 02-Dec-21 |
| **4** | Vacant | CDN Commercial | | | |
| **5** | Johnson, James | | USA Commercial | 17-Apr-19 | 16-Apr-23 |
| **6** | Kauffman, Jeff | | USA Commercial | 09-May-19 | 08-May-23 |
| **7** | Odegaard, Per | | USA Commercial | 09-May-17 | 08-May-21 |
| **8** | Falvey, Dan | | USA Commercial | 09-May-17 | 08-May-21 |
| **First Nations/ Tribal fisheries (2-4)** | | | | | |
| **1** | Lane, Jim | CDN First Nations | | 09-May-17 | 08-May-21 |
| **2** | Vacant | CDN First Nations | | | |
| **3** | Mazzone, Scott | | USA Treaty Tribes | 09-May-19 | 08-May-23 |
| **4** | Petersen, Joe | | USA Treaty Tribes | 7-May-20 | 6-May-22 |
| **Government Agencies (4-8)** | | | | | |
| **1** | Keizer, Adam | DFO | | 09-May-19 | 08-May-23 |
| **2** | Huang, Ann-Marie | CDN Science Advisor | | 10-May-18 | 09-May-22 |
| **3** | Vacant | DFO | | | |
| **4** | Merrill, Glenn | | NOAA-Fisheries | 07-May-18 | 06-May-22 |
| **5** | McGilliard, Carey | | USA Science Advisor | 09-May-17 | 08-May-21 |
| **6** | Baker, Rachel | | FMC rep. | 23-Oct-19 | 22-Oct-21 |
| **7** | Webster, Sarah | | ADFG | 24-Sep-19 | 23-Sep-23 |
| **8** | Sommer, Maggie | | FMC rep. | 14-Apr-20 | 13-Apr-22 |
| **Processors (2-4)** | | | | | |
| **1** | Parker, Peggy | US/CDN Processing | USA/CDN Processing | 09-May-19 | 08-May-23 |
| **2** | Mirau, Brad | CDN Processing | | 09-May-19 | 08-May-23 |
| **3** | Morelli, Joseph | | USA Processing | 29-Aug-18 | 28-Aug-22 |
| **4** | Drobnica, Angel | | USA Processing | 17-Apr-19 | 16-Apr-23 |
| **Recreational/ Sport fisheries (2-4)** | | | | | |

| Membership category | Member | Canada | U.S.A. | Current Term commence-ment | Current Term expiration |
|---|---|---|---|---|---|
| **1** | Chuck Ashcroft | CDN Sport Fishing Advisory Board | | 17-Apr-19 | 16-Apr-23 |
| **2** | Marking, Tom | | USA Sportfishing (CA) | 09-May-19 | 08-May-23 |
| **3** | Braden, Forrest | | USA sportfishing (AK) | 17-Apr-19 | 16-Apr-23 |
| **4** | Vacant | | Open | | |

## APPENDIX V
## PROPOSED MANAGEMENT PROCEDURES FROM IPHC-2020-MSAB015-R

Management procedures to be evaluated by the MSAB in 2020 and the priority of investigation.

| MP | Coastwide | Regional | IPHC Regulatory Area |
|---|---|---|---|
| MP 15-A | SPR 30:20 | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] |
| MP 15-B | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] |
| MP 15-C | SPR 30:20 MaxChange15% | Biological Regions, O32 stock distribution<br>Rel HRs[3]: R2=1, R3=1, R4=0.75, R4B=0.75 | • O32 stock distribution<br>• Relative harvest rates not applied<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] |
| MP 15-D | SPR 30:20 MaxChange15% Max FI (36%) | | First<br>• O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>Second within buffer (pro-rated if exceeds buffer)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] |
| MP 15-E | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1] |
| MP 15-F | SPR 30:20 MaxChange15% | National Shares: 20% to 2B, 80% to other | • O32 stock distribution to areas other than 2B<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) |
| MP 15-G | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) |
| MP 15-H | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Relative harvest rates (1 for 2-3, 4A, 4CDE, 0.75 for 4B) |
| MP 15-I | SPR 30:20 MaxChange15% | | • All sizes stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) |
| MP 15-J | SPR 30:20 MaxChange15% | | • O32 stock distribution (5-year moving average)<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) |
| MP 15-K | SPR 30:20 MaxChange15% | | • 5-year shares determined from 5-year O32 stock distribution (vary over time but change only every 5$^{th}$ year) |

[1] paragraph 97b IPHC-2020-AM096-R
[2] paragraph 97c of IPHC-2020-AM096-R
[3] R2 refers to Biological Region 2 (2A, 2B, 2C); R3 refers to Biological Region 3 (3A, 3B); R4 refers to Biological Region 4 (4A, 4CDE), and R4B refers to Biological Region 4B.

## APPENDIX VI
## PRIMARY OBJECTIVES AND PERFORMANCE METRICS

Primary measurable objectives, evaluated over a simulated ten-year period, accepted by the Commission at the 6th Special Session of the Commission (IPHC-2020-CR-007). Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives.

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

# APPENDIX VII
## RANKINGS OF MANAGEMENT PROCEDURES AGAINST MEASURABLE OUTCOMES

Management procedures ranked by measurable outcomes using the default MSE Explorer settings.

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

## APPENDIX VIII
## RANKINGS OF MANAGEMENT PROCEDURES AGAINST GENERAL OBJECTIVES

Management procedures ranked by general objectives using the default MSE Explorer settings.

| 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 |

SB: Spawning Biomass

# APPENDIX IX
## CONSOLIDATED SET OF RECOMMENDATIONS AND REQUESTS OF THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)

### *RECOMMENDATIONS*

***Results investigating fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries***

MSAB016-Rec.1 (para. 35) The MSAB **RECOMMENDED** that the performance metrics related to the current primary objectives (Appendix VI) be considered when evaluating MPs.

***MSAB Program of work***

MSAB016-Rec.2 (para. 53) The MSAB **RECOMMENDED** the following MPs for analysis and consideration in 2021:

a) MP-J in combination with a fixed TCEY of 1.65 Mlbs in Regulatory Area 2A, as in paragraph 97 b) of IPHC-2020-AM096-R, with total mortality rebalanced among remaining U.S.A. IPHC Regulatory Areas to maintain a constant SPR;

b) MP-J in combination with a minimum TCEY of 1.65 Mlbs in Regulatory Area 2A which allows the TCEY to exceed 1.65 in IPHC Regulatory Area 2A with total mortality rebalanced among remaining U.S.A. IPHC Regulatory Areas to maintain a constant SPR.

### *REQUESTS*

***MSAB Program of work***

MSAB016-Req.1 (para. 58) The MSAB **REQUESTED** that an MSAB meeting be scheduled to discuss a Program of Work for 2021 and beyond.

# AGENDA & SCHEDULE FOR THE 16th SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)

**Date**: 19-22 October 2020
**Location**: Electronic
**Venue**: G-To-Meeting
**Time**: 09:00-17:00 PDT daily
**Co-Chairpersons**: Mr. Adam Keizer (Canada) and Dr. Carey McGilliard (U.S.A.)

## 1. OPENING OF THE SESSION

## 2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

- *IPHC-2020-MSAB016-01: Agenda & Schedule for the 16th Session of the Management Strategy Advisory Board (MSAB016)*
- *IPHC-2020-MSAB016-02: List of Documents for the 16th Session of the Management Strategy Advisory Board (MSAB016)*

## 3. IPHC PROCESS

3.1. MSAB Membership (D. Wilson)
- *IPHC-2020-MSAB016-03: MSAB Membership (D. Wilson)*

3.2. Update on the actions arising from the 15th Session of the IPHC MSAB (MSAB015) (A. Hicks)
- *IPHC-2020-MSAB016-04: Update on the actions arising from the 15th Session of the MSAB (MSAB015) (A. Hicks)*

3.3. Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) (D. Wilson)
- *IPHC-2020-MSAB016-05: Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) (D. Wilson)*

3.4. Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and the 6th Special Session of the IPHC (SS06) (D. Wilson & A. Hicks)
- *IPHC-2020-MSAB016-06: Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and the 6th Special Session of the IPHC (SS06) (D. Wilson & A. Hicks)*

## 4. A REVIEW OF MANAGEMENT PROCEDURES TO DETERMINE THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) BY IPHC REGULATORY AREAS FOR PACIFIC HALIBUT FISHERIES

- *IPHC-2020-MSAB016-07: Potential management procedures to determine the total constant exploitation yield (TCEY) by IPHC Regulatory Areas for Pacific halibut fisheries (P. Carpi, A. Hicks, I. Stewart)*

4.1. Management procedures for coastwide scale (A. Hicks)
4.2. Management procedures for distributing the TCEY (P. Carpi)

**5. A FRAMEWORK TO INVESTIGATE FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES**

- *IPHC-2020-MSAB016-08: Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries. (A. Hicks, P. Carpi, S. Berukoff & I. Stewart)*

5.1. Multi-area operating model (A. Hicks)
5.2. Framework to investigate distributing the TCEY among IPHC Regulatory Areas (P. Carpi)

**6. RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES**

- *IPHC-2020-MSAB016-09 Rev_1: Results investigating fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries (A. Hicks, P. Carpi, I. Stewart & S. Berukoff)*

6.1. Performance metrics for evaluation (P. Carpi)
6.2. Results from the closed-loop simulations (A. Hicks)

**7. MSE PROGRAM OF WORK**

- *IPHC-2020-MSAB016-10: IPHC Secretariat program of work for MSAB related activities in 2020–21 (A. Hicks, P. Carpi, S. Berukoff)*

7.1. MSAB program of work (2020-21) (A. Hicks)

**8. OTHER BUSINESS**

**9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 16TH SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)**

# SCHEDULE FOR THE 16th SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)

**Monday, 19 October 2020**

| Time | Agenda item | Lead |
|---|---|---|
| 09:00-09:30 | 1. OPENING OF THE SESSION<br>2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION | Co-chairs & D. Wilson |
| 09:30-10:30 | 3. IPHC PROCESS<br>3.1 MSAB membership<br>3.2 Update on the actions arising from the 15th Session of the MSAB (MSAB015)<br>3.3 Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017)<br>3.4 Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and the 6th Special Session of the IPHC (SS06) | A. Hicks & D. Wilson |
| 10:30-10:45 | Break | |
| 10:45-12:00 | 4. A REVIEW OF MANAGEMENT PROCEDURES TO DETERMINE THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) BY IPHC REGULATORY AREAS FOR PACIFIC HALIBUT FISHERIES<br>4.1 Management procedures for coastwide scale<br>4.2 Management procedures for distributing the TCEY | A. Hicks & P. Carpi |
| 12:00-13:00 | Lunch | |
| 13:00-15:00 | 5. A FRAMEWORK TO INVESTIGATE FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES<br>5.1 Multi-area operating model<br>5.2 Framework to investigate distributing the TCEY among IPHC Regulatory Areas | A. Hicks & P. Carpi |
| 15:00-15:15 | Break | |
| 15:15-16:15 | MSAB drafting session | MSAB drafting group |
| 16:15 | Close | |

| **Tuesday, 20 October 2020** | | |
|---|---|---|
| **Time** | **Agenda item** | **Lead** |
| 09:00-09:15 | Review of Day 1 and discussion of MSAB Recommendations from Day 1 | Co-chairs |
| 09:15-10:30 | 6. RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES<br>6.1 Performance metrics for evaluation<br>6.2 Results from the closed-loop simulations | A. Hicks & P. Carpi |
| 10:30-10:45 | Break | |
| 10:45-12:00 | 6. (Cont.) RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES | A. Hicks & P. Carpi |
| 12:00-13:00 | Lunch | |
| 13:00-15:00 | 6. (Cont.) RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES | A. Hicks & P. Carpi |
| 15:00-15:30 | Break | |
| 15:30-16:00 | Unfinished business and review of the day | Co-chairs |
| 16:00-17:00 | MSAB drafting session | MSAB drafting group |
| 17:00 | Close | |

| **Wednesday, 21 October 2020** | | |
|---|---|---|
| **Time** | **Agenda item** | **Lead** |
| 09:00-09:15 | Review of Day 1 and discussion of MSAB Recommendations from Day 1 | Co-chairs |
| 09:15-10:30 | 6. RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES<br>6.1 Performance metrics for evaluation<br>6.2 Results from the closed-loop simulations | A. Hicks & P. Carpi |
| 10:30-10:45 | Break | |
| 10:45-12:00 | 6. (Cont.) RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES | A. Hicks & P. Carpi |
| 12:00-13:00 | Lunch | |
| 13:00-14:30 | 6. (Cont.) RESULTS INVESTIGATING FISHING INTENSITY AND DISTRIBUTING THE TOTAL CONSTANT EXPLOITATION YIELD (TCEY) FOR PACIFIC HALIBUT FISHERIES | A. Hicks & P. Carpi |
| 14:30-15:00 | Break | |

| | | |
|---|---|---|
| 15:00-15:30 | Unfinished business and review of the day | Co-chairs |
| 15:30-17:00 | MSAB drafting session | MSAB drafting group |
| 17:00 | Close | |
| **Thursday, 22 October 2020** | | |
| **Time** | **Agenda item** | **Lead** |
| 09:00-09:15 | Review of Day 1 and discussion of MSAB Recommendations from Day 1 | Co-chairs |
| 09:15-10:30 | 7. MSE PROGRAM OF WORK<br>7.1 MSAB program of work (2020–21) | A. Hicks |
| 10:30-10:45 | Break | |
| 10:45-11:15 | 8. OTHER BUSINESS | Co-Chairpersons |
| 11:15-12:30 | MSAB drafting session | MSAB drafting group |
| 12:30-13:00 | IPHC drafting session | IPHC Secretariat |
| 12:30-13:30 | Lunch | |
| 13:30-17:00 | 9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 16th SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016) | Co-chairs & A. Hicks |
| 17:00 | Close | |

# LIST OF DOCUMENTS FOR THE 16th SESSION OF THE IPHC MANAGEMENT STRATEGY ADVISORY BOARD (MSAB016)

| Document | Title | Availability |
|---|---|---|
| IPHC-2020-MSAB016-01 | Agenda & Schedule for the 16th Session of the IPHC Management Strategy Advisory Board (MSAB016) | ✓ 21 Jul 2020<br>✓ 28 Jul 2020<br>✓ 18 Oct 2020 |
| IPHC-2020-MSAB016-02 | List of Documents for the 16th Session of the IPHC Management Strategy Advisory Board (MSAB016) | ✓ 28 Jul 2020<br>✓ 19 Sep 2020<br>✓ 19 Oct 2020 |
| IPHC-2020-MSAB016-03 | MSAB Membership (D. Wilson) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-04 | Update on the actions arising from the 15th Session of the MSAB (MSAB015) (A. Hicks) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-05 | Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) (D. Wilson) | ✓ 25 Sep 2020 |
| IPHC-2020-MSAB016-06 | Outcomes of the 96th Session of the IPHC Annual meeting (AM096) and the 6th Special Session of the IPHC (SS06) (D. Wilson & A. Hicks) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-07 | Potential management procedures to determine the total constant exploitation yield (TCEY) by IPHC Regulatory Areas for Pacific halibut fisheries (P. Carpi, A. Hicks, I. Stewart) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-08 | Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries. (A. Hicks, P. Carpi, S. Berukoff & I. Stewart) | ✓ 19 Sep 2020 |
| IPHC-2020-MSAB016-09 Rev_1 | Results investigating fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries (A. Hicks, P.Carpi, I. Stewart & S. Berukoff) | ✓ 19 Sep 2020<br>✓ 09 Oct 2020 |
| IPHC-2020-MSAB016-10 | IPHC Secretariat program of work for MSAB related activities in 2020-21 (A. Hicks, P. Carpi, & S. Berukoff) | ✓ 19 Sep 2020 |
| ***Information papers*** | | |
| IPHC-2020-MSAB016-INF01 | Technical details of the IPHC MSE framework (A. Hicks, P. Carpi, S. Berukoff) | ✓ 18 Oct 2020 |
| IPHC-2020-MSAB016-INF02 | Independent peer review of the 2020 IPHC Management Strategy Evaluation process (T. Branch) | ✓ 25 Sep 2020 |
| IPHC-2020-MSAB016-INF03 | Description of management procedures proposed from MSAB015 (A. Hicks & P. Carpi) | ✓ 19 Oct 2020 |

# MSAB MEMBERSHIP

**PREPARED BY:** IPHC SECRETARIAT (D, WILSON; 19 SEPTEMBER 2020)

## PURPOSE

To provide the MSAB with the updated membership.

## BACKGROUND

Rule 4 of Appendix V [Management Strategy Advisory Board (MSAB) – Terms of Reference and Rules of Procedure] of the IPHC Rules of Procedure (2020), states:

> *4. The term of MSAB members will be four years, and members may serve additional terms at the discretion of the IPHC. Member terms have a staggered expiry such that no more than half of the member terms expire at a given time. Member continuity on the MSAB is key to the success of the MSE process. However, MSAB members serve at the discretion of the IPHC.*"

## DISCUSSION

Departures/replacements:

Nil.

## RECOMMENDATION/S

That the MSAB **NOTE** paper IPHC-2020-MSAB016-03 which details the MSAB membership as of 19 September 2020.

## APPENDICES

**Appendix A:** MSAB Membership as of 19 September 2020

# APPENDIX A
## MANAGEMENT STRATEGY ADVISORY BOARD (MSAB) MEMBERSHIP
(*AS OF 19 SEPTEMBER 2020*)

| Membership category | Member | Canada | U.S.A. | Current Term commence-ment | Current Term expiration |
|---|---|---|---|---|---|
| **Commercial harvesters (6-8)** | | | | | |
| **1** | Sporer, Chris | CDN Commercial | | 09-May-17 | 08-May-21 |
| **2** | Hauknes, Robert | CDN Commercial | | 09-May-17 | 08-May-21 |
| **3** | Grout, Angus | CDN Commercial | | 03-Dec-19 | 02-Dec-21 |
| **4** | Vacant | CDN Commercial | | | |
| **5** | Johnson, James | | USA Commercial | 17-Apr-19 | 16-Apr-23 |
| **6** | Kauffman, Jeff | | USA Commercial | 09-May-19 | 08-May-23 |
| **7** | Odegaard, Per | | USA Commercial | 09-May-17 | 08-May-21 |
| **8** | Falvey, Dan | | USA Commercial | 09-May-17 | 08-May-21 |
| **First Nations/ Tribal fisheries (2-4)** | | | | | |
| **1** | Lane, Jim | CDN First Nations | | 09-May-17 | 08-May-21 |
| **2** | Vacant | CDN First Nations | | | |
| **3** | Mazzone, Scott | | USA Treaty Tribes | 09-May-19 | 08-May-23 |
| **4** | Vacant | | USA Treaty Tribes | | |
| **Government Agencies (4-8)** | | | | | |
| **1** | Keizer, Adam | DFO | | 09-May-19 | 08-May-23 |
| **2** | Huang, Ann-Marie | CDN Science Advisor | | 10-May-18 | 09-May-22 |
| **3** | Vacant | DFO | | | |
| **4** | Merrill, Glenn | | NOAA-Fisheries | 07-May-18 | 06-May-22 |
| **5** | McGilliard, Carey | | USA Science Advisor | 09-May-17 | 08-May-21 |
| **6** | Baker, Rachel | | FMC rep. | 23-Oct-19 | 22-Oct-21 |
| **7** | Webster, Sarah | | ADFG | 24-Sep-19 | 23-Sep-23 |
| **8** | Sommer, Maggie | | FMC rep. | 14-Apr-20 | 13-Apr-22 |
| **Processors (2-4)** | | | | | |
| **1** | Parker, Peggy | US/CDN Processing | USA/CDN Processing | 09-May-19 | 08-May-23 |
| **2** | Mirau, Brad | CDN Processing | | 09-May-19 | 08-May-23 |
| **3** | Morelli, Joseph | | USA Processing | 29-Aug-18 | 28-Aug-22 |
| **4** | Vacant | | CDN Processing | | |
| **Recreational/ Sport fisheries (2-4)** | | | | | |
| **1** | Chuck Ashcroft | CDN Sport Fishing Advisory Board | | 17-Apr-19 | 16-Apr-23 |

| Membership category | Member | Canada | U.S.A. | Current Term commence-ment | Current Term expiration |
|---|---|---|---|---|---|
| **2** | Marking, Tom | | USA Sportfishing (CA) | 09-May-19 | 08-May-23 |
| **3** | Braden, Forrest | | USA sportfishing (AK) | 17-Apr-19 | 16-Apr-23 |
| **4** | Vacant | | Open | | |

# Update on actions arising from the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015)

**PREPARED BY: IPHC SECRETARIAT (A. HICKS; 19 SEPTEMBER 2020)**

## PURPOSE

To provide the MSAB with an opportunity to consider the progress made during the inter-sessional period in relation to the recommendations and requests of the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015).

## BACKGROUND

At the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015), participants agreed on a series of actions to be taken by the Commission, Subsidiary Bodies, and the IPHC Secretariat on a range of topics as detailed in Appendix A.

## DISCUSSION

Noting that best practice governance requires the prompt delivery of core tasks assigned by the Commission, at each subsequent session of the Commission and its subsidiary bodies, attempts will be made to ensure that any recommendations and 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 (i.e., a specific Contracting Party, the IPHC Secretariat, a subsidiary body of the Commission, or the Commission itself);
3) a desired time frame for delivery of the action (i.e., by the next session of an subsidiary body, or other date).

This involves numbering and tracking all action items (see Appendix A) from the MSAB, as well as including clear progress updates and document reference numbers.

## RECOMMENDATION/S

That the MSAB:

1) **NOTE** paper IPHC-2020-MSAB016-04, which provided the MSAB with an opportunity to consider the progress made during the inter-sessional period in relation to the recommendations and requests of the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015).
2) **AGREE** to consider and revise as necessary, the actions arising from the MSAB015, and for these to be combined with any new actions arising from the MSAB016.

## APPENDICES

**Appendix A:** Update on actions arising from the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015)

## APPENDIX A

### Update on actions arising from the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015)

| Action No. | Description | Update |
|---|---|---|
| | ***RECOMMENDATIONS*** | |
| | Nil | |
| | ***REQUESTS*** | |
| MSAB015–Req.01 (para. 20) | ***Management procedures for distributing the TCEY*** The MSAB **REQUESTED** that a procedure to distribute the coastwide TCEY be flexible to allow for distribution directly to IPHC Regulatory Areas, or to Biological Regions or Management Zones before distributing to IPHC Regulatory Areas. Methods of distribution may be based on stock distribution, relative fishing intensities, and other allocation adjustments. | COMPLETED: The framework for defining management procedures is very flexible and the MSE framework can accommodate a wide range of management procedures for simulation and evaluation. |
| MSAB015–Req.02 (para. 32) | ***Multi-area operating model*** The MSAB **REQUESTED** separating recreational and subsistence fishing mortality for IPHC Regulatory Areas 2B, 2C, and 3A in the OM to assist with the evaluation of results and allow for testing management procedures against scenarios that depart from recent observations of subsistence fishing mortality | COMPLETED: These sectors are separate for each IPHC Regulatory Area and performance metrics are reported where possible. |
| MSAB015–Req.03 (para. 33) | ***Multi-area operating model*** The MSAB **REQUESTED** that the non-directed fishing mortality sector be modelled by IPHC Regulatory Area rather than Biological Region because this will be useful when evaluating results at the IPHC Regulatory Area level and necessary to properly calculate the sector allocations in each IPHC Regulatory Area | COMPLETED: The non-directed fishing mortality is modelled at the IPHC Regulatory Area level. |

| | | |
|---|---|---|
| MSAB015–Req.04 (para. 43) | ***MSAB Program of Work (2020-21) and identification of management procedures to evaluate*** The MSAB **REQUESTED** a comparison of previous coastwide MSE simulation results with coastwide MSE simulations using the new MSE framework, expanding on the result that the current OM in the new framework is able to match spawning biomass expectations closely. This will assist in determining if changes in management procedure performance are due to a change in the MSE framework | IN PROGRESS The results are currently being compiled and will be reported at the 16th Session of the Management Strategy Advisory Board (MSAB016). |
| MSAB015–Req.05 (para. 44) | ***MSAB Program of Work (2020-21) and identification of management procedures to evaluate*** The MSAB **REQUESTED** results from the management procedures provided in Appendix V are presented at the next MSAB meeting | IN PROGRESS The results are being updated as simulations are completed. It is expected that the results for all management procedures will be available before the 16th Session of the Management Strategy Advisory Board (MSAB016). |
| MSAB015–Req.06 (para. 46) | ***MSAB Program of Work (2020-21) and identification of management procedures to evaluate*** The MSAB **REQUESTED** an inter-sessional meeting be held online 17-18 August 2020 to review the results from the prioritized management procedures described in Appendix V | COMPLETED: An ad hoc meeting took place 17-18 August electronically. Preliminary results were presented and performance metrics were discussed. |

# Outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017)

**PREPARED BY: IPHC SECRETARIAT (D. WILSON; 25 SEPTEMBER 2020)**

## PURPOSE

To provide the MSAB with the outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) relevant to the mandate of the MSAB.

## BACKGROUND

The agenda of the 17th Session of the IPHC Scientific Review Board (SRB) included two agenda items dedicated to Management Strategy Evaluation (MSE).

## DISCUSSION

During the course of the 17th Session of the IPHC Scientific Review Board (SRB017), a number of specific requests and recommendations regarding the IPHC MSE process where proposed by the SRB. Relevant sections from the report of the meeting are provided in Appendix A for the MSAB's consideration.

## RECOMMENDATION

That the MSAB:

1) **NOTE** paper IPHC-2020-MSAB016-05 which details the outcomes of the 17th Session of the IPHC Scientific Review Board (SRB017) relevant to the mandate of the MSAB.

## APPENDICES

**Appendix A:** Excerpt from the 17th Session of the IPHC Scientific Review Board (SRB017) Report (IPHC-2020-SRB017-R).

## APPENDIX A
## Excerpt from the 17th Session of the IPHC Scientific Review Board (SRB017) Report (IPHC-2020-SRB017-R)

**SECTION 6**

## 6. PEER REVIEW OF THE IPHC MANAGEMENT STRATEGY EVALUATION PROCESS

25 The SRB **NOTED** the presentation provided by Dr Trevor Branch, the independent peer reviewer of the IPHC MSE process. Dr Branch presented his draft report, with the intention of seeking additional feedback from the SRB before finalising the report. The following is a summary of the report findings, as provided by Dr Branch:

> "*The management strategy evaluation (MSE) of IPHC is intended to simulation test rules for setting allowable catch for Pacific halibut and the allocation of catch and bycatch among IPHC Regulatory Areas. In my judgment the MSE is technically sound. Furthermore, the MSE team led by Allan Hicks was praised by all interviewed participants involved in the process for their technical work, collaboration with stakeholders in developing harvest control rules, and communication of results to stakeholders. However, the following issues need to be resolved to ensure the continued success and accuracy of MSE simulation for IPHC: (1) decide soon on the future of the MSE process beyond January 2021 and allocate necessary funding; (2) treat the MSE framework as an ongoing process that will be used over many years alongside the stock assessment, to test the effectiveness of data gathering, stock assessment assumptions, and catch -setting in IPHC; (3) require the Commission to codify the rules they used to adjust catch levels within each Regulatory Area after the harvest control rule is applied, so that the MSE framework accurately evaluates risk to the stock and catches within each such Area.*"

26 The SRB **AGREED** that the peer review was a thorough analysis, and met the desired objectives of providing a fully independent external review of the IPHC's Management Strategy Evaluation work undertaken to date.

27 The SRB **AGREED** with conclusions of the independent peer reviewer that:

a) the MSE framework establishes a valuable new tool for formally evaluating and prioritizing research objectives;

b) uncertainty regarding staffing for MSE work is inconsistent with the long-term role of MSE in addressing critical strategic needs of the Commission in setting and distributing Pacific halibut yield among regulatory areas;

c) the IPHC Secretariat continue to improve and develop communication tools and participation in the MSE process;

d) the IPHC Secretariat establish a formal process for determining whether Exceptional Circumstances exist in a given year that would justify deviating from the harvest control rule.

28 The SRB **NOTED** that the independent peer review suggested a further round of development may be necessary on the spatial allocation of TCEY.

**SECTION 8**

# 8. MANAGEMENT STRATEGY EVALUATION: UPDATE

## *8.1 An update on the IPHC Management Strategy Evaluation (MSE) process*

55 The SRB **NOTED** paper IPHC-2020-SRB017-09 which provided the SRB with a description of the IPHC MSE framework, a description of the specifications of the multi-area operating model, results from conditioning the multi-area operating model, and an overview of the implementation of management procedures.

56 The SRB **NOTED** the MSE Explorer tool available online to present and evaluate MSE results. The SRB was impressed by the flexibility of the tool to facilitate stakeholder education of fishery management and MSE concepts, as well as the power to analyze complex outputs from the simulations.

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.

58 The SRB **NOTED** that results from the multi-region simulations showed a higher average TCEY and lower probabilities of low stock status for a given SPR than the previous coastwide MSE results, but average stock status was similar. This is consistent with the lower variability incorporated in the multi-region approach due to the use of a single operating model as opposed to the 2 used in the coast-wide operating model. Low biomass regionally and the need for the model to maintain all populations means the parameter space may be more restrictive resulting in greater stability.

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.

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.

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.

# Outcomes of the 96th Session of the IPHC Annual Meeting (AM096) and 6th Special Session of the Commission (SS06)

**PREPARED BY: IPHC SECRETARIAT (D. WILSON, A. HICKS; 19 SEPTEMBER 2020)**

## PURPOSE

To provide the MSAB with the outcomes of the 96th Session of the IPHC Annual Meeting (AM096), and the 6th Special Session of the Commission (SS06) relevant to the mandate of the MSAB.

## BACKGROUND

The agenda of the Commission's 96th Session of the Annual Meeting (AM096) included an agenda item (Section 10) dedicated to Management Strategy Evaluation (MSE). The Commission also held a Special Session on 3 March 2020 to consider MSE related matters.

## DISCUSSION

During the course of the 96th Session of the IPHC Annual Meeting (AM095) the Commission made a number of specific recommendations and requests for action regarding the MSE process. Relevant sections from the report of the meeting are provided in Appendix A for the MSAB's consideration.

## RECOMMENDATION

That the MSAB:

1) **NOTE** paper IPHC-2020-MSAB016-06 which details the outcomes of the 96th Session of the IPHC Annual Meeting (AM096), and the 6th Special Session of the Commission (SS06), relevant to the mandate of the MSAB.

## APPENDICES

**Appendix A:** Excerpt from the 96th Session of the IPHC Annual Meeting (AM096) Report (IPHC-2020-AM096-R), and the 6th Special Session of the Commission (SS06)

**APPENDIX A**
**Excerpt from the 96th Session of the IPHC Annual Meeting (AM096) Report**
**(IPHC-2020-AM096-R)**

# 10. MANAGEMENT STRATEGY EVALUATION

## *10.1 IPHC Management Strategy Evaluation: update*

75. The Commission **NOTED** paper IPHC-2020-AM096-12 which provided the Commission with an update on the IPHC MSE process including defining objectives, developing management procedures for scale and distribution, a framework for distributing the TCEY, and a program of work.

76. The Commission **RECALLED** the IPHC interim Management Procedure (https://www.iphc.int/the-commission/harvest-strategy-policy) includes the following components:

    a) A biological limit (SB20%), the minimum relative spawning biomass needed to meet conservation objectives;

    b) A fishery trigger (SB30%), the relative spawning biomass below which the reference level of fishing intensity is reduced to avoid reaching the SB20% biological limit;

    c) A reference level of fishing intensity, F46%, corresponding to a Spawning Potential Ratio (SPR) of 46%;

    d) A control rule, reducing the fishing intensity linearly from the reference level at SB30% to no directed fishing at SB20%.

77. The Commission **NOTED** that non-directed fishing discard mortality is currently treated as a scenario in the MSE with a simulated level representing a reasonable range of potential non-directed fishing discard mortality based on recent observations and **RECALLED** paragraph 37 of IPHC-2017-AM093-R:

"The Commission **NOTED** the presentation of an SPR-based harvest policy to update the current harvest policy, and that MSE will be used to evaluate alternative SPR values that are robust to possible bycatch scenarios."

78. The Commission **AGREED** that although the relative spawning biomass has been retrospectively estimated to have fallen below SB30% over the period 2009-2015, it was not determined to be below the fishery trigger during that time period when the mortality limits were set.

79. The Commission **NOTED** the following recommendations from the MSAB and IPHC Secretariat, and **AGREED** to hold an inter-sessional meeting soon after the AM096 to provide direction:

    - *Recommended that the primary coastwide biological sustainability objective of maintaining the female spawning biomass above a biomass limit of SB20% at least 95% of the time be used to evaluate management procedures.*

    - *Recommended primary coastwide fishery objectives to be used for evaluation of management procedures (Table 1), including:*

        *a) maintain the female spawning biomass around a proxy target biomass of SB36%;*

*b) limit annual changes in the TCEY; and*

*c) optimize directed fishing yield.*

- *Recommended that the primary biological sustainability objective of conserving spatial population structure across Biological Regions be used to evaluate management procedures.*

- *Recommended primary fishery objectives at the IPHC Regulatory Area scale for evaluation of management procedures (Table 1), including*

  *a) limit annual changes in the TCEY for each IPHC Regulatory Area;*

  *b) optimize the TCEY among IPHC Regulatory Areas;*

  *c) optimize a percentage of the coastwide TCEY among IPHC Regulatory Areas;*

  *d) maintain the TCEY above a minimum absolute level within each IPHC Regulatory Area; and*

  *e) maintain a percentage of the coastwide TCEY above a minimum level within each IPHC Regulatory Area;*

- *Recommended that given the results from the coastwide MSE, the following elements from the scale (coastwide) component of the management procedure meet the coastwide objectives*

  *a) SPR values greater than 40%;*

  *b) A control rule of 30:20;*

  *c) A constraint on the annual change in the TCEY do one of the following: limit it to 15%, use a slow-up, fast-down approach, or fix the mortality limits for three-year periods.*

- *Recommended a reference SPR fishing intensity of 43% with a 30:20 control rule and allocations to 2A and 2B, as defined in IPHC-2019-AM095-R paragraphs 69 b and c, be used as an updated interim management procedure consistent with MSE results for the development of 2020 stock assessment results pending delivery of the final MSE results at AM097.*

80. The Commission **NOTED** that various elements of the scale and distribution components of the management procedure, including those listed in IPHC-2019-MSAB014-R will be evaluated for consideration at AM097 in 2021.

81. The Commission **NOTED** that an independent peer review of the MSE will take place in April 2020 and August 2020 with a report supplied to the SRB, MSAB, and Commission.

82. The Commission **NOTED** that the SRB will review MSE results in September 2020, and these results including scale and distribution management procedures will be presented to the Commission at AM097 in 2021.

83. The Commission **NOTED** that MSE is the appropriate tool to evaluate management procedures related to discard mortality for non-directed fisheries (bycatch) because it can capture downstream effects, biological implications, and the management performance relative to objectives.

### *10.2 Reports of the 13th and 14th Sessions of the IPHC Management Strategy Advisory Board (MSAB013 and MSAB014)*

84. The Commission **NOTED** the Reports of the 13th and 14th Sessions of the IPHC Management Strategy Advisory Board (MSAB013 - IPHC-2019-MSAB013-R; MSAB014 - IPHC-2019-MSAB014-R) which was presented by Mr Adam Keizer (Canada) and Dr Carey McGillard (USA).

85. The Commission **NOTED** that the MSAB014 made five (5) recommendations to the Commission as follows:

***A review of the coastwide goals and objectives of the IPHC MSE process***

*MSAB014–Rec.01 (para. 34) The MSAB RECOMMENDED a coastwide fishery objective, in response to a request from the Commissioners, to maintain the spawning biomass above a target reference point of RSB36%, 50% of the time over the long-term.*

***Identification of goals and objectives related to distributing the TCEY***

*MSAB014–Rec.02 (para. 41) The MSAB RECOMMENDED the primary objectives and associated performance metrics detailed in Appendix V to be used for the evaluation of management procedures at MSAB015.*

***Performance metrics for evaluation***

*MSAB014–Rec.03 (para. 46) NOTING the current progress on evaluating coastwide fishing intensity, the MSAB RECOMMENDED that:*

1) *a coastwide fishing intensity SPR of 43%, with a 30:20 HCR, and with one of two constraints 1) +/-15% maximum change in total mortality, and/or 2) slow up, fast down, be used in harvest strategy development process; and*
2) *a range of management procedures including fishing intensity SPR of 40-46% be considered in light of implementation variability within the closed-loop simulations when investigating distribution.*

***Management procedures for coastwide scale***

*MSAB014–Rec.04 (para. 49) The MSAB RECOMMENDED that SPR values of 0.3, 0.34, 0.38, 0.40, 0.42, 0.46, and 0.50 with a 30:20 control rule be evaluated at MSAB015 along with constraints defined by a maximum change in the TCEY of 15%, a slow-up fast-down approach, and/or setting quotas every third year.*

***Management procedures for distributing the TCEY***

*MSAB014–Rec.05 (para. 56) The MSAB RECOMMENDED that the management procedures listed in Table 2 in Appendix VI be evaluated at MSAB015.*

86. The Commission **NOTED** that the MSAB will use the primary objectives and associated performance metrics detailed in Appendix V of IPHC-2019-MSAB014-R for the evaluation of management procedures.

87. The Commission **NOTED** that relative harvest rates will be evaluated as a component of management procedures at MSAB015 and MSAB016.

88. The Commission **NOTED** the MSE Program of Work (2019–21) and that the MSAB and IPHC Secretariat will continue its program of work with delivery of recommended

management procedures at AM097.

89. The Commission **REQUESTED** the MSAB to confirm the proposed topics of work beyond the 2021 deliverables in time for the Interim Meeting (IM096), including work to investigate and provide advice on approaches for accounting for the impacts of bycatch in one Regulatory Area on harvesting opportunities in other Regulatory Areas.

## RESULTS AND ACTION ITEMS FROM THE 6th SPECIAL SESSION OF THE IPHC (SS06)

**(IPHC-2020-CR-007)**

### I. Management Strategy Evaluation (MSE)

**IPHC-2020-ID001**: The Commission **RECOMMENDED** that the primary coastwide and area-specific objectives outlined in Table 1 of Appendix A be used for evaluating MSE results conditional on future consideration of the objectives after preliminary MSE results are presented at MSAB015 in May 2020.

**IPHC-2020-ID002**: The Commission **RECOMMENDED** a reference SPR fishing intensity of 43% with a 30:20 control rule be used as an updated interim harvest policy consistent with MSE results pending delivery of the final MSE results at AM097, noting the additional components intended to apply for a period of 2020 to 2022 as defined in IPHC-2020-AM096-R paragraphs 97 b, c, d, and e. Specifically, these additional components are allocations to 2A and 2B, accounting for some impacts of U26 non-directed discard mortality, and the use of a rolling three-year average for projecting non-directed fishery discard mortality.

## APPENDIX A

**Table 1.** Primary measurable objectives, evaluated over a simulated ten-year period. Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives. Reproduced from IPHC-2020-AM096-12.

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

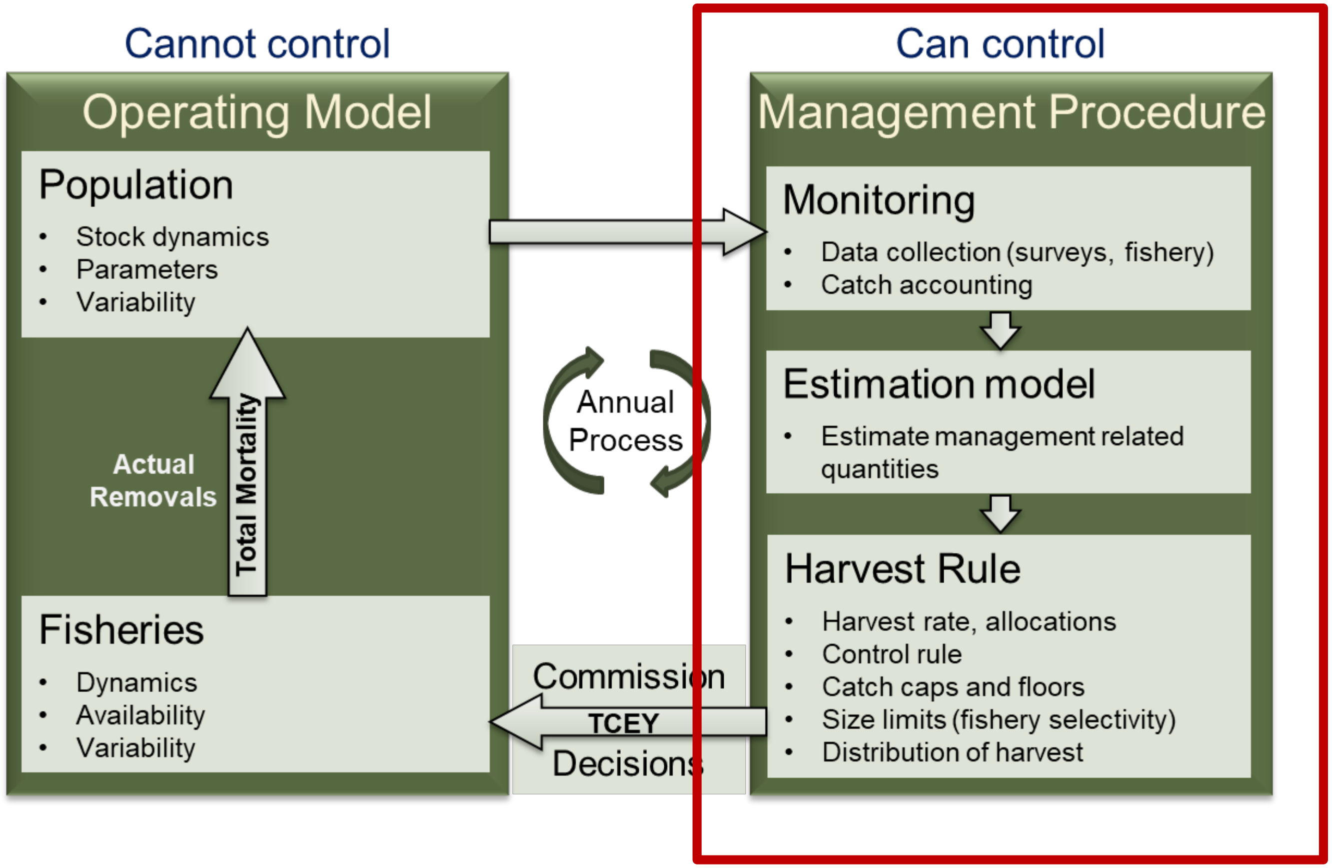

INTERNATIONAL PACIFIC
HALIBUT COMMISSION

# Management Procedures

Agenda Item 4

IPHC-2020-MSAB016-07

# The closed loop framework



# Monitoring

- Data generated with error from the OM
  - Indices of abundance (FISS NPUE & commercial WPUE)
  - Catch-at-age

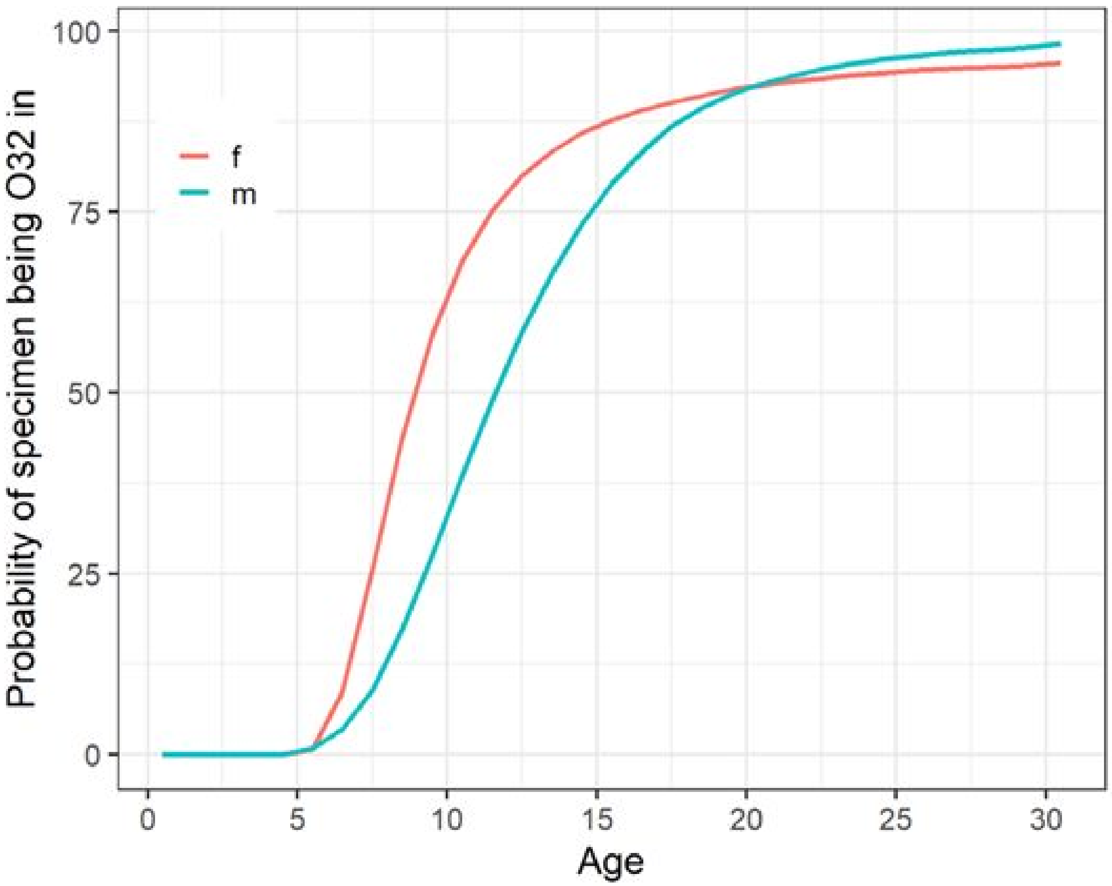
- Data provided at coastwide, Biological Region, and IPHC Regulatory Area levels

# Monitoring

- The Pacific halibut population is modelled in the OM at a Biological Region level.
- Stock distribution is calculated for each region and error is introduced resampling from a lognormal distribution.
- Fixed proportions are used to calculate the stock distribution at a regulatory area level.
- For O32 stock distribution a fixed proportions of length at age is used.

- Catch-at-age data are generated with error for each fishery using a Dirichlet distribution

# Probability O32



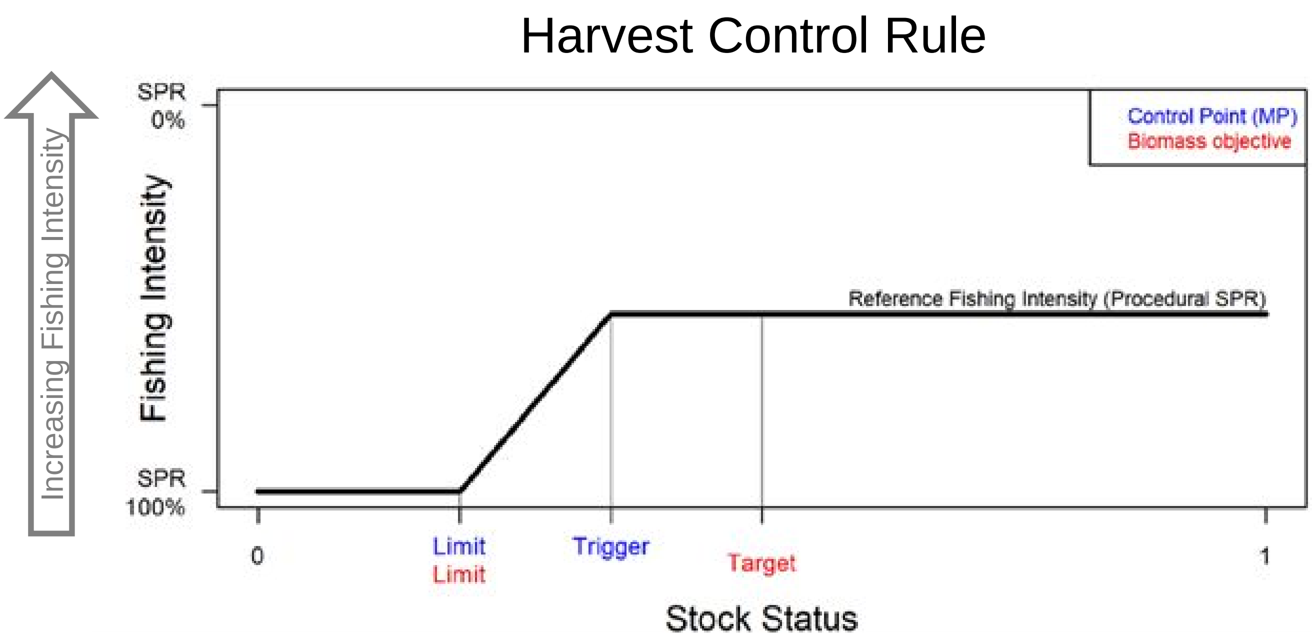
# Harvest rule

- The HR is the application of the estimation model output to determine mortality limits for the upcoming year or years.

  1. Coastwide component
  2. Distribution component

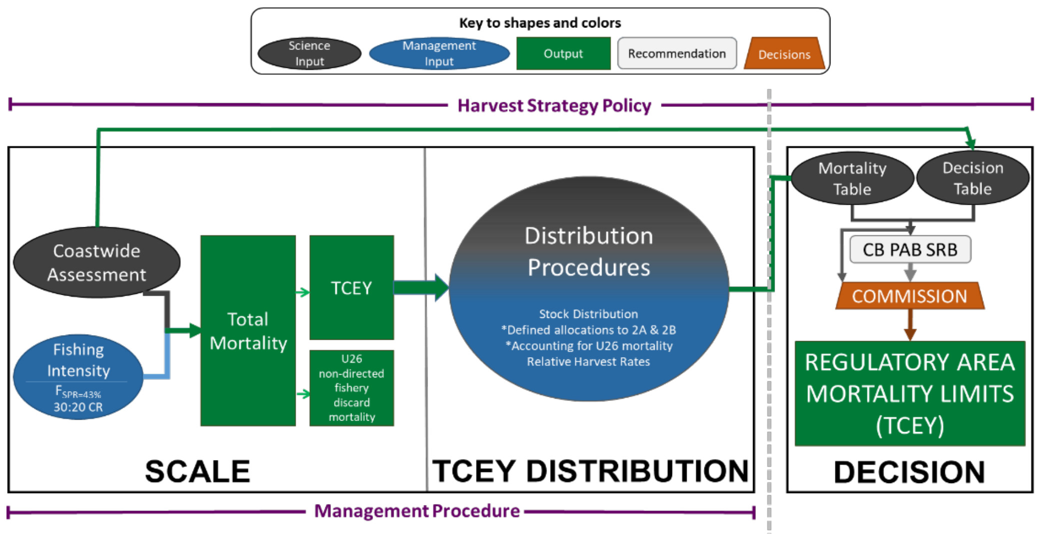
# Coastwide Scale (fishing intensity)

- SPR
  - Various values
- Control rule
  - 30:20
- Constraint
  - Maximum change in TCEY of 15%
  - Slow-up, fast-down



# IPHC Harvest Strategy Policy

1. Coastwide target fishing intensity (science-based & management-derived)
2. Regional Stock Distribution (science-based & management-derived)
3. Regulatory Area Allocation (science-based & management-derived)
4. Annual Regulatory Area Adjustment (policy-based)

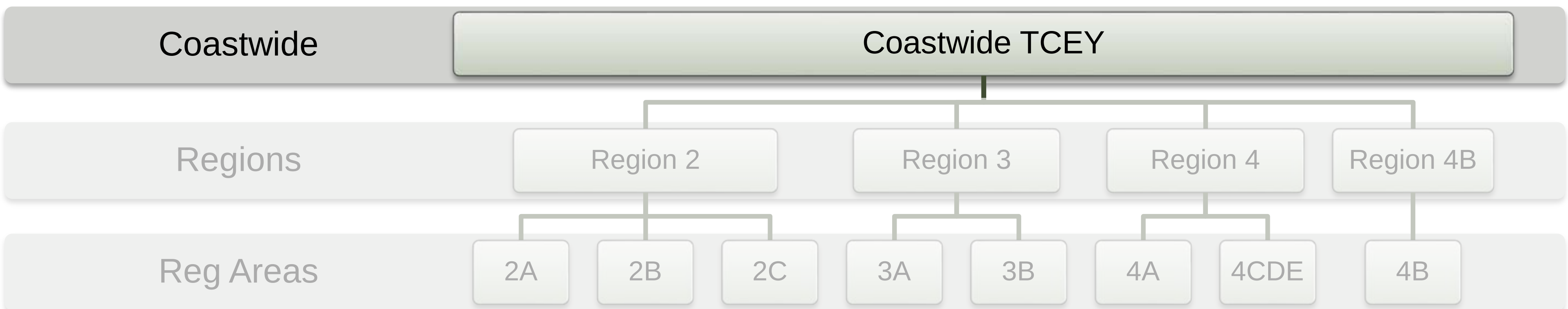


# A procedure for distributing the TCEY (2)

## 1. Coastwide Target Fishing Intensity

Required

- Determine coastwide Total Mortality from Scale MP
- Separate TM into O26 (TCEY) and U26 components

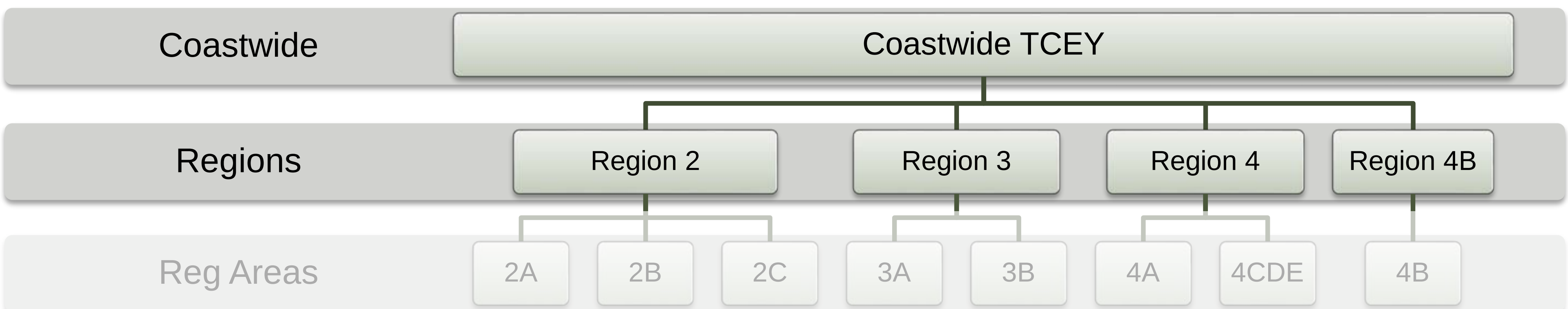


# A procedure for distributing the TCEY (3)

## 2. Regional Stock Distribution

Optional

- Stock distribution using proportion of the stock estimated from the WPUE index.
- Relative fishing intensity to adjust the distribution in account of migration, productivity, etc…
- Regional Allocation adjustment to account for other factors.

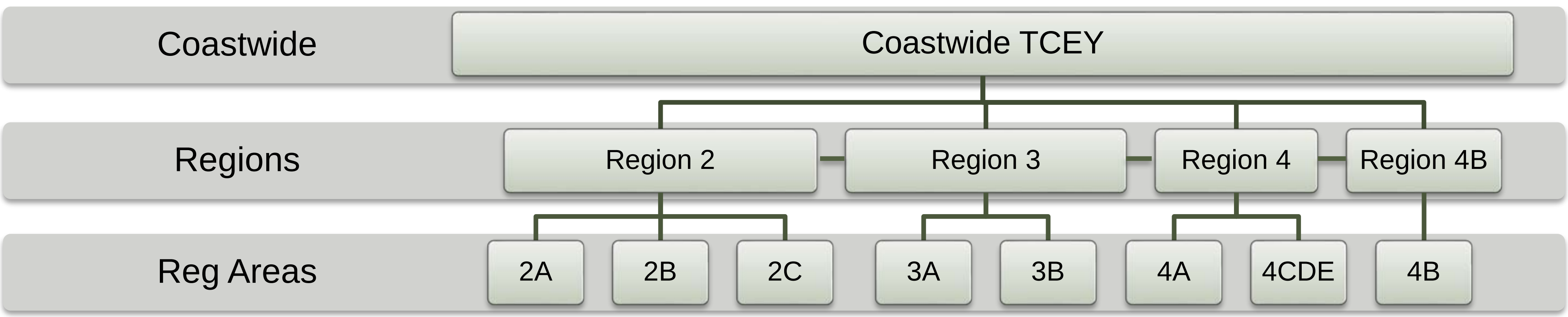


# A procedure for distributing the TCEY (4)

## 3. Regulatory Area Allocation

- Stock distribution using proportion of the stock estimated from the WPUE index.
- Relative harvest rates

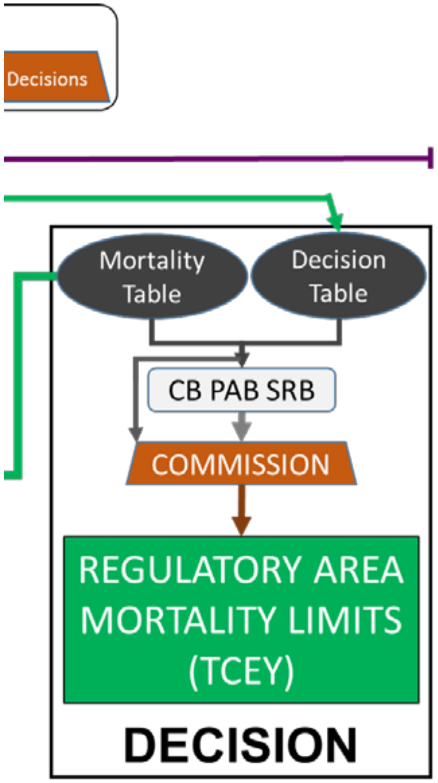
Required



# A procedure for distributing the TCEY (5)

## 4. Annual Regulatory Area Adjustment

- Adjust Regulatory Area TCEY's to account for other factors as needed
- May deviate from the management procedure
  - Will have unpredictable consequences



# MPs for evaluation in 2020

| MP | Coastwide | Regional | IPHC Regulatory Area | Priority |
|---|---|---|---|---|
| **MP 15-A** | SPR 30:20 | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A<br>• Formula percentage for 2B | 1 |
| **MP 15-B** | SPR 30:20 MaxChange15 % | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A<br>• Formula percentage for 2B | 1 |
| **MP 15-C** | SPR 30:20 MaxChange15 % | O32 stock distn Rel HRs: R2, R3=1, R4, R4B=0.75, | • O32 stock distribution<br>• Relative harvest rates not applied<br>• 1.65 Mlbs floor in 2A<br>• Formula percentage for 2B | 2 |
| **… K** | | | | |

https://www.iphc.int/uploads/pdf/msab/msab015/iphc-2020-msab015-r.pdf

# MSAB015

- ***IPHC-2020-MSAB015-R, para. 42****.The MSAB* ***AGREED*** *that the following elements of interest for defining constraints on changes in the TCEY, and distribution procedures be considered for the Program of Work in 2020:*
  - *constraints on the change in the TCEY can be applied annually or over multiple years at the coastwide or IPHC Regulatory Area level. Constraints on the change in TCEY currently considered include a maximum annual change in the TCEY of 15%, a slow-up fast down approach, multi-year mortality limits, and multi-year averages on abundance indices;*
  - *indices of abundance in Biological Regions or IPHC Regulatory Area (e.g. O32 or All sizes from modelled survey results);*
  - *a minimum TCEY for an IPHC Regulatory Area;*
  - *defined shares by Biological Region, Management Zone, or IPHC Regulatory Area;*
  - *maximum coastwide fishing intensity (e.g. SPR equal to 36% or 40%) not to be exceeded when distributing the TCEY;*
  - *relative harvest rates between Biological Regions or IPHC Regulatory Areas.*

# MP comparison

| Element | MP-A | MP-B | MP-C | MP-D | MP-E | MP-F | MP-G | MP-H | MP-I | MP-J | MP-K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| maxChange15% | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| max FI buffer (36%) | | | | ■ | | | | | | | |
| O32 stock distribution | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | |
| O32 stock distribution (5-year moving avg) | | | | | | | | | | ■ | |
| All sizes stock distribution | | | | | | | | | ■ | | |
| 5-year shares form O32 stock distribution | | | | | | | | | ■ | | ■ |
| Relative harvest rates 1 for 2-3A, 0.75 for 3B-4 | ■ | ■ | | ■ | ■ | ■ | ■ | | ■ | ■ | |
| Relative harvest rates 1 for 2-3, 4A, 4CDE, 0.75 for 4B | | | | | | | | ■ | | | |
| 1.65 Mlbs floor in 2A | ■ | ■ | ■ | ■ | ■ | | | | | | |
| Formula percentage for 2B | ■ | ■ | ■ | ■ | | | | | | | |
| National Shares (2B=20%) | | | | | | ■ | | | | | |

# Potential Additional MPs

- Different constraints:
  - MPA and MPG already examine maxChange15%
  - SUFD
  - Fixed 3 years TCEY
  - Combinations
  - At IPHC Regulatory Area level
- MPC modification
  - balancing agreement within region 2 only
- Distribution to Biological Regions using all sizes or O32, and then use fixed proportions for IPHC Reg Areas
- Data-based MPs (i.e. FISS data only)

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

# Potential management procedures to determine the total constant exploitation yield (TCEY) by IPHC Regulatory Area for Pacific halibut fisheries

PREPARED BY: IPHC SECRETARIAT (P. CARPI, A. HICKS, & I. STEWART; 19 SEPTEMBER 2020)

## PURPOSE

To provide an update on management procedures related to distributing the TCEY for use in the MSE process.

## 1. INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) completed an initial phase of evaluating management procedures relative to the coastwide scale of the Pacific halibut stock and fishery. Results of the MSE simulations were presented at the 96th Session of the IPHC Annual Meeting (AM096) and endorsed by the Commission at the Intersessional Meeting held on 3 March, 2020 (IPHC-2020-CR-007). The next phase is to investigate management procedures related to the distribution of the Total Constant Exploitation Yield (TCEY). The TCEY is the mortality limit composed of mortality from all sources except under 26 inch (66.0 cm, U26) non-directed discard mortality, and is determined by the Commission at each Annual Meeting for each IPHC Regulatory Area.

Preliminary results were presented during a two-day intersessional meeting held online in August 2020. During this meeting MSAB members had the opportunity to review the proposed Management Procedures (MPs), to familiarize themselves with the MSE Explorer tool for results evaluation, and to identify useful performance metrics.

A management procedure consists of three elements: the monitoring (data generation), the Estimation Model (EM) and the Harvest Rule (HR) (Figure 1). Data are generated from the Operating Model (OM) to simulate the data collection and sampling process. Variability and bias are introduced in the data in this phase. The EM is analogous to the stock assessment and simulates estimation error in the process. Using the data generated, it produces an annual estimate of stock size and status and provides the inputs for applying the HR. The HR is the application of the estimation model output using various specifications to determine mortality limits for the upcoming year or years.

This document presents and discusses the Management Procedures (MPs) for determining the TCEY for each IPHC Regulatory Area. First, a summary of recent developments in the Management Procedures for Pacific Halibut that arised from the last most recent MSAB meeting and the Commission recent meetings is provided (Section 2). Next, the general framework under which both the current and the recently proposed MPs operate is described (Section 3). It will then review the current interim management procedure, including the recent short-term agreements for 2021 and 2022 (Section 4). Finally, an overview is provided of the MPs that will be tested during this second phase of the MSE process, highlighting limits and benefits of the tools used (Section 5).

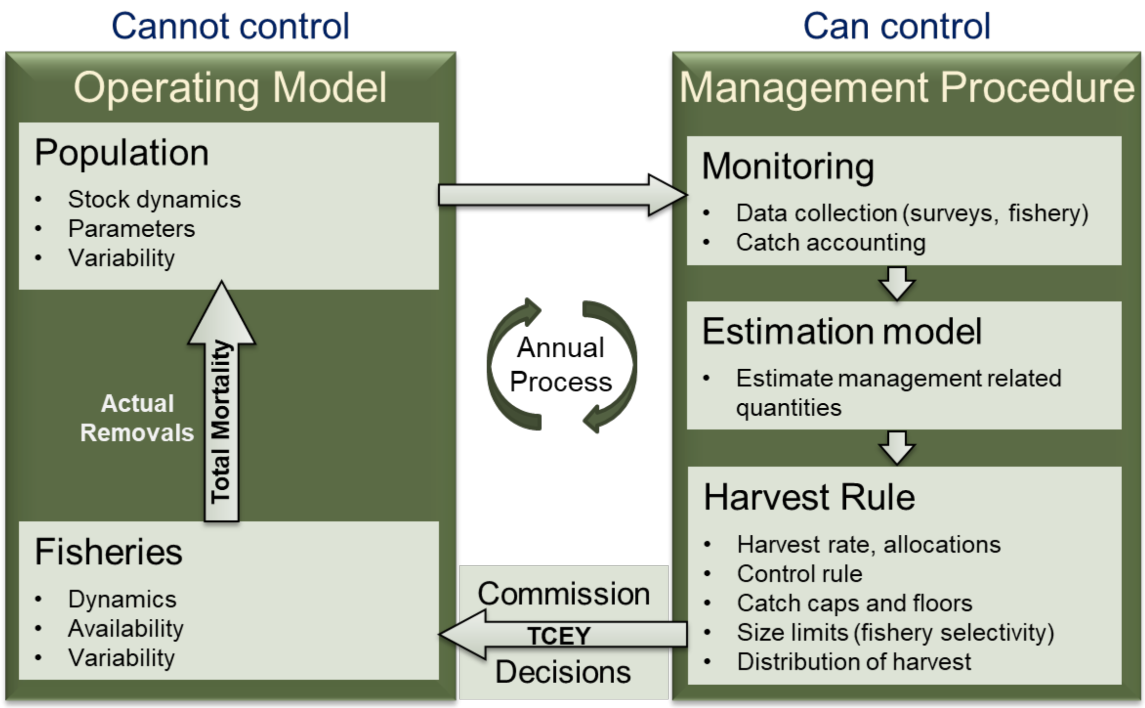



**Figure 1**: Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). The annual process represents a single loop of this framework.

## 2. Management procedures for coastwide scale and distribution of the TCEY

The 96th Session of the IPHC Annual Meeting (AM096) discussed the recommendations from the MSAB and the IPHC Secretariat on the coastwide results of the MSE and agreed to hold an inter-sessional meeting soon after AM096 to provide further direction. During this inter-sessional meeting, the Commission endorsed the coastwide and area-specific objectives defined at MSAB014, and the revision of the reference Spawning Potential Ratio (SPR, or fishing intensity) from 46% to 43% based on the analysis presented to SRB015 and MSAB014 to be used in the interim harvest policy.

The MSAB has defined a list of candidate management procedures for distributing the coastwide TCEY. At MSAB014, the distribution framework was formalized in 3 steps: a coastwide TCEY, an optional distribution of the TCEY to Biological Regions or Management Zones, and the final distribution to IPHC Regulatory Areas. Specific elements of MPs were considered at MSAB014 (IPHC-2019-MSAB014-R, para 55, 57 and 58). At MSAB015, some of these elements were identified as important for the 2020 evaluation (paragraph 42 of IPHC-2020-MSAB015-R):

a) constraints on the change in the TCEY can be applied annually or over multiple years at the coastwide or IPHC Regulatory Area level. Constraints on the change in TCEY currently considered include a maximum annual change in the TCEY of 15%, a slow-up fast down approach, multi-year mortality limits, and multi-year averages on abundance indices;

b) indices of abundance in Biological Regions or IPHC Regulatory Area (e.g. O32 or All sizes from modelled survey results);

c) a minimum TCEY for an IPHC Regulatory Area;

d) defined shares by Biological Region, Management Zone, or IPHC Regulatory Area;

e) maximum coastwide fishing intensity (e.g. SPR equal to 36% or 40%) not to be exceeded when distributing the TCEY;

f) relative harvest rates between Biological Regions or IPHC Regulatory Areas.

## 3. The General framework

The framework for distributing the TCEY begins with the coastwide TCEY determined from the stock assessment and fishing intensity defined by a reference SPR. The TCEY can be distributed to Biological Regions first and then to Regulatory Areas, or directly to Regulatory Areas; however, maintaining spawning biomass in each Biological Region is a primary objective. Relative adjustments can be applied in each step of the distribution process. Typically, the distribution procedure does not alter the overall fishing intensity (i.e., reference SPR).

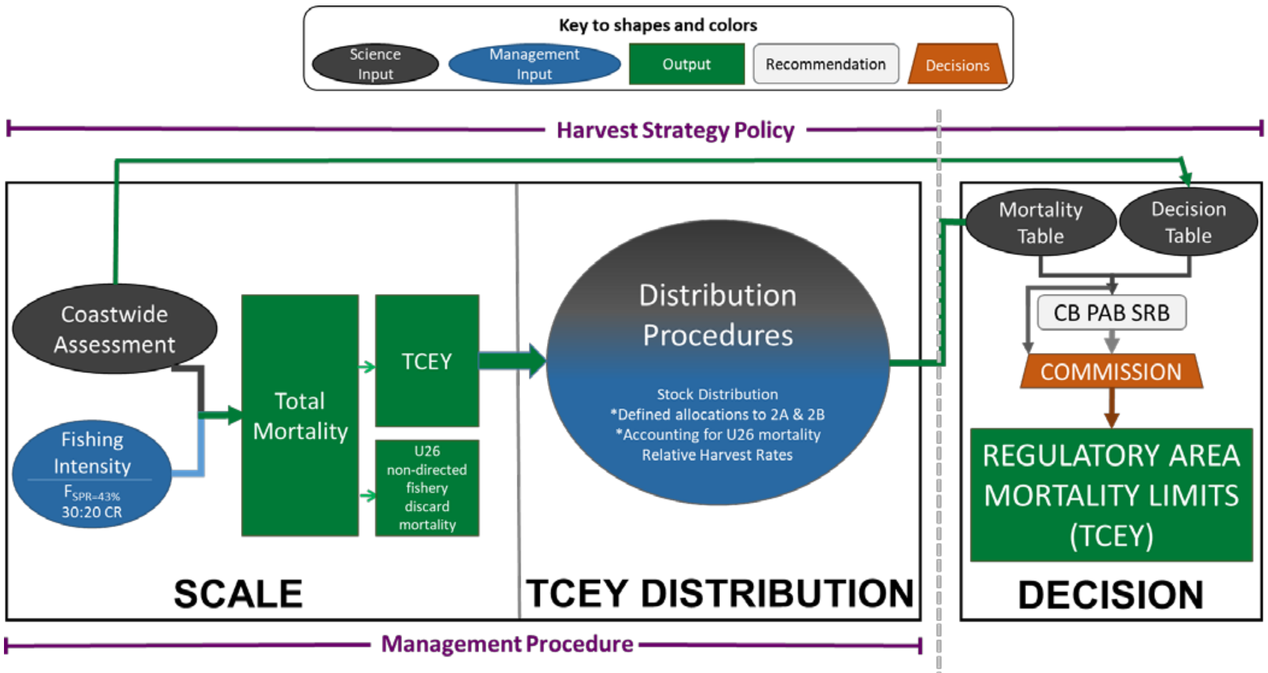



**Figure 2**: Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC CIRCULAR 2020-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are three-year interim agreements to 2022. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

The framework is described below. Only steps 1 and 3 are required and steps 2 and 4 are optional.

1. **Coastwide scale (*required*)**
   1.1. **Estimation model (science-based, *required*)**: A statistical analysis or summary of data to inform the current status of the stock and possibly projections given various mortality limits. This may be as complex as a stock assessment or as straightforward as the estimate of relative coastwide abundance/biomass from the modelled survey index.
   1.2. **Reference Fishing Intensity (management-derived, *required for an assessment-based approach*):** Determine the coastwide total mortality using a reference SPR that is most consistent with IPHC coastwide objectives defined by the Commission, removing the U26 non-directed fishing discard mortality from the Total Mortality to determine the coastwide TCEY.

2. **Regional distribution (*optional*)**
   2.1. **Regional Stock Distribution (science-based, *required when using the Regional step*):** Distribute the coastwide TCEY to four (4) biologically-based Regions (Figure 3) using the proportion of the stock estimated in each Biological Region for all sizes of Pacific halibut using information from the IPHC space-time model. “All sizes” WPUE is the most congruent metric to distribute the TCEY at this scale.
   2.2. **Regional Relative Fishing Intensity (science-based, *optional*):** Adjust the distribution of the TCEY among Biological Regions to account for migration, productivity, and other biological characteristics of the Pacific halibut observed in each Biological Region.
   2.3. **Regional Allocation Adjustment (management derived, *optional*):** Adjust the distribution of the TCEY among Biological Regions to account for other factors. This may include evaluation of recent trends in estimated quantities (such as fishery-independent WPUE), inspection of historical trends in fishing intensity, recent or historical fishery performance, and uncertainty. Regional relative harvest rates may also be determined through negotiation, leading to an allocation agreement for further regional adjustment of the TCEY.
3. **Regulatory Area Allocation (*required with at least one sub-option*)**
   3.1. **Regulatory Area Stock Distribution (science-based):** Distribute the coastwide (if step 2 is omitted) or regional TCEY to IPHC Regulatory Areas using the proportion of the stock estimated in each IPHC Regulatory Area for all sizes or O32 Pacific halibut using information from the IPHC space-time model.
   3.2. **Regulatory Area Allocation (management derived):** Apply IPHC Regulatory Area allocation to the coastwide TCEY (if step 2 is omitted) or within each Biological Region to distribute the TCEY to Regulatory Areas. This management or policy decision may be informed by data or defined by an allocation agreement and may include different relative harvest rates by Regulatory Area. For example, recent trends in estimated all sizes WPUE from the modelled survey or fishery data, age composition, or size composition may be used to distribute the TCEY to IPHC Regulatory Areas. Inspection of historical trends in fishing intensity or catches by IPHC Regulatory Area may also be used. Finally, predetermined fixed percentages are also an option. This allocation to IPHC Regulatory Areas may be a procedure with multiple adjustments using different information or agreements.

The steps described above would be contained within the IPHC Harvest Strategy Policy as part of the Management Procedure and are predetermined steps with a predictable outcome. The decision-making process would then occur (Figure 2).

4. **Annual Regulatory Area Adjustment (policy, *optional*)**: Adjust individual Regulatory Area TCEY limits to account for other factors as needed. This is the policy component of the harvest strategy policy and occurs as a final step where other objectives are considered (e.g., economic, social, etc.). A departure from the reference SPR may be a desired outcome for a particular year (short-term, tactical decision making based on current trends estimated in the stock assessment) but would deviate from the management procedure and the long-term management objectives. Departures from the management procedure could take advantage of current situations but may result in unpredictable longer-term outcomes.

### 3.1. Coastwide TCEY

The stock assessment along with a target fishing intensity determine the coastwide Total Mortality (TM). The stock assessment model estimates the status of the stock (i.e, relative spawning biomass, RSB) and uses a target fishing intensity (i.e, SPR) to determine the TM for the next year. If the stock status is below a trigger reference level, the fishing intensity for the upcoming year is reduced accordingly based on a harvest control rule (i.e., 30:20 control rule). Additional elements, such as constraints on how much the TM can change from year to year, may also occur at the coastwide level. The coastwide TM is split into the TCEY and under 26" non-directed fishery discard mortality.

### 3.2. Distributing the TCEY

The TCEY is then distributed to IPHC Regulatory Areas where catch sharing plans and other agreements determine the ultimate allocation to sectors within an IPHC Regulatory Area (the management procedures considered here only go as far as the TCEY in each IPHC Regulatory Area). The allocation to sectors within an IPHC Regulatory Area is not currently being evaluated and is consistent for all management procedures. For a description of these within IPHC Regulatory Area allocation procedures see IPHC-2020-MSAB016-08. The distribution of the TCEY to IPHC Regulatory Areas has several components, that range from purely scientific, to describe the stock distribution and shifts in harvest rates due to differences in productivity, to policy driven, that modify the distribution based on additional considerations.

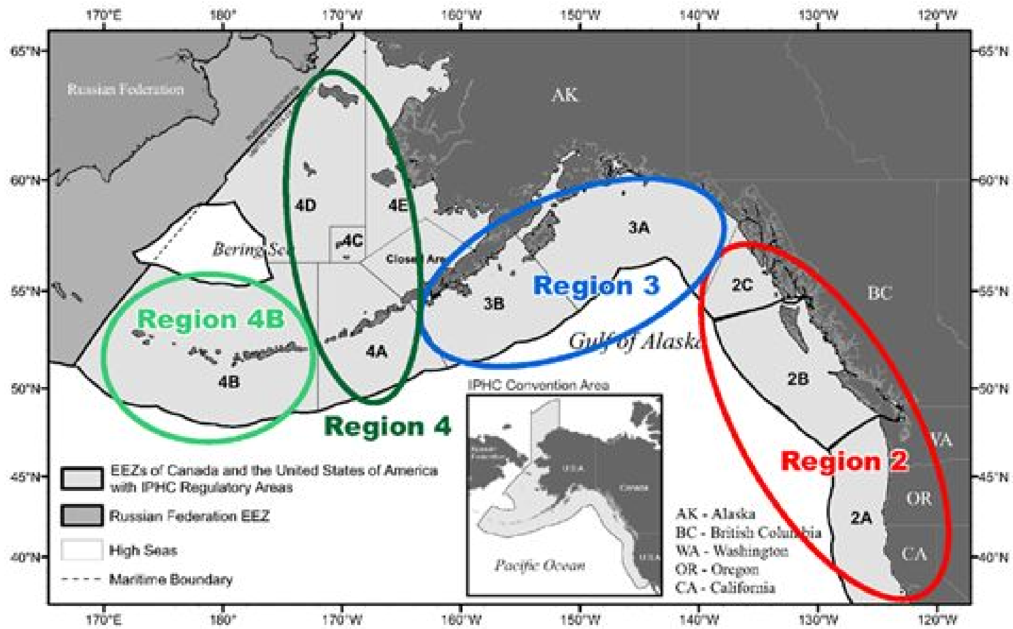



**Figure 3**: Biological Regions overlaid on IPHC Regulatory Areas. Region 2 comprises 2A, 2B, and 2C, Region 3 comprises 3A and 3B, Region 4 comprises 4A and 4CDE, and Region 4B comprises solely 4B.

The overarching conservation goal for Pacific halibut is to maintain a healthy coastwide stock, which implies an objective to retain viable spawning activity in all geographic components of the stock. This goal is well reflected in both the coastwide and area specific objectives defined by the MSAB (MSAB012, MSAB013, MSAB014) and recommended by the Commission at the 6$^{th}$ Special Session of the Commission. Pacific Halibut is a highly migratory species and years of research have contributed to an understanding of the general pattern of movement of the species and helped define Biological Regions (Figure 3). Each Biological Region encompasses multiple IPHC Regulatory Areas and shares common environmental and demographic features. In general, within a year fish move regularly across IPHC Regulatory Areas, but tend to remain within the same Biological Regions (Loher and Seitz 2006; Seitz et al. 2007; Webster et al. 2013). Hence, spawning components are defined by Biological Region. Shifts in productivity will most likely be detected at a Biological Regions level, and will affect each regional component differently. For these reasons, Biological Regions are the most logical scale over which consider conservation objectives related to distribution of the fishing mortality.

Additional steps for further modification of the distribution of the TCEY among Biological Regions and subsequent distribution among IPHC Regulatory Areas within Biological Regions may be based on external factors, such as area specific observations (e.g. fishery-dependent WPUE), higher uncertainty of data collected or observed mortality levels in each area, defined allocations, national shares, and so on.

Overall, science (e.g., analysing data and understanding the life-history of Pacific halibut) and policy (e.g, including management objectives, fishery performance and economic considerations) in each Biological Region will help inform the construction of management procedures related to distributing the TCEY among Biological Regions and IPHC Regulatory Areas. Both these aspects have been included in the MPs proposed during MSAB014.

## 4. CURRENT INTERIM MANAGEMENT PROCEDURE

### 4.1. Coastwide TCEY

The current interim management procedure uses a coastwide reference fishing intensity (SPR) which defines the scale of the coastwide Total Mortality (TM).The TM is divided into the under 26-inch (U26) non-directed fishery discard mortality and the TCEY. The stock assessment estimates the stock status as the current spawning biomass relative to unfished spawning biomass (B0), or relative spawning biomass (RSB). The reference fishing intensity is a fishing mortality rate that would reduce the SPR in the coastwide stock to 43% ($F_{43\%}$, as recommended in IPHC-2020-ID002 of IPHC Circular 2020-007). The 30:20 harvest control rule adjusts the reference SPR if the estimated stock status falls below the 30% trigger value. Specifically, the fishing intensity is reduced linearly if the stock status falls below 30% of unfished spawning stock biomass, and is reduced to zero if the stock status falls below 20% of unfished spawning stock biomass.

### 4.2. Distributing the TCEY

The coastwide TCEY is then distributed among IPHC Regulatory Areas. The current interim management procedure to distribute the TCEY uses the proportion of modelled survey O32 biomass (i.e. biomass of fish over 32 inches) and 25% lower relative harvest rates in the western areas (i.e. 3B, 4A, 4CDE, and 4B) compared to the eastern areas (i.e. 2A, 2B, 2C, 3A). The lower harvest rate assigned to western areas was first implemented in 2004 (Clark & Hare 2005, Hare 2005, Hare 2006, Hare 2009) as a ‘precautionary’ measure based on declining trends in spawning biomass and CPUE, the presence of small fish, differences in yield-per-recruit, differences in emigration and immigration, and greater uncertainty in the data and analyses available at the time (Hare 2009). Recent changes in productivity of these areas, modelled through a simple Yield-per-Recruit (YpR) analysis, showed that the past yield-per-recruit justifications for such difference were consistent 20 to 30 years ago, but may not be as consistent in recent years (IPHC-2019-MSAB014-07).

### 4.3. Regulatory areas adjustment

The current interim procedure added further adjustments to the distributed TCEY in 2019, including a fixed 1.65 million pounds for IPHC Regulatory Area 2A and an allocation for IPHC Regulatory Area 2B based on both stock distribution and a fixed percentage. This is defined as a weighted average of 30% weight to the current interim management procedure's target TCEY distribution and 70% weight to a value of 20%. In 2020, the Commission decided to also account for some impacts of U26 non-directed fishery discard mortality from U.S. IPHC Regulatory Areas on available harvest in IPHC Regulatory Area 2B. The accounting increases the 2B TCEY by 50% of the estimated yield lost due to U26 non-directed discard mortality in Alaskan waters. These adjustments are intended to apply through 2022.

## 5. MANAGEMENT PROCEDURES FOR TESTING AND EVALUATION

At MSAB014, a list of ten Management procedures were defined to be tested during the next phase of the MSE process. At MSAB015, this list was reviewed and the main modification concerned the application of a constraint at the coastwide level as well as the addition of one MP. In particular, a maximum change in the TCEY from year to year of 15% was included in all MPs, with the exception of one (labeled MP-A). On the contrary, the use of Slow-up,Fast-Down constraint was removed from the updated list, but was noted to be of continued interest. In addition, some MPs have been prioritized over others, a priority of 1 meaning a focus on producing precise performance metrics (Table 1).

The tools used in the definition of these MPs can be grouped in three categories:

a) Modelled Survey estimates (e.g. relative biomass estimates by Biological Region, IPHC Regulatory Areas or other scale, O32 WPUE, trend in O32 WPUE, etc..).

b) Fishery Dependent Data (e.g. trend in CPUE by Biological Region, IPHC Regulatory Area or other scale).

c) Practical Tools (e.g. relative harvest rate, percentage allocation to an IPHC Regulatory Areas, proportion of adopted TCEY, etc…).

In the definition of the different MPs, the MSAB has also highlighted the importance of testing a number of additional tools, such as i) the application or not of one or more constraints to the TCEY (i.e. 15% maximum change in TCEY, slow-up, fast-down approach, multi-year mortality limits, multi-year averages on abundance indices), ii) the application of O32 estimates of stock distribution or the use of the 'all-sizes' estimates, iii) the application of a minimum TCEY limit, ii) the definition of shares by Biological Region, Management Zone or IPHC Regulatory Area, iv) the application of a maximum coastwide fishing intensity not to be exceed when distributing the TCEY and v) the application or not of different harvest rates across IPHC Regulatory Areas or Biological Regions These points are reflected in the combination of different tools between MPs (Table 1).

**Table 1**: Recommended management procedures to be evaluated by the MSAB in 2020 and the priority of investigation. A priority of 1 denotes a focus on producing precise performance metrics. A priority of 2 denotes potentially fewer simulations are desired, if time is constrained..

| MP | Coastwide | Regional | IPHC Regulatory Area | Priority |
|---|---|---|---|---|
| MP 15-A | SPR 30:20 | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 1 |
| MP 15-B | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 1 |
| MP 15-C | SPR 30:20 MaxChange15% | Biological Regions, O32 stock distribution Rel HRs[3]: R2=1, R3=1, R4=0.75, R4B=0.75 | • O32 stock distribution<br>• Relative harvest rates not applied<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 2 |
| MP 15-D | SPR 30:20 MaxChange15% Max FI (36%) | | First<br>• O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>Second within buffer (pro-rated if exceeds buffer)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 2 |
| MP 15-E | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1] | 2 |
| MP 15-F | SPR 30:20 MaxChange15% | National Shares: 20% to 2B, 80% to other | • O32 stock distribution to areas other than 2B<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 1 |
| MP 15-G | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 1 |
| MP 15-H | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Relative harvest rates (1 for 2-3, 4A, 4CDE, 0.75 for 4B) | 1 |
| MP 15-I | SPR 30:20 MaxChange15% | | • All sizes stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 2 |

| MP | Coastwide | Regional | IPHC Regulatory Area | Priority |
|---|---|---|---|---|
| MP 15-J | SPR 30:20 MaxChange15% | | • O32 stock distribution (5-year moving average)<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 1 |
| MP 15-K | SPR 30:20 MaxChange15% | | • 5-year shares determined from 5-year O32 stock distribution (vary over time but change only every 5th year) | 2 |

[1] paragraph 97b IPHC-2020-AM096-R

[2] paragraph 97c of IPHC-2020-AM096-R

[3] R2 refers to Biological Region 2 (2A, 2B, 2C); R3 refers to Biological Region 3 (3A, 3B); R4 refers to Biological Region 4 (4A, 4CDE), and R4B refers to Biological Region 4B

### 5.1. Coastwide TCEY

All of the management procedures proposed at MSAB015 (Table 1) for testing are based on the current interim MP including a fishing intensity (SPR), and a harvest control rule (30:20). A maximum constrained in the change in the TCEY from one year to the next not higher than 15% was included for testing across all but one of the different management procedures. In addition, the inclusion of a maximum fishing intensity buffer not higher than an SPR of 36% or 40% (meaning a SPR greater than or equal to 36% or 40%) was included in one MP. The rationale behind it is in accordance with the analysis on dynamic reference points presented at MSAB014 (IPHC-2019-MSAB014-07), which identifies a potential range for $SPR_{MSY}$ to likely be between 30 and 35%.

An additional "Slow-Up, Fast-Down" constraint, has been recommended for testing if time allows or in future MSE iterations. The SUFD enforces a TM limit increase by one-third of the increase suggested by harvest control rule and a TM limit decrease by one-half of the decrease suggested by the management procedure. It was suggested because it also met the objectives in the coastwide MSE (IPHC-2019-MSAB013-08) and has some properties that may result in less annual variability in the TCEY.

### 5.2. Distributing the TCEY

Most of the management procedures proposed distribute the TCEY directly to IPHC Regulatory Areas, and only one MP distributes the TCEY first to Biological Regions. In one MP, a fixed allocation is introduced at the coastwide level, assigning 20% to IPHC Regulatory Area 2B and 80% to all other areas. The modelled survey O32 stock distribution is the main tool used for distributing the TCEY both at the Biological Region and IPHC Regulatory Area levels, and it is used in ten MPs. One MP (labelled MP-I) uses the modelled all sizes stock distribution for distributing the TCEY at a IPHC Regulatory Area level. Different relative harvest rate adjustments are used across different MPs to test the effects on western and eastern areas given the potential changes in productivity that may have occurred in the last decade. This tool is also applied to Biological Regions when distributing the TCEY to regions first. Finally, five of the MPs include at least one of the interim agreements for IPHC Regulatory Areas 2A and 2B.

## 6. Recommendations

That the MSAB:

a) **NOTE** paper IPHC-2020-MSAB016-07 which includes a discussion of management procedures to distribute the TCEY and eleven management procedures defined for testing and evaluation.

b) **RECOMMEND** additional elements of management procedures that would be useful to test and evaluate.

## 7. References


Clark WG, & Hare SR. 2005. Assessment of the Pacific halibut stock at the end of 2004. IPHC Report of Assessment and Research Activities 2004: 103-124.

Hare SR. 2005. Investigation of the role of fishing in the Area 4C CPUE decline. IPHC Report of Assessment and Research Activities 2004: 185-197.

Hare SR. 2006. Area 4B population decline - should yield be lowered? IPHC Report of Assessment and Research Activities 2005: 145-149.

Hare SR. 2009. Assessment of the Pacific halibut stock at the end of 2009. IPHC Report of Assessment and Research Activities 2009. 91-170. https://www.iphc.int/library/documents/report-of-research-assessment-and-research-activities-rara/2009-report-of-assessment-and-research-activities.

IPHC-2020-AM096-R. 2020. Report of the 96th Session of the IPHC Annual Meeting (AM096). 51 p. https://www.iphc.int/uploads/pdf/am/2020am/iphc-2020-am096-r.pdf

IPHC-2020-CR-007. 2020. IPHC Circular 2020-007. Intersessional Decisions (1 January-17 March 2020). https://www.iphc.int/uploads/pdf/cir/2020/iphc-2020-cr-007.pdf

IPHC-2020-MSAB016-08. Hicks A, Berukoff S, Carpi P, & Stewart I. 2020. Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries. 27 p. https://www.iphc.int/venues/details/16th-session-of-the-iphc-management-strategy-advisory-board-msab016

IPHC-2020-MSAB015-R. 2020. Report of the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015). 23 p. https://www.iphc.int/uploads/pdf/msab/msab014/iphc-2019-msab014-r.pdf

IPHC-2019-MSAB014-07. Hicks A, Carpi P, Stewart I. 2019. Objectives and management procedures for the IPHC Management Strategy Evaluation (MSE). 24p. https://www.iphc.int/uploads/pdf/msab/msab014/iphc-2019-msab014-07.pdf

IPHC-2019-MSAB014-R. 2019. Report of the 14th Session of the IPHC Management Strategy Advisory Board (MSAB014). 27 p. https://www.iphc.int/uploads/pdf/msab/msab014/iphc-2019-msab014-r.pdf

IPHC-2019-MSAB013-08. Hicks A, & Stewart I. 2019. Further Investigation of Management Procedures Related to Coastwide Fishing Intensity. 18 p. https://www.iphc.int/uploads/pdf/msab/msab13/iphc-2019-msab013-08.pdf

Loher, T., & Seitz, A. C. 2006. Seasonal migration and environmental conditions experienced by Pacific halibut in the Gulf of Alaska, elucidated from Pop-up Archival Transmitting (PAT) tags. IPHC Scientific Report No. 82. 40p. https://www.iphc.int/uploads/pdf/sr/IPHC-2006-SR082.pdf

Seitz, A. C., Loher, T., & Nielsen, J. L. (2007). Seasonal movements and environmental conditions experienced by Pacific halibut in the Bering Sea, examined by pop-up satellite tags. IPHC Scientific Report No. 84. 43p. https://www.iphc.int/uploads/pdf/sr/IPHC-2007-SR084.pdf

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

## 8. Appendices

Nil


INTERNATIONAL PACIFIC HALIBUT COMMISSION

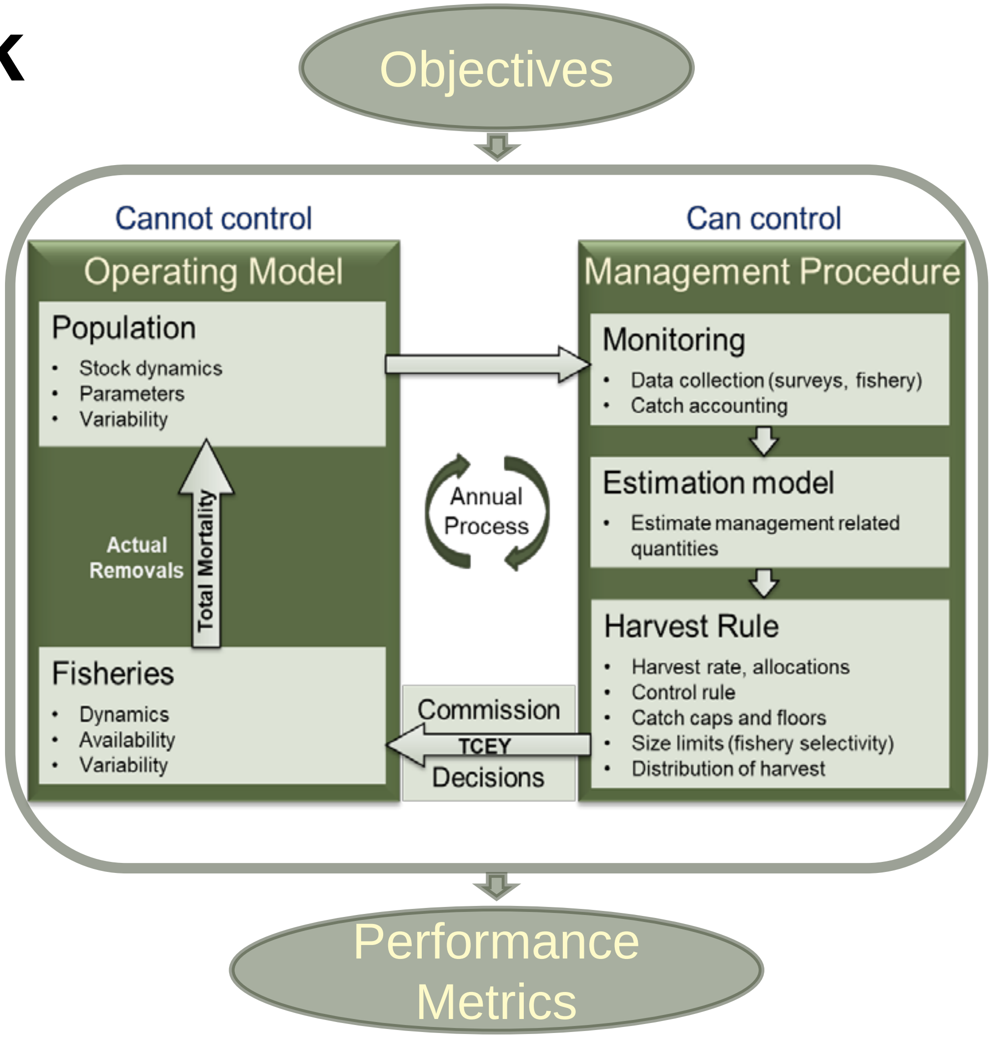
# MSE Framework

Agenda Item 5

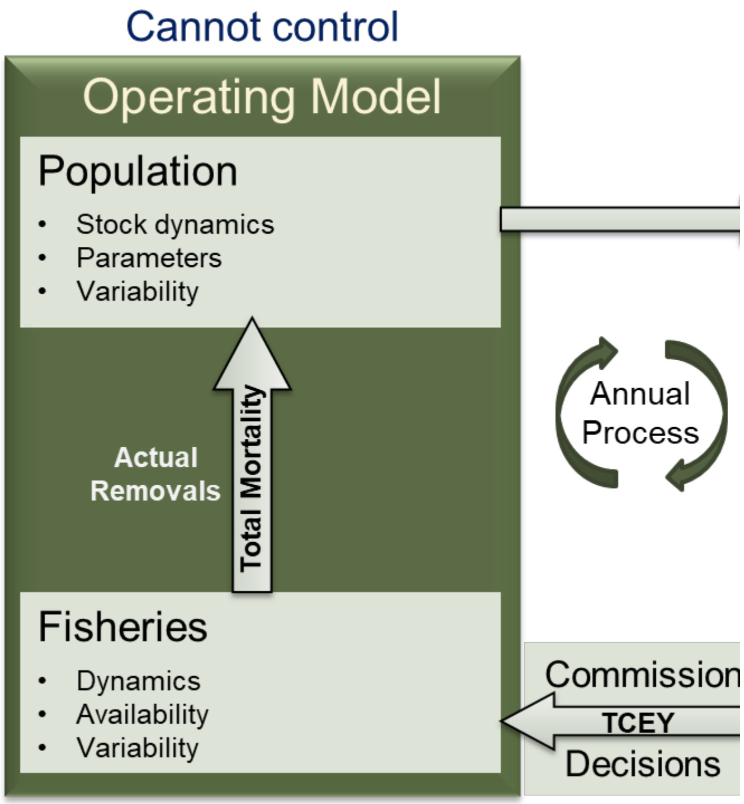
IPHC-2020-MSAB016-08

# Simulation Framework

- The framework contains
  - The elements of the closed-loop simulations
  - The input of objectives and output of performance metrics



# Operating Model (OM)




For technical details, see:

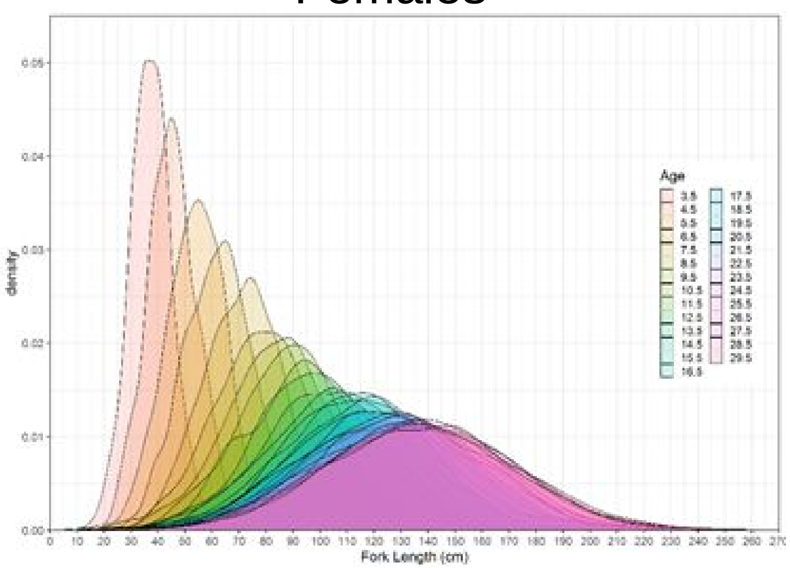
https://iphc.int/venues/details/17th-session-of-the-iphc-scientific-review-board-srb017

and future updates

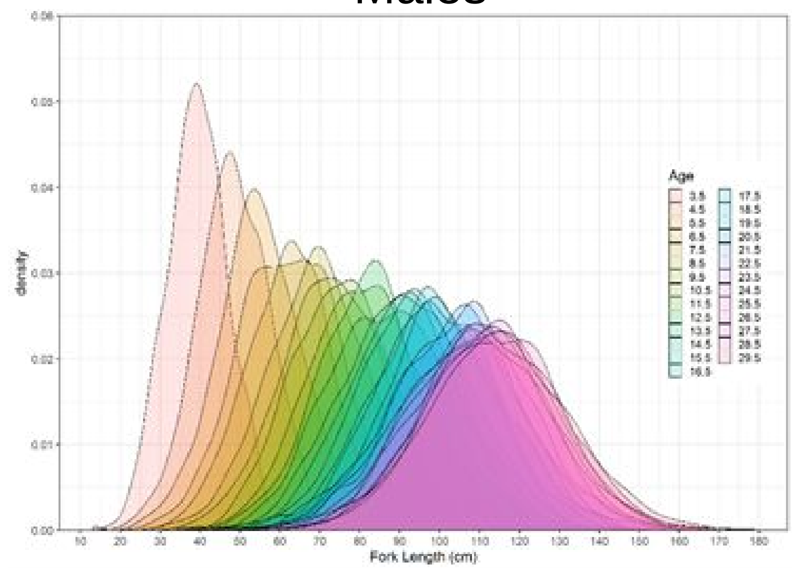
# OM specifications

- Age-structured, plus group at 30
- Lengths not modelled
  - U26/O26/O32 determined from assumed length-at-age

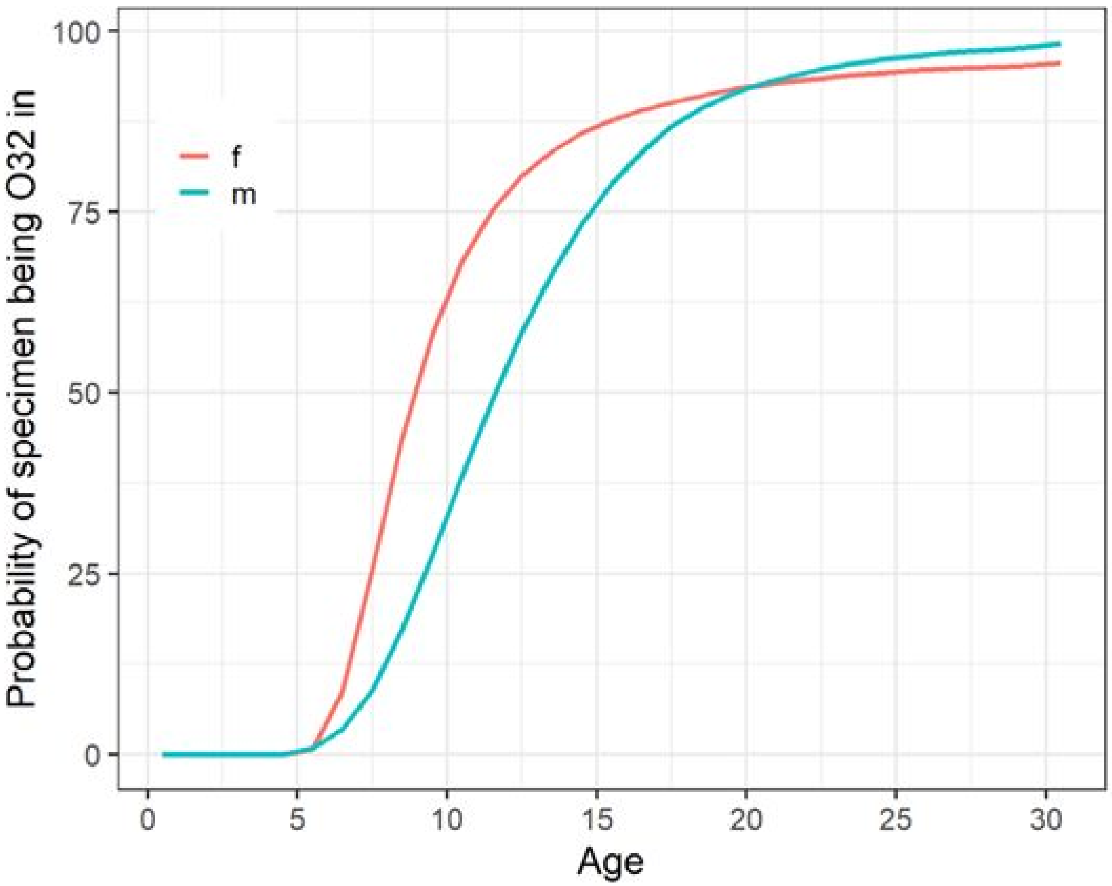
Females




Males

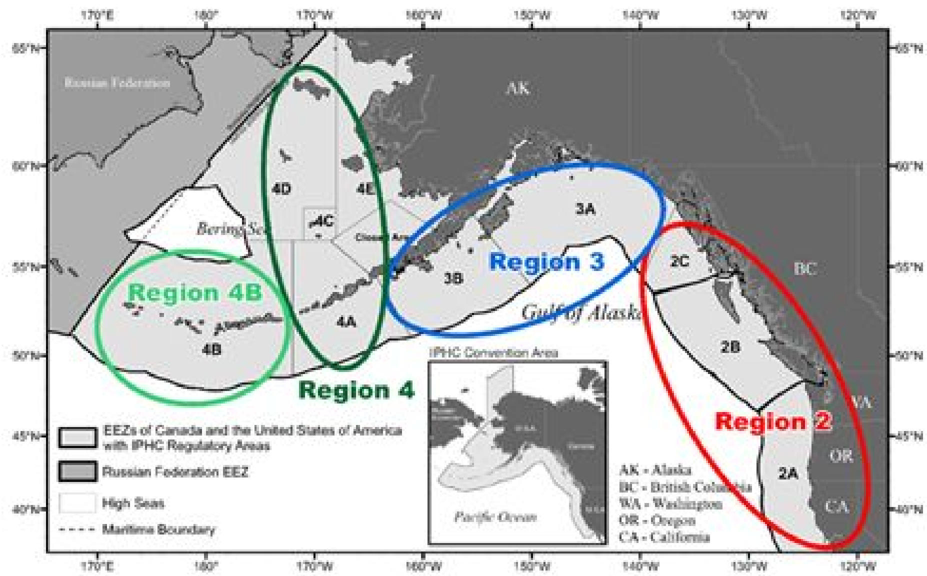


# Probability O32



# OM specifications: Regions

- Four Biological Regions to model biological processes
- Eight IPHC Regulatory Areas for fisheries



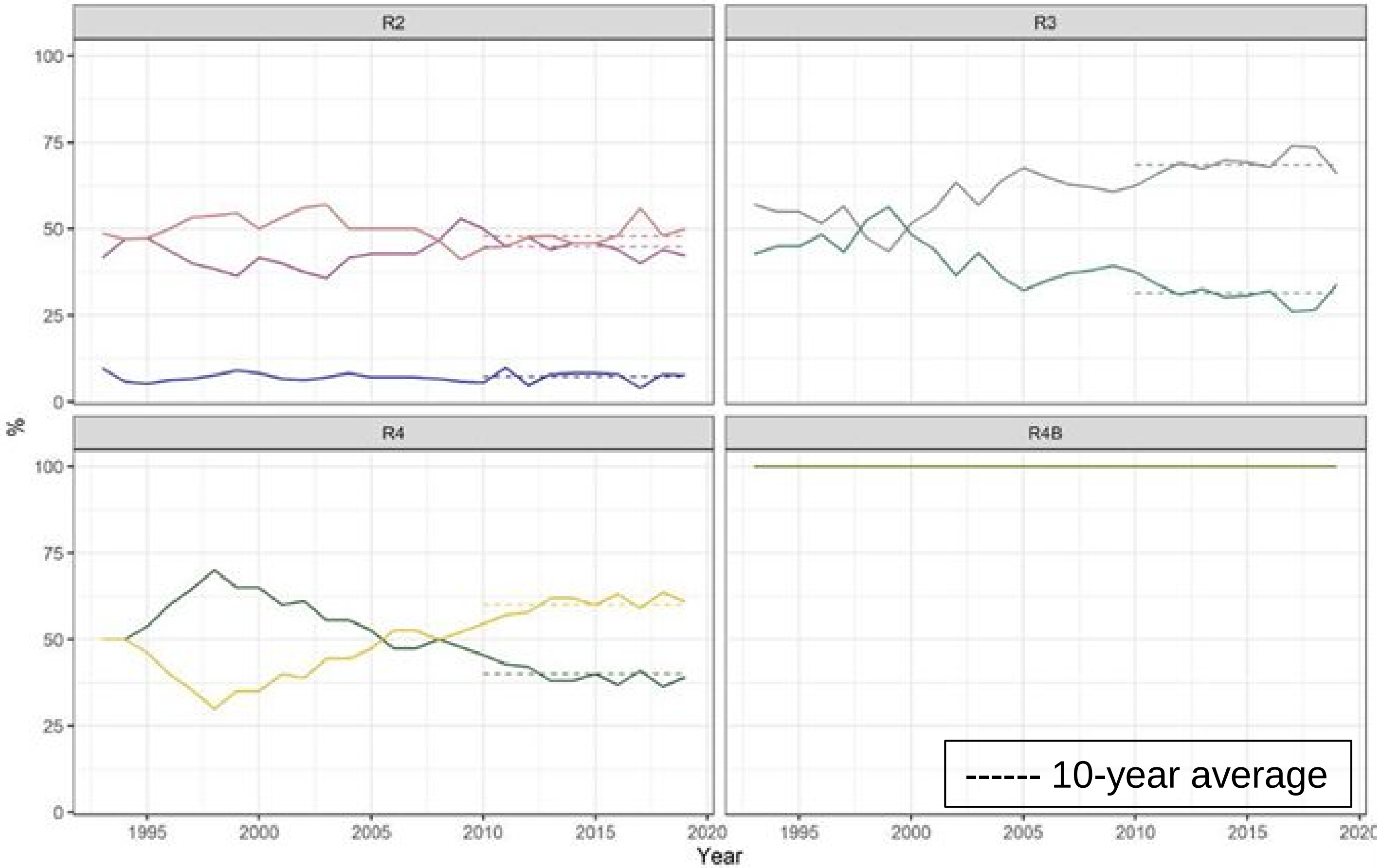
# OM specifications: Fishing Sectors

- Five sectors
  1. Directed commercial fishery
     - O32 mortality from directed fisheries
  2. Directed commercial discard mortality (*directed discards*)
     - U32 mortality from directed fisheries
  3. Non-directed commercial discard mortality (*non-directed*)
     - Mortality from non-directed fisheries
  4. Recreational
     - Mortality from recreational landings and discards
  5. Subsistence
     - Mortality from non-commercial, customary and traditional use

# Modelling fisheries

- Need fisheries metrics at IPHC Regulatory Area
- Movement between Reg Areas much more complex
  – Interannual seasonal movement within a Biological Region
- Areas-as-fleets approach
  – Fleets intercept fish in Biological Region
  – Different selectivity patterns
- Survey
  – Specified proportion of biomass in IPHC Regulatory Areas within a Biological Region

# Proportion of survey in Regulatory Areas



# OM specifications: 33 Fisheries

| Fishery | IPHC Reg Areas | 2019 Mortality |
|---|---|---|
| Directed Commercial 2A | 2A | 0.89 |
| Directed Commercial 2B | 2B | 5.22 |
| Directed Commercial 2C | 2C | 3.67 |
| Directed Commercial 3A | 3A | 8.16 |
| Directed Commercial 3B | 3B | 2.31 |
| Directed Commercial 4A | 4A | 1.45 |
| Directed Commercial 4B | 4B | 1.00 |
| Directed Commercial 4CDE | 4CDE | 1.65 |

| Fishery | IPHC Reg Areas | 2019 Mortality |
|---|---|---|
| Directed Commercial Discards 2A | 2A | 0.03 |
| Directed Commercial Discards 2B | 2B | 0.13 |
| Directed Commercial Discards 2C | 2C | 0.06 |
| Directed Commercial Discards 3A | 3A | 0.32 |
| Directed Commercial Discards 3B | 3B | 0.15 |
| Directed Commercial Discards 4A | 4A | 0.09 |
| Directed Commercial Discards 4B | 4B | 0.03 |
| Directed Commercial Discards 4CDE | 4CDE | 0.07 |

| Fishery | IPHC Reg Areas | 2019 Mortality |
|---|---|---|
| Non-Directed Comm Discards 2A | 2A | 0.13 |
| Non-Directed Comm Discards 2B | 2B | 0.24 |
| Non-Directed Comm Discards 2C | 2C | 0.09 |
| Non-Directed Comm Discards 3A | 3A | 1.65 |
| Non-Directed Comm Discards 3B | 3B | 0.48 |
| Non-Directed Comm Discards 4A | 4A | 0.35 |
| Non-Directed Comm Discards 4B | 4B | 0.15 |
| Non-Directed Comm Discards 4CDE | 4CDE | 3.5 |

| Fishery | IPHC Reg Areas | 2019 Mortality |
|---|---|---|
| Recreational 2B | 2B | 0.86 |
| Recreational 2C | 2C | 1.89 |
| Recreational 3A | 3A | 3.69 |
| Subsistence 2B | 2B | 0.41 |
| Subsistence 2C | 2C | 0.37 |
| Subsistence 3A | 3A | 0.19 |
| Recreational/Subsistence 2A | 2A | 0.48 |
| Recreational/Subsistence 3B | 3B | 0.02 |
| Recreational/Subsistence 4 | 4A,4CDE | 0.06 |

# TCEY fishery limits

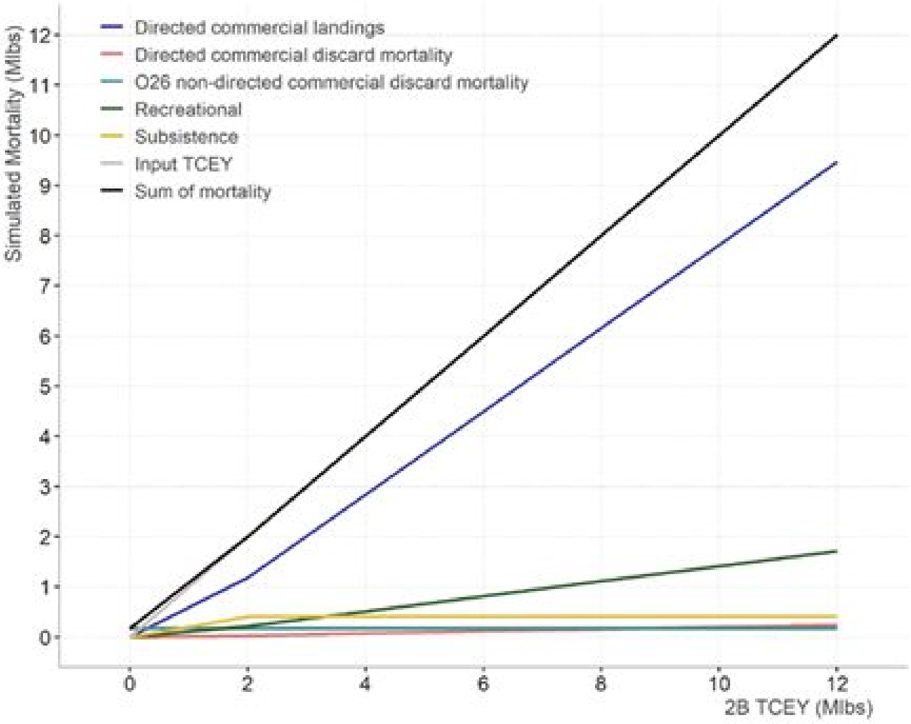
- TCEY = TM – U26 NDDM (previous year's Non-directed Commercial Discard Mortality)
- DirectedTCEY = TCEY – O26 NDDM

**Catch-Sharing Plan (CSP)**

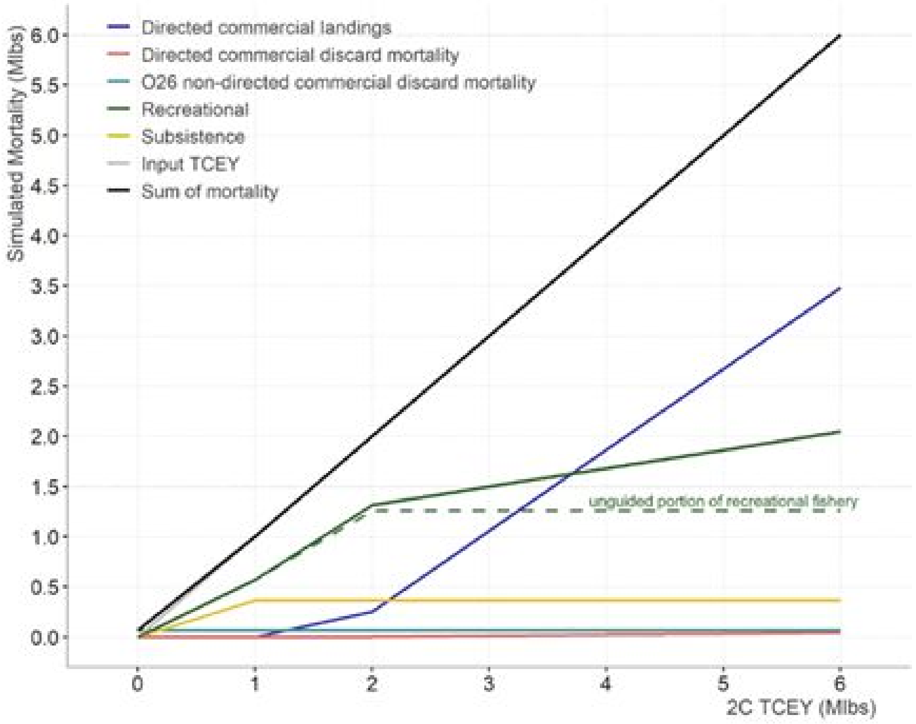
- Subsistence:
  - Observed from previous year, except 2A = 30,000lbs
- Recreational Mortality:
  - Unguided Recreational: 2C and 3A only
    - Random lognormal deviate with mean 1.257 or 1.579 Mlbs, CV=5%
  - CSP limit summed with unguided
- Directed Commercial Discard Mortality
  - Ratio of directed discard mortality to directed commercial mortality from previous year
- Directed Commercial Mortality
  - Remainder after subtracting other sources from DirectedTCEY

# Example fishery mortality limits

2B

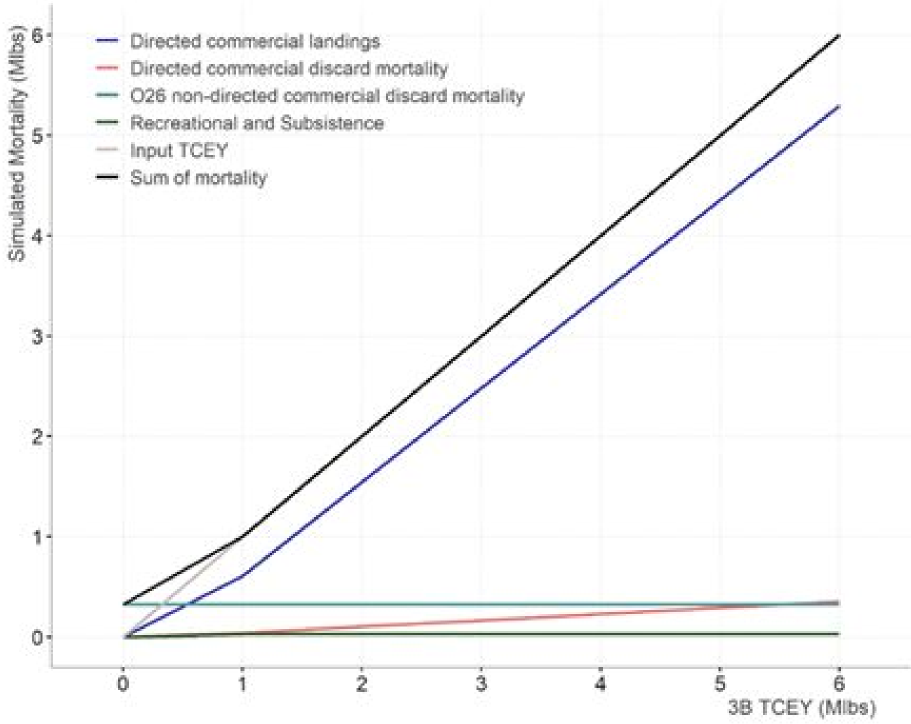



2C

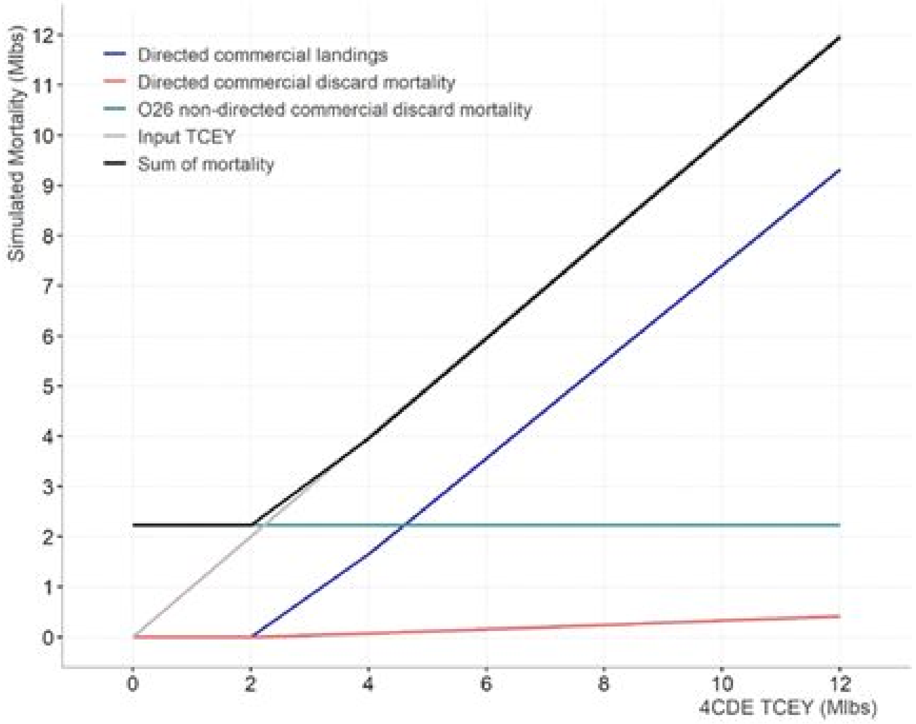


# Example fishery mortality limits

3B




4CDE



# Realized fishery mortality

- TCEY = TM – U26 NDDM (simulated Non-directed Commercial Discard Mortality)
- DirectedTCEY = TCEY – O26 NDDM

**Catch-Sharing Plan (CSP)**

- Subsistence:
  - Simulated from lognormal with mean equal to fixed value and CV=15%
  - Not greater than one-half coastwide TCEY, but no lower than a minimum
- Recreational Mortality:
  - Unguided Recreational: 2C and 3A only
    - Random lognormal deviate with mean 1.257 or 1.579 Mlbs, CV=5%
  - CSP limit summed with unguided
- Directed Commercial Discard Mortality
  - Function of total directed mortality and male weight at age 8
  - Minimum of 0.05%
- Directed Commercial Mortality
  - Remainder after subtracting other sources from DirectedTCEY

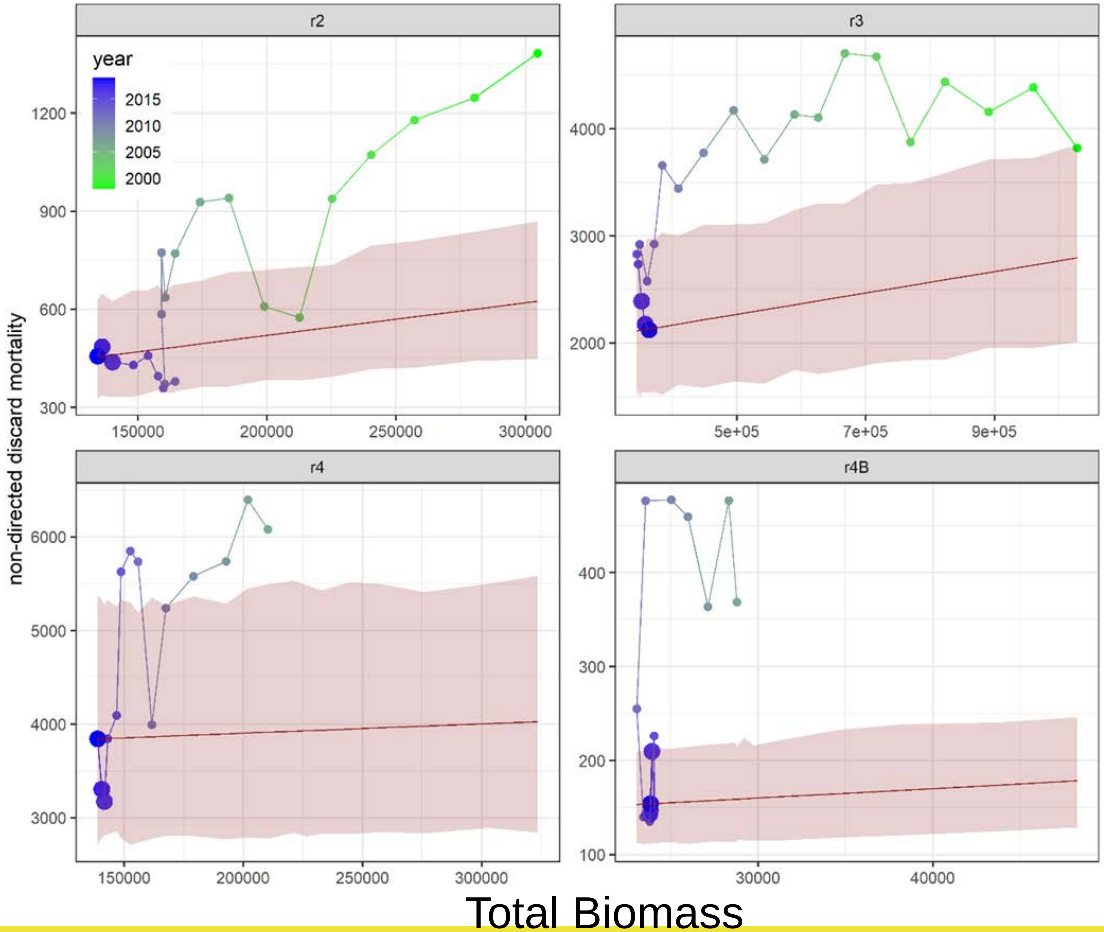
# Ad hoc MSAB meeting (1)

*Para 8.1: Explanation of how realized non-directed commercial discard mortality is modelled:*

- Linear relationship between the non-directed discard mortality by region and the total biomass in that region.
- Fit forced through the last observed year (2019).
- The realized non-directed discard mortality was then randomly drawn from the value determined from total biomass by region using a log normal distribution with a 20% CV

# Ad hoc MSAB meeting (1)

- Non-directed commercial discard mortality (NDDM) plotted against total biomass from the conditioned multi-region OM
- U26 and O26 determined using length-at-age relationship



# Ad hoc MSAB meeting (2)

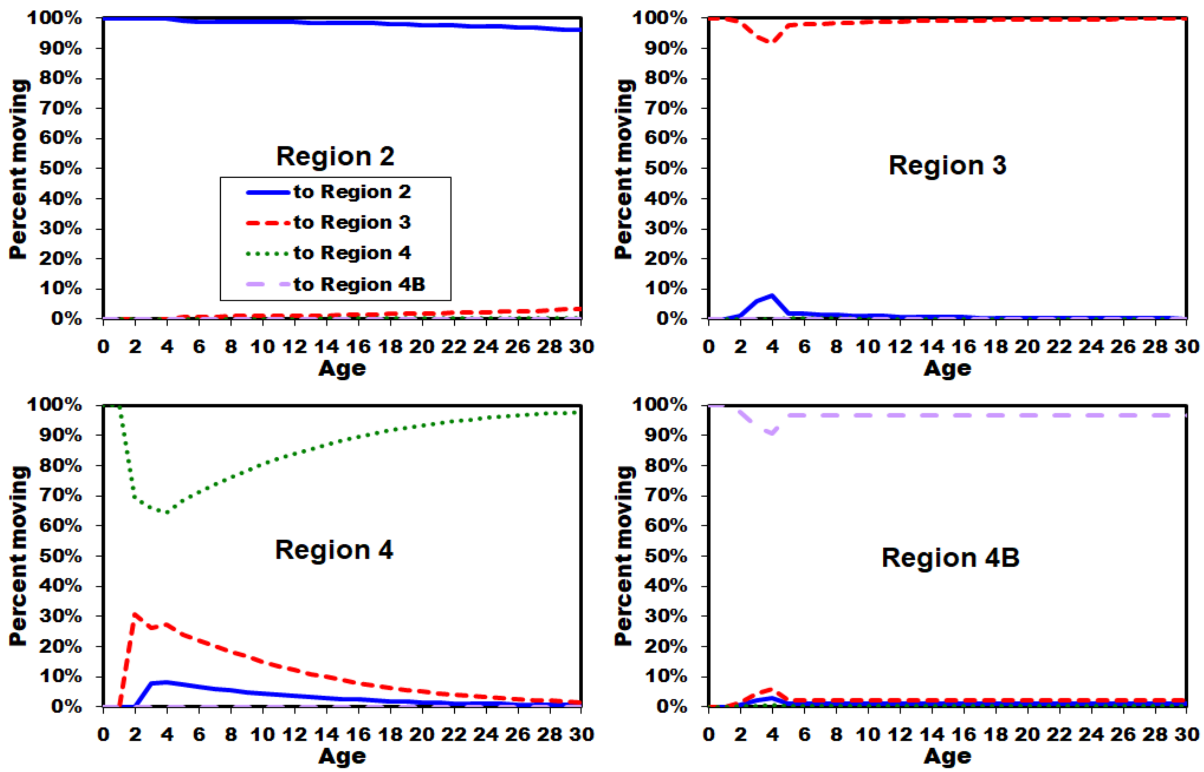
*Para 8.2: Allocation at low TCEY values*

- Sequential approach
  1. Remove non-directed discard mortality from each IPHC Regulatory Areas TCEY;
  2. Remove Subsistence from each IPHC Regulatory Areas TCEY;
  3. Remove unguided recreational from each IPHC Regulatory Areas TCEY.

This way at low TCEY values, subsistence will always have some share (if non-directed discard mortality allows it), and unguided recreational will get whatever is left (if any).

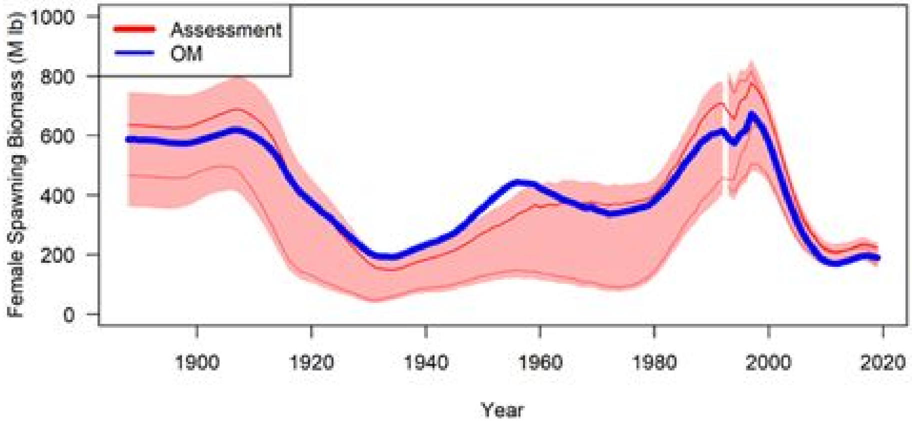
# Movement

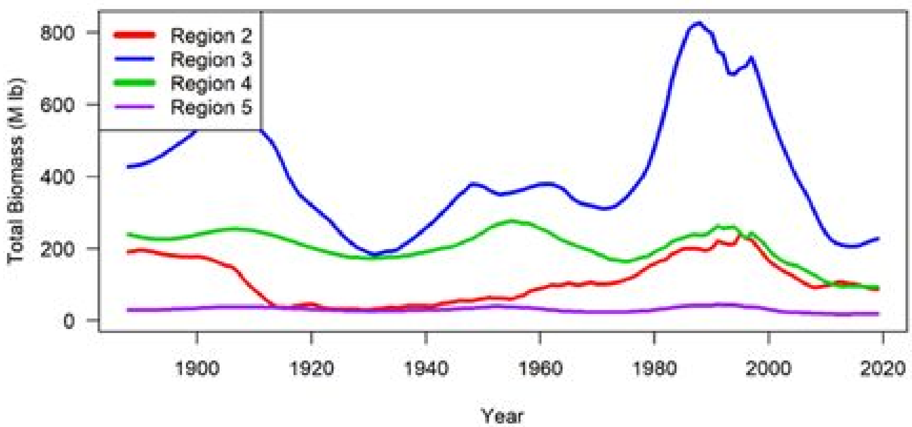
- Integration of information from many sources
  - Recent review of halibut movement
  - Estimated annual movement rates
  - Tuned to observations

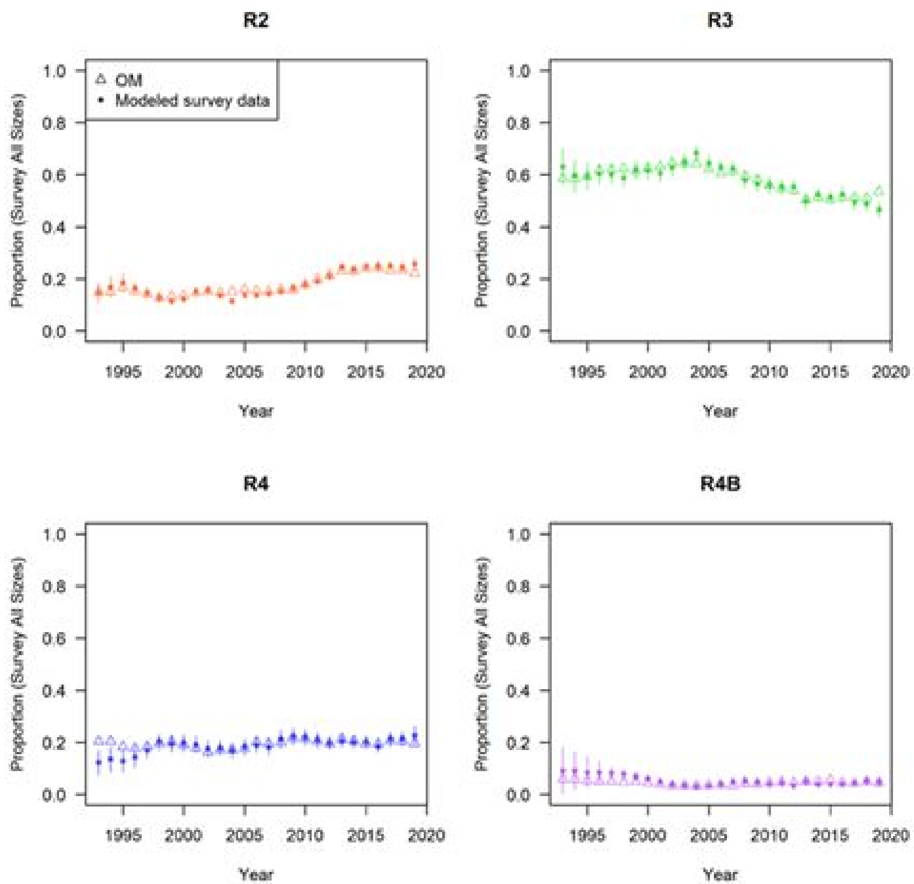



Estimated aggregate annual movement rates by age from Biological Regions (panels) based on currently available data

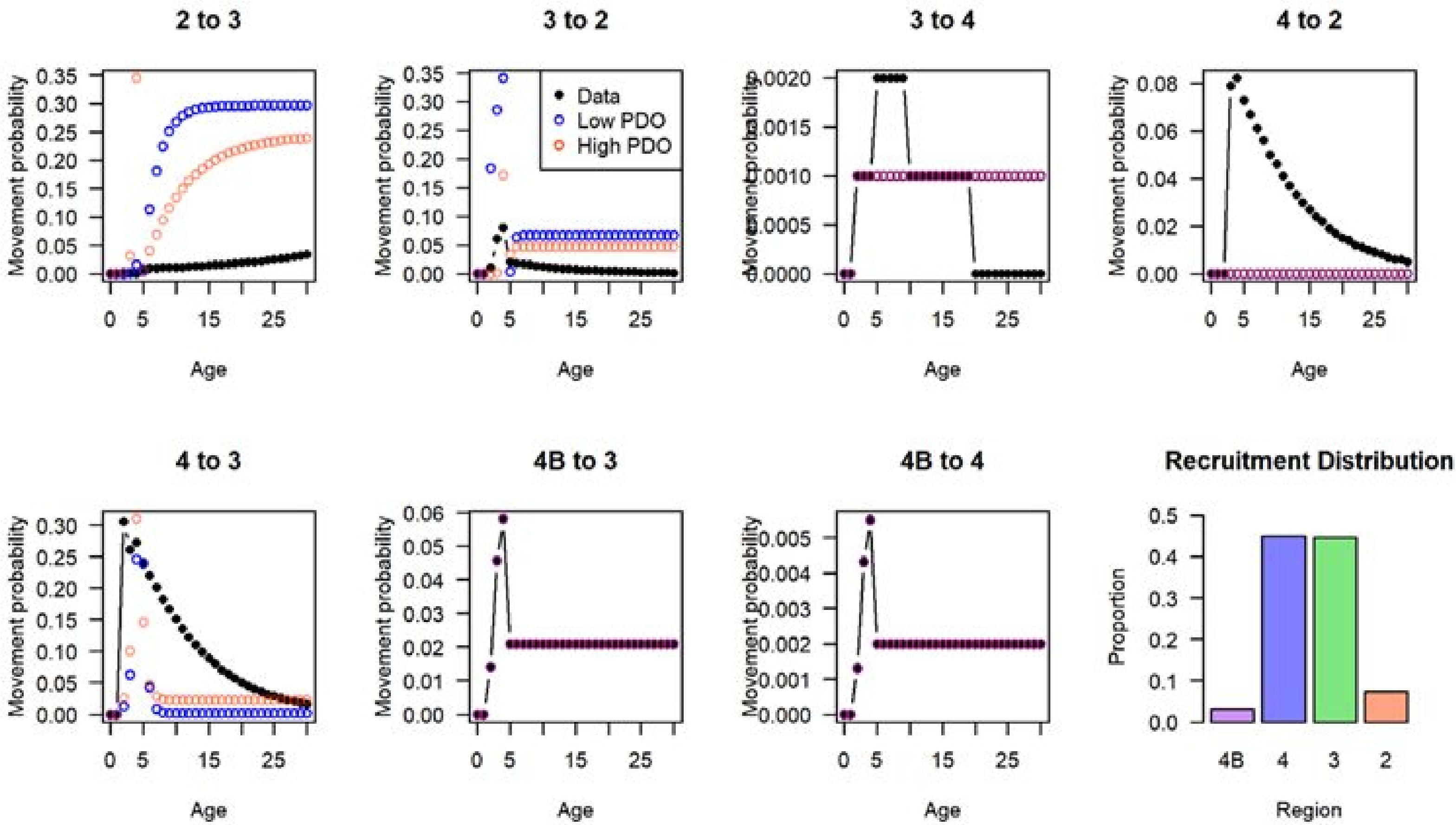
# Conditioned model



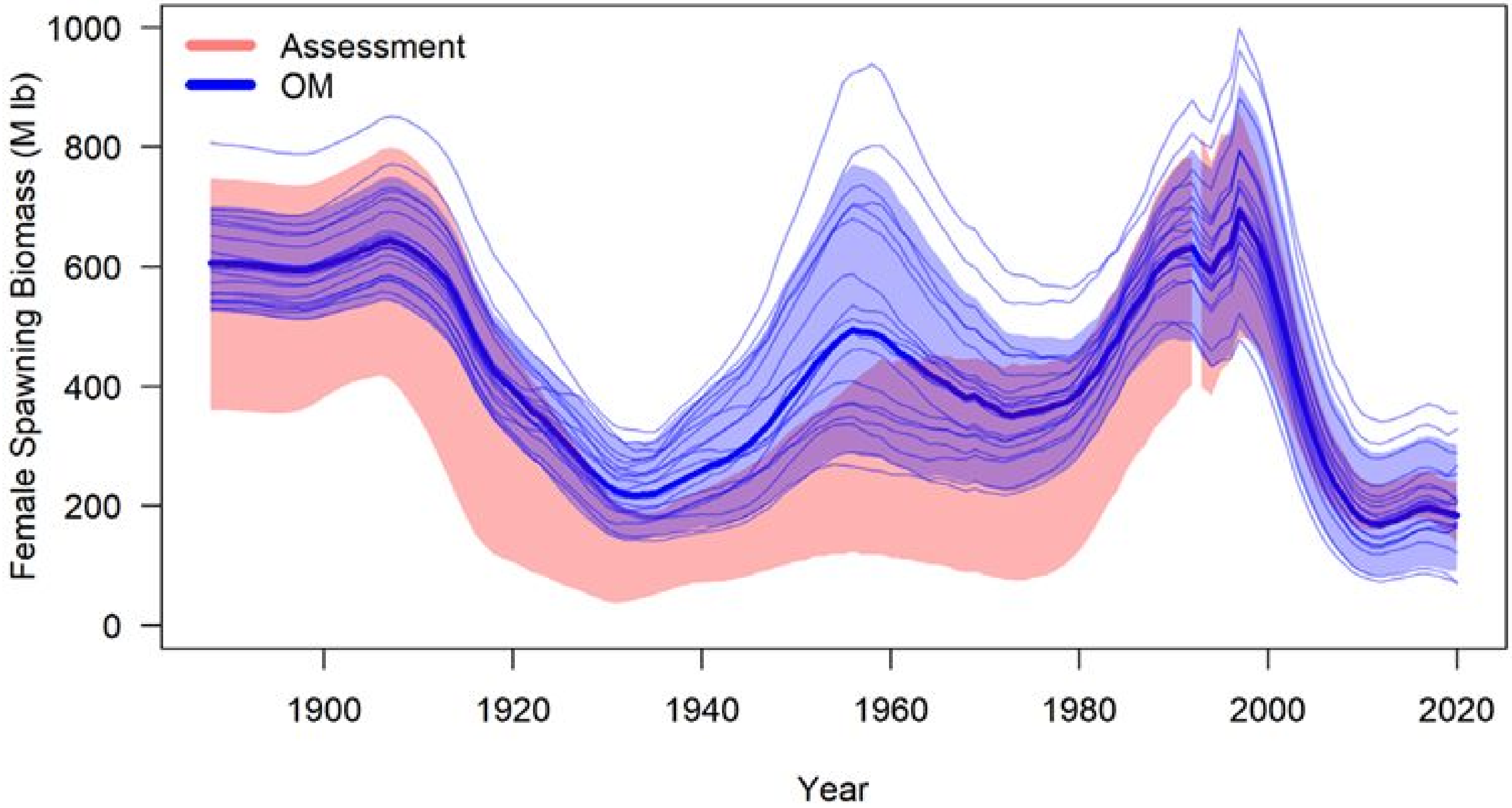
# Conditioned Model



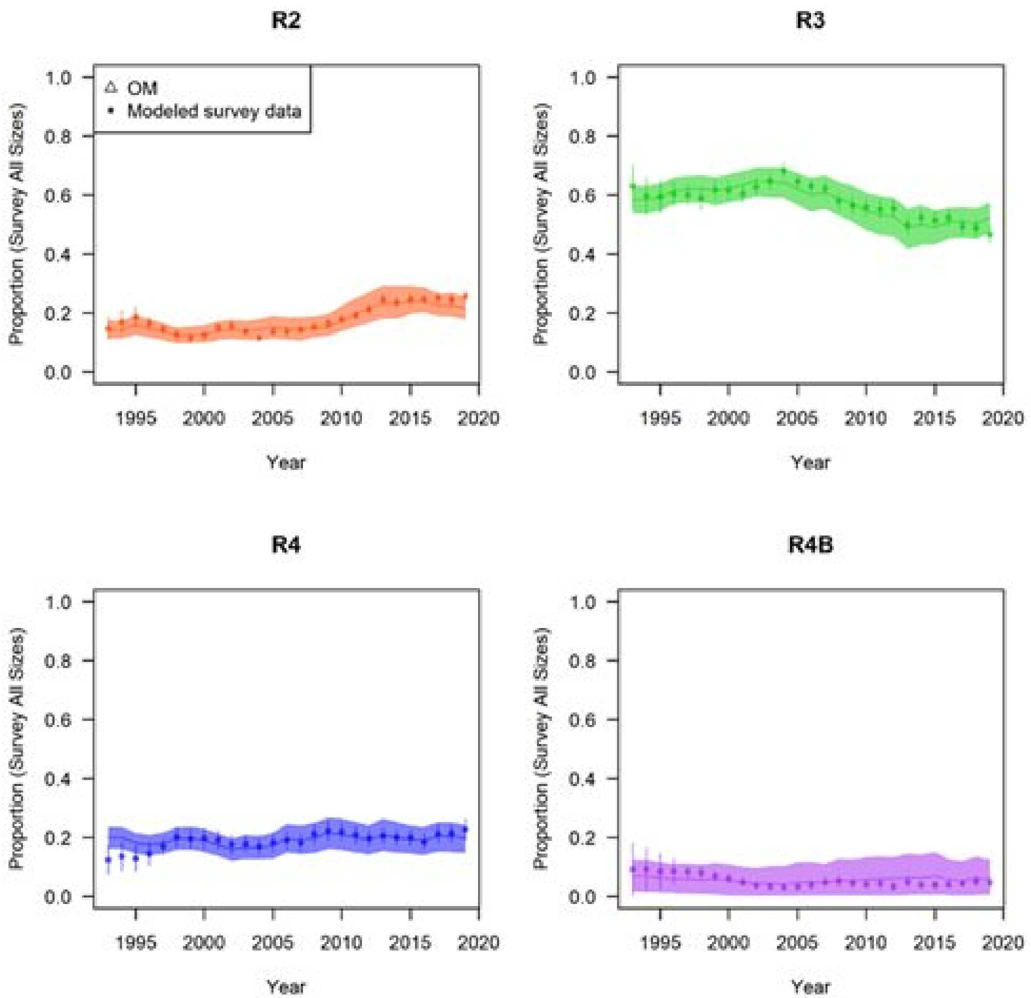
# Uncertainty and variability

1. Integrated uncertainty
   - Uncertain parameters
     - M, $R_0$, recruitment, movement
   - Variability in projections
     - weight-at-age, recruitment, movement
2. Scenarios
   - Specific case to investigate departure in an assumption
     - Weight-at-age at a specified level
     - Non-directed mortality at a specific amount
     - Movement at specific amounts or alternative hypotheses
   - May or may not be integrated into results

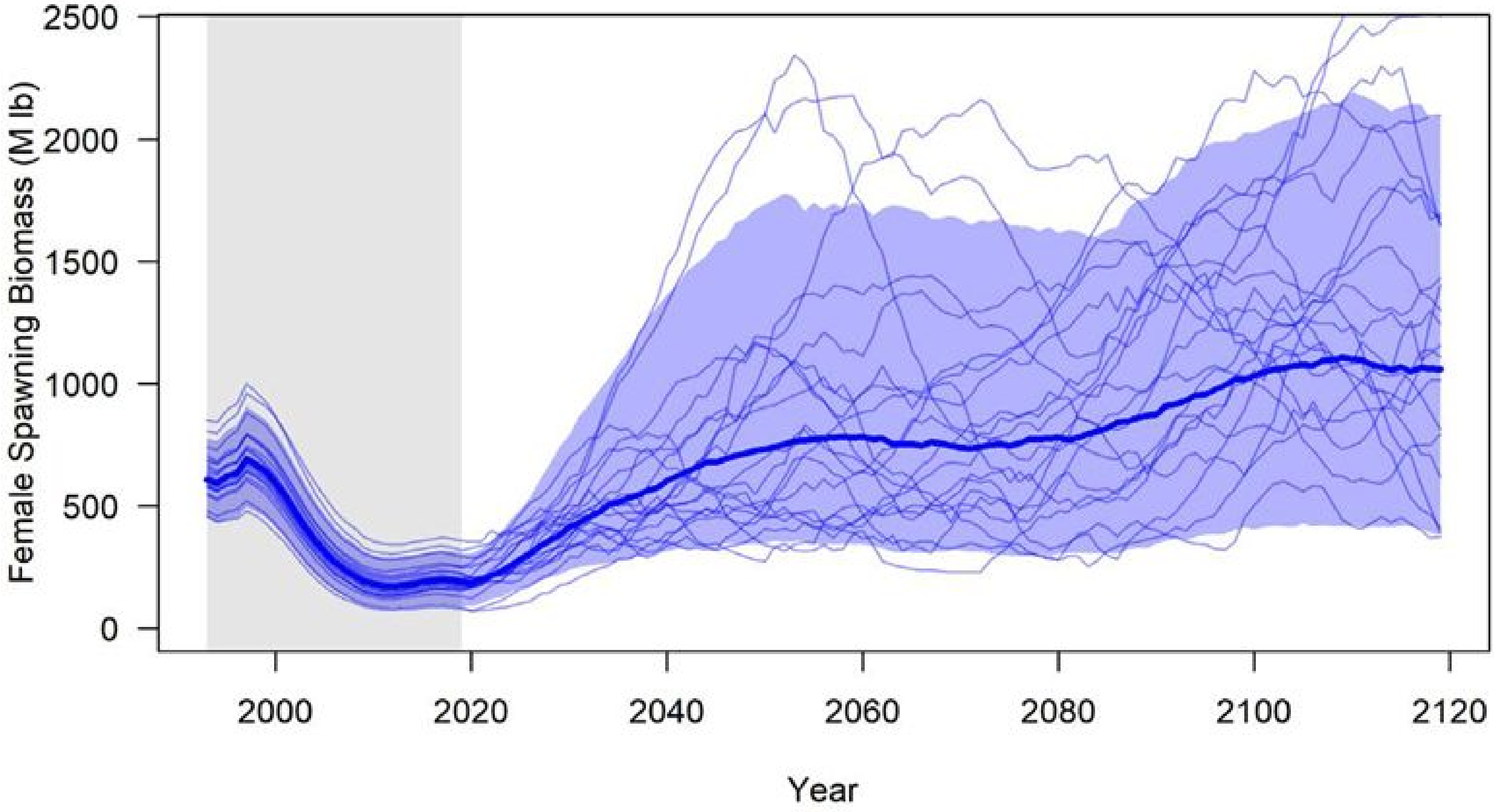
# Variability in conditioned model trajectories



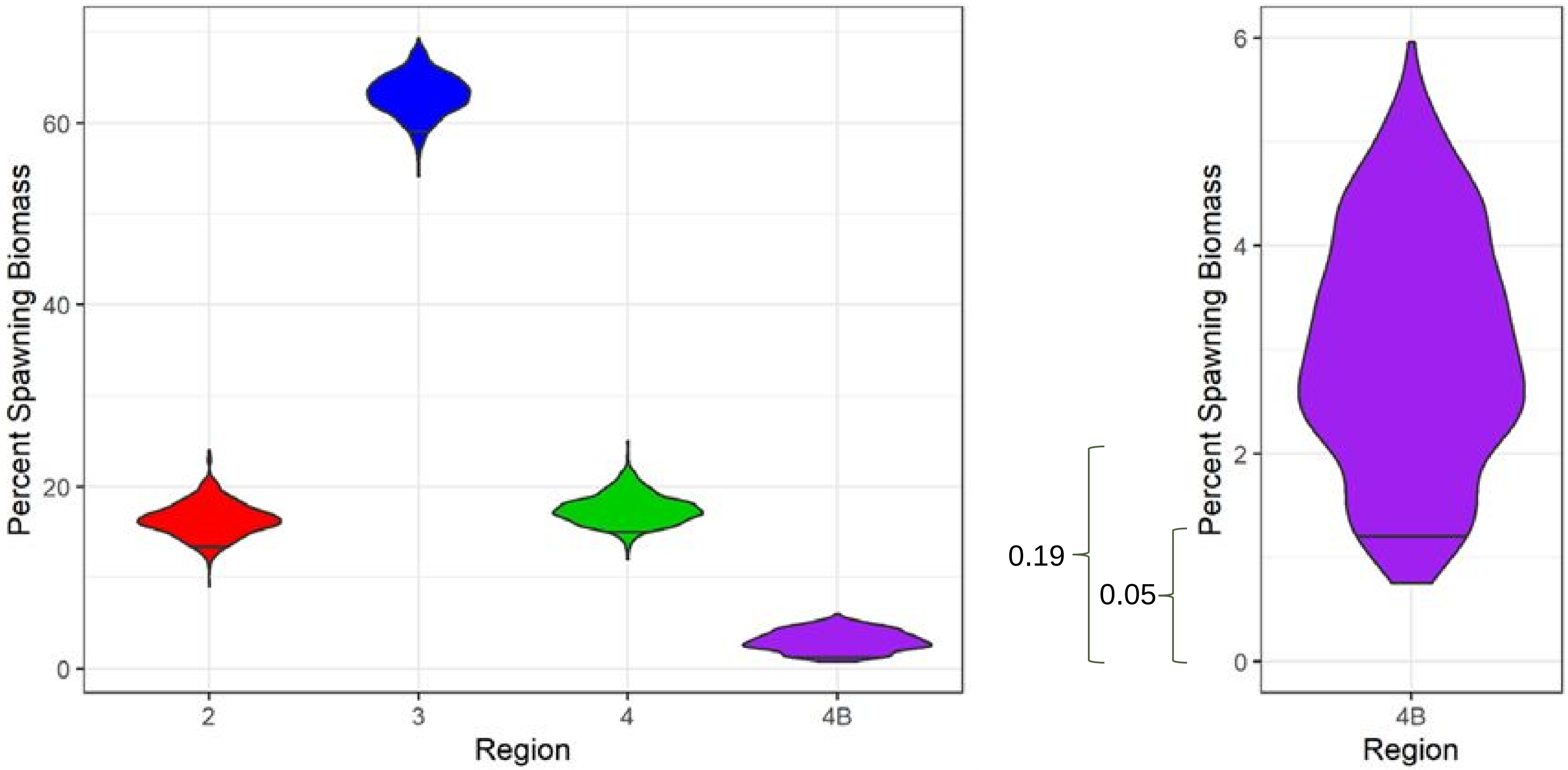
# Variability in conditioned distribution



# Projections without fishing

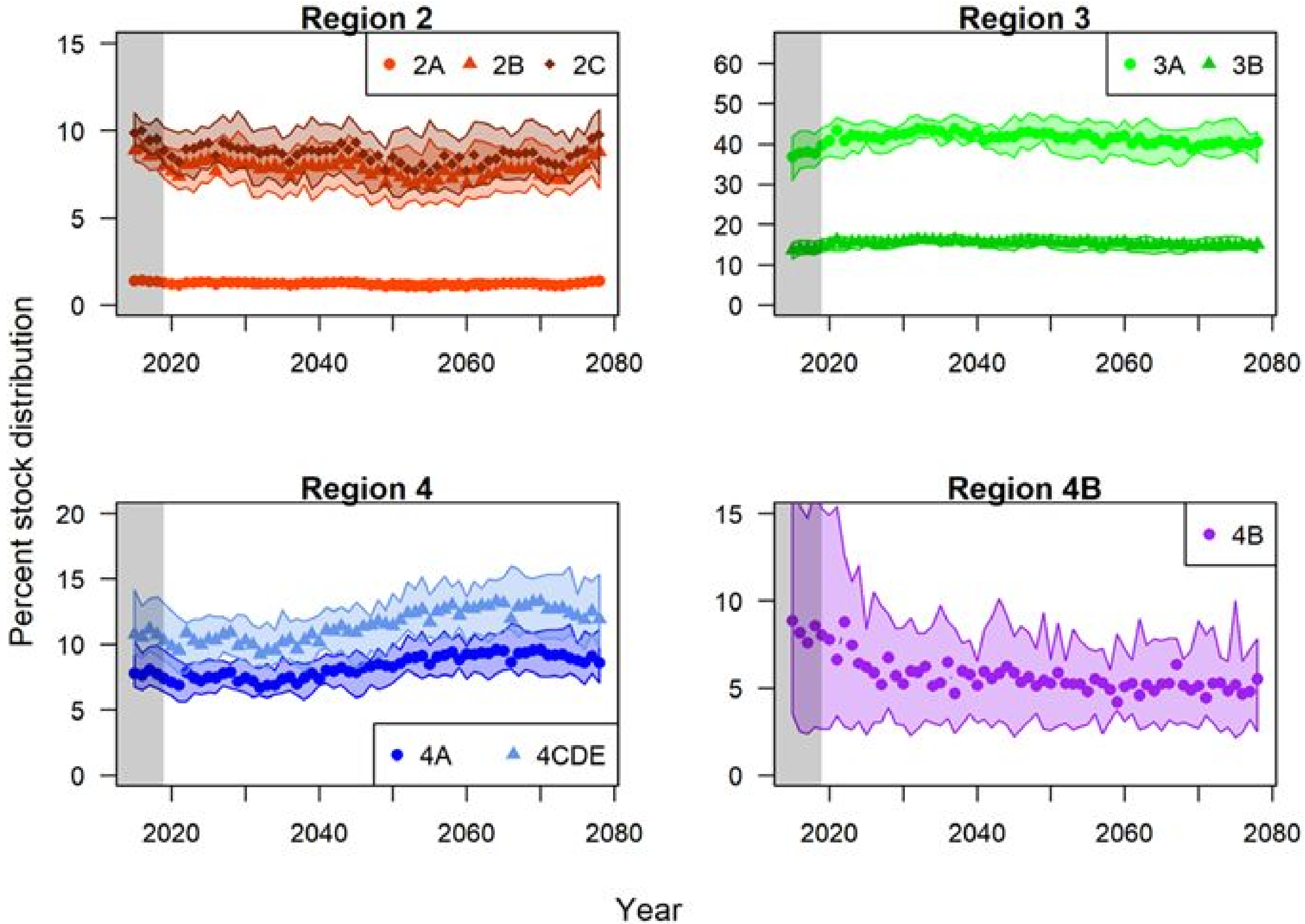


# Projected year 2100 %SB in each Region



# Projected O32 stock distribution

SPR=43%
MP-G



# Implementation variability

1. Decision-making (not currently simulated)
   – Adopted TCEYs may depart from the MP outcomes
2. Actual fishing mortality (some simulated)
   – Fisheries do not exactly catch the set limit
3. Uncertainty in the estimated amount of mortality (not currently simulated)

- Can look at past observations to determine reasonable methods

# Ad hoc MSAB meeting (3)

*Para 20*: Future improvements & considerations

- Whale depredation
- Model bycatch with different assumptions
- Changes in productivity
- Accounting of non-directed commercial U26 mortality
- Impacts of climate change
- Phasing in application of management procedures

# Other future improvements & considerations

- Migration
  - Investigate alternative migrations as sensitivities and robustness tests
- Recruitment distribution
  - Time-varying recruitment distribution
- Selectivity
- Additional variability
  - Parameter uncertainty
  - Parameter variability
  - Implementation variability

# Recommendations from 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.

**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.

# Recommendations

a) **NOTE** paper IPHC-2020-MSAB016-08 which provides a description of the IPHC MSE framework, a description of the specifications of the multi-area operating model, and a brief overview of the implementation of management procedures.

b) **RECOMMEND** alternative specifications and additional features needed to evaluate management procedures related to coastwide scale and distribution of the TCEY, also **NOTING** document IPHC-2020-MSAB016-INF01.

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

# Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries

PREPARED BY: IPHC SECRETARIAT (A. HICKS, P. CARPI, S. BERUKOFF, & I. STEWART; 19 SEPTEMBER 2020)

## PURPOSE

To provide an update of International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) activities relating to the definition and development of a framework to evaluate management procedures for distributing the TCEY.

## 1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) has completed an initial phase of evaluating management procedures (MPs) relative to the coastwide scale of the Pacific halibut stock and fishery, and has developed a framework to investigate MPs related to distributing the Total Constant Exploitation Yield (TCEY) to IPHC Regulatory Areas. The TCEY is the mortality limit composed of mortality from all sources except under-26-inch (66.0 cm, U26) non-directed discard mortality, and is determined by the Commission at each Annual Meeting for each IPHC Regulatory Area.

The development of an MSE framework aims to support the scientific, forecast-driven study of the trade-offs between fisheries management scenarios. Crafting this tool requires

- the definition and specification of a multi-area operating model;
- an ability to condition model parameters using historical catch and survey data and other observations;
- integration with, use of, or comparison against stock assessment outputs or data;
- identification and development of management procedures with closed-loop feedback into the operating model;
- definition and calculation of performance metrics to evaluate the efficacy of applied management procedures.

Updates on the recent efforts in these areas are outlined in Section 2. Likewise, details on the software developed to perform these simulations are outlined in section 3.

## 2 FRAMEWORK ELEMENTS

The MSE framework includes elements that simulate the Pacific halibut population and fishery (Operating Model, OM) and management procedures with a closed-loop feedback (Figure 1). Specifications of some elements are described below, with additional technical details in document IPHC-2020-MSAB016-INF01.

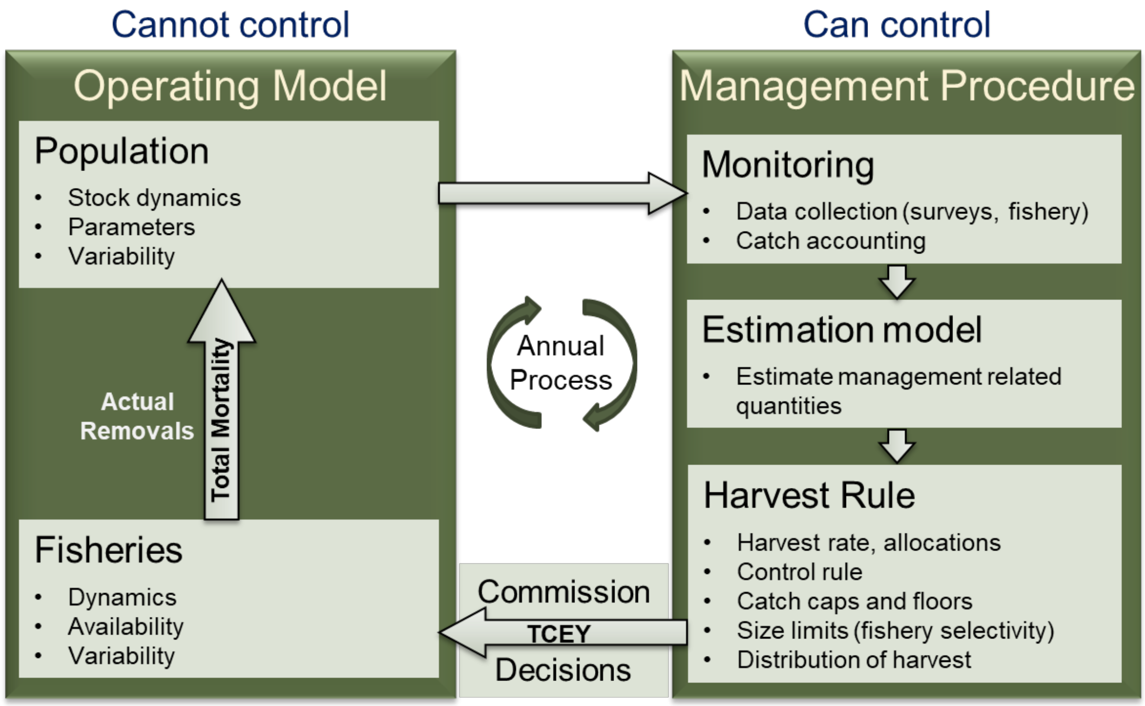



**Figure 1**: Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

### 2.1 Multi-area operating model

The generalized operating model is able to model multiple spatial components, which is necessary because mortality limits are set at the IPHC Regulatory Area level (Figure 2) and some objectives are defined at that level. Written in the programming language C++ with JavaScript Object Notation (JSON) input files, the OM is flexible, fast, modular, and easily adapted to many different assumptions. The operating model is a simulation tool and does not currently perform estimation or optimisation but will be a very useful tool for many investigations of the Pacific halibut fishery in the future.

#### 2.1.1 General process of the operating model

The use of multiple input JSON-formatted files allows for the simulation of many configurations of the Pacific halibut population and associated fisheries. Any number of areas/regions can be specified along with any number of fisheries that operate in those areas at a specified time in the year. Various parameters, such as natural mortality, movement probabilities, selectivity, etc., are specified and most can vary over time, region, sex, fishery, and age where relevant.

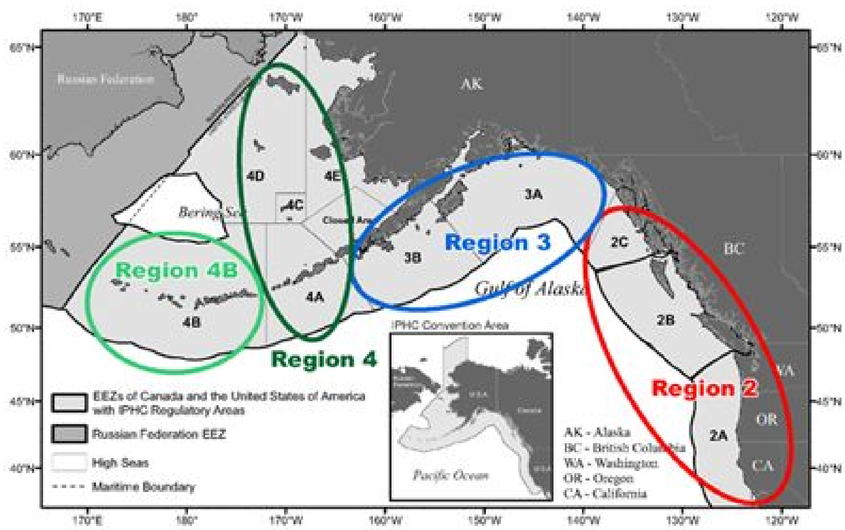



**Figure 2**: Biological Regions overlaid on IPHC Regulatory Areas. Region 2 comprises 2A, 2B, and 2C, Region 3 comprises 3A and 3B, Region 4 comprises 4A and 4CDE, and Region 4B comprises solely 4B.

The OM begins by calculating the unfished equilibrium population given an input set of biological parameters. It then simulates the annual process during what is called an “initial period” with a fixed mortality level for each fleet (i.e., catch + discard mortality). This initial period allows for the stock to distribute across modelled areas to an equilibrium state given recruitment deviations and fishing mortality. During a subsequent “main period”, the population and dynamics are simulated using input annual fishing mortality, time-varying parameters such as selectivity, recruitment variability, and annual movement between areas. The parameterized model that is run through the main period is called the conditioned model. It is from this point that closed-loop simulations, called the “projection period,” begin.

A script written in the R statistical language (R Core Team 2020) containing all the details of the management procedure being evaluated is called during the projection period, which does the following. It reads the current OM state from ‘csv’ files written by the OM. It generates data with observation error that are needed for estimation models (EMs) and MPs. It runs the estimation models, if required, to determine mortality limits and realized mortality for each fishery. The mortalities for each fishery feed back into the OM along with other projected annual processes (e.g., weight-at-age) to simulate the fish population one year forward. Weight-at-age for the projection year is generated before starting the simulations as a random process, as described in section 2.1.7.2 and in IPHC-2020-MSAB015-08.

### 2.1.2 Population and fishery spatial specification

The emerging understanding of Pacific halibut diversity across the geographic range of its stock indicates that IPHC Regulatory Areas should be only considered as management units and do not represent relevant sub-populations (Seitz et al. 2017). The structure of two of the four current Pacific halibut stock assessment models was developed around identifying portions of the data (fishery-independent and fishery-dependent data) that correspond to differing biological and population processes within the larger Pacific halibut stock. This approach, referred to as 'areas-as-fleets' is commonly used in stock assessments (Waterhouse et al. 2014), and was the approach recommended for inclusion in the ensemble developed in 2014 during the SRB review of models and used in all assessments since (Cox et al. 2016, Stewart & Martell 2015, 2016).

Biological Regions (Figure 2) were therefore defined with boundaries that matched some of the IPHC Regulatory Area boundaries for the following reasons. First, data for stock assessment and other analyses are most often reported at the IPHC Regulatory Area scale and are largely unavailable for sub-Regulatory Area evaluation. Particularly for historical sources, there is little information to partition data to a portion of a Regulatory Area. Second, it is necessary to distribute TCEY to IPHC Regulatory Areas for quota management. If a Region is not defined by boundaries of IPHC Regulatory Areas (i.e. a single IPHC Regulatory Area is in multiple Regions) it will be difficult to create a distribution procedure that accounts for biological stock distribution and distribution of the TCEY to Regulatory Areas for management purposes. Further, the structure of the current directed fisheries does not delineate fishing zones inside individual IPHC Regulatory Areas, so there would be no way to introduce management at that spatial resolution. It is unlikely that there is a set of Regions that accurately delineates the stock biologically since different aspects of the stock differ over varying scales, biological boundaries may shift over time, and movement occurs among Biological Regions.

To a certain degree, Pacific halibut within the same Biological Region share common biological traits different from adjacent Biological Regions. These traits include sex ratios, age composition, and size-at-age, and historical trends in these data may be indicative of biological diversity within the greater Pacific halibut population. Furthermore, tagging studies have indicated that within a year, larger Pacific halibut tend to undertake feeding and spawning migrations within a Biological Region, and movement between Biological Regions typically occurs between years (Loher and Seitz 2006; Seitz et al. 2007; Webster et al. 2013).

Given the goals to divide the Pacific halibut stock into somewhat biologically distinct regions and preserve biocomplexity across the entire range of the Pacific halibut stock, Biological Regions are considered by the IPHC Secretariat, and supported by the SRB (paragraph 31 IPHC-2018-SRB012-R), to be the best option for biologically-based areas to meet management needs. They also offer an appropriate and parsimonious spatial separation for modeling inter-annual population dynamics.

However, as mentioned earlier, mortality limits are set for IPHC Regulatory Areas and thus directed fisheries operate at that spatial scale. Furthermore, since some fishery objectives have been defined at the IPHC Regulatory Area level, the TCEY will need to be distributed to that scale. Even though the population is modelled at the Biological Region scale, fisheries can be modelled at the IPHC Regulatory Area scale by using an areas-as-fleets approach within Biological Regions. This requires modelling each fleet with separate selectivities and harvest rates that operate on the biomass occurring in the entire Biological Region in each year. The following is a discussion of the pros and cons of this method.

First, modelling the population dynamics at the IPHC Regulatory Area scale would require intra-annual dynamics to be modelled, dividing the year into seasons to model movement between IPHC Regulatory Areas. There is evidence that such intra-annual movements occur (Loher and Seitz, 2006) and fisheries in adjacent IPHC Regulatory Areas may intercept the same pool of fish (Loher 2011). Using Biological Regions assumes that all fisheries within a Region have access to the pool of Pacific halibut in that Region in that year. This greatly simplifies the calculations and eliminates the need to parameterize intra-annual movement. However, if a fishery does not interact with the pool of fish in a Biological Region, harvest rates determined for each fishery may be inaccurate because the biomass to which selectivity is applied would be incorrect, and some fisheries may intercept ages/sizes of Pacific halibut that they commonly do not interact with. This is unlikely to occur and will have very little effect on the results of this MSE because harvest rates are not explicitly used in the management procedures (mortality limits are used for management) and similarity of age/size compositions were used to define Biological Regions.

Additionally, calculating statistics specific to IPHC Regulatory Areas requires assumptions about distribution of biomass within a Biological Region. For example, simulating the observed proportion of biomass in each IPHC Regulatory Area (e.g., to mimic the current interim management procedure) requires simulating a survey biomass for each IPHC Regulatory Area. Likewise, determining some objectives related to IPHC Regulatory Area may be difficult to calculate (such as the proportion of O26 fish in each IPHC Regulatory Area). The distribution of the population within a Biological Region is currently approximated assuming specified proportions of the population in each IPHC Regulatory Area within a Biological Region. These proportions are constant over ages and allows for the calculation of statistics specific to IPHC Regulatory Areas. Future improvements to the framework will allow for different options such as determining proportions from historically observed distributions and accounting for year to year variability.

Fisheries were defined by IPHC Regulatory Areas (or combinations of areas if fishing mortality in that area was small) and for five general sectors consistent with the definitions in the recent IPHC stock assessment (IPHC-2020-SA-01):

- **directed commercial** representing the O32 mortality from the directed commercial fisheries including O32 discard mortality;
- **directed commercial discard** representing the U32 discard mortality from the directed commercial fisheries, comprised of Pacific halibut that die on lost or abandoned fishing gear, and Pacific halibut discarded for regulatory compliance reasons;
- **non-directed commercial discard** representing the mortality from incidentally caught Pacific halibut in non-directed commercial fisheries;

- **recreational** representing recreational landings (including landings from commercial leasing) and recreational discard mortality; and
- **subsistence** representing non-commercial, customary, and traditional use of Pacific halibut for direct personal, family, or community consumption or sharing as food, or customary trade.

Table 1 shows the summed mortality realized from 1992 through 2019 for each of these sectors by IPHC Regulatory Area or Biological Region. Thirty-three (33) fisheries were defined as a sector/area combination based on the amount of mortality in the combination, data availability, and MSAB recommendations (Table 2).

**Table 1**: Summed mortality (millions of net pounds) from 1992 through 2019 by fisheries and IPHC Regulatory Area or Biological Region. Darker colors indicate higher values.

| Year | 2A | 2B | 2C | 3A | 3B | 4A | 4CDE | 4B |
|---|---|---|---|---|---|---|---|---|
| Commercial | 17.5 | 259.8 | 205.5 | 551.2 | 252.4 | 78.2 | 72.5 | 62.8 |
| Sublegal discards | 0.5 | 7.1 | 5.2 | 16.7 | 10.7 | 2.1 | 1.3 | 0.8 |
| Non-directed discard mortality | 11.8 | 12 | 4.5 | 73.6 | 36.2 | 39.2 | 128.6 | 16.2 |
| Recreational | 13.7 | 31.8 | 71.1 | 152.2 | 0.5 | 1.4 | <0.1 | <0.1 |
| Subsistence | 0.7 | 9.6 | 10.3 | 7.6 | 1 | 0.6 | <0.1 | 2.4 |

### 2.1.3 Maturity

Spawning biomass for Pacific halibut is currently calculated from a maturity-at-age ogive that is assumed to be constant over years. There is currently no evidence (IPHC-2020-SA-02) for skip spawning or maternal effects (increased reproductive output or offspring survival for larger/older females) and they are not modelled, but could be added. Stewart & Hicks (2017) examined the sensitivity to a trend in declining spawning potential (caused by a shift in maturity or increased skip spawning) and found that under that condition there was a bias in both scale and trend of recent estimated spawning biomass. Ongoing research on maturity and skip spawning will help to inform future implementations of the basis for variability in the determination of spawning output.

### 2.1.4 Weight-at-age

Empirical weights-at-age by region for the population, fisheries, and survey are determined using observations from the FISS and the fisheries, as is done with the stock assessment models (IPHC-2020-SA-01) and as described in detail in Stewart and Martell (2016). Smoothed observations of weight-at-age from NMFS trawl surveys were used to augment ages 1-7 fishery and survey weights-at-age. Population weight-at-age is smoothed across years to reduce observation error. Finally, survey and population weight-at-age prior to 1997 is scaled to fishery data because survey observations are limited if present at all.

**Table 2**: The twenty-five fisheries in the OM, the IPHC Regulatory Areas they are composed of, and the 2019 mortality (millions of net pounds) for each.

| Fishery | IPHC Regulatory Areas | 2019 Mortality Mlbs | 2019 Mortality tonnes |
|---|---|---|---|
| Directed Commercial2A | 2A | 0.89 | 404 |
| Directed Commercial 2B | 2B | 5.22 | 2,368 |
| Directed Commercial 2C | 2C | 3.67 | 1,665 |
| Directed Commercial 3A | 3A | 8.16 | 3,701 |
| Directed Commercial 3B | 3B | 2.31 | 1,048 |
| Directed Commercial 4A | 4A | 1.45 | 658 |
| Directed Commercial 4B* | 4B | 1.00 | 454 |
| Directed Commercial 4CDE | 4CDE | 1.65 | 748 |
| Directed Commercial Discards 2A | 2A | 0.03 | 14 |
| Directed Commercial Discards 2B | 2B | 0.13 | 59 |
| Directed Commercial Discards 2C | 2C | 0.06 | 27 |
| Directed Commercial Discards 3A | 3A | 0.32 | 145 |
| Directed Commercial Discards 3B | 3B | 0.15 | 68 |
| Directed Commercial Discards 4A | 4A | 0.09 | 41 |
| Directed Commercial Discards 4B | 4B | 0.03 | 14 |
| Directed Commercial Discards 4CDE | 4CDE | 0.07 | 32 |
| Non-directed Commercial Discards 2A | 2A | 0.13 | 59 |
| Non-directed Commercial Discards 2B | 2B | 0.24 | 109 |
| Non-directed Commercial Discards 2C | 2C | 0.09 | 41 |
| Non-directed Commercial Discards 3A | 3A | 1.65 | 748 |
| Non-directed Commercial Discards 3B | 3B | 0.48 | 218 |
| Non-directed Commercial Discards 4A | 4A | 0.35 | 159 |
| Non-directed Commercial Discards 4CDE | 4CDE | 3.50 | 1,588 |
| Non-directed Commercial Discards 4B | 4B | 0.15 | 68 |
| Recreational 2B | 2B | 0.86 | 390 |
| Recreational 2C | 2C | 1.89 | 857 |
| Recreational 3A | 3A | 3.69 | 1,674 |
| Subsistence 2B | 2B | 0.41 | 186 |
| Subsistence 2C | 2C | 0.37 | 168 |
| Subsistence 3A | 3A | 0.19 | 86 |
| Recreational/Subsistence 2A | 2A | 0.48 | 218 |
| Recreational/Subsistence 3B | 3B | 0.02 | 9 |
| Recreational/Subsistence 4 | 4A, 4CDE | 0.06 | 27 |

*The small amount of recreational and subsistence mortality from IPHC Regulatory Area 4B is included in Directed Commercial 4B

### 2.1.5 Movement

Many data sources are available to inform Pacific halibut movement. Decades of tagging studies and observations have shown that important migrations characterize both the juvenile and adult stages and apply across all regulatory areas. The conceptual model of halibut ontogenetic and seasonal migration, including main spawning and nursery grounds, as per the most current knowledge, was presented in IPHC-2019-MSAB014-08 and was used to assist in parameterizing movement rates in the OM.

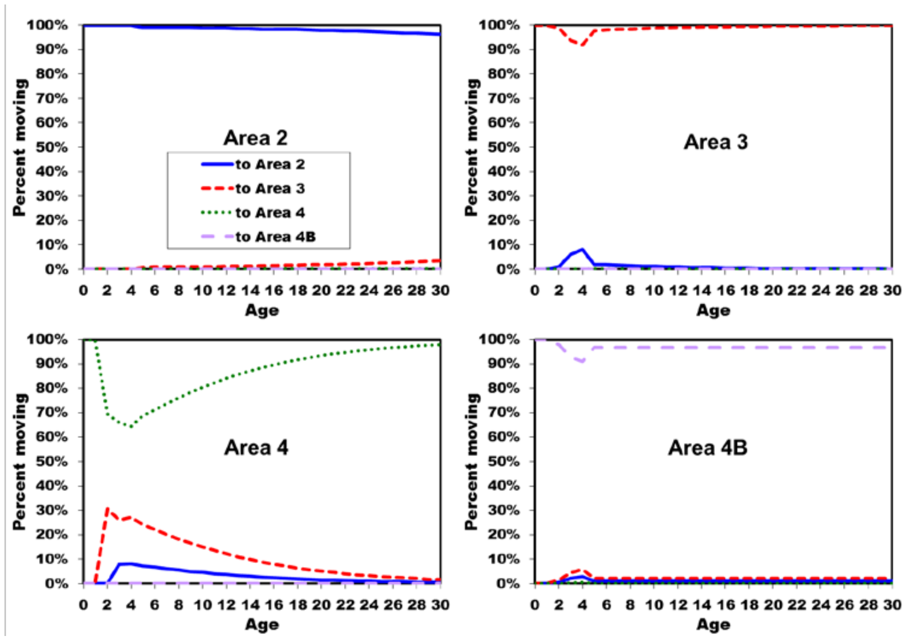



**Figure 3**: Estimated aggregate annual movement rates by age from Biological Regions (panels) based on currently available data (from IPHC-2019-AM095-08).

In 2015, the many sources of information were assembled into a single framework representing the IPHC's best available information regarding movement-at-age among Biological Regions. Key assumptions in constructing this hypothesis included:

- ages 0-1 do not move (most of the young Pacific halibut reported in Hilborn et al. (1995) were aged 2-4),
- movement generally increases from ages 2-4,
- age-2 Pacific halibut cannot move from Region 4 to Region 2 in a single year, and
- relative movement rates of Pacific halibut age 2-4 to/from Region 4 are similar to those observed for 2-4-year-old Pacific halibut compared to older Pacific halibut in Region 3.

Based on these assumptions, appreciable emigration is estimated to occur from Region 4, decreasing with age. Pacific halibut age-2 to age-4 move from Region 3 to Region 2 and from Region 4B to Regions 3 and 2, and some movement of older Pacific halibut is estimated to occur from Region 2 back to Region 3 (Figure 3).

The conceptual model and assembled movement rates were used to inform the development of the MSE operating model framework and is being used as a starting point to incorporate variability and alternative movement hypotheses in Pacific halibut movement dynamics. Movement in the OM is modelled using a transition matrix as the proportion of individuals that move from one Biological Region to another for each age class in each year.

### 2.1.6 Fishery and survey selectivity and retention

Selectivity and retention determine the age composition of fishery mortality and ensure the removal of appropriate numbers-at-age from the population when mortality occurs in the annual time-step. Selectivity represents the proportion at each age that is encountered by the gear. Retention represents the proportions-at-age that are retained and landed if caught (i.e., 1 - retention is the proportion-at-age that is released). The product of selectivity and retention is called the "keep curve" and represents the proportions-at-age from the population that are landed. Some fish that are not retained may survive; thus, a discard mortality rate is used to indicate the proportion of fish that are not retained and die after release.

Parameters for selectivity and retention were determined from the estimated parameters in the recent stock assessment (IPHC-2020-SA-01) including annual deviations in selectivity for the directed fisheries and the survey.

### 2.1.7 Uncertainty in the operating model

Uncertainty is important to consider, as the goal of an MSE is to develop management procedures that are robust to uncertainty. The OM should simulate potential states of the population in the future, uncertainties within the management procedure, and variability when implementing the management procedure.

#### *2.1.7.1 Uncertainty in the conditioned OM*

The conditioned OM is a representation of the Pacific halibut population and matches observations from the fishery, survey, and research. Uncertainty in these observations are included in the OM by varying parameters. Parameters vary between simulated trajectories and are drawn from correlated probability distributions that are derived from the stock assessment models when conditioning the OM. These sets of parameters resulted in multiple historical population trajectories from which to begin the projections. The major sources of uncertainty in the OM are described in Table 3.

**Table 3:** Major sources of parameter uncertainty and variability in the conditioned operating model (OM).

| Process | Uncertainty |
|---|---|
| Natural Mortality (*M*) | Variability determined from assessment |
| Average recruitment ($R_0$) | Effect of the coastwide environmental regime shift and variability determined from conditioning |
| Recruitment | Random lognormal deviations. Variability on distribution to Biological Regions determined from conditioning |
| Movement | Change in parameters synchronized with PDO regime shift |

### *2.1.7.2 Projected population variability*

Variability in the projected population is a result of initializing the population with a range of parameters to recreate a range of historical trajectories and including additional variability in certain population processes in the projection. The major sources of variability in the projections are shown in Table 4 and some are described in more detail below.

**Table 4:** Major sources of projected variability in the operating model (OM).

| Process | Variability |
|---|---|
| Average recruitment ($R_0$) | Effect of the coastwide environmental regime shift, modelled as an autocorrelated indicator based on properties of the PDO |
| Recruitment | Random lognormal deviations. Variability on distribution to Biological Regions. |
| Movement | Variability on movement parameters determined from conditioning process |
| Size-at-age | Annual and cohort deviations in weight-at-age by Biological Region, with approximate historical bounds |
| Sector mortality | Sector mortality allocation variability on non-directed commercial discard mortality, directed discard mortality, and unguided recreational mortality within an area |
| Movement | Change in parameters synchronized with PDO regime shift |

**Projected weight-at-age**

It is important to simulate time-varying weight-at-age because it is an influential contributor to the yield and status of Pacific halibut. Weight-at-age varies over time historically, and the projections capture that variation using a random walk from the previous year. This variability was implemented using the same general procedure as in the coastwide MSE (IPHC-2018-MSAB011-08), with a few modifications to allow for slight departures between regions and fisheries. The method is described in IPHC-2020-MSAB015-08.

**Linkage between average recruitment and environmental conditions**

The average recruitment ($R_0$) is related to the Pacific Decadal Oscillation index[1], expressed as a positive or negative regime (IPHC-2020-SA-02). $R_0$ is multiplied by $e^{I\delta}$, where $I$ is an indicator of the negative (0) or positive (1) regime, and $\delta$ is a parameter determining the magnitude of that multiplier. The parameter $\delta$ was determined from the stock assessment.

The regime was simulated in the MSE by generating a 0 or 1 to indicate the regime in that future year, as described in IPHC-2018-MSAB011-08. To encourage runs of a regime between 15 and 30 years (an assumption of the common periodicity, although recent years have suggested less), the environmental index was simulated as a semi-Markov process, where the next year depends on recent years. However, the probability of changing to the opposite regime was a function of the length of the current regime with a probability of changing being equal to 0.5 at 30 years, and a very high probability of changing at 40 years. The simulated length of a regime was most often between 20 and 30 years, with occasional runs between 5 and 20 years or greater than 30 years.

[1] https://oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_OC_PDO.htmlTable?time,PDO

**Implementation variability**

Implementation variability consists of three components. The first is the departure from the management procedure during the decision-making process. For example, the MP may result in a total mortality of 40 Mlbs, but the decision may be to implement a total mortality of 36 Mlbs for various economic and social reasons. The second component of implementation variability is the fact that the fisheries do not achieve the mortality limits exactly. In recent years, the actual total fishery mortality has been slightly less than mortality limits, although some sectors have exceeded the limits. The third component is the estimation of mortality, which is likely to deviate from the actual realize mortality. This is an important component to consider especially if catch accounting is inaccurate and subject to bias.

The second component (realized mortality) is implemented in the OM for the non-directed discard mortality, the directed discard mortality, subsistence mortality, and the unguided recreational mortality. The methodology used to simulate this variability for these sectors is described in Section 2.3.2. All other sectors (i.e. recreational and commercial) are assumed to achieve the mortality limits every year.

## 2.2 Four-region operating model

A multi-area OM was specified with four Biological Regions (2, 3, 4, and 4B; Figure 2), thirty-three (33) fisheries (Table 2), and four (4) surveys. The model was initiated in 1888 and initially parameterized using estimates from the long areas-as-fleets (AAF) assessment model. Selectivity was kept the same as the regional estimates from the long AAF assessment model except that the directed commercial and survey selectivities were made asymptotic (i.e., no descending limb) since movement in the spatially explicit OM accounted for availability among the Biological Regions.

Parameters for R0, proportion of recruitment to each Biological Region, movement from 2 to 3, 3 to 2, and 4 to 3 were estimated by minimizing an objective function based on lognormal likelihoods for spawning biomass predictions and region-specific modelled survey indices. A robustified multivariate normal (Fournier et al 1990, Starr et al 1999) was used to fit to the survey proportions-at-age and the regional stock distribution estimates. Other movement parameters were fixed to estimates from data (Figure 3) except that movement probabilities from 4 to 2, 2 to 4, 4B to 2, and 2 to 4B were set to zero for all ages. This makes the assumption that a Pacific halibut cannot travel between these areas in an annual time step even though significant probabilities of movement-at-age from 4 to 2 are predicted to occur from the data (Figure 3).

The OM was conditioned using five sets of observations: the average predicted spawning biomass from the long AAF and long coastwide stock assessment models (1888–1992), predicted spawning biomass from the stock assessment ensemble (1993–2019), survey indices of abundance for each Biological Region, survey proportions-at-age for each Biological Region, and the proportion of “all selected sizes” modelled survey biomass in each Biological Region (stock distribution).

A subset of all possible parameters was used for conditioning by estimating the parameters that minimized the summed weighted negative log likelihood components for each observation type. The parameters estimated are listed in Table 5.

**Table 5**: Descriptions of the parameters estimated when conditioning the OM. Separate sets of parameters were estimated for movement in poor and good PDO regimes.

| Parameters | # parameters | Description |
|---|---|---|
| $\ln(R_0)$ | 1 | Natural log of unfished equilibrium recruitment. Determines the scale of the population trajectory. |
| $p_{y,r}^{R}$ | 3 | Proportion of $R_0$ distributed to each Biological Region. Only three of the four parameters need to be estimated to sum to 1. |
| $\Psi_{2\rightarrow3}$ | 5 + 5 | Probability of movement-at-age from Region 2 to Region 3, modelled using a double exponential function (equation 3). The left and right λs, left maximum probability, right maximum probability, and right asymptote were estimated. |
| $\Psi_{3\rightarrow2}$ | 5 + 5 | Probability of movement-at-age from Region 3 to Region 2, modelled using a double-exponential function (equation 3). The left and right λs, left maximum probability, right maximum probability, and right asymptote were estimated. |
| $\Psi_{4\rightarrow3}$ | 5 + 5 | Probability of movement-at-age from Region 4 to Region 3, modelled using a double-exponential function (equation 3). The left and right λs, left maximum probability, right maximum probability, and right asymptote were estimated. |

The parameters in Table 5 were fit to the five data sources individually to determine similarities and differences in the estimates of parameters and derived quantities that each data source implied. This was done for different parameterizations of movement to understand how changes to the structure affected the fit to the different data sets. Those results (not shown here) identified that fitting to the modelled survey distribution of biomass in each Biological Region was important because fitting to no other single data source resulted in a close prediction of the distribution. Stock distribution is an important component of many management procedures to be tested, thus must be represented accurately by the conditioned OM. Secondly, fitting to index data resulted in predicted spawning biomass trajectories that were generally in the envelope of predicted spawning biomass from the stock assessment models. Index data are an important data source as they reflect trends in abundance by Biological Region. Fitting to proportion-at-age did not greatly improve the overall general trends in recent estimates of proportion-at-age in each region but did result in low predicted spawning biomass. Therefore, the final model was fit to the modelled survey proportion of biomass in each Biological Region, the modelled survey indices of abundance (NPUE) as used in the stock assessment, the estimated spawning biomass from 1888 to 1992 from the two long assessment models, and the estimated spawning biomass from the ensemble assessment from 1993–2019 with each given *ad hoc* weights of 1.0, 0.1, 0.4, and 0.4, respectively, in the joint likelihood.

The predicted spawning biomass fell mostly within the range of estimated spawning biomass from the four stock assessment models in the ensemble (Figure 4). The multi-region operating model predicted a female spawning biomass at the upper part and slightly above the 90% credible interval from about 1930 to 1960 for the long assessment models due to a large amount of predicted total biomass in Biological Regions 3 and 4. The predicted stock distribution matched closely for most years, although the end of the time-series in Biological Regions 2 and 3 and beginning of the time-series in Biological Regions 4 and 4B showed departures. These departures from the observed stock distribution were consistent for all models examined and suggest that the current structural specifications cannot capture these trends.

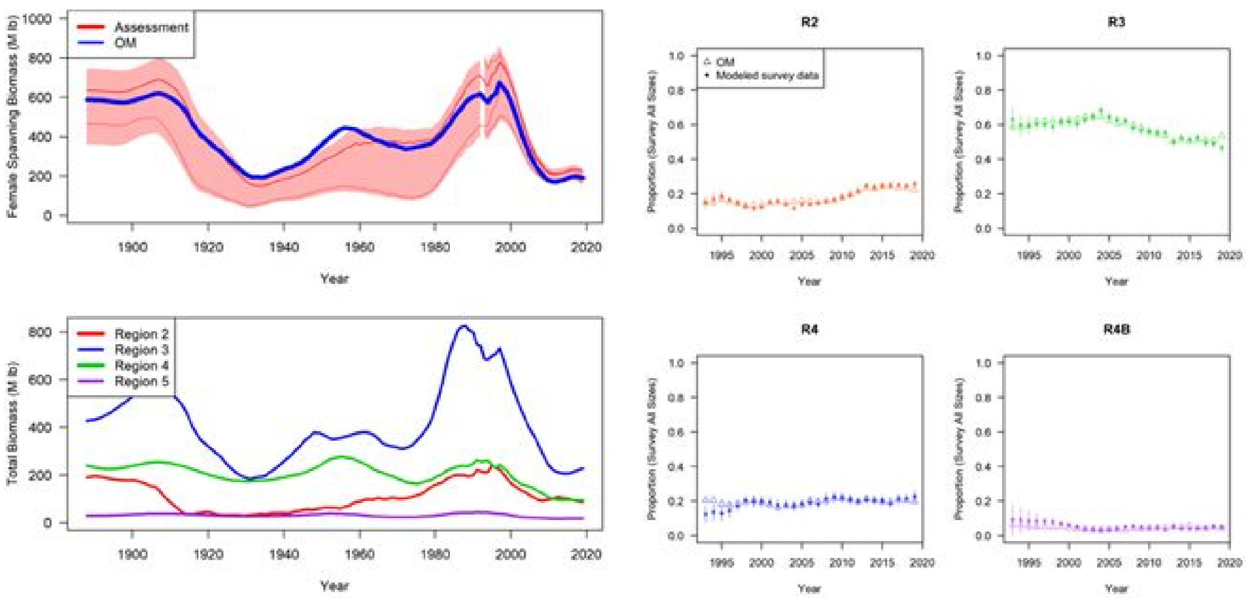



**Figure 4**: Predicted coastwide spawning biomass (top left), total biomass by Biological Region (bottom left), and the proportion of biomass in each Biological Region (right plots; Region 4B is denoted by “Region 5”) from the final OM. The blue line is predicted spawning biomass from the OM and red lines are the predicted spawning biomass from each model in the stock assessment ensemble and the red shaded area in the 90% credible interval from the ensemble stock assessment (top left). The proportion of biomass from the modelled survey results by year and Biological Region (filled circles) with estimated uncertainty are compared to the predicted proportion of biomass from the OM by year and Biological Region in the plots on the right.

Fits to the modelled survey index were reasonable for all Biological Regions, but showed some patterns in residuals in Biological Region 2 (Figure 5). Few models that were examined were able to fit the time-series in Biological Region 2 much better, and those that did show an improved fit had poor fits to stock distribution.

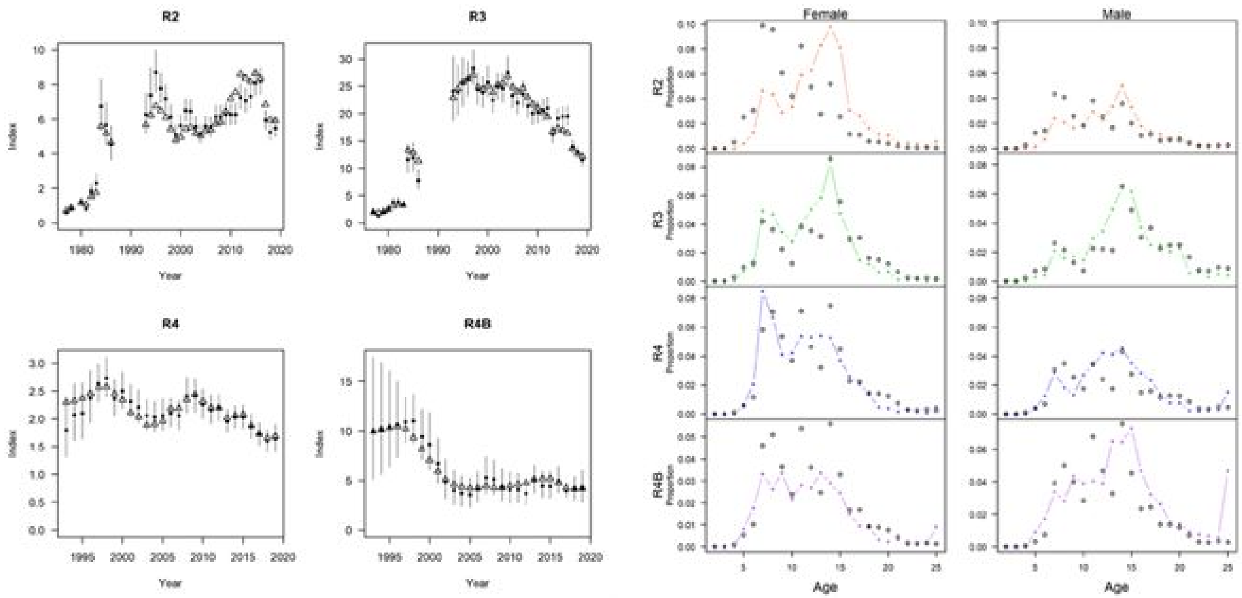



**Figure 5**: Fits to modelled survey NPUE index data (four panels on the top left), fits to proportions-at-age by sex and Biological Region from the year 2019 (eight panels on the top right), and estimated movement-at-age for the final OM (bottom row). Filled circles in the index plots are modelled survey NPUE with 95% credible intervals and the open triangles are predictions from the final OM. Filled circles connected by lines are the proportions-at-age determined from FISS data and the open circles are predictions from the final OM.

Estimated and assumed movement probabilities-at-age from one Biological Region to another are shown in Figure 6. Movement from 2 to 3 is estimated to be much greater than the data suggest with higher movement of very young fish and lower movement rates of older fish during high PDO regimes. The generally higher movement of older fish from 2 to 3 may be to counter-balance the high movement rates of young fish from 3 to 2. The OM has movement rates near 5% for movement of older fish from 3 to 2. Younger fish tend to move at higher rates from 4 to 3 with little movement once they are age 8 and older. The OM assumes that this is a closed population with no movement in or out of the four Biological Regions, which may explain some of the differences observed from the movement rates based on observations.

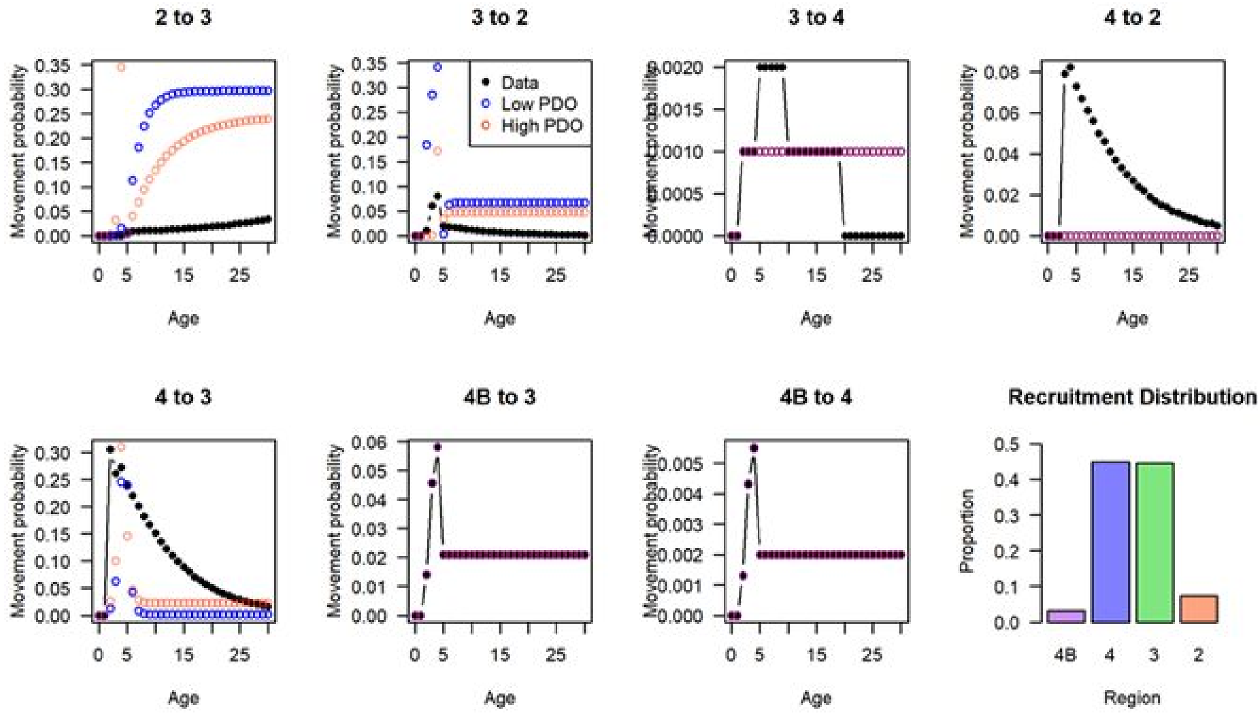



**Figure 6**: Probabilities of movement-at-age from the data and assumptions (Figure 3) and the conditioned OM (blue and red circles for low and high PDO regimes, respectively). The proportion of recruitment distributed to each Biological Region is shown in the lower right.

The final OM shown here is a reasonable representation of the Pacific halibut population but has some shortcomings. For example, the lack of fit to the 2019 stock distribution in Biological Regions 2 and 3 (Figure 4) and the high predictions of young fish in Biological Region 2 in 2019 (Figure 5). The lack of fit to the proportions-at-age in 2019 are balanced by better fits in previous years (not shown). There are many changes to the model and conditioning process that could be made to potentially improve these fits. For example, movement may be sex-specific, but tagging data are lacking this information.

Overall, the conditioned multi-region model represents the general trends of the Pacific halibut population and is a useful model to simulate the population forward in time and test management strategies.

### 2.2.1 Uncertainty in the four-region operating model

Uncertainty in population trajectories was captured by adding variability to the parameters of the operating model as specified in Table 3. The correlation matrix estimated from the long AAF model for the $R_0$, natural mortality (female and male), and recruitment deviations was combined with the correlation matrix for the movement and recruitment distribution parameters as estimated from the conditioning process. The $R_0$ parameter was estimated in both models and correlations with $R_0$ were available for all parameters. Otherwise only the correlations for the parameters within a model were available. Parameters were drawn from a multivariate normal distribution to add variability. Correlations and standard deviations for the movement and recruitment distribution parameters were divided by 4 to ensure that the covariance matrix was invertible and to avoid large deviations in movement that may have unknown and undesirable consequences. Hypotheses of movement extremely different than the OM will be investigated through sensitivities and robustness tests.

Fifty trajectories of the OM with parameter variability show a wider range than the 90% credible interval from the ensemble stock assessment (Figure 7). Prior to 1993, the trajectories are in and above the upper portion of the ensemble assessment 90% credible interval, but from 1993 to 2019 the trajectories encompass and extend beyond the credible interval. Therefore, the OM is a reasonable representation of the Pacific halibut population in recent decades and is modelled with variability that will allow for the robust testing of MPs.

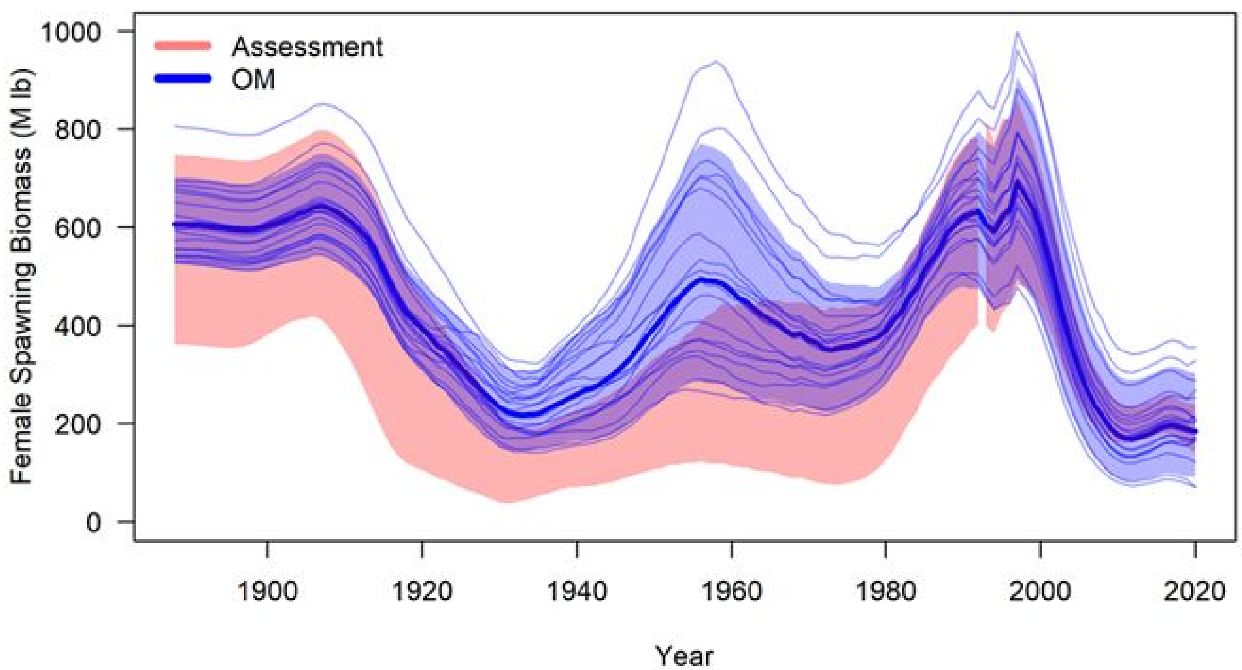



**Figure 7**: The 90% credible interval from six-hundred trajectories of the OM with parameter variability included (blue shaded area), shown against the 90% credible interval of the ensemble stock assessment (two models before 1993 and four models for 1993–2019, red shaded area). An example twenty trajectories are shown (thin blue lines) along with the median of all 600 trajectories (thick blue line).

The stock distribution with variability does not show a large departure from the observed stock distribution (Figure 8). The variability is consistent with the observations except at the beginning of the time-series in Biological Region 4 and in 2019 for Biological Regions 2 and 3. The beginning of the time-series in Biological Region 4 was estimated with few data. The recent year may have seen a shift in movement that is not explained by the OM.

Projections with the OM incorporated parameter variability (Table 3) and projection variability (Table 4) produced a wide range of trajectories. Figure 9 shows the median of six-hundred simulations to 2119 without mortality due to fishing, along with the interval between the 5th and 95th percentiles. Individual trajectories (twenty plotted) show that a single trajectory may cover a wide range of that interval in this 100-year period. The variability looks like it has reached its full range after 30 years, although there is an increasing trend near year 2090. This may occur because without fishing, some trajectories may take a long time to recover to unfished conditions when starting at low values. It is likely that with fishing, the spawning biomass equilibrates much faster.

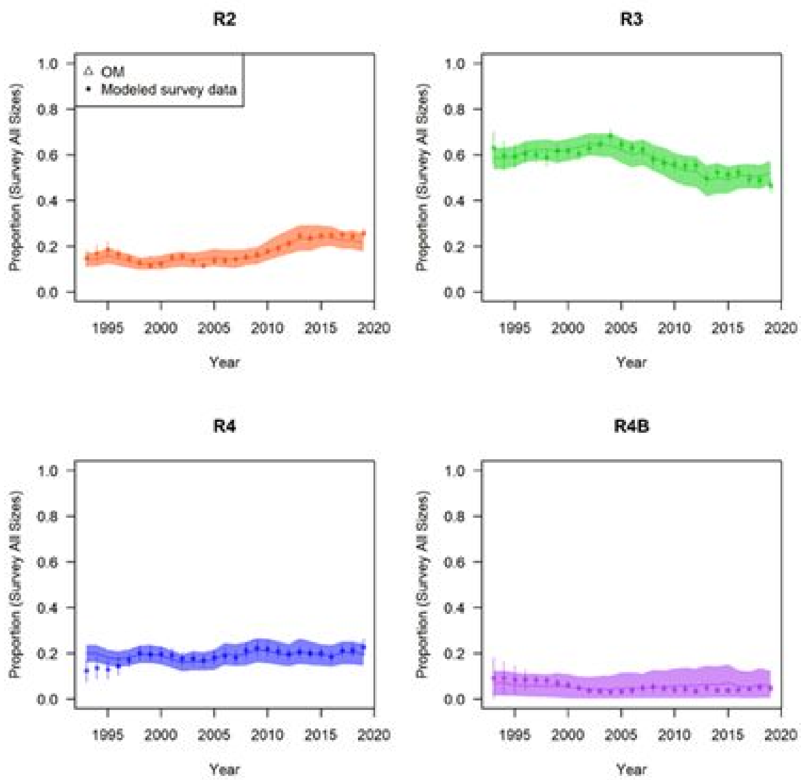



**Figure 8**: Stock distribution determined from FISS observations (points) and from the OM with variability (shaded areas).

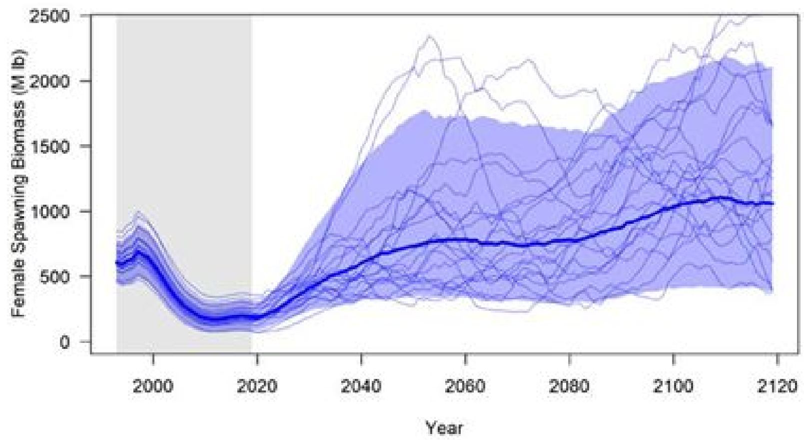



**Figure 9**: The 90% credible interval from six-hundred simulated projections for 100 years without fishing mortality. The blue line is the median and the pink shaded area show the interval between the 5th and 95th percentiles. The light shaded grey area between 1993 and 2019 is the historical period, and 2020 has fixed fishing mortality based on the already defined catch limits for 2020. The grey lines are the first 20 individual trajectories.

### 2.3 Management Procedure

The management procedure consists of three elements. Monitoring (data generation) is the code that simulates the data from the operating model. The data generation routine attempts to simulate the data collection and sampling process, and introduces in the data variability, bias, and any other desired property. The data so generated are then used by the estimation model. The Estimation Model (EM) is analogous to the stock assessment and simulates estimation error in the process. Using the data generated, it produces an annual estimate of stock size and status and provides the advice for setting the catch levels for the next time step. Simplification of the full stock assessment are in general necessary to keep simulation times within reason. The Harvest Rule is the application of the estimation model output along with the scale and distribution management procedures (Figure 1) to produce the mortality limit for that year.

#### 2.3.1 Uncertainty in the management procedure

The major source of uncertainty in the management procedure is from the generation of data. The data generation step simulates the process of observation by resampling from probability distributions that approximate the uncertainty in the observed data. These simulated data are then fed into the estimation model to approximate the current stock assessment ensemble or used in the management procedure (e.g., stock distribution).

The observation model generates the data for the EMs during projections from the OM with error. In particular, deviates to the absolute index of abundance and the stock distribution are generated by region from a lognormal distribution with standard deviation equal to the average standard error by region from the last 5 years. Age composition data are simulated using a Dirichlet distribution. The nominal sample size is used as the scale parameter of the Dirichlet distribution, to control the variance of the distribution, i.e. a higher sample size implies lower variance. The nominal sample size is generated using an average fixed proportion of the sector mortality. The resulting sample size values are bounded between a minimum and a maximum, which varies between sectors: these limits have been chosen based on the historical sample size values and help both to stabilize the EM, as well as to avoid unrealistic distribution in the simulated age composition.

Three methods are available for simulating the estimation process. First, there is the option of no estimation model where the data are produced without error and the estimation model returns the population and predicted mortality values determined exactly from the OM. The second method simulates the estimation error (autocorrelated estimation error about the true population values) as was done in the coastwide MSE. This method is simple and less prone to errors during simulation that some other methods may experience. The third method is to use a stock assessment model, such as stock synthesis and enter the generated data. The model chosen to emulate the current stock assessment ensemble is the long coastwide model in stock synthesis, which has been appropriately simplified to reduce run time. Using actual stock assessment models may better characterize the estimation variability than simpler approaches.

The values generated from the estimation model are used in the application of the harvest rule to determine mortality limits by IPHC Regulatory Area. The simulated application of this rule will therefore include uncertainty in the status, the size of the population, stock distribution, etc., all of which will be propagated into management actions.

#### *2.3.1.1 No estimation error*

The stock status, total mortality given the input SPR, the stock distribution, and any other quantities needed for the MP are known exactly for this option. This is useful to identify variability that is due to estimation.

#### *2.3.1.2 Simulated estimation error*

For this method, error is added to the stock status and total mortality given the input SPR that are used in the MP by adding deviates to each that are sampled from a bivariate normal distribution with a 15% coefficient of variation on each and a correlation of 0.5. Additionally, an autocorrelation of 0.4 is used with the deviate from the previous year. This is the same method that was used in the coastwide MSE as described in IPHC-2018-MSAB012-07 Rev_1. Stock distribution is determined from survey data generated with random error similar to error estimates from the current survey time-series.

#### *2.3.1.3 Estimation models using stock synthesis*

Two approaches were used to speed up the long coastwide estimation model for use in the MSE simulations: reducing the reading time and reducing the computation time.

To reduce the reading time, the amount of data included in the model was reduced compared to the full assessment, while ensuring similar trajectories in the estimated quantities such as spawning stock biomass, exploitation and virgin biomass. Once this condition was met, the trend in dynamic B0 for the most recent period and the forecasted TM were also verified. The number of years of age composition data was shortened, and for each additional year of age data added during the projection period, an early year in the time series was removed. A minimum of at least 50 years of age composition for the directed commercial fleet is required before the removal of historical data begins. Only the beginning of the CPUE time series was maintained, removing all subsequent years starting from 1994. Additionally, the model was started in 1935 instead of 1888.

The major change to the data is the use of an absolute index of abundance to replace the NPUE from the survey. The index is generated with error from the numbers at age and the survey selectivity at age for the whole time series. The catchability is fixed to 1.

To reduce the computation time, the 'opt' (optimized) version of stock synthesis was used, and the number of estimated parameters was reduced, mostly by removing some time-varying options. The remaining annual deviations in selectivity parameters were fixed at the values estimated by the original assessment model, and only the deviations for the most recent 10 or 20 years (depending on the parameter) were left free to be estimated. In the first projected year, optimization was initiated using the parameters estimated by this streamlined version of the assessment model (i.e., the 'ss.par' file). For each subsequent year in the projection, the 'ss.par' file from the previous year was used, manually adding one extra parameter where necessary. The parameter estimation was also set to start from the last phase.

Finally, the convergence criterion was set to 0.1, the Hessian was not estimated (therefore uncertainty in the estimates is not calculated), and the amount of information printed on screen was reduced to a minimum. The number of iterations for a model to reach convergence was fixed to a maximum of 800. If the model did not converge after 800 iterations (i.e., convergence > 0.1), the initial value for the R0 parameter was increased by 5% and the model was restarted. If the model still did not converge, it was restarted for a third time, but estimation was started from phase 1.

For each OM, data for the historical period were generated and input files for the long coastwide assessment models were created, so to have each set of estimation models consistent with the historical period of the correspondent OM. The initial parameter files used are the same across all simulations.

*Performance of the stock synthesis estimation model*

Ten simulations with 60 years projections were run to evaluate the performance of the long coastwide stock synthesis assessment as estimation model with different OMs. The stock synthesis estimation model closely matches the stock status and the fishing intensity from the operating model (Figure 10).

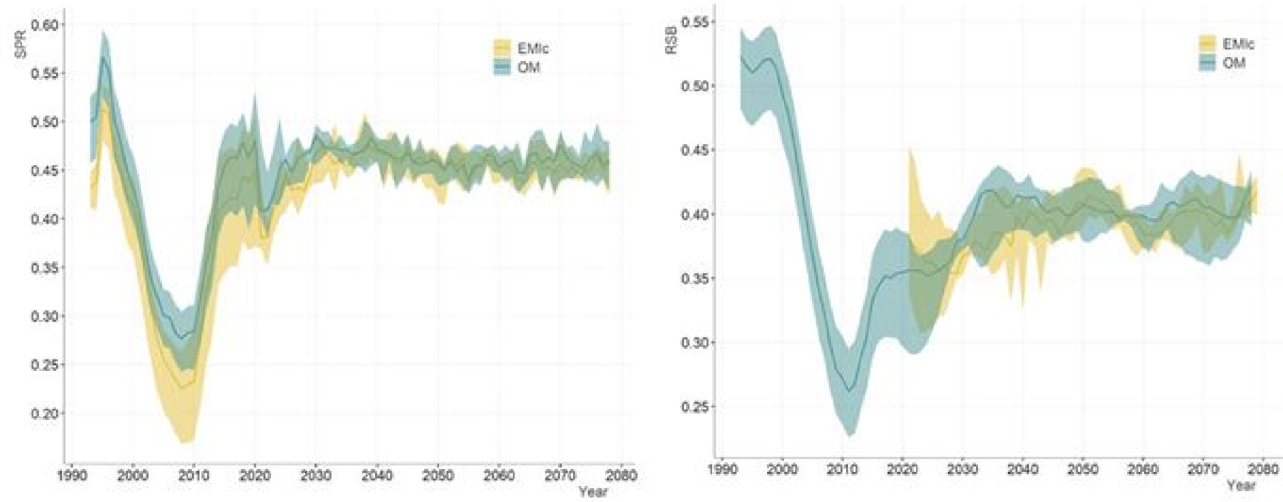



Figure 10: SPR and RSB as estimated by the OM (blue) and the long coastwide estimation model (yellow) for 10 simulations.

### 2.3.2 Allocating simulated total mortality to sectors

The outputs of the management procedure are TCEY limits for each IPHC Regulatory Area, which then need to be allocated to the different sectors specific to the IPHC Regulatory Area. See Table 2 for a complete list of the fishing sectors by IPHC Regulatory Area.

There are two parts to the allocation procedure: the calculation of the upcoming mortality limits by sector, and the calculation of the realized mortality by sector. The calculation of mortality limits is necessary because some sector's mortality limits are determined from the limits for other sectors. In the current framework, the calculation of the realized mortality differs from the calculation of the mortality limits for the non-directed discard, directed discard, subsistence, and unguided recreational mortalities. Mortality limits and realized mortality for the recreational and directed commercial sectors are assumed to be equal (i.e., no implementation error for these sectors).

The allocation procedure begins by subtracting the non-directed commercial O26 discard mortality by IPHC Regulatory Area from the corresponding IPHC Regulatory Area TCEY. The remainder is referred to as the directed TCEY for convenience (it is not used as a management quantity). The directed TCEY is then allocated to directed fishery sectors. Each IPHC Regulatory Area has a unique catch-sharing plan (CSP) or allocation procedure, and these CSPs were matched as closely as possible. When the TCEY for an IPHC Regulatory Area is low, the CSP may deteriorate and alternative decisions may be necessary. At low TCEY, it is assumed that the sum of the directed non-FCEY components does not exceed the directed TCEY: this is evaluated removing sequentially the non-directed discard mortality, the subsistence and unguided recreational (where available) from the TCEY. If any of these mortalities exceed the remaining TCEY, the FCEY components are set to zero.

*Non-directed commercial discard mortality*: the U26 and O26 components of the non-directed discard mortality limit is calculated from the previous year's non-directed discard mortality for each IPHC Regulatory Area. However, the realized non-directed discard mortality is determined from a linear relationship between the non-directed discard mortality by region and the total biomass in that region. Given changes in non-directed commercial discard mortality in recent years the fit was forced through the last observed year (2019). The realized non-directed discard mortality was then randomly drawn from the value determined from total biomass by region using a log normal distribution with a 20% CV (Figure 11). The non-directed commercial discard mortality by region is then distributed to IPHC Regulatory Area using the proportion of non-directed commercial discard mortality recently observed in each IPHC Regulatory Area.

*Directed commercial discard mortality*: directed commercial discard mortality limits are calculated using the ratio of directed discard mortality to directed commercial mortality from the previous year. The realized directed discard mortality is modelled as a function of the directed commercial plus directed discard mortality and the weight at age 8 for a male Pacific halibut. The resulting proportion of directed discard mortality relative to different values of the commercial plus directed discard mortality is shown in Figure 12. A minimum of 0.05% of directed discard mortality over commercial plus directed discard mortality is applied.

*Subsistence*: subsistence mortality limits are set equal to the values observed in the previous year, except for IPHC Regulatory Area 2A, for which the subsistence value is set to 30,000 pounds (13.6 t). The realized subsistence mortality is randomly drawn from a lognormal distribution with a median equal to the limit subsistence mortality and a CV of 15%. The coastwide subsistence is then compared to the coastwide TCEY: if the allocation to the subsistence sector is higher than half of the overall TCEY, then the subsistence mortality in each regulatory area is adjusted so that the coastwide value will not exceed 50% of the coastwide TCEY.

*Unguided recreational mortality*: unguided recreational mortality is relevant only for IPHC Regulatory Areas 2C and 3A and it is randomly drawn from a lognormal distribution with a median equal to an average historical value (1.257 Mlb or 570 t for 2C and 1.579 Mlb or 716 t for 3A) and a 5% CV.

*Recreational mortality*: recreational mortality follows the catch sharing plans (CSPs) for IPHC Regulatory Areas in Region 2 and IPHC Regulatory Area 3A, noting that guided recreational mortality limits are only under the CSP in IPHC Regulatory Areas 2C and 3A and the total recreational mortality is the sum of guided and unguided. In IPHC Regulatory Areas 3B, 4A, 4B, and 4CDE, recreational mortality is included with subsistence because almost negligible.

*Commercial mortality*: is the remainder of the total mortality after subtracting all other sources of mortality.

Figure 13 and Figure 14 illustrate the results of the allocation procedure for each IPHC Regulatory Area when non-directed commercial discard mortality and unguided recreational are held constant at an average value. The recreational and subsistence allocations for IPHC

Regulatory Areas 4A and 4CDE are fixed at low values and aggregated to Biological Region in the OM. For this reason, these two sectors are not shown in Figure 14.

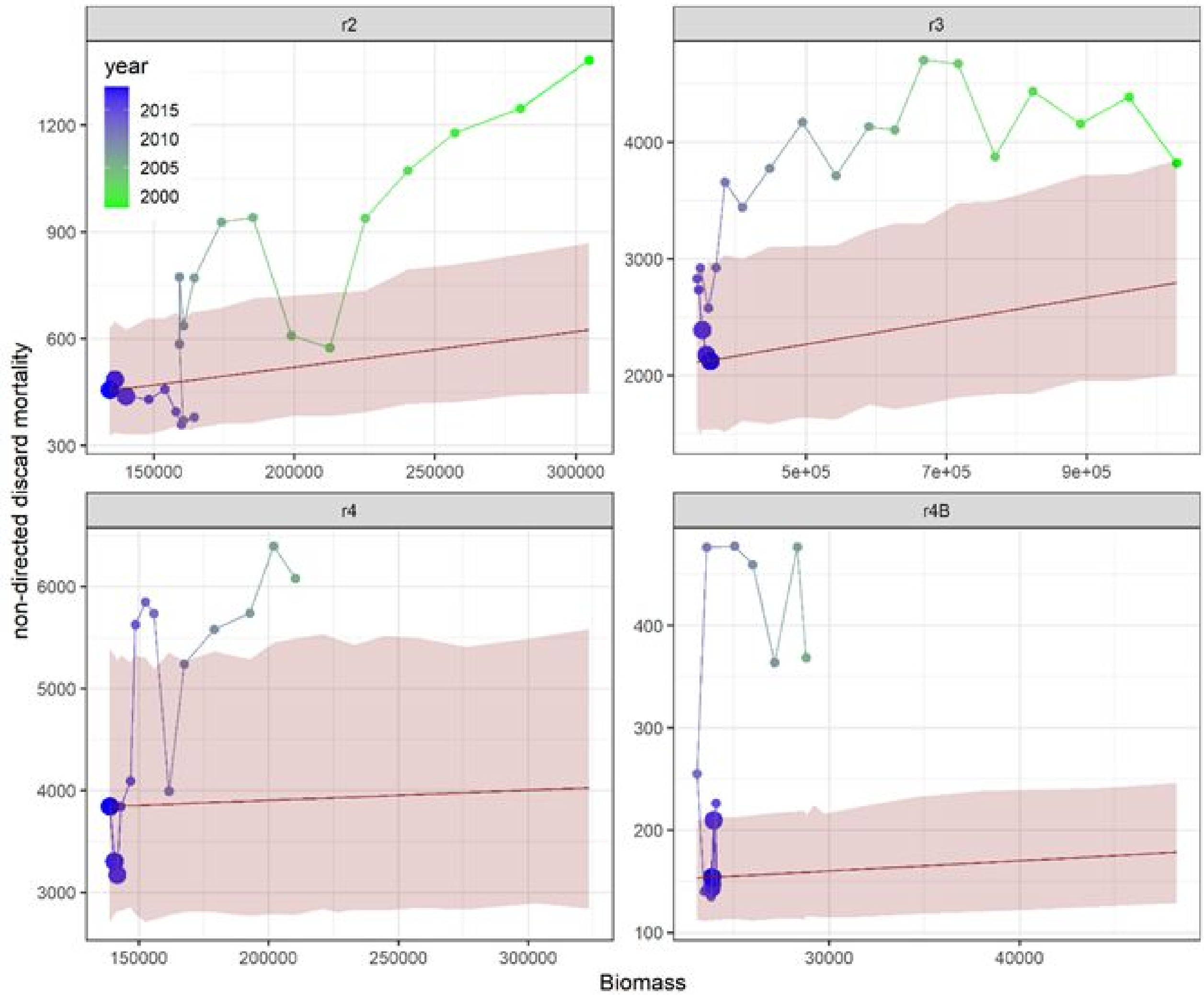



**Figure 11**: Non-directed commercial discard mortality plotted against total biomass from the conditioned multi-region OM. The colors in the points represent the sequence of time from 1998 to 2019. The years 2017–2019 are represented by larger dots. The red line represents the linear relationship used for predicting the non-directed discard mortality from the biomass. The shaded red area around it represents the 0.05 and 0.95 quantiles of the non-directed discard mortality simulated from a log-normal distribution with a 20% CV.

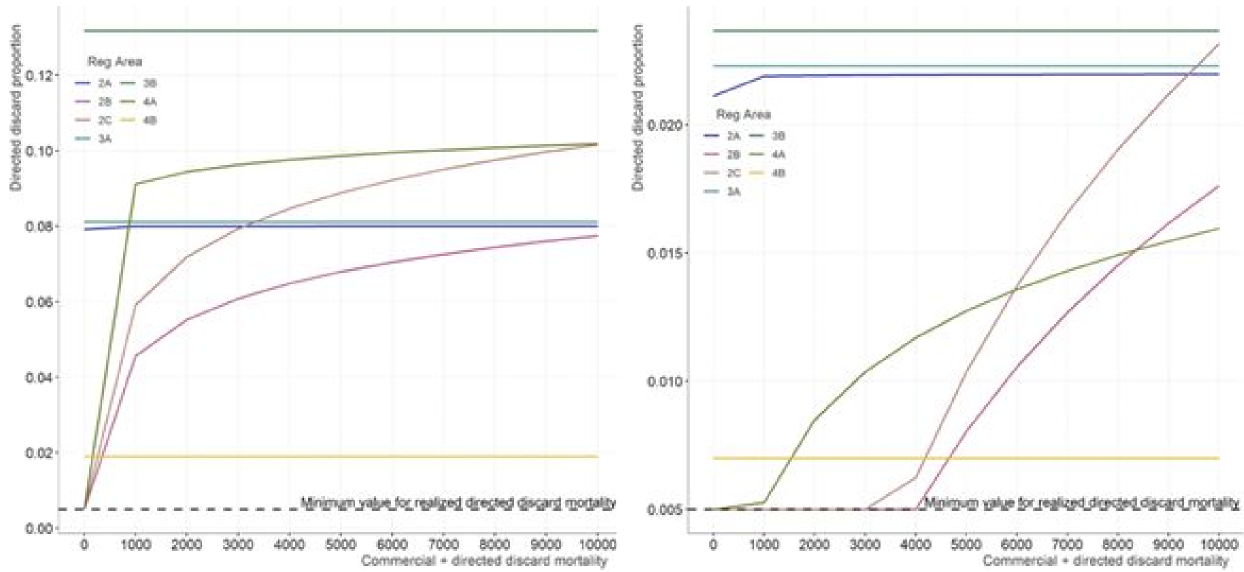



**Figure 12**: Proportion of directed discard mortality by IPHC Regulatory Area relative to different values of the commercial plus directed discard mortality with a male weight at age 8 equal to 4 lb (left) and 8 lb (right). The dashed line shows the 0.5% minimum.

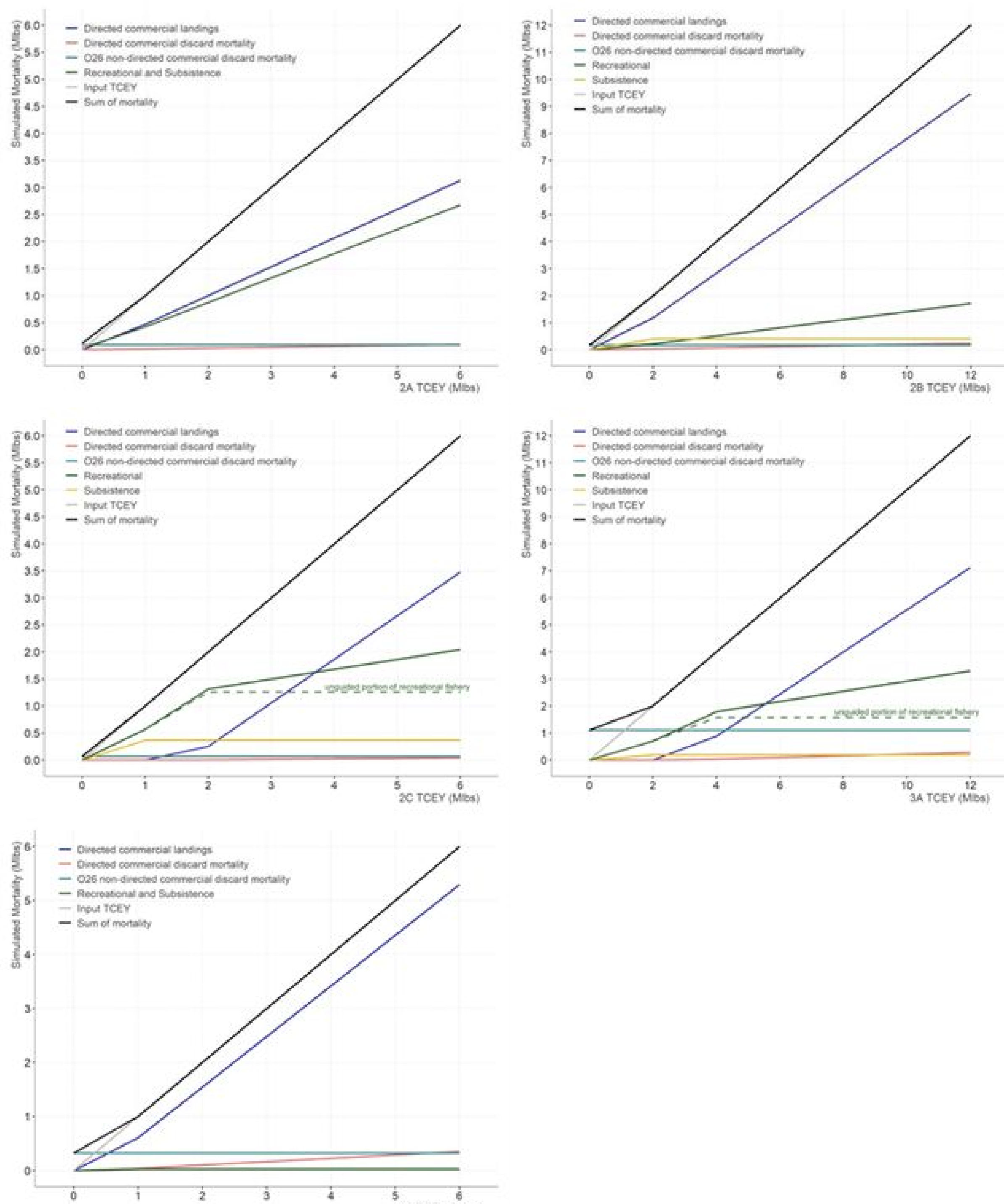



**Figure 13**: Allocation of the TCEY to sectors for IPHC Regulatory Areas 2A (top left) to 3B (bottom left) when O26 non-directed commercial discard mortality and unguided recreational are is assumed constant at average values. The input TCEY provided to the allocation function is shown in light gray, while the sum of mortalities after allocation is shown in black.

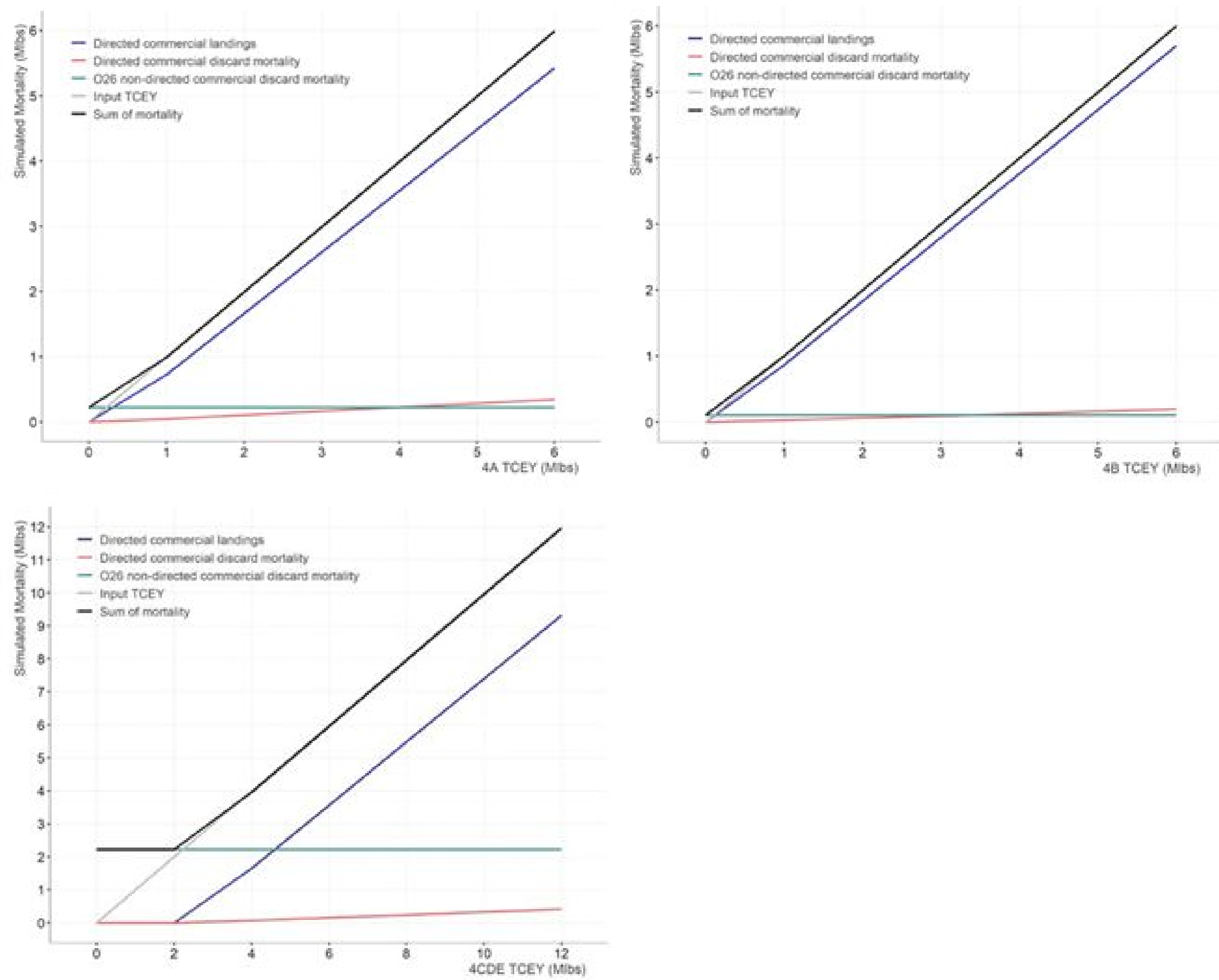



**Figure 14**: Allocation of the TCEY to sectors for IPHC Regulatory Areas 4A (top left), 4B (top right), and 4CDE (lower left) when O26 non-directed commercial discard mortality is assumed constant at an average value. The input TCEY provided to the allocation function is shown in light gray, while the sum of mortalities after allocation is shown in black.

## 3 Recommendations

That the MSAB:

a) **NOTE** paper IPHC-2020-MSAB016-08 which provides a description of the IPHC MSE framework, a description of the specifications of the multi-area operating model, and a brief overview of the implementation of management procedures.

b) **RECOMMEND** alternative specifications and additional features needed to evaluate management procedures related to coastwide scale and distribution of the TCEY, also **NOTING** document IPHC-2020-MSAB016-INF01.

## 4 References

IPHC-2019-AM095-08. Stewart I, Webster R. 2019. Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses. 76 p. https://www.iphc.int/uploads/pdf/am/2019am/iphc-2019-am095-08.pdf

IPHC-2020-SA-01. 2020. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2019. 32 p. https://www.iphc.int/uploads/pdf/sa/2020/iphc-2020-sa-01.pdf

IPHC-2020-SA-02. 2020. Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses. 53 p. https://iphc.int/uploads/pdf/sa/2020/iphc-2020-sa-02.pdf

IPHC-2020-MSAB016-INF01. Technical details of the IPHC MSE framework.

IPHC-2020-MSAB015-08 Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries. 13 p. https://iphc.int/uploads/pdf/msab/msab015/iphc-2020-msab015-08.pdf

IPHC-2018-SRB012-R. Report of the 12th Session of the IPHC Scientific Review Board (SRB012). 17 p. https://www.iphc.int/uploads/pdf/srb/srb012/iphc-2018-srb012-r.pdf

Loher, T. 2011. Analysis of match–mismatch between commercial fishing periods and spawning ecology of Pacific halibut (*Hippoglossus stenolepis*), based on winter surveys and behavioural data from electronic archival tags. ICES J. Mar. Sci. 68(10): 2240-2251.

Loher, T., & Seitz, A. C. 2006. Seasonal migration and environmental conditions experienced by Pacific halibut in the Gulf of Alaska, elucidated from Pop-up Archival Transmitting (PAT) tags. IPHC, Scientific Report No. 82.

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

Seitz, A. C., Farrugia, T. J., Norcross, B. L., Loher, T., & Nielsen, J. L. 2017. Basin-scale reproductive segregation of Pacific halibut (Hippoglossus stenolepis). Fisheries Management and Ecology, 24(4), 339–346.

Seitz, A. C., Loher, T., & Nielsen, J. L. 2007. Seasonal movements and environmental conditions experienced by Pacific halibut in the Bering Sea, examined by pop-up satellite tags. IPHC, Scientific Report No. 84. 24pp.

Stewart, I. J. and Hicks, A. C. 2017. Assessment of the Pacific halibut stock at the end of 2016. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2016: 365-394.

Stewart, I.J. and Martell, S. J. D. 2016. Development of the 2015 stock assessment. IPHC Report of Assessment and Research Activities 2015. https://iphc.int/uploads/pdf/rara/iphc-2015-rara25.pdf

## 5 APPENDICES

Nil


INTERNATIONAL PACIFIC HALIBUT COMMISSION

# MSE Results

Agenda Item 6

IPHC-2020-MSAB016-09

# General Objectives

- Primary biological sustainability objectives
- Primary fishery objectives
  - Target Spawning Biomass to optimise fishing activities
  - Stability in mortality limits
  - Provide directed fishing yield

MSE Webpage:

https://www.iphc.int/management/science-and-research/management-strategy-evaluation

# Primary Performance Metrics

*Biological Sustainability*

- Probability female SB > 20% of B0
- Probability female SB in R2 > 5% of coastwide SB
- Probability female SB in R3 > 33% of coastwide SB
- Probability female SB in R4 > 10% of coastwide SB
- Probability female SB in R4B > 2% of coastwide SB

# Primary Performance Metrics

*Fishery*

- Probability coastwide female SB > 36% of B0
- Probability Annual Change in TCEY > 15% in any 3 yrs of 10
  - coastwide and by IPHC Regulatory Area
- Median AAV
  - coastwide and by IPHC Regulatory Area
- Median TCEY
  - coastwide and by IPHC Regulatory Area
- Median %TCEY in each IPHC Regulatory Area
- Minimum TCEY in each IPHC Regulatory Area
- Minimum %TCEY in IPHC Regulatory Area

# Ad hoc MSAB meeting (1)

*Para 11 to 14*: Improvements to MSE Explorer

- Tables to summarise the simulations available;
- Clear identification of primary objectives and relative performance metrics;
- Ranking tables

*Para 15 to 16*: Performance Metrics

- Guided and unguided recreational (not possible at this time)
- TCEY at IPHC Regulatory Areas level
- Relative percentages of TCEY across IPHC Regulatory Areas
- Anything that is part of a catch-sharing plan

# Ad hoc MSAB meeting (2)

*Para 21*: Potential bugs

- MP-B: *fixed*
- MP-C: *fixed*
- Total mortality: *now reporting TCEY*

# Estimation Error

- Three methods for implementing estimation error
  1. No estimation error
     - For comparison, not to choose from
  2. Simulated estimation error (as with coastwide MSE)
     - Currently the best method
  3. Modelled estimation error (a stock assessment model)
     - For comparison

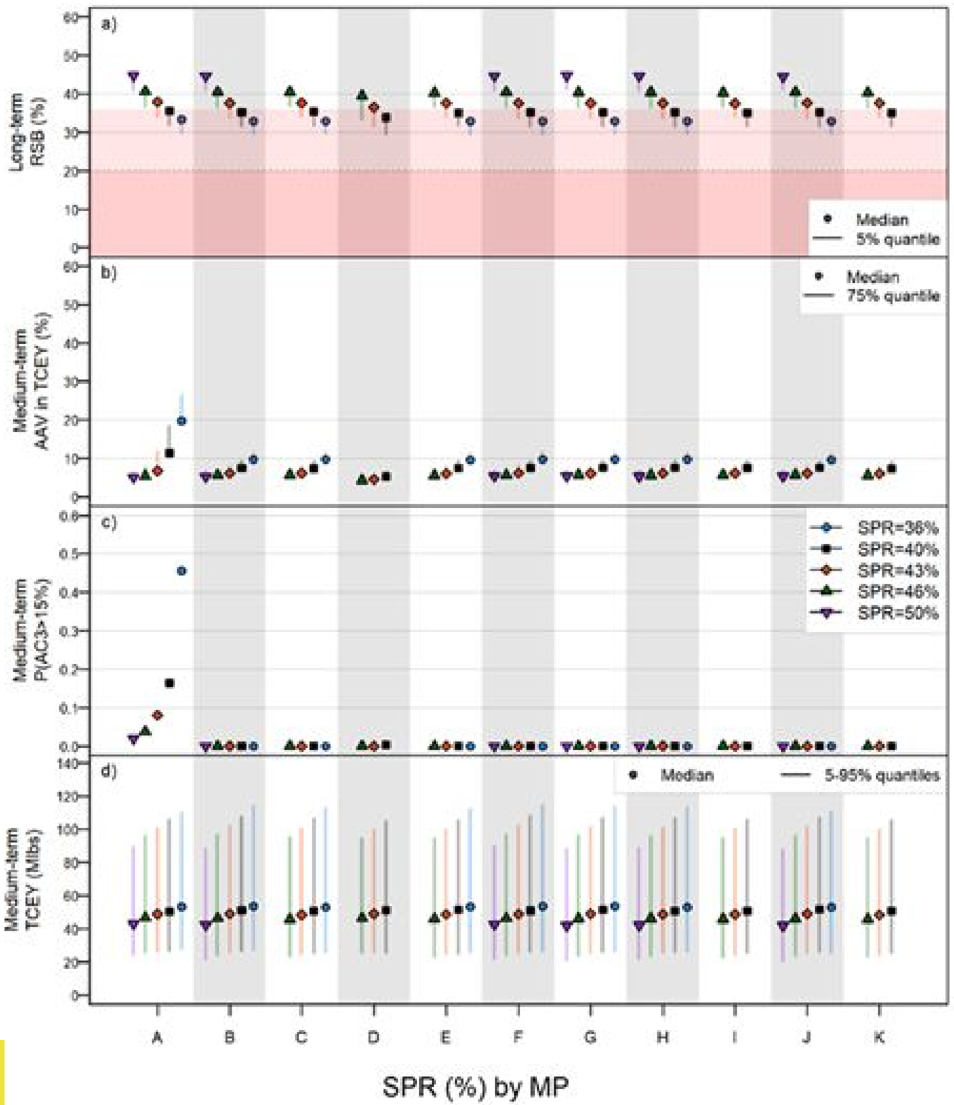
# MP comparison

| Element | MP-A | MP-B | MP-C | MP-D | MP-E | MP-F | MP-G | MP-H | MP-I | MP-J | MP-K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| maxChange15% | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| max FI buffer (36%) | | | | ■ | | | | | | | |
| O32 stock distribution | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | |
| O32 stock distribution (5-year moving avg) | | | | | | | | | | ■ | |
| All sizes stock distribution | | | | | | | | | ■ | | |
| 5-year shares form O32 stock distribution | | | | | | | | | ■ | | ■ |
| Relative harvest rates 1 for 2-3A, 0.75 for 3B-4 | ■ | ■ | | ■ | ■ | ■ | ■ | | ■ | ■ | |
| Relative harvest rates 1 for 2-3, 4A, 4CDE, 0.75 for 4B | | | | | | | | ■ | | | |
| 1.65 Mlbs floor in 2A | ■ | ■ | ■ | ■ | ■ | | | | | | |
| Formula percentage for 2B | ■ | ■ | ■ | ■ | | | | | | | |
| National Shares (2B=20%) | | | | | | ■ | | | | | |

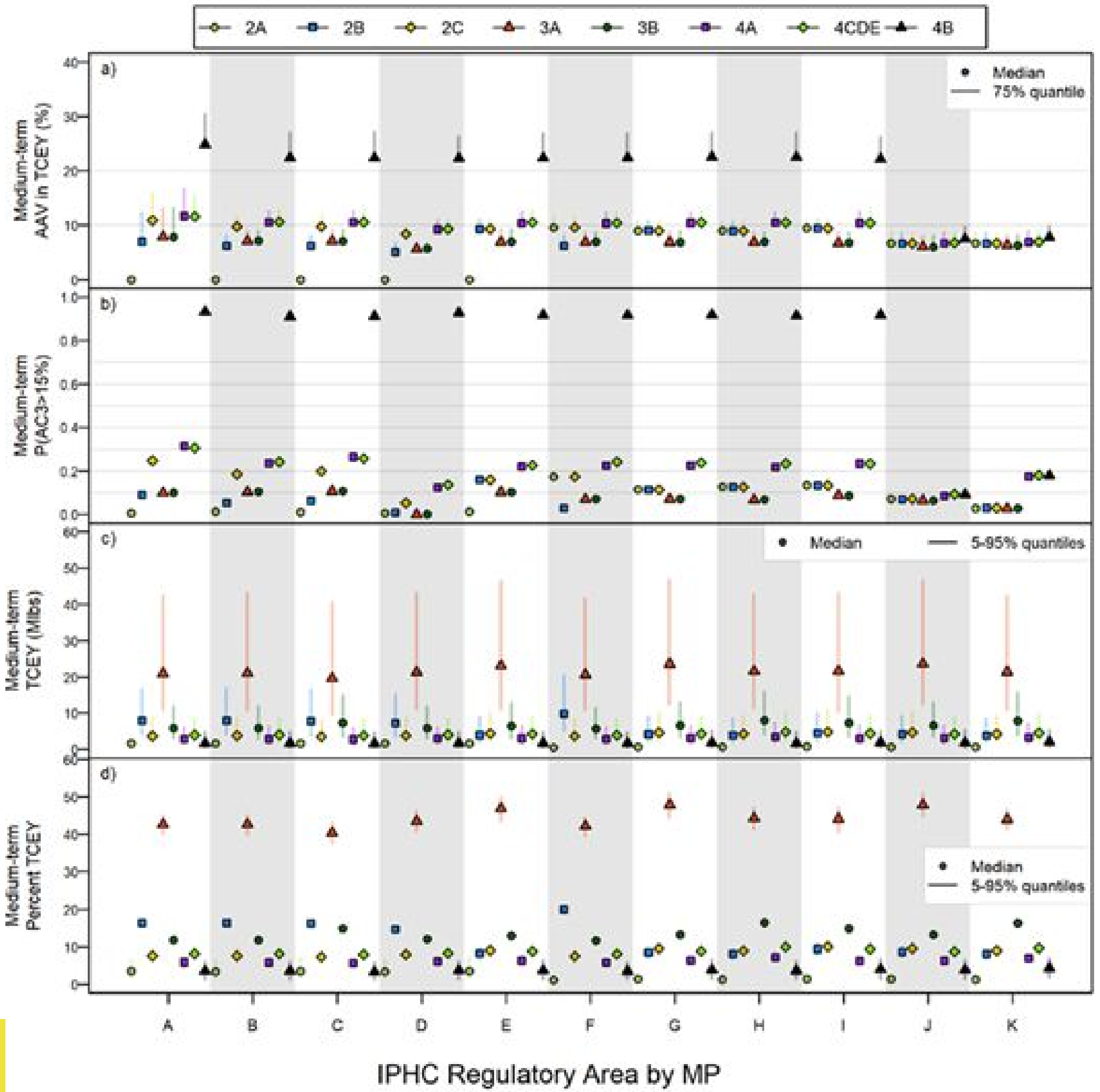
# Coastwide Performance Metrics

| Input SPR/TM | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Management Procedure | A | B | C | D | E | F | G | H | I | J | K |
| Number of Simulations | 500 | 500 | 400 | 300 | 300 | 500 | 500 | 500 | 300 | 500 | 300 |
| **Biological Sustainability** | | | | | | | | | | | |
| P(any RSB_y<20%) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| **Fishery Sustainability** | | | | | | | | | | | |
| P(all RSB<36%) | 0.25 | 0.28 | 0.28 | 0.45 | 0.29 | 0.28 | 0.28 | 0.29 | 0.29 | 0.28 | 0.29 |
| Median average TCEY | 48.89 | 49.10 | 48.56 | 49.14 | 48.82 | 48.90 | 49.08 | 48.73 | 48.65 | 49.01 | 48.43 |
| P(any3 change TCEY > 15%) | 0.18 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Median AAV TCEY | 6.8% | 6.1% | 6.1% | 4.6% | 6.0% | 6.2% | 6.1% | 6.1% | 6.1% | 6.1% | 6.0% |

# Coastwide performance metrics



# Regulatory Area Performance Metrics



# Ranking Biological Sustainability objectives

| Objective | PM | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 |
| 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 |
| 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 |
| Maintain a minimum proportion of female SB | $P(\%SB_{R=4B} < 2\%)$ | 0.15 | 0.15 | 0.16 | 0.14 | 0.15 | 0.15 | 0.16 |

# 2.1 Fishery objective

| Objectives | PMs | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|
| Maintain the coastwide female SB above a target at least 50% of the time | $P(SB < SB_{36\%})$ | 11 | 6 | 6 | 1 | 2 | 6 | 6 | 2 |

# 2.2 Fishery stability objectives

| Objectives | PMs | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Limit TCEY AC | P($AC_8$ > 15%) | 11 | 1 | 1 | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Limit TCEY AAV | Median AAV TCEY | 11 | 4 | 4 | 1 | 2 | 10 | 4 | 4 | 4 | 4 | 2 |
| Limit AC in Reg Areas TCEY | P($AC_8$ 2A > 15%) | 1 | 1 | 1 | 1 | 1 | 11 | 8 | 9 | 9 | 7 | 6 |
| | P($AC_8$ 2B > 15%) | 7 | 4 | 5 | 1 | 11 | 2 | 8 | 9 | 9 | 6 | 2 |
| | P($AC_8$ 2C > 15%) | 11 | 9 | 10 | 2 | 7 | 8 | 4 | 5 | 5 | 3 | 1 |
| | P($AC_8$ 3A > 15%) | 8 | 8 | 11 | 1 | 8 | 4 | 4 | 4 | 7 | 3 | 2 |
| | P($AC_8$ 3B > 15%) | 8 | 8 | 11 | 1 | 8 | 4 | 4 | 4 | 7 | 3 | 2 |
| | P($AC_8$ 4A > 15%) | 11 | 9 | 10 | 2 | 4 | 6 | 6 | 4 | 6 | 1 | 3 |
| | P($AC_8$ 4CDE > 15%) | 11 | 7 | 10 | 2 | 4 | 7 | 7 | 4 | 4 | 1 | 3 |
| | P($AC_8$ 4B > 15%) | 10 | 3 | 3 | 10 | 6 | 6 | 6 | 3 | 6 | 1 | 2 |
| Limit AAV in Reg Areas TCEY | Median AAV 2A | 1 | 1 | 1 | 1 | 1 | 11 | 9 | 8 | 10 | 6 | 6 |
| | Median AAV 2B | 7 | 2 | 2 | 1 | 10 | 2 | 9 | 8 | 11 | 5 | 5 |
| | Median AAV 2C | 11 | 9 | 9 | 3 | 6 | 8 | 5 | 4 | 7 | 1 | 1 |
| | Median AAV 3A | 11 | 9 | 9 | 1 | 5 | 5 | 5 | 5 | 4 | 2 | 3 |
| | Median AAV 3B | 11 | 9 | 9 | 1 | 5 | 5 | 5 | 5 | 4 | 2 | 3 |
| | Median AAV 4A | 11 | 10 | 9 | 3 | 5 | 4 | 5 | 5 | 5 | 1 | 2 |
| | Median AAV 4CDE | 11 | 9 | 9 | 3 | 5 | 4 | 5 | 5 | 5 | 1 | 2 |
| | Median AAV 4B | 1 | 5 | 5 | 4 | 5 | 5 | 10 | 9 | 3 | 1 | 2 |

# 2.3 Fishery yield objectives

| Objectives | PMs | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimize TCEY | Median TCEY | 5 | 1 | 9 | 1 | 7 | 5 | 1 | 8 | 9 | 4 | 11 |
| Maintain minimum TCEY by Reg Areas | Median Min 2A | 1 | 1 | 1 | 1 | 1 | 11 | 7 | 7 | 6 | 7 | 7 |
| | Median Min 2B | 4 | 2 | 3 | 5 | 9 | 1 | 8 | 10 | 6 | 7 | 10 |
| | Median Min 2C | 11 | 8 | 10 | 7 | 4 | 8 | 2 | 6 | 1 | 2 | 4 |
| | Median Min 3A | 10 | 8 | 11 | 4 | 3 | 9 | 2 | 6 | 5 | 1 | 6 |
| | Median Min 3B | 11 | 9 | 3 | 8 | 7 | 10 | 6 | 1 | 3 | 5 | 1 |
| | Median Min 4A | 11 | 8 | 9 | 5 | 5 | 9 | 3 | 1 | 5 | 3 | 1 |
| | Median Min 4CDE | 10 | 8 | 10 | 5 | 5 | 8 | 5 | 2 | 3 | 4 | 1 |
| | Median Min 4B | 11 | 8 | 8 | 3 | 3 | 8 | 3 | 3 | 3 | 2 | 1 |
| Optimize Reg Areas TCEY | Median TCEY2A | 1 | 1 | 1 | 1 | 1 | 11 | 6 | 9 | 6 | 6 | 9 |
| | Median TCEY2B | 2 | 2 | 4 | 5 | 9 | 1 | 7 | 9 | 6 | 7 | 11 |
| | Median TCEY2C | 9 | 7 | 11 | 7 | 4 | 10 | 3 | 5 | 1 | 2 | 6 |
| | Median TCEY3A | 9 | 8 | 11 | 7 | 3 | 10 | 2 | 4 | 5 | 1 | 6 |
| | Median TCEY3B | 9 | 9 | 4 | 8 | 7 | 11 | 6 | 1 | 3 | 5 | 2 |
| | Median TCEY4A | 8 | 8 | 11 | 6 | 3 | 8 | 3 | 1 | 6 | 3 | 2 |
| | Median TCEY4CDE | 7 | 7 | 11 | 7 | 5 | 10 | 4 | 1 | 2 | 5 | 2 |
| | Median TCEY4B | 6 | 6 | 11 | 6 | 3 | 6 | 3 | 6 | 2 | 3 | 1 |

# 2.3 Fishery yield objectives (percentage)

| Objectives | PMs | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maintain minimum % TCEY by Reg Areas | Median Min % 2A | 5 | 2 | 1 | 2 | 2 | 11 | 8 | 10 | 6 | 6 | 8 |
| | Median Min % 2B | 2 | 2 | 4 | 5 | 10 | 1 | 8 | 11 | 6 | 7 | 8 |
| | Median Min % 2C | 9 | 8 | 11 | 7 | 5 | 10 | 3 | 6 | 2 | 1 | 4 |
| | Median Min % 3A | 9 | 8 | 11 | 7 | 3 | 10 | 2 | 5 | 6 | 1 | 4 |
| | Median Min % 3B | 10 | 9 | 3 | 8 | 7 | 11 | 6 | 2 | 4 | 5 | 1 |
| | Median Min % 4A | 8 | 8 | 11 | 7 | 5 | 8 | 4 | 2 | 5 | 3 | 1 |
| | Median Min % 4CDE | 8 | 8 | 11 | 7 | 6 | 10 | 5 | 2 | 3 | 3 | 1 |
| | Median Min % 4B | 7 | 7 | 11 | 5 | 5 | 10 | 3 | 7 | 3 | 2 | 1 |
| Optimize TCEY percentage among Reg Areas | Median % TCEY2A | 1 | 4 | 1 | 4 | 1 | 11 | 7 | 9 | 6 | 7 | 9 |
| | Median % TCEY2B | 2 | 2 | 2 | 5 | 9 | 1 | 7 | 11 | 6 | 7 | 10 |
| | Median % TCEY2C | 8 | 8 | 11 | 7 | 4 | 10 | 3 | 6 | 1 | 2 | 5 |
| | Median % TCEY3A | 9 | 8 | 11 | 7 | 3 | 10 | 1 | 4 | 5 | 1 | 6 |
| | Median % TCEY3B | 9 | 9 | 3 | 8 | 7 | 11 | 5 | 1 | 4 | 5 | 2 |
| | Median % TCEY4A | 8 | 8 | 11 | 7 | 4 | 10 | 3 | 1 | 6 | 4 | 2 |
| | Median % TCEY 4CDE | 8 | 9 | 11 | 7 | 4 | 10 | 4 | 1 | 3 | 6 | 2 |
| | Median % TCEY4B | 8 | 8 | 11 | 5 | 5 | 10 | 3 | 5 | 2 | 3 | 1 |

# Average ranks

| Objectives | PMs | 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 | $P(SB < SB_{36\%})$ | 2 | 4 | 4 | 1 | 4 | 11 | 4 | 4 | 3 | 4 | 4 |
| Limit AC in coastwide TCEY | $P(AC_3 > 15\%)$ | 11 | 1 | 1 | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Limit AC in coastwide TCEY | Median AAV TCEY | 11 | 4 | 4 | 1 | 2 | 10 | 4 | 4 | 4 | 4 | 2 |
| Optimize average coastwide TCEY | Median TCEY | 5 | 1 | 9 | 1 | 7 | 5 | 1 | 8 | 9 | 4 | 11 |
| Limit AC in Reg Areas TCEY | $P(AC_3 > 15\%)$ RegAreas | 9.25 | 6.75 | 6.62 | 2.12 | 5.25 | 5.5 | 6.62 | 6.12 | 6.12 | 2.38 | 3 |
| Limit AAV in Reg Areas TCEY | Median AAV TCEY RegAreas | 8.38 | 6.12 | 7.62 | 2.5 | 6.12 | 6 | 5.88 | 5.25 | 6.62 | 3.12 | 2.62 |
| Optimize Reg Areas TCEY | Median TCEY RegAreas | 7.25 | 6.5 | 7.88 | 6 | 5.38 | 8.88 | 4.88 | 5.62 | 4.38 | 3.5 | 3.5 |
| Optimize TCEY % among Reg Areas | Median % TCEY RegAreas | 8.62 | 6.5 | 6.88 | 4.75 | 4.62 | 8 | 4.5 | 4.5 | 4 | 3.88 | 3.88 |
| Maintain minimum TCEY by Reg Areas | Median Min(TCEY) RegAreas | 6.38 | 6 | 8 | 5.88 | 4.38 | 8.38 | 4.25 | 4.5 | 3.88 | 4 | 4.88 |
| Maintain minimum % TCEY by Reg Areas | Median Min(% TCEY) RegAreas | 6.62 | 7 | 7.62 | 6.25 | 4.62 | 9.12 | 4.12 | 4.75 | 4.12 | 4.38 | 4.62 |

# Simulations and Results

http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/MSE-Explorer/

# Recommendations

a) **NOTE** paper IPHC-2020-MSAB016-09 which provides performance metrics for primary objectives for MSE simulations using six priority 1 management procedures.

b) **RECOMMEND** management procedures that meet primary objectives and perform best given consideration of trade-offs and possibly additional performance metrics.

c) **RECOMMEND** additional performance metrics that would be useful for the evaluation of management procedures.

d) **RECOMMEND** alternative ways to display and communicate results to assist in the evaluation of management procedures.

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

# Results investigating fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries

**PREPARED BY: IPHC SECRETARIAT (A. HICKS, P. CARPI, I. STEWART, & S. BERUKOFF; 19 SEPTEMBER, AND 9 OCTOBER 2020)**

## PURPOSE

To provide results from the International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) for the evaluation of management procedures (MPs) for distributing the TCEY.

## 1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) has now completed initial development of a framework (IPHC-2020-MSAB016-08) to investigate MPs related to distributing the Total Constant Exploitation Yield (TCEY) to IPHC Regulatory Areas. 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. These results will be evaluated by the MSAB to provide guidance to the IPHC Secretariat and to Commissioners for future MSE work and on identifying best performing MPs relative to the objectives defined by the Commission (Appendix I).

This document presents results available at the time of publication and it is expected that additional results will be available at MSAB016. MPs presented here will likely have additional simulations completed to increase precision of the performance metrics and additional MPs will likely be added. Primary and secondary priority MPs are identified in IPHC-2020-MSAB016-07, which is repeated in Appendix II for convenience.

This document provides a static view of results and a presentation of important outcomes. For additional insights and the most up to date set of results, readers are referred to the MSE Explorer online.

http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/MSE-Explorer/

## 2 SPECIFICS OF THE MANAGEMENT PROCEDURES

The full set of management procedures presented in Appendix II will be presented at MSAB016. In this document, only the priority 1 MPs are presented (MP-A, MP-B, MP-F, MP-G, MP-H, and MP-J) with SPR values of 40%, 43%, and 46%. A wider range of SPR values will also be presented at MSAB016.

Estimation error is important to include in MSE simulations, but it is also useful to present results without estimation error to understand the effect of estimation error. Three different types of estimation error are presented.

1. **No Estimation Error (noEE)**: The stock status, total mortality given the input SPR, the stock distribution, and any other quantities needed for the MP are known exactly.
2. **Simulated Estimation Error (EE)**: Error is added to the stock status and total mortality given the input SPR that are used in the MP by adding deviates to each that are sampled from a bivariate normal distribution with a 15% coefficient of variation on each and a correlation of 0.5. Additionally, an autocorrelation of 0.4 is used with the deviate from the previous year. This is the same method that was used in the coastwide MSE as described in IPHC-2018-MSAB012-07 Rev_1. Stock distribution is determined from survey data generated with random error similar to error estimates from the current survey time-series.
3. **Simulated assessment (SS)**: This method simulates the long coastwide stock assessment model that is included in the stock assessment ensemble and uses stock synthesis (SS). Data needed for the assessment model are generated with random error. These data are included in the assessment model which estimates the population parameters needed for the management procedure. This method is useful because it is likely a closer approximation of the stock assessment and includes bias, autocorrelation, and variability that the stock assessment may produce over time. This method can be expanded to include additional models (e.g., short coastwide model) but further testing is needed with those models to ensure that they perform adequately in the simulated projections.

## 3 RESULTS

The results below provide insights into the performance of the operating model as well as the performance of management procedures.

### 3.1 Projections without fishing mortality

Projections with parameter variability (e.g., natural morality, movement, etc.) and projection variability (e.g. simulated weight-at-age) produced a wide range of trajectories. Figure 1 shows the median of one-hundred simulations to 2099 without mortality due to fishing along with the interval between the $5^{th}$ and $95^{th}$ percentiles. Individual trajectories show that a single trajectory may cover a wide range of that interval in this 80-year period. The variability looks like it has reached its full range after 30 years, although there is an increasing trend near year 2090. This could be due to the small number of simulations and the expected high variability without fishing mortality. The inclusion of fishing mortality reduces this variability because SPR-based MPs are adjusting the harvest rate to remove an appropriate amount of biomass.

Overall, the population is highly variable and shows a wide range of potential unfished spawning biomass. This is largely due to changes in weight-at-age, but in these simulations is also due to the parameter variability. With fishing, the high variability will influence the variability in mortality limits.

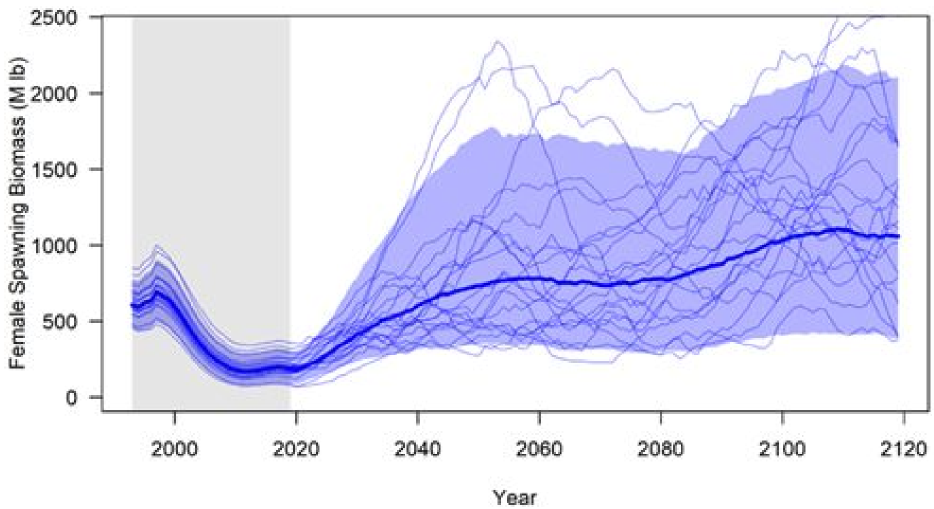



**Figure 1.** Six-hundred simulations for 100 years without fishing mortality. The blue line is the median and the blue shaded area shows the interval between the 5$^{th}$ and 95$^{th}$ percentiles. The light shaded grey area between 1993 and 2019 is the historical period, and 2020 has fixed fishing mortality based on the already defined catch limits for 2020. The thin blue lines are the first 20 individual trajectories.

### 3.2 Closed-loop simulation results

For brevity, only the simulated estimation error (EE) is used to compare across SPR values and tables with only an SPR of 43% are presented. Simulations with alternative estimation error modelling are available on the MSE Explorer.

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. No MP exceeds the 10% tolerance for RSB dropping below 20% SPR, and the median RSB resulting from an SPR of 40% is slightly less than 36%. Table 1 shows that the probability of being below 36% is slightly less for MP-A compared to all other MPs. The 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% was greater than zero for MP-A and zero for all other MPs. Median TCEY was slightly greater than 40 Mlbs for all MPs and SPR values, and showed slight variations between MPs. The difference in the median TCEY was less than 1 Mlbs between MPs for an SPR of 43% (Table 1).

Performance metrics for the TCEY in each IPHC Regulatory Area are shown in Figure 3 and Tables 2 & 3. These are the median minimum and median average TCEY over a ten-year period (long term) and the median minimum and median average percentage of TCEY in each IPHC Regulatory Area over a ten-year period (medium term). MPs F–K show decreased TCEY in 2A and MPS E–K show decreased TCYE 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 increases in 3B, 4A, and 4B with the increased relative harvest rate included in MP-H and MP-K, with decreases 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 (Table 4). Stability related performance metrics differences are evident at the IPHC Regulatory Area with MP-J, even though stability was not much different than 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.

Overall, the eleven MPs show minor differences 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 group of ranks (e.g., over IPHC Regulatory Areas) can assist in identify MPs that perform best overall.

The Biological Sustainability objectives have a tolerance defined, thus it can be determined if the 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 5). This distribution of the projected percentage of spawning biomass in Biological Region 4B has a probability of 0.19 to be less than 2% with no fishing mortality (Figure 4). This probability is slightly less with fishing mortality (Table 5) because the spawning biomass is less variable with fishing. The fact that this objective is not met without fishing or with any of the management procedures suggests two things: 1) the objective should be revisited and/or 2) the operating model is not adequately representing the population across Biological Regions.

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 a separate 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 results in Biological Region containing a small percentage of the spawning biomass even though the absolute spawning biomass is at a high level. Regardless, the spawning biomass persists in that Biological Region and in addition to revisiting the assumptions in the operating model, it would be prudent to revisit the regional spawning biomass objective.

The ranking of performance metrics for the Fishery Sustainability objectives are shown in Tables 6–9. Higher ranks generally occurred for MPs I, J, and K, although not necessarily for IPHC Regulatory Areas 2A and 2B when agreements were in place for those areas. The general objectives were averaged over IPHC Regulatory Areas to produce a summary of ranks as shown in Table 10. This summary shows that MPs J and K generally have higher ranks for stability and yield objectives specific to IPHC Regulatory Areas. However, the coastwide median average

TCEY is the lowest for MP J, although it varies by less than one million pounds across all MPs (Table 2).

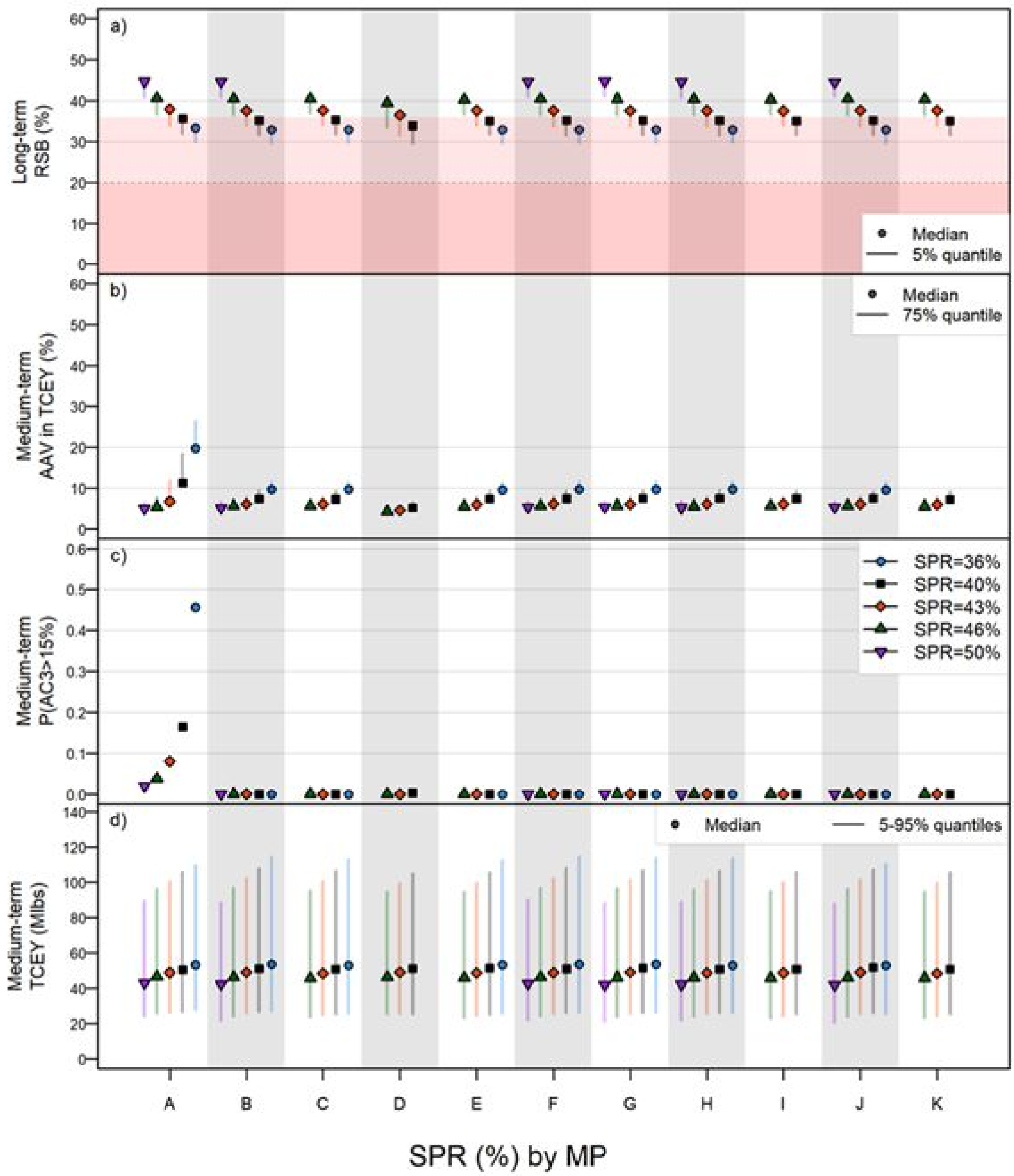



**Figure 2.** Coastwide performance metrics for MPs A through K using simulated estimation error with SPR values of 40%, 43%, and 46% for all and 36% and 50% for some. The relative spawning biomass and the thresholds of 20% and 36% are shown in a). The AAV for TCEY is shown in b). The probability that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

**Table 1.** Coastwide long-term performance metrics for the biological sustainability objective and P(all RSB<36%) and medium-term performance metrics for the remaining fishery sustainability objectives for MPs A through K for an SPR value of 43% using simulated estimation error.

| **Input SPR/TM** | **43** | **43** | **43** | **43** | **43** | **43** | **43** | **43** | **43** | **43** | **43** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Management Procedure** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** |
| Number of Simulations | 500 | 500 | 400 | 300 | 300 | 500 | 500 | 500 | 300 | 500 | 300 |
| **Biological Sustainability** | | | | | | | | | | | |
| P(any RSB_y<20%) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| **Fishery Sustainability** | | | | | | | | | | | |
| P(all RSB<36%) | 0.25 | 0.28 | 0.28 | 0.45 | 0.29 | 0.28 | 0.28 | 0.29 | 0.29 | 0.28 | 0.29 |
| Median average TCEY | 48.89 | 49.10 | 48.56 | 49.14 | 48.82 | 48.90 | 49.08 | 48.73 | 48.65 | 49.01 | 48.43 |
| P(any3 change TCEY > 15%) | 0.18 | <0.01 | <0.01 | 0.01 | <0.01 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | <0.01 |
| Median AAV TCEY | 6.8% | 6.1% | 6.1% | 4.6% | 6.0% | 6.2% | 6.1% | 6.1% | 6.1% | 6.1% | 6.0% |

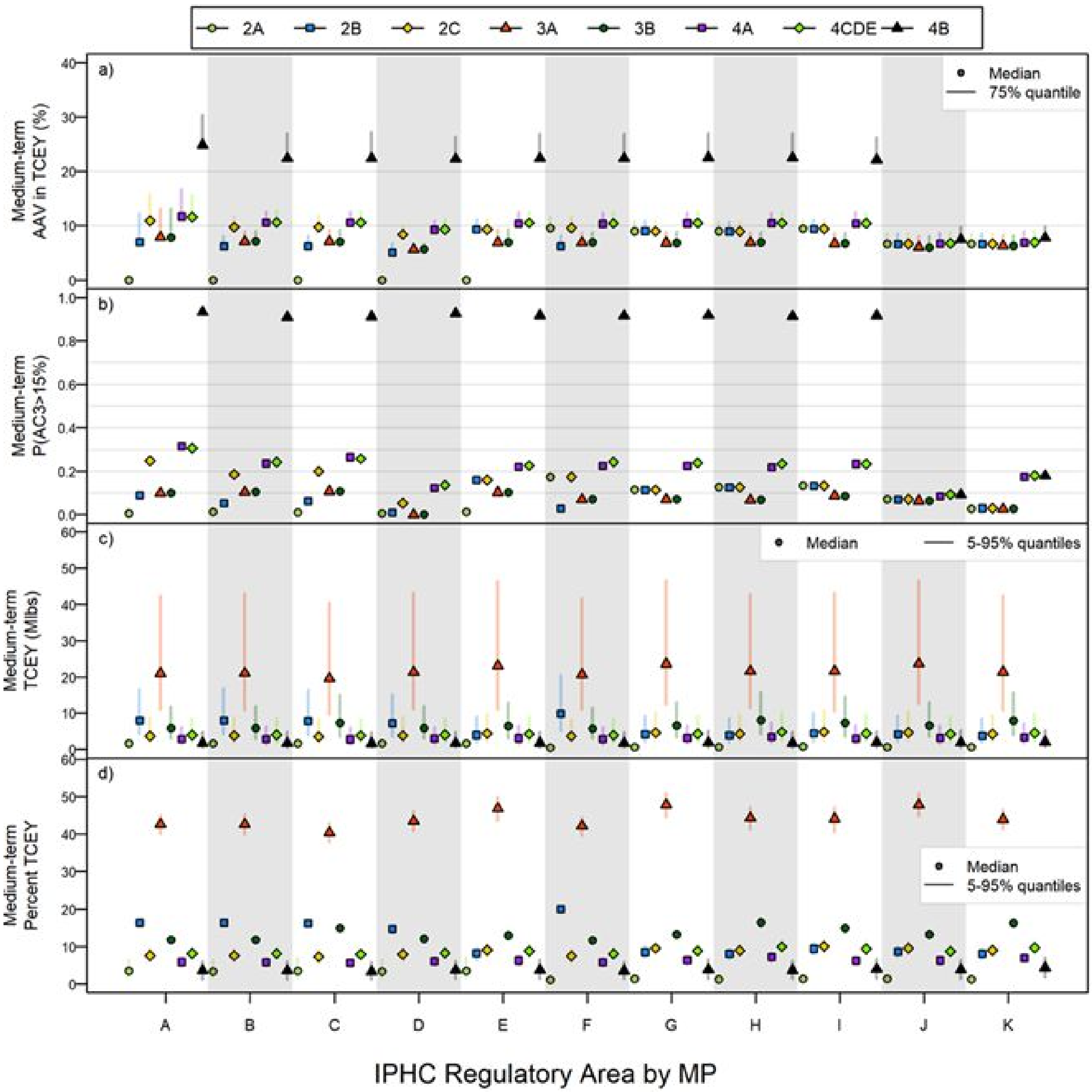



**Figure 3.** Performance metrics by IPHC Regulatory Areas for MPs A through K using simulated estimation error with an SPR value of 43%. The AAV for TCEY is shown in a). The probability that the annual change exceeds 15% in 3 or more years is shown in b). The median TCEY with 5th and 95th quantiles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

**Table 2.** Long-term spawning biomass performance metrics by Biological Region and TCEY medium-term performance metrics by IPHC Regulatory Areas for MPs A through K with an SPR value of 43% using simulated estimation error.

| **Input SPR/TM**<br>**Distribution Procedure** | **43%**<br>**A** | **43%**<br>**B** | **43%**<br>**C** | **43%**<br>**D** | **43%**<br>**E** | **43%**<br>**F** | **43%**<br>**G** | **43%**<br>**H** | **43%**<br>**I** | **43%**<br>**J** | **43%**<br>**K** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Simulations | 500 | 500 | 400 | 300 | 300 | 500 | 500 | 500 | 300 | 500 | 300 |
| **Biological Sustainability** | | | | | | | | | | | |
| $P(\%SB_{R=2} < 5\%)$ | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| $P(\%SB_{R=3} < 33\%)$ | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| $P(\%SB_{R=4} < 10\%)$ | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| $P(\%SB_{R=4B} < 2\%)$ | 0.15 | 0.15 | 0.16 | 0.14 | 0.15 | 0.15 | 0.16 | 0.15 | 0.15 | 0.16 | 0.17 |
| **Fishery Sustainability** | | | | | | | | | | | |
| Median Minimum TCEY 2A | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 0.40 | 0.51 | 0.48 | 0.55 | 0.52 | 0.48 |
| Median Minimum TCEY 2B | 6.06 | 6.40 | 6.29 | 5.94 | 3.06 | 7.81 | 3.22 | 2.99 | 3.52 | 3.26 | 3.01 |
| Median Minimum TCEY 2C | 2.65 | 2.82 | 2.66 | 3.05 | 3.40 | 2.78 | 3.59 | 3.33 | 3.75 | 3.63 | 3.35 |
| Median Minimum TCEY 3A | 15.83 | 16.54 | 15.66 | 17.73 | 18.03 | 16.40 | 18.53 | 17.14 | 17.24 | 18.69 | 17.07 |
| Median Minimum TCEY 3B | 4.39 | 4.59 | 5.79 | 4.92 | 5.00 | 4.55 | 5.14 | 6.34 | 5.81 | 5.18 | 6.31 |
| Median Minimum TCEY 4A | 2.04 | 2.18 | 2.07 | 2.31 | 2.33 | 2.15 | 2.37 | 2.66 | 2.27 | 2.42 | 2.71 |
| Median Minimum TCEY 4CDE | 2.79 | 2.98 | 2.83 | 3.16 | 3.19 | 2.95 | 3.24 | 3.64 | 3.38 | 3.31 | 3.71 |
| Median Minimum TCEY 4B | 1.02 | 1.14 | 1.07 | 1.22 | 1.22 | 1.12 | 1.24 | 1.16 | 1.23 | 1.44 | 1.64 |
| | | | | | | | | | | | |
| Median average TCEY-2A | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 0.52 | 0.66 | 0.62 | 0.70 | 0.67 | 0.60 |
| Median average TCEY-2B | 7.99 | 8.00 | 7.85 | 7.20 | 3.94 | 9.78 | 4.17 | 3.87 | 4.52 | 4.20 | 3.78 |
| Median average TCEY-2C | 3.70 | 3.76 | 3.53 | 3.83 | 4.39 | 3.64 | 4.64 | 4.31 | 4.82 | 4.68 | 4.21 |
| Median average TCEY-3A | 20.95 | 21.07 | 19.55 | 21.31 | 23.06 | 20.70 | 23.58 | 21.66 | 21.61 | 23.71 | 21.39 |
| Median average TCEY-3B | 5.81 | 5.84 | 7.23 | 5.91 | 6.40 | 5.74 | 6.54 | 8.01 | 7.28 | 6.58 | 7.91 |
| Median average TCEY-4A | 2.92 | 2.91 | 2.78 | 2.95 | 3.08 | 2.86 | 3.14 | 3.50 | 2.99 | 3.09 | 3.30 |
| Median average TCEY-4CDE | 4.00 | 3.99 | 3.81 | 4.04 | 4.23 | 3.91 | 4.31 | 4.80 | 4.46 | 4.24 | 4.53 |
| Median average TCEY-4B | 1.71 | 1.70 | 1.62 | 1.72 | 1.80 | 1.67 | 1.84 | 1.73 | 1.94 | 1.83 | 2.06 |

**Table 3.** Percentage of TCEY medium-term performance metrics by IPHC Regulatory Areas for MPs A through K with an SPR value of 43% using simulated estimation error.

| **Input SPR/TM** | **43%** | **43%** | **43%** | **43%** | **43%** | **43%** | **43%** | **43%** | **43%** | **43%** | **43%** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Distribution Procedure** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** |
| Number of Simulations | 500 | 500 | 400 | 300 | 300 | 500 | 500 | 500 | 300 | 500 | 300 |
| **Fishery Sustainability** | | | | | | | | | | | |
| Median Minimum % TCEY 2A | 2.7% | 2.8% | 2.9% | 2.8% | 2.8% | 0.9% | 1.2% | 1.1% | 1.3% | 1.3% | 1.2% |
| Median Minimum % TCEY 2B | 16.1% | 16.1% | 16.0% | 14.3% | 7.4% | 20.0% | 7.7% | 7.2% | 8.5% | 8.2% | 7.7% |
| Median Minimum % TCEY 2C | 6.7% | 6.8% | 6.4% | 7.0% | 8.2% | 6.6% | 8.6% | 8.0% | 9.1% | 9.2% | 8.5% |
| Median Minimum % TCEY 3A | 40.4% | 40.6% | 38.6% | 41.4% | 44.5% | 40.2% | 45.4% | 42.0% | 41.8% | 46.7% | 43.1% |
| Median Minimum % TCEY 3B | 11.2% | 11.3% | 14.3% | 11.5% | 12.3% | 11.1% | 12.6% | 15.5% | 14.1% | 13.0% | 15.9% |
| Median Minimum % TCEY 4A | 5.1% | 5.1% | 5.0% | 5.3% | 5.5% | 5.1% | 5.6% | 6.3% | 5.5% | 6.0% | 6.7% |
| Median Minimum % TCEY 4CDE | 7.1% | 7.1% | 6.9% | 7.2% | 7.6% | 7.0% | 7.7% | 8.7% | 8.2% | 8.2% | 9.3% |
| Median Minimum % TCEY 4B | 2.6% | 2.6% | 2.4% | 2.7% | 2.7% | 2.5% | 2.8% | 2.6% | 2.8% | 3.5% | 3.9% |
| | | | | | | | | | | | |
| Median average % TCEY 2A | 3.5% | 3.4% | 3.5% | 3.4% | 3.5% | 1.1% | 1.4% | 1.3% | 1.5% | 1.4% | 1.3% |
| Median average % TCEY 2B | 16.3% | 16.3% | 16.3% | 14.7% | 8.2% | 20.0% | 8.6% | 8.0% | 9.4% | 8.6% | 8.1% |
| Median average % TCEY 2C | 7.6% | 7.6% | 7.3% | 7.9% | 9.1% | 7.5% | 9.5% | 8.9% | 10.0% | 9.6% | 9.0% |
| Median average % TCEY 3A | 42.6% | 42.7% | 40.5% | 43.5% | 46.8% | 42.2% | 47.9% | 44.3% | 44.1% | 47.9% | 44.0% |
| Median average % TCEY 3B | 11.8% | 11.8% | 15.0% | 12.1% | 13.0% | 11.7% | 13.3% | 16.4% | 14.9% | 13.3% | 16.3% |
| Median average % TCEY 4A | 5.9% | 5.9% | 5.7% | 6.1% | 6.3% | 5.8% | 6.4% | 7.2% | 6.2% | 6.3% | 7.0% |
| Median average % TCEY 4CDE | 8.2% | 8.1% | 7.9% | 8.3% | 8.8% | 8.0% | 8.8% | 10.0% | 9.4% | 8.7% | 9.7% |
| Median average % TCEY 4B | 3.6% | 3.6% | 3.3% | 3.7% | 3.7% | 3.5% | 3.9% | 3.7% | 4.0% | 3.9% | 4.4 |

**Table 4.** Medium-term fishery stability performance metrics by IPHC Regulatory Areas for MPs A through K with an SPR value of 43% using simulated estimation error.

| **Input SPR/TM**<br>**Distribution Procedure** | **43%**<br>**A** | **43%**<br>**B** | **43%**<br>**C** | **43%**<br>**D** | **43%**<br>**E** | **43%**<br>**F** | **43%**<br>**G** | **43%**<br>**H** | **43%**<br>**I** | **43%**<br>**J** | **43%**<br>**K** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Simulations | 500 | 500 | 400 | 300 | 300 | 500 | 500 | 500 | 300 | 500 | 300 |
| **Fishery Sustainability** | | | | | | | | | | | |
| P(any3 change TCEY 2A > 15%) | 0.006 | 0.014 | 0.010 | 0.007 | 0.013 | 0.172 | 0.114 | 0.126 | 0.133 | 0.070 | 0.027 |
| P(any3 change TCEY 2B > 15%) | 0.090 | 0.054 | 0.063 | 0.010 | 0.160 | 0.028 | 0.114 | 0.126 | 0.133 | 0.070 | 0.030 |
| P(any3 change TCEY 2C > 15%) | 0.248 | 0.186 | 0.200 | 0.053 | 0.160 | 0.174 | 0.114 | 0.126 | 0.133 | 0.070 | 0.030 |
| P(any3 change TCEY 3A > 15%) | 0.100 | 0.104 | 0.108 | 0.000 | 0.103 | 0.070 | 0.070 | 0.068 | 0.087 | 0.064 | 0.027 |
| P(any3 change TCEY 3B > 15%) | 0.100 | 0.104 | 0.108 | 0.000 | 0.103 | 0.070 | 0.070 | 0.068 | 0.087 | 0.064 | 0.027 |
| P(any3 change TCEY 4A > 15%) | 0.314 | 0.236 | 0.265 | 0.123 | 0.220 | 0.226 | 0.226 | 0.218 | 0.233 | 0.084 | 0.173 |
| P(any3 change TCEY 4CDE > 15%) | 0.306 | 0.242 | 0.258 | 0.137 | 0.227 | 0.242 | 0.238 | 0.234 | 0.233 | 0.092 | 0.180 |
| P(any3 change TCEY 4B > 15%) | 0.932 | 0.910 | 0.913 | 0.927 | 0.917 | 0.916 | 0.918 | 0.914 | 0.917 | 0.092 | 0.180 |
| | | | | | | | | | | | |
| Median AAV TCEY 2A | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 9.6% | 9.0% | 8.9% | 9.4% | 6.6% | 6.6% |
| Median AAV TCEY 2B | 7.0% | 6.2% | 6.2% | 5.1% | 9.3% | 6.2% | 9.0% | 8.9% | 9.4% | 6.6% | 6.6% |
| Median AAV TCEY 2C | 10.9% | 9.8% | 9.8% | 8.4% | 9.3% | 9.6% | 9.0% | 8.9% | 9.4% | 6.6% | 6.6% |
| Median AAV TCEY 3A | 7.8% | 7.1% | 7.1% | 5.7% | 6.9% | 6.9% | 6.9% | 6.9% | 6.7% | 6.0% | 6.3% |
| Median AAV TCEY 3B | 7.8% | 7.1% | 7.1% | 5.7% | 6.9% | 6.9% | 6.9% | 6.9% | 6.7% | 6.0% | 6.3% |
| Median AAV TCEY 4A | 11.7% | 10.6% | 10.5% | 9.3% | 10.4% | 10.3% | 10.4% | 10.4% | 10.4% | 6.7% | 6.9% |
| Median AAV TCEY 4CDE | 11.6% | 10.6% | 10.6% | 9.3% | 10.5% | 10.4% | 10.5% | 10.5% | 10.5% | 6.8% | 6.9% |
| Median AAV TCEY 4B | 24.9% | 22.4% | 22.4% | 22.3% | 22.4% | 22.4% | 22.6% | 22.5% | 22.2% | 7.5% | 7.7% |

**Table 5.** 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 currently defined objective is not met, and green shading indicates that the objective is met. Values in the cells are the calculated probability.

| Objective | PM | 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 | 0.16 | 0.14 | 0.15 | 0.15 | 0.16 | 0.15 | 0.15 | 0.16 | 0.17 |

**Table 6.** 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. Blue shading represents the ranking with light coloring indicating the objective is better met compared to other management procedures.

| Objectives | PMs | 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 | 6 | 6 | 1 | 2 | 6 | 6 | 2 | 2 | 6 | 2 |

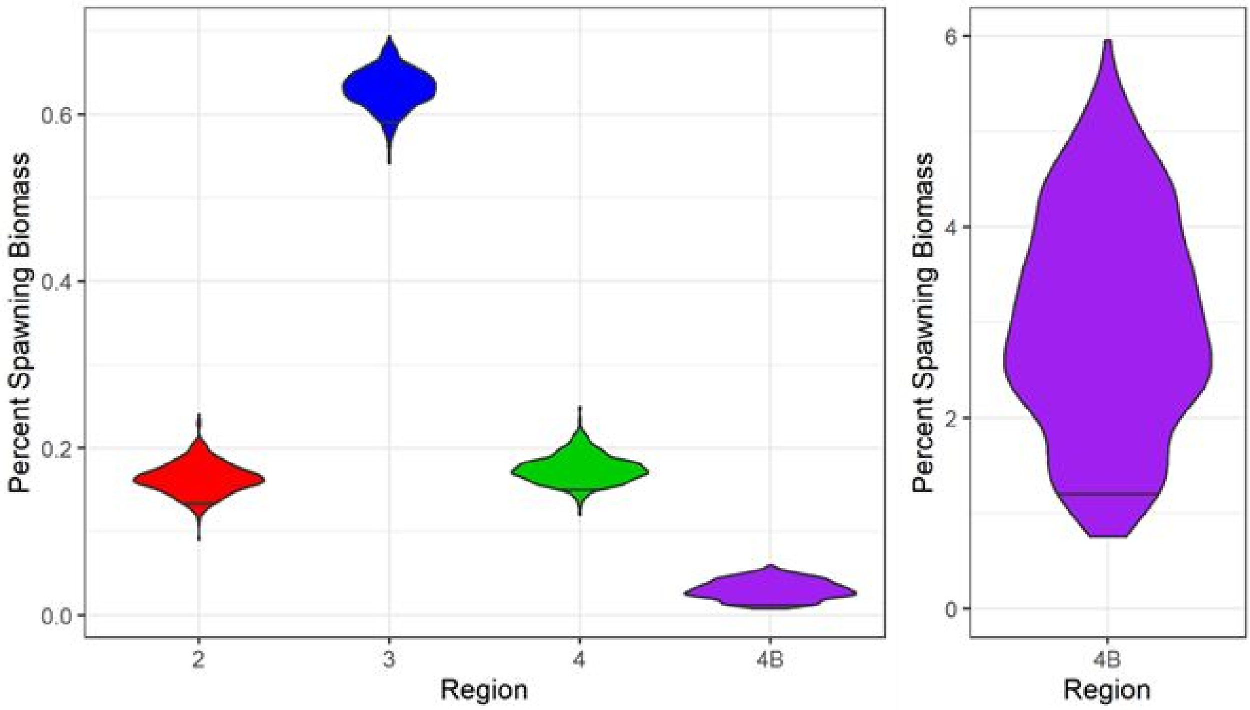



**Figure 4.** Distribution of the percentage of spawning biomass in each Biological Region after 60 years of projections with no fishing mortality. The right panel is zoomed in on Biological Region 4B. A horizontal line shows the 5% quantile in each plot.

**Table 7.** Medium-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.

| Objectives | PMs | 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 | 4 | 4 | 1 | 2 | 10 | 4 | 4 | 4 | 4 | 2 |
| Limit AC in Reg Areas TCEY | P($AC_3$ 2A > 15%) | 1 | 1 | 1 | 1 | 1 | 11 | 8 | 9 | 9 | 7 | 6 |
| | P($AC_3$ 2B > 15%) | 7 | 4 | 5 | 1 | 11 | 2 | 8 | 9 | 9 | 6 | 2 |
| | P($AC_3$ 2C > 15%) | 11 | 9 | 10 | 2 | 7 | 8 | 4 | 5 | 5 | 3 | 1 |
| | P($AC_3$ 3A > 15%) | 8 | 8 | 11 | 1 | 8 | 4 | 4 | 4 | 7 | 3 | 2 |
| | P($AC_3$ 3B > 15%) | 8 | 8 | 11 | 1 | 8 | 4 | 4 | 4 | 7 | 3 | 2 |
| | P($AC_3$ 4A > 15%) | 11 | 9 | 10 | 2 | 4 | 6 | 6 | 4 | 6 | 1 | 3 |
| | P($AC_3$ 4CDE > 15%) | 11 | 7 | 10 | 2 | 4 | 7 | 7 | 4 | 4 | 1 | 3 |
| | P($AC_3$ 4B > 15%) | 10 | 3 | 3 | 10 | 6 | 6 | 6 | 3 | 6 | 1 | 2 |
| Limit AAV in Reg Areas TCEY | Median AAV 2A | 1 | 1 | 1 | 1 | 1 | 11 | 9 | 8 | 10 | 6 | 6 |
| | Median AAV 2B | 7 | 2 | 2 | 1 | 10 | 2 | 9 | 8 | 11 | 5 | 5 |
| | Median AAV 2C | 11 | 9 | 9 | 3 | 6 | 8 | 5 | 4 | 7 | 1 | 1 |
| | Median AAV 3A | 11 | 9 | 9 | 1 | 5 | 5 | 5 | 5 | 4 | 2 | 3 |
| | Median AAV 3B | 11 | 9 | 9 | 1 | 5 | 5 | 5 | 5 | 4 | 2 | 3 |
| | Median AAV 4A | 11 | 10 | 9 | 3 | 5 | 4 | 5 | 5 | 5 | 1 | 2 |
| | Median AAV 4CDE | 11 | 9 | 9 | 3 | 5 | 4 | 5 | 5 | 5 | 1 | 2 |
| | Median AAV 4B | 1 | 5 | 5 | 4 | 5 | 5 | 10 | 9 | 3 | 1 | 2 |

**Table 8.** Medium-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.

| Objectives | PMs | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimize TCEY | Median TCEY | 5 | 1 | 9 | 1 | 7 | 5 | 1 | 8 | 9 | 4 | 11 |
| Maintain minimum TCEY by Reg Areas | Median Min 2A | 1 | 1 | 1 | 1 | 1 | 11 | 7 | 7 | 6 | 7 | 7 |
| | Median Min 2B | 4 | 2 | 3 | 5 | 9 | 1 | 8 | 10 | 6 | 7 | 10 |
| | Median Min 2C | 11 | 8 | 10 | 7 | 4 | 8 | 2 | 6 | 1 | 2 | 4 |
| | Median Min 3A | 10 | 8 | 11 | 4 | 3 | 9 | 2 | 6 | 5 | 1 | 6 |
| | Median Min 3B | 11 | 9 | 3 | 8 | 7 | 10 | 6 | 1 | 3 | 5 | 1 |
| | Median Min 4A | 11 | 8 | 9 | 5 | 5 | 9 | 3 | 1 | 5 | 3 | 1 |
| | Median Min 4CDE | 10 | 8 | 10 | 5 | 5 | 8 | 5 | 2 | 3 | 4 | 1 |
| | Median Min 4B | 11 | 8 | 8 | 3 | 3 | 8 | 3 | 3 | 3 | 2 | 1 |
| Optimize Reg Areas TCEY | Median TCEY2A | 1 | 1 | 1 | 1 | 1 | 11 | 6 | 9 | 6 | 6 | 9 |
| | Median TCEY2B | 2 | 2 | 4 | 5 | 9 | 1 | 7 | 9 | 6 | 7 | 11 |
| | Median TCEY2C | 9 | 7 | 11 | 7 | 4 | 10 | 3 | 5 | 1 | 2 | 6 |
| | Median TCEY3A | 9 | 8 | 11 | 7 | 3 | 10 | 2 | 4 | 5 | 1 | 6 |
| | Median TCEY3B | 9 | 9 | 4 | 8 | 7 | 11 | 6 | 1 | 3 | 5 | 2 |
| | Median TCEY4A | 8 | 8 | 11 | 6 | 3 | 8 | 3 | 1 | 6 | 3 | 2 |
| | Median TCEY4CDE | 7 | 7 | 11 | 7 | 5 | 10 | 4 | 1 | 2 | 5 | 2 |
| | Median TCEY4B | 6 | 6 | 11 | 6 | 3 | 6 | 3 | 6 | 2 | 3 | 1 |

**Table 9.** Medium-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

| Objectives | PMs | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maintain minimum % TCEY by Reg Areas | Median Min % 2A | 5 | 2 | 1 | 2 | 2 | 11 | 8 | 10 | 6 | 6 | 8 |
| | Median Min % 2B | 2 | 2 | 4 | 5 | 10 | 1 | 8 | 11 | 6 | 7 | 8 |
| | Median Min % 2C | 9 | 8 | 11 | 7 | 5 | 10 | 3 | 6 | 2 | 1 | 4 |
| | Median Min % 3A | 9 | 8 | 11 | 7 | 3 | 10 | 2 | 5 | 6 | 1 | 4 |
| | Median Min % 3B | 10 | 9 | 3 | 8 | 7 | 11 | 6 | 2 | 4 | 5 | 1 |
| | Median Min % 4A | 8 | 8 | 11 | 7 | 5 | 8 | 4 | 2 | 5 | 3 | 1 |
| | Median Min % 4CDE | 8 | 8 | 11 | 7 | 6 | 10 | 5 | 2 | 3 | 3 | 1 |
| | Median Min % 4B | 7 | 7 | 11 | 5 | 5 | 10 | 3 | 7 | 3 | 2 | 1 |
| Optimize TCEY percentage among Reg Areas | Median % TCEY2A | 1 | 4 | 1 | 4 | 1 | 11 | 7 | 9 | 6 | 7 | 9 |
| | Median % TCEY2B | 2 | 2 | 2 | 5 | 9 | 1 | 7 | 11 | 6 | 7 | 10 |
| | Median % TCEY2C | 8 | 8 | 11 | 7 | 4 | 10 | 3 | 6 | 1 | 2 | 5 |
| | Median % TCEY3A | 9 | 8 | 11 | 7 | 3 | 10 | 1 | 4 | 5 | 1 | 6 |
| | Median % TCEY3B | 9 | 9 | 3 | 8 | 7 | 11 | 5 | 1 | 4 | 5 | 2 |
| | Median % TCEY4A | 8 | 8 | 11 | 7 | 4 | 10 | 3 | 1 | 6 | 4 | 2 |
| | Median % TCEY4CDE | 8 | 9 | 11 | 7 | 4 | 10 | 4 | 1 | 3 | 6 | 2 |
| | Median % TCEY4B | 8 | 8 | 11 | 5 | 5 | 10 | 3 | 5 | 2 | 3 | 1 |

**Table 10.** Ranks for fishery yield and stability performance metrics averaged with equal weighting over IPHC Regulatory Areas for those that are reported by IPHC Regulatory Areas. Medium-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.

| Objectives | PMs | 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 | $P(SB < SB_{36\%})$ | 2 | 4 | 4 | 1 | 4 | 11 | 4 | 4 | 3 | 4 | 4 |
| Limit AC in coastwide TCEY | $P(AC_3 > 15\%)$ | 11 | 1 | 1 | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Limit AC in coastwide TCEY | Median AAV TCEY | 11 | 4 | 4 | 1 | 2 | 10 | 4 | 4 | 4 | 4 | 2 |
| Optimize average coastwide TCEY | Median TCEY | 5 | 1 | 9 | 1 | 7 | 5 | 1 | 8 | 9 | 4 | 11 |
| Limit AC in Reg Areas TCEY | $P(AC_3 > 15\%)$ RegAreas | 9.25 | 6.75 | 6.62 | 2.12 | 5.25 | 5.5 | 6.62 | 6.12 | 6.12 | 2.38 | 3 |
| Limit AAV in Reg Areas TCEY | Median AAV TCEY RegAreas | 8.38 | 6.12 | 7.62 | 2.5 | 6.12 | 6 | 5.88 | 5.25 | 6.62 | 3.12 | 2.62 |
| Optimize Reg Areas TCEY | Median TCEY RegAreas | 7.25 | 6.5 | 7.88 | 6 | 5.38 | 8.88 | 4.88 | 5.62 | 4.38 | 3.5 | 3.5 |
| Optimize TCEY percentage among Reg Areas | Median % TCEY RegAreas | 8.62 | 6.5 | 6.88 | 4.75 | 4.62 | 8 | 4.5 | 4.5 | 4 | 3.88 | 3.88 |
| Maintain minimum TCEY by Reg Areas | Median Min(TCEY) RegAreas | 6.38 | 6 | 8 | 5.88 | 4.38 | 8.38 | 4.25 | 4.5 | 3.88 | 4 | 4.88 |
| Maintain minimum % TCEY by Reg Areas | Median Min(% TCEY) RegAreas | 6.62 | 7 | 7.62 | 6.25 | 4.62 | 9.12 | 4.12 | 4.75 | 4.12 | 4.38 | 4.62 |

## 4 RECOMMENDATIONS

That the MSAB:

a) **NOTE** paper IPHC-2020-MSAB016-09 Rev_1 which provides performance metrics for primary objectives for MSE simulations using six priority 1 management procedures.

b) **RECOMMEND** management procedures that meet primary objectives and perform best given consideration of trade-offs and possibly additional performance metrics.

c) **RECOMMEND** additional performance metrics that would be useful for the evaluation of management procedures.

d) **RECOMMEND** alternative ways to display and communicate results to assist in the evaluation of management procedures.

## 5 REFERENCES

IPHC-2018-MSAB012-07 Rev_1. Hicks A; Stewart I. 2018. IPHC Management Strategy Evaluation to investigate fishing intensity. 33 p. https://iphc.int/uploads/pdf/msab/msab12/iphc-2018-msab012-07.pdf

IPHC-2020-MSAB016-07. Potential management procedures to determine the total constant exploitation yield (TCEY) by IPHC Regulatory Area for Pacific halibut fisheries.

## 6 APPENDICES

Appendix I: Primary objectives defined by the Commission for the MSE

Appendix II: Proposed and Recommended Management Procedures from MSAB015

# APPENDIX I
## PRIMARY OBJECTIVES DEFINED BY THE COMMISSION FOR THE MSE

**Table 11.** Primary measurable objectives, evaluated over a simulated ten-year period, accepted by the Commission at the 7th Special Session of the Commission (SS07). Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives.

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

## APPENDIX II
## PROPOSED AND RECOMMENDED MANAGEMENT PROCEDURES FROM MSAB015

Recommended management procedures to be evaluated by the MSAB in 2020 and the priority of investigation. A priority of 1 denotes a focus on producing precise performance metrics. Reproduced from IPHC-2020-MSAB015-R.

**Table II.1.** Recommended management procedures to be evaluated by the MSAB in 2020 and the priority of investigation. A priority of 1 denotes a focus on producing precise performance metrics. A priority of 2 denotes potentially fewer simulations are desired, if time is constrained.

| MP | Coastwide | Regional | IPHC Regulatory Area | Priority |
|---|---|---|---|---|
| MP 15-A | SPR 30:20 | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 1 |
| MP 15-B | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 1 |
| MP 15-C | SPR 30:20 MaxChange15% | Biological Regions, O32 stock distribution Rel HRs[3]: R2=1, R3=1, R4=0.75, R4B=0.75 | • O32 stock distribution<br>• Relative harvest rates not applied<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 2 |
| MP 15-D | SPR 30:20 MaxChange15% Max FI (36%) | | First<br>• O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>Second within buffer (pro-rated if exceeds buffer)<br>• 1.65 Mlbs floor in 2A[1]<br>• Formula percentage for 2B[2] | 2 |
| MP 15-E | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Proportional relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4)<br>• 1.65 Mlbs floor in 2A[1] | 2 |
| MP 15-F | SPR 30:20 MaxChange15% | National Shares: 20% to 2B, 80% to other | • O32 stock distribution to areas other than 2B<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 1 |
| MP 15-G | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 1 |

| MP | Coastwide | Regional | IPHC Regulatory Area | Priority |
|---|---|---|---|---|
| MP 15-H | SPR 30:20 MaxChange15% | | • O32 stock distribution<br>• Relative harvest rates (1 for 2-3, 4A, 4CDE, 0.75 for 4B) | 1 |
| MP 15-I | SPR 30:20 MaxChange15% | | • All sizes stock distribution<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 2 |
| MP 15-J | SPR 30:20 MaxChange15% | | • O32 stock distribution (5-year moving average)<br>• Relative harvest rates (1.0 for 2-3A, 0.75 for 3B-4) | 1 |
| MP 15-K | SPR 30:20 MaxChange15% | | • 5-year shares determined from 5-year O32 stock distribution (vary over time but change only every 5th year) | 2 |

[1] paragraph 97b IPHC-2020-AM096-R
[2] paragraph 97c of IPHC-2020-AM096-R
[3] R2 refers to Biological Region 2 (2A, 2B, 2C); R3 refers to Biological Region 3 (3A, 3B); R4 refers to Biological Region 4 (4A, 4CDE), and R4B refers to Biological Region 4B

## APPENDIX III
## PERFORMANCE METRICS FOR PRIORITY MPS AND SELECT SPR VALUES

**Table 12.** Coastwide long-term performance metrics for the biological sustainability objective and P(all RSB<36%) and medium-term performance metrics for the remaining fishery sustainability objectives for MPs A, B, F, G, H, and J for SPR values of 40%, 43%, and 46% using simulated estimation error.

| **Input SPR/TM**<br>**Distn Proc** | **40**<br>**A** | **40**<br>**B** | **40**<br>**F** | **40**<br>**G** | **40**<br>**H** | **40**<br>**J** |
|---|---|---|---|---|---|---|
| nSims | 500 | 500 | 500 | 500 | 500 | 500 |
| **Biological Sustainability** | | | | | | |
| P(any RSB_y<20%) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| **Fishery Sustainability** | | | | | | |
| P(all RSB<36%) | 0.565 | 0.617 | 0.617 | 0.616 | 0.618 | 0.610 |
| Median average TCEY | 50.67 | 51.12 | 51.02 | 51.56 | 50.94 | 51.75 |
| P(any3 change TCEY > 15%) | 0.37 | 0 | 0 | 0 | 0 | 0 |
| Median AAV TCEY | 11.3% | 7.4% | 7.5% | 7.6% | 7.6% | 7.6% |

| **Input SPR/TM**<br>**Distn Proc** | **43**<br>**A** | **43**<br>**B** | **43**<br>**F** | **43**<br>**G** | **43**<br>**H** | **43**<br>**J** |
|---|---|---|---|---|---|---|
| nSims | 500 | 500 | 500 | 500 | 500 | 500 |
| **Biological Sustainability** | | | | | | |
| P(any RSB_y<20%) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| **Fishery Sustainability** | | | | | | |
| P(all RSB<36%) | 0.251 | 0.279 | 0.278 | 0.284 | 0.289 | 0.283 |
| Median average TCEY | 48.89 | 49.10 | 48.90 | 49.08 | 48.73 | 49.01 |
| P(any3 change TCEY > 15%) | 0.178 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Median AAV TCEY | 6.8% | 6.1% | 6.2% | 6.1% | 6.1% | 6.1% |

| **Input SPR/TM**<br>**Distn Proc** | **46**<br>**A** | **46**<br>**B** | **46**<br>**F** | **46**<br>**G** | **46**<br>**H** | **46**<br>**J** |
|---|---|---|---|---|---|---|
| nSims | 500 | 500 | 500 | 500 | 500 | 500 |
| **Biological Sustainability** | | | | | | |
| P(any RSB_y<20%) | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| **Fishery Sustainability** | | | | | | |
| P(all RSB<36%) | 0.043 | 0.044 | 0.044 | 0.049 | 0.050 | 0.048 |
| Median average TCEY | 46.67 | 46.42 | 46.36 | 46.24 | 46.18 | 46.21 |
| P(any3 change TCEY > 15%) | 0.092 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Median AAV TCEY | 5.5% | 5.6% | 5.6% | 5.7% | 5.6% | 5.7% |

**Table 13.** TCEY medium-term performance metrics by IPHC Regulatory Areas for MPs A, B, F, G, H, and J with an SPR value of 40% using simulated estimation error.

| **Input SPR/TM**<br>**Distribution Procedure** | **40%**<br>**A** | **40%**<br>**B** | **40%**<br>**F** | **40%**<br>**G** | **40%**<br>**H** | **40%**<br>**J** |
|---|---|---|---|---|---|---|
| Number of Simulations | 500 | 500 | 500 | 500 | 500 | 500 |
| **Fishery Sustainability** | | | | | | |
| Median average TCEY-2A | 1.65 | 1.65 | 0.54 | 0.70 | 0.65 | 0.71 |
| Median average TCEY-2B | 8.37 | 8.42 | 10.20 | 4.38 | 4.09 | 4.43 |
| Median average TCEY-2C | 3.84 | 3.94 | 3.80 | 4.88 | 4.56 | 4.94 |
| Median average TCEY-3A | 21.58 | 21.84 | 21.33 | 24.66 | 22.74 | 24.85 |
| Median average TCEY-3B | 5.99 | 6.06 | 5.92 | 6.84 | 8.41 | 6.89 |
| Median average TCEY-4A | 3.06 | 3.10 | 3.04 | 3.33 | 3.71 | 3.29 |
| Median average TCEY-4CDE | 4.20 | 4.24 | 4.17 | 4.57 | 5.09 | 4.51 |
| Median average TCEY-4B | 1.80 | 1.80 | 1.78 | 1.96 | 1.84 | 1.93 |
| | | | | | | |
| Median AAV TCEY 2A | 0.0% | 0.0% | 10.3% | 9.6% | 9.6% | 7.9% |
| Median AAV TCEY 2B | 11.5% | 7.5% | 7.5% | 9.6% | 9.6% | 7.9% |
| Median AAV TCEY 2C | 14.5% | 10.4% | 10.3% | 9.6% | 9.6% | 7.9% |
| Median AAV TCEY 3A | 12.4% | 8.2% | 8.0% | 8.1% | 8.1% | 7.5% |
| Median AAV TCEY 3B | 12.4% | 8.2% | 8.0% | 8.1% | 8.1% | 7.5% |
| Median AAV TCEY 4A | 15.2% | 11.2% | 11.0% | 11.2% | 11.2% | 7.9% |
| Median AAV TCEY 4CDE | 14.7% | 11.2% | 11.1% | 11.2% | 11.2% | 8.0% |
| Median AAV TCEY 4B | 28.1% | 23.0% | 22.8% | 23.2% | 23.2% | 8.6% |
| | | | | | | |
| P(any3 change TCEY 2A > 15%) | 0.0040 | 0.0100 | 0.2320 | 0.1900 | 0.1920 | 0.1000 |
| P(any3 change TCEY 2B > 15%) | 0.1720 | 0.0820 | 0.0260 | 0.1900 | 0.1920 | 0.1000 |
| P(any3 change TCEY 2C > 15%) | 0.3960 | 0.2480 | 0.2340 | 0.1900 | 0.1920 | 0.1000 |
| P(any3 change TCEY 3A > 15%) | 0.1980 | 0.1520 | 0.0900 | 0.1000 | 0.1020 | 0.0820 |
| P(any3 change TCEY 3B > 15%) | 0.1980 | 0.1520 | 0.0900 | 0.1000 | 0.1020 | 0.0820 |
| P(any3 change TCEY 4A > 15%) | 0.4380 | 0.3300 | 0.2960 | 0.2980 | 0.3040 | 0.1200 |
| P(any3 change TCEY 4CDE > 15%) | 0.4360 | 0.3120 | 0.3020 | 0.3100 | 0.3080 | 0.1300 |
| P(any3 change TCEY 4B > 15%) | 0.9440 | 0.9160 | 0.9160 | 0.9200 | 0.9240 | 0.1340 |
| | | | | | | |
| Median average TCEY percentage 2A | 3.5% | 3.3% | 1.1% | 1.4% | 1.3% | 1.4% |
| Median average TCEY percentage 2B | 16.3% | 16.3% | 20.0% | 8.6% | 8.0% | 8.6% |
| Median average TCEY percentage 2C | 7.6% | 7.6% | 7.4% | 9.6% | 9.0% | 9.6% |
| Median average TCEY percentage 3A | 42.5% | 42.7% | 42.1% | 47.8% | 44.3% | 47.8% |
| Median average TCEY percentage 3B | 11.8% | 11.8% | 11.7% | 13.3% | 16.4% | 13.3% |
| Median average TCEY percentage 4A | 5.9% | 5.9% | 5.9% | 6.4% | 7.2% | 6.3% |
| Median average TCEY percentage 4CDE | 8.3% | 8.2% | 8.1% | 8.9% | 10.0% | 8.7% |
| Median average TCEY percentage 4B | 3.6% | 3.6% | 3.5% | 3.9% | 3.7% | 3.9% |

**Table 14.** TCEY medium-term performance metrics by IPHC Regulatory Areas for MPs A, B, F, G, H, and J with an SPR value of 43% using simulated estimation error.

| **Input SPR/TM**<br>**Distribution Procedure** | **43%**<br>**A** | **43%**<br>**B** | **43%**<br>**F** | **43%**<br>**G** | **43%**<br>**H** | **43%**<br>**J** |
|---|---|---|---|---|---|---|
| Number of Simulations | 500 | 500 | 500 | 500 | 500 | 500 |
| **Fishery Sustainability** | | | | | | |
| Median average TCEY-2A | 1.65 | 1.65 | 0.52 | 0.66 | 0.62 | 0.67 |
| Median average TCEY-2B | 7.99 | 8.00 | 9.78 | 4.17 | 3.87 | 4.20 |
| Median average TCEY-2C | 3.70 | 3.76 | 3.64 | 4.64 | 4.31 | 4.68 |
| Median average TCEY-3A | 20.95 | 21.07 | 20.70 | 23.58 | 21.66 | 23.71 |
| Median average TCEY-3B | 5.81 | 5.84 | 5.74 | 6.54 | 8.01 | 6.58 |
| Median average TCEY-4A | 2.92 | 2.91 | 2.86 | 3.14 | 3.50 | 3.09 |
| Median average TCEY-4CDE | 4.00 | 3.99 | 3.91 | 4.31 | 4.80 | 4.24 |
| Median average TCEY-4B | 1.71 | 1.70 | 1.67 | 1.84 | 1.73 | 1.83 |
| | | | | | | |
| Median AAV TCEY 2A | 0.0% | 0.0% | 9.6% | 9.0% | 8.9% | 6.6% |
| Median AAV TCEY 2B | 7.0% | 6.2% | 6.2% | 9.0% | 8.9% | 6.6% |
| Median AAV TCEY 2C | 10.9% | 9.8% | 9.6% | 9.0% | 8.9% | 6.6% |
| Median AAV TCEY 3A | 7.8% | 7.1% | 6.9% | 6.9% | 6.9% | 6.0% |
| Median AAV TCEY 3B | 7.8% | 7.1% | 6.9% | 6.9% | 6.9% | 6.0% |
| Median AAV TCEY 4A | 11.7% | 10.6% | 10.3% | 10.4% | 10.4% | 6.7% |
| Median AAV TCEY 4CDE | 11.6% | 10.6% | 10.4% | 10.5% | 10.5% | 6.8% |
| Median AAV TCEY 4B | 24.9% | 22.4% | 22.4% | 22.6% | 22.5% | 7.5% |
| | | | | | | |
| P(any3 change TCEY 2A > 15%) | 0.0060 | 0.0140 | 0.1720 | 0.1140 | 0.1260 | 0.0700 |
| P(any3 change TCEY 2B > 15%) | 0.0900 | 0.0540 | 0.0280 | 0.1140 | 0.1260 | 0.0700 |
| P(any3 change TCEY 2C > 15%) | 0.2480 | 0.1860 | 0.1740 | 0.1140 | 0.1260 | 0.0700 |
| P(any3 change TCEY 3A > 15%) | 0.1000 | 0.1040 | 0.0700 | 0.0700 | 0.0680 | 0.0640 |
| P(any3 change TCEY 3B > 15%) | 0.1000 | 0.1040 | 0.0700 | 0.0700 | 0.0680 | 0.0640 |
| P(any3 change TCEY 4A > 15%) | 0.3140 | 0.2360 | 0.2260 | 0.2260 | 0.2180 | 0.0840 |
| P(any3 change TCEY 4CDE > 15%) | 0.3060 | 0.2420 | 0.2420 | 0.2380 | 0.2340 | 0.0920 |
| P(any3 change TCEY 4B > 15%) | 0.9320 | 0.9100 | 0.9160 | 0.9180 | 0.9140 | 0.0920 |
| | | | | | | |
| Median average TCEY percentage 2A | 3.5% | 3.4% | 1.1% | 1.4% | 1.3% | 1.4% |
| Median average TCEY percentage 2B | 16.3% | 16.3% | 20.0% | 8.6% | 8.0% | 8.6% |
| Median average TCEY percentage 2C | 7.6% | 7.6% | 7.5% | 9.5% | 8.9% | 9.6% |
| Median average TCEY percentage 3A | 42.6% | 42.7% | 42.2% | 47.9% | 44.3% | 47.9% |
| Median average TCEY percentage 3B | 11.8% | 11.8% | 11.7% | 13.3% | 16.4% | 13.3% |
| Median average TCEY percentage 4A | 5.9% | 5.9% | 5.8% | 6.4% | 7.2% | 6.3% |
| Median average TCEY percentage 4CDE | 8.2% | 8.1% | 8.0% | 8.8% | 10.0% | 8.7% |
| Median average TCEY percentage 4B | 3.6% | 3.6% | 3.5% | 3.9% | 3.7% | 3.9% |

**Table 15.** TCEY performance metrics by IPHC Regulatory Areas for MPs A, B, F, G, H, and J with an SPR value of 46% using simulated estimation error.

| **Input SPR/TM**<br>**Distribution Procedure** | **46%**<br>**A** | **46%**<br>**B** | **46%**<br>**F** | **46%**<br>**G** | **46%**<br>**H** | **46%**<br>**J** |
|---|---|---|---|---|---|---|
| Number of Simulations | 500 | 500 | 500 | 500 | 500 | 500 |
| **Fishery Sustainability** | | | | | | |
| Median average TCEY-2A | 1.65 | 1.65 | 0.50 | 0.63 | 0.58 | 0.63 |
| Median average TCEY-2B | 7.61 | 7.58 | 9.27 | 3.93 | 3.66 | 3.96 |
| Median average TCEY-2C | 3.56 | 3.57 | 3.48 | 4.38 | 4.07 | 4.42 |
| Median average TCEY-3A | 20.12 | 19.86 | 19.54 | 22.38 | 20.56 | 22.43 |
| Median average TCEY-3B | 5.58 | 5.51 | 5.42 | 6.21 | 7.60 | 6.22 |
| Median average TCEY-4A | 2.75 | 2.74 | 2.69 | 2.96 | 3.34 | 2.91 |
| Median average TCEY-4CDE | 3.77 | 3.75 | 3.69 | 4.06 | 4.58 | 4.00 |
| Median average TCEY-4B | 1.60 | 1.59 | 1.57 | 1.72 | 1.61 | 1.73 |
| | | | | | | |
| Median AAV TCEY 2A | 0.0% | 0.0% | 9.4% | 8.6% | 8.6% | 6.1% |
| Median AAV TCEY 2B | 5.6% | 5.7% | 5.6% | 8.6% | 8.6% | 6.1% |
| Median AAV TCEY 2C | 9.5% | 9.3% | 9.4% | 8.6% | 8.6% | 6.1% |
| Median AAV TCEY 3A | 6.5% | 6.5% | 6.3% | 6.6% | 6.5% | 5.6% |
| Median AAV TCEY 3B | 6.5% | 6.5% | 6.3% | 6.6% | 6.5% | 5.6% |
| Median AAV TCEY 4A | 10.3% | 10.0% | 9.9% | 10.0% | 10.1% | 6.3% |
| Median AAV TCEY 4CDE | 10.3% | 10.1% | 10.0% | 10.1% | 10.1% | 6.4% |
| Median AAV TCEY 4B | 23.4% | 22.4% | 22.3% | 22.5% | 22.4% | 7.0% |
| | | | | | | |
| P(any3 change TCEY 2A > 15%) | 0.0040 | 0.0120 | 0.1380 | 0.0940 | 0.1040 | 0.0580 |
| P(any3 change TCEY 2B > 15%) | 0.0460 | 0.0460 | 0.0240 | 0.0940 | 0.1040 | 0.0580 |
| P(any3 change TCEY 2C > 15%) | 0.1540 | 0.1520 | 0.1400 | 0.0940 | 0.1040 | 0.0580 |
| P(any3 change TCEY 3A > 15%) | 0.0540 | 0.0760 | 0.0500 | 0.0560 | 0.0540 | 0.0540 |
| P(any3 change TCEY 3B > 15%) | 0.0540 | 0.0760 | 0.0500 | 0.0560 | 0.0540 | 0.0540 |
| P(any3 change TCEY 4A > 15%) | 0.2400 | 0.2180 | 0.1920 | 0.1780 | 0.1740 | 0.0620 |
| P(any3 change TCEY 4CDE > 15%) | 0.2480 | 0.2140 | 0.2140 | 0.1940 | 0.1820 | 0.0700 |
| P(any3 change TCEY 4B > 15%) | 0.9180 | 0.9060 | 0.9060 | 0.9060 | 0.9020 | 0.0680 |
| | | | | | | |
| Median average TCEY percentage 2A | 3.6% | 3.6% | 1.1% | 1.4% | 1.3% | 1.4% |
| Median average TCEY percentage 2B | 16.4% | 16.4% | 20.0% | 8.6% | 8.0% | 8.6% |
| Median average TCEY percentage 2C | 7.7% | 7.6% | 7.6% | 9.5% | 8.9% | 9.6% |
| Median average TCEY percentage 3A | 42.6% | 42.6% | 42.3% | 48.0% | 44.4% | 48.0% |
| Median average TCEY percentage 3B | 11.8% | 11.8% | 11.7% | 13.3% | 16.4% | 13.3% |
| Median average TCEY percentage 4A | 5.8% | 5.8% | 5.8% | 6.4% | 7.2% | 6.3% |
| Median average TCEY percentage 4CDE | 8.1% | 8.1% | 8.0% | 8.8% | 10.0% | 8.7% |
| Median average TCEY percentage 4B | 3.6% | 3.5% | 3.5% | 3.9% | 3.7% | 3.9% |


INTERNATIONAL PACIFIC HALIBUT COMMISSION

# MSE Program of Work

Agenda Item 7.1

IPHC-2020-MSAB016-10

## Program of Work for 2020/2021

| **15th Session of the IPHC MSAB – May 2020** | **Progress** |
|---|---|
| Review Goals and Objectives (Distribution & Scale) | Completed |
| Review simulation framework | Completed |
| Review multi-area model | Completed |
| Review preliminary results | |
| Identify MPs (Distribution & Scale) | Completed |
| **16th Session of the IPHC SRB – June 2020** | |
| Review simulation framework | Completed |
| Review multi-area model | Completed |
| Review preliminary results | |
| **Ad Hoc Meeting of the MSAB – August 2020** | |
| Examine preliminary results | Completed |
| **17th Session of the IPHC SRB – September 2020** | |
| Review penultimate results | Completed |
| **17th Session of the IPHC MSAB – October 2020** | |
| Review final results | On schedule |
| Provide recommendations on MPs for scale and distribution | |
| **97th Session of the IPHC Annual Meeting – January 2020** | |
| Presentation of complete MSE product to the Commission<br>Recommendations on Scale and Distribution MP<br>Implementation of Commission decisions arising from AM097 | |

# Program of Work

- Eight tasks

Active Investigation | Lower priority | Specific task | Deliver Results | MSAB/SRB Review

# Potential elements for moving forward

- **IPHC-2020-AM096-R, para. 83.** *The Commission NOTED that MSE is the appropriate tool to evaluate management procedures related to discard mortality for non-directed fisheries (bycatch)*

# Recommendations

1) **NOTE** paper IPHC-2020-MSAB016-10 which describes the IPHC Program of Work for MSAB related activities for 2020-21, and discuss options for possible future work.
2) **NOTE** the delivery date of late January 2021 (97th Session of the IPHC Annual Meeting, AM097) for the complete MSE results including Scale and Distribution components of the management procedure for potential adoption by the Commission and subsequent implementation.
3) **SUGGEST** tasks to investigate beyond 2021.

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

# IPHC Secretariat Program of Work for MSAB Related Activities in 2020-21

**PREPARED BY: IPHC SECRETARIAT (A. HICKS, P. CARPI, & S. BERUKOFF; 19 SEPTEMBER 2020)**

## PURPOSE

To update the IPHC Program of Work for MSAB related activities for 2020-21, and options for possible future work.

## 1 INTRODUCTION

This Program of Work is a description of activities related to the Management Strategy Advisory Board (MSAB) that IPHC Secretariat staff will engage over the next 6 months, and options for future work. It describes each of the priority tasks, lists some of the resources needed for each task, and provides a timeline for each task.

It is important to have a set of working definitions, and this is especially true to the Management Strategy Evaluation (MSE) process since it involves many technical terms that may be interpreted or used differently by different people. 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

### 1.1 MANAGEMENT STRATEGY EVALUATION (MSE)

Management Strategy Evaluation (MSE) is a process to evaluate alternative management procedures and identify those that are robust to uncertainty and meet the defined objectives. This process, in general, involves the following:

1. defining fishery goals and objectives with the involvement of stakeholders and managers,
2. identifying management procedures to evaluate,
3. simulating a population with application of the management procedures,
4. evaluating and presenting the results in a way that examines trade-offs between objectives,
5. applying a chosen management procedure, and
6. repeating this process in the future to address changes in objectives, assumptions, and expectations.

Figure 1 shows these different components and that the process is not necessarily sequential, but may iterate between components as learning progresses. The involvement of stakeholders and managers in every component of the process is extremely important to guide the MSE and evaluate the outcomes.

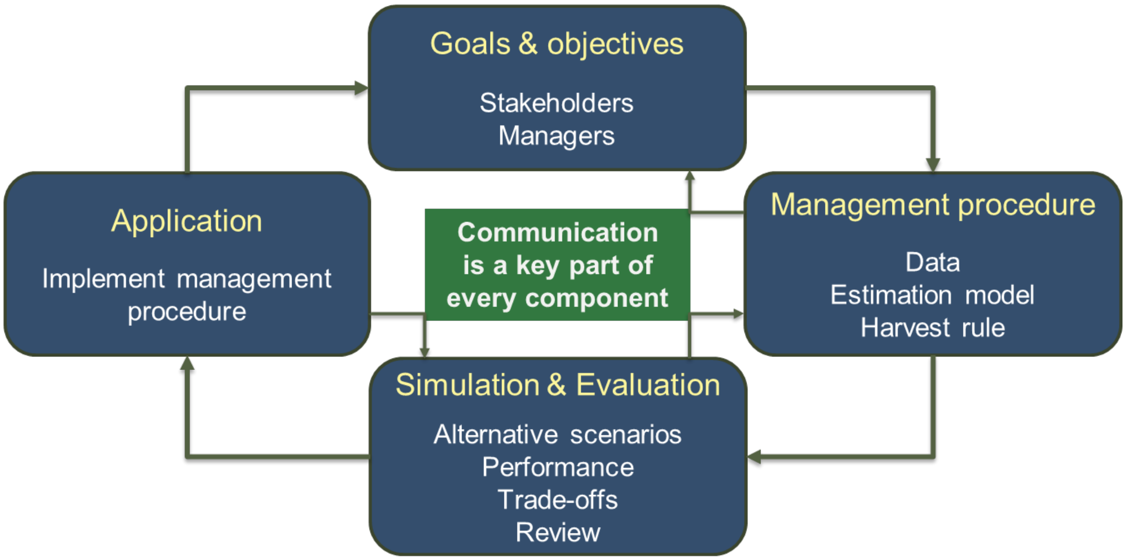



**Figure 1**: A depiction of the Management Strategy Evaluation (MSE) process showing the iterative nature of the process with the possibility of moving either direction between most components.

### 1.2 Background

Many important tasks have been completed or started regarding the MSE for Pacific halibut (*Hippoglossus stenolepis*). Much of the work proposed will use past accomplishments to further the MSE process. The past accomplishments include the following:

1. Familiarization with the MSE process.
2. Defining conservation and fishery goals.
3. Defining objectives and performance metrics for those goals.
4. Developing coast-wide (single-area) and spatial (multiple-area) models.
5. Identifying management procedures for the coastwide fishing intensity and distributing the TCEY to IPHC Regulatory Areas.
6. Presentation of results investigating coastwide fishing intensity (IPHC-2020-MSAB013-08) and results incorporating procedures to distribute the TCEY to IPHC Regulatory Areas (IPHC-2020-MSAB016-09).

Management Strategy Evaluation is a process that can develop over many years with many iterations. 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 fisheries will be ongoing as new objectives are defined, more complex models are built, new management procedures are defined, and results are updated. This time will include continued consultation with stakeholders and managers via the MSAB meetings. Along the way, there will be useful outcomes that may be used to improve existing management and will influence recommendations for future work. Embracing this iterative process, the program of work identifies the tasks to continue to make progress on the investigation of management strategies.

## 2 POTENTIAL ONGOING ACTIVITIES

Task 1: Review, update, and further define goals and objectives

Task 2: Develop performance metrics to evaluate objectives

Task 3: Identify realistic management procedures of interest to evaluate

Task 4: Design and code a closed-loop simulation framework

Task 5: Further the development of operating models

Task 6: Run closed-loop simulations and evaluate results

Task 7: Develop tools that will engage stakeholders and facilitate communication

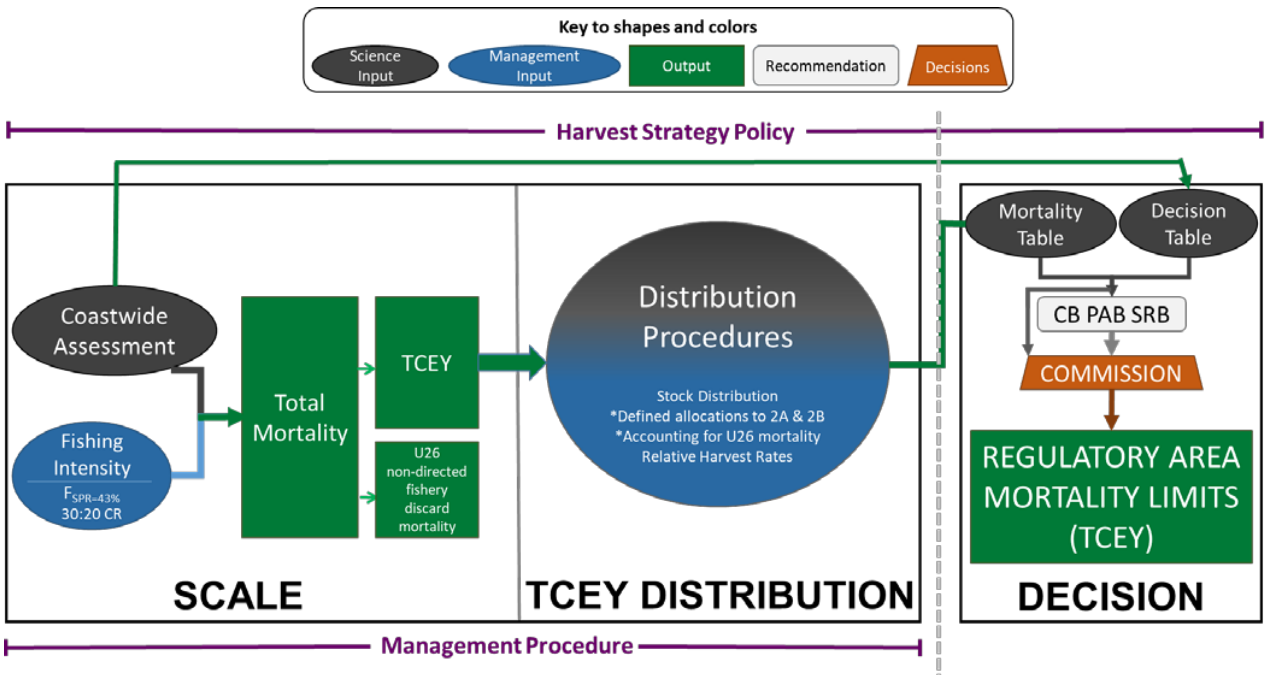



**Figure 2**: Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC CIRCULAR 2020-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are three-year interim agreements to 2022. The decision component is the Commission decision-making procedure, which considers inputs from many sources.

## 3 PROGRAM OF WORK FOR 2020/21

The full MSE results incorporating coastwide scale and distribution components of the management procedure (Figure 2) will be presented at the 97th IPHC Annual Meeting (AM097) in January 2021. Therefore, results of simulations incorporating various management procedures based on the framework shown in Figure 2 will be commented upon by the SRB and evaluated by the MSAB in 2020 before presentation to the Commission in January 2021. There are three main tasks to accomplish in 2020: 1) identify management procedures incorporating coastwide and distribution components to simulate, 2) condition a multi-area operating model and prepare a framework for closed-loop simulations, and 3) present results in various ways in order to evaluate the management procedures. These three main tasks are described below and Table 1 identifies the tasks that will be undertaken at each MSAB and SRB meeting in 2020.

**Table 1**: Tasks to complete in 2020/21 at the two scheduled MSAB meetings.

| |
|---|
| **15th Session of the IPHC MSAB - May 2020** |
| Review Goals and Objectives (Distribution & Scale) |
| Review simulation framework |
| Review multi-area model |
| Review preliminary results |
| Identify MPs (Distribution & Scale) |
| **16th Session of the IPHC SRB - June 2020** |
| Review simulation framework |
| Review multi-area model |
| Review preliminary results |
| **17th Session of the IPHC SRB - September 2020** |
| Review penultimate results |
| **17th Session of the IPHC MSAB - October 2020** |
| Review final results |
| Provide recommendations on MPs for scale and distribution |
| **97th Session of the IPHC Annual Meeting (AM097)** |
| Presentation of complete MSE product to the Commission<br>Recommendations on Scale and Distribution MP |
| Implementation of Commission decisions arising from AM097 |

### 3.1 IDENTIFY MANAGEMENT PROCEDURES OF INTEREST TO EVALUATE

The coastwide MSE investigated management procedures related to the coastwide fishing intensity including the SPR associated with a fishing mortality rate ($F_{SPR}$), the trigger in a control rule determining at what level of relative spawning biomass the fishing intensity is linearly reduced, and various constraints that dampen the annual change in the TCEY. The results from the coastwide MSE provided insight into options and a range of SPR values to further evaluate along with distribution procedures. These are listed in paragraph 49 of IPHC-2019-MSAB014-R.

*49. The MSAB RECOMMENDED that SPR values of 0.3, 0.34, 0.38, 0.40, 0.42, 0.46, and 0.50 with a 30:20 control rule be evaluated at MSAB015 along with constraints defined by a maximum change in the TCEY of 15%, a slow-up fast-down approach, and/or setting quotas every third year.*

Various procedures related to distributing the TCEY were discussed at MSAB014 and listed in paragraphs 55, 57, and 58 of IPHC-2019-MSAB014-R.

*55. The MSAB **REQUESTED** that a number of elements in distribution management procedures be included for evaluation at MSAB015:*

a) *A coastwide constraint using a slow-up, fast-down approach with a maximum change in the TCEY of 15%;*

b) *evaluating different relative harvest rates across IPHC Regulatory Areas or Biological Regions;*

c) *distributing the TCEY directly to IPHC Regulatory Area;*

d) *A fixed shares concept for all or some IPHC Regulatory Areas, Biological Regions, or Management Zones with options to distribute the TCEY to the areas without a fixed share. The determination of these shares may be fixed or varying over time; and*

e) *A maximum fishing intensity defined by an SPR of 36% to act as a buffer when distributing the TCEY to IPHC Regulatory Areas.*

*57. The MSAB **NOTED** additional elements for distribution procedures to consider as sensitivities when developing management procedures for evaluation at MSAB015 as follows:*

*a. a constraint applied to the TCEY for each IPHC Regulatory Area using a slow-up, fast-down approach with a maximum change in the TCEY of 15%;*

*b. using O32 estimates of stock distribution or “all sizes” estimates of stock distribution from the modelled survey results;*

*c. evaluating different relative harvest rates across IPHC Regulatory Areas or Biological Regions (e.g. harvest rates for Biological Region 2, IPHC Regulatory Areas 2A and/or 4CDE);*

*d. calculating shares across Biological Regions, Management Zones, or IPHC Regulatory Areas using approaches that blend multiple sources of information (e.g., using historical TCEYs and stock distribution results for all IPHC Regulatory Area, a 5-year window of estimated stock distribution, etc.);*

*e. the importance the order of applying elements in the distribution procedure when limiting the maximum SPR (i.e. using a buffer).*

*58. The MSAB **NOTED** additional elements for distribution procedures to consider when developing management procedures for evaluation at MSAB016 as follows:*

a. *a constraint applied to the TCEY for each IPHC Regulatory Area using a slow-up, fast-down approach;*
b. *a constraint applied to the TCEY for each IPHC Regulatory Area implementing a maximum change in the TCEY of 15%;*
c. *a maximum fishing intensity defined by an SPR of 40% to act as a buffer when distributing the TCEY to IPHC Regulatory Areas;*
d. *adjusting relative harvest rates to reflect current stock productivity (note that this will be explored before MSAB015);*
e. *using trends in fishery CPUE to adjust allocation percentages by IPHC Regulatory Area (note that this will be explored before MSAB015);*
f. *additional approaches to first distribute the TCEY to Biological Region or Management Zone.*

There are many combinations of elements and it would be nearly impossible to simulate and evaluate all possible combinations. Therefore, eleven specific management procedures for distributing the TCEY to IPHC Regulatory Areas were identified in Appendix V of IPHC-2020-MSAB015-R. These management procedures will be simulated and evaluated throughout 2020.

# 4 POTENTIAL ELEMENTS FOR A PROGRAM OF WORK MOVING FORWARD

The MSE program has been focused on the delivery of simulation results examining management procedures incorporating scale and distribution components (Figure 2) in January 2021, but some items have been discussed for consideration after the MSE is complete. A discussion of potential work categorized by the seven tasks listed above is provided here.

## 4.1 REVIEW, UPDATE, AND FURTHER DEFINE GOALS AND OBJECTIVES

Well defined goals and objectives are the key to evaluating management procedures. Using performance metrics derived from the objectives, outcomes and tradeoffs can be examined to identify management procedures that best meet the defined objectives. For each iteration, objectives may be redefined, deleted, or added given changes in the fisheries, management paradigm, or insights from past results. Because objectives are the key to evaluating the management procedures, it is important to ensure that they are current, accurate, and useful. Therefore, after the first round of MSE results are presented in 2021, it would be useful to revisit objectives in the near future. Current objectives are provided in Appendix I.

## 4.2 DEVELOP PERFORMANCE METRICS TO EVALUATE OBJECTIVES

Objectives are the key to evaluating management procedures, but that evaluation occurs through the use of performance metrics derived from the objectives. These may be probabilities of an event occurring or a summary statistic of a quantity. Multiple performance objectives may be developed for a single objective that summarizes the results in slightly different ways. With well developed objectives, it is easy to derive useful performance metrics. However, additional performance metrics may be useful to investigate the results in slightly different ways, to look at a different concept, or to even provide an alternative statistic that is not related to any primary objectives. A defined set of performance metrics that stakeholders and managers agree to, understand, and are familiar with is essential to the evaluation process. If new objectives are defined, performance metrics should be derived for those. Additionally, it would be useful to list the performance metrics found useful in the evaluation of the first round of MSE results to carry forward, and to identify potential performance metrics that may be useful in the future.

### 4.3 IDENTIFY REALISTIC MANAGEMENT PROCEDURES TO EVALUATE

The goal of an MSE is to identify management procedures that are robust to variability and uncertainty, and meet the defined objectives. Therefore, a set of management procedures is pre-defined for testing and evaluation. The process is also iterative and what is learned from previous evaluations will inform the development of additional management procedures to evaluate, especially in the early iterations of an MSE.

The SRB, MSAB, and Commission have highlighted some elements of management procedures that may be useful to examine in the future. The following are from various past reports.

> **IPHC-2018-SRB013-R, para. 29**: *The SRB REQUESTED that in future iterations of the MSE, the IPHC Secretariat and MSAB consider: […] c) the current conditioned operating model used to simulate coast-wide survey index and that such data be used to consider an alternative survey-based management procedure (this may provide a more transparent TMq-setting algorithm than the current SPR based control-rule and help with MSAB deliberations).*

> **IPHC-2020-AM096-R, para. 83.** *The Commission NOTED that MSE is the appropriate tool to evaluate management procedures related to discard mortality for non-directed fisheries (bycatch) because it can capture downstream effects, biological implications, and the management performance relative to objectives.*

> **IPHC-2020-MSAB015-R, para. 20.** *The MSAB REQUESTED that a procedure to distribute the coastwide TCEY be flexible to allow for distribution directly to IPHC Regulatory Areas, or to Biological Regions or Management Zones before distributing to IPHC Regulatory Areas. Methods of distribution may be based on stock distribution, relative fishing intensities, and other allocation adjustments.*

> **IPHC-2020-MSAB015-R, para. 22**. *The MSAB NOTED that alternative management procedures may use area-specific data (e.g. modelled survey results) without using a coastwide TCEY, rather than the procedure described in paragraph 21. This example is a sub-category of a broader category of management procedures that are data-based rather than assessment-based.*

Two investigations are highlighted here that have not been investigated in the current MSE. First, the Commission at AM096 (IPHC-2020-AM096-R, para. 83) indicated that the MSE would be an appropriate tool to investigate management procedures related to non-directed fishery discard mortality. Second, the SRB (IPHC-2018-SRB013-R) and MSAB (IPHC-2020-MSAB015-R) identified that it would be useful to investigate management procedures directly using FISS data in each IPHC Regulatory Area instead of integrating many sources of data in a stock assessment. Many other management procedures can be identified and evaluated.

### 4.4 Design and code a closed-loop simulation framework

The simulation framework includes all components that are necessary to conduct the closed-loop simulations including an operating model to simulate the Pacific halibut population and the elements of management procedures which generally includes monitoring, estimation, and rules (Figure 3). The first complete Pacific halibut MSE is being reviewed by the SRB as well as an independent reviewer, and many items have been identified for improvement. Most of these will require additions or modifications to the current framework. For example, how the weight-at-age are simulated, the ability to incorporate alternative management procedures, and the inclusion of alternative operating models are important improvements that could be made in the future. The current simulation framework was developed with future improvements in mind, thus is generalized and modular to allow for quick expansion and modification.

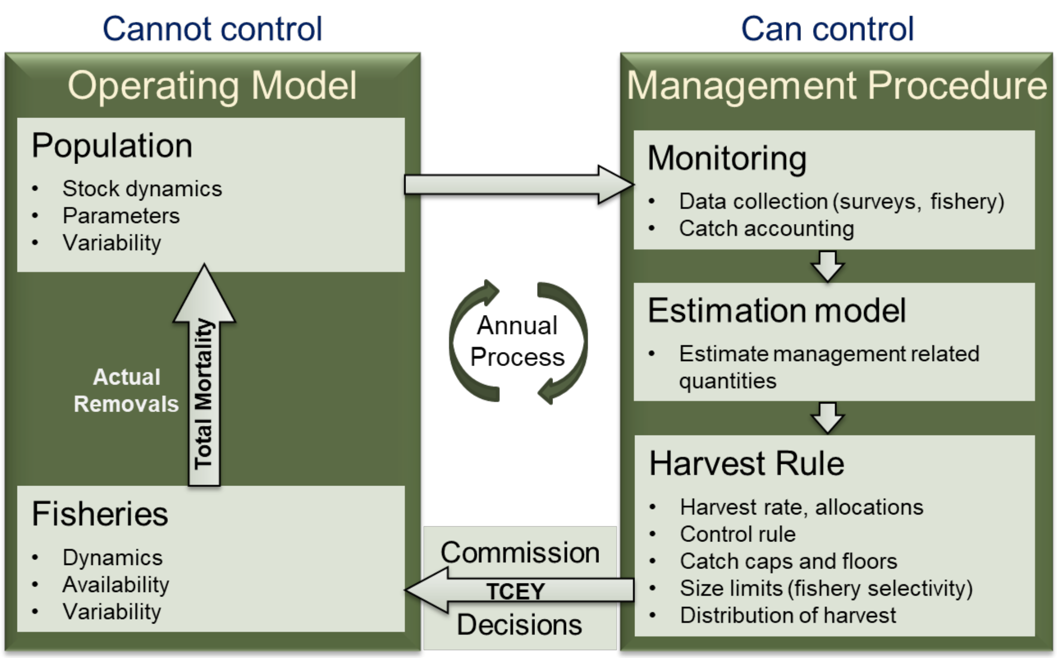



**Figure 3:** Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

### 4.5 Further the development of operating models

The operating model simulates the Pacific halibut population and interacts with simulated management in the closed-loop simulations. The assumptions of productivity, movement, and other population processes as well as variability are included in the operating model, which are unknown but represent reasonable hypotheses based on past observations. The operating model may be based on multiple hypotheses by incorporating multiple models, as the stock assessment ensemble does. The coastwide MSE used two models to represent multiple hypotheses, but the current multi-regional MSE incorporates a single model with variability. It would be useful to investigate alternative hypotheses about the Pacific halibut population to either include as a model within the operating model or as a specific scenario to investigate an exceptional circumstance (e.g. an assumption that is unlikely but would be examined to provide a picture of the robustness of a management procedure).

### 4.6 Run closed-loop simulations and evaluate results

Given progress on the above tasks, it will be necessary to run new simulations to incorporate those changes and additions. The simulation framework is complex and each simulation takes time to complete. Additionally, the variability included requires a large number of simulations to adequately characterize the outcomes. Therefore, it is necessary to consider the time it takes to run simulations and compile results in the program of work.

### 4.7 Develop tools that will engage stakeholders and facilitate communication

Involvement from stakeholders and managers is essential for the success of an MSE, thus communication is imperative. Tools to assist in that communication must be developed jointly between the developers and end users. Currently, results are communicated through tables and figures in documents, online via the MSE Explorer interactive tool, and through presentation at IPHC meetings. Iteration with stakeholders and managers to determine beneficial tools to aid with evaluation is essential to the success of the MSE.

## 5 Recommendation/s

That the MSAB:

1) **NOTE** paper IPHC-2020-MSAB016-10 which describes the IPHC Program of Work for MSAB related activities for 2020-21, and options for possible future work.
2) **NOTE** the delivery date of January 2021 (97th Annual Meeting) for the complete MSE results including Scale and Distribution components of the management procedure for potential adoption by the Commission and subsequent implementation.
3) **SUGGEST** tasks to investigate beyond 2021.

## 6 Additional Documentation / References

IPHC-2018-SRB013-R. 2018. Report of the 13th Session of the IPHC Scientific Review Board (SRB013). Seattle, WA, U.S.A. 25-27 September 2018. 17 pp. https://iphc.int/uploads/pdf/srb/srb013/iphc-2018-srb013-r.pdf

IPHC-2019-MSAB013-08. 2019. Further Investigation of Management Procedures Related to Coastwide Fishing Intensity. 5 April 2019. 18 pp. https://www.iphc.int/uploads/pdf/msab/msab13/iphc-2019-msab013-08.pdf

IPHC-2019- MSAB014-09. 2019. IPHC Secretariat Program of Work for MSAB Related Activities 2019-23. 20 September 2019. 17 pp. https://iphc.int/uploads/pdf/msab/msab014/iphc-2019-msab014-09.pdf

IPHC-2019-MSAB014-R. Report of the 14th Session of the IPHC Management Strategy Advisory Board (MSAB014). Seattle, WA, U.S.A. 21–24 October 2019. 27 pp. https://iphc.int/uploads/pdf/msab/msab014/iphc-2019-msab014-r.pdf

IPHC-2020-AM096-R. 2020. Report of the 96th Session of the IPHC Annual Meeting (AM096). Anchorage, Alaska, USA. 3–7 February 2020. https://iphc.int/uploads/pdf/am/2020am/iphc-2020-am096-r.pdf

IPHC-2020-MSAB015-R. 2020. Report of the 15th Session of the IPHC Management Strategy Advisory Board (MSAB015). Meeting held electornically. 11–14 May 2020. 23 pp. https://iphc.int/uploads/pdf/msab/msab015/iphc-2020-msab015-r.pdf

IPHC-2020-MSAB016-09. 2020. Results investigating fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries.

## 7 Appendices:

Appendix I: Primary objectives defined by the Commission for the MSE

# APPENDIX I
## PRIMARY OBJECTIVES DEFINED BY THE COMMISSION FOR THE MSE

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

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

# Technical details of the IPHC MSE framework

**PREPARED BY: IPHC SECRETARIAT (A. HICKS, P. CARPI, & S. BERUKOFF; 18 OCTOBER 2020)**

## PURPOSE

To provide technical details of the International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) framework.

## 1 INTRODUCTION

This document provides technical details of the International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) framework. Some sections are incomplete and additional details can be found in other documents for the 16th Session of the IPHC Management Strategy Advisory Board Meeting (MSAB016).

## 2 APPENDICES

I. Technical details of the IPHC MSE framework

# APPENDIX I
## Technical Details Of the IPHC MSE Framework

---

IPHC-2020-MSAB016-INF01


Compiled By

Allan Hicks
Piera Carpi
Steve Berukoff


DRAFT
October 18, 2020

International Pacific
Halibut Commission

# Contents

**1 Introduction** **5**

1.1 Management Strategy Evaluation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 5

**2 Operating model** **8**

2.1 The state object . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 9

2.2 Notation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 10

2.3 Population dynamics . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 11

2.3.1 Age increment . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12

2.3.2 Recruitment . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12

2.3.3 Movement . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15

2.3.4 Mortality . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 17

2.3.5 Maturity . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 25

2.3.6 Spawning biomass . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 25

2.3.7 Size-at-age . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

2.3.8 Initial population . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

2.3.9 Parameter evolution through time . . . . . . . . . . . . . . . . . . . . . . . 30

2.4 Conditioning the Operating Models . . . . . . . . . . . . . . . . . . . . . . . . . . . 30

2.4.1 Observations and Data . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 30

2.4.2 Predictions from the stock assessment . . . . . . . . . . . . . . . . . . . . . 32

2.5 Projecting the Operating Models . . . . . . . . . . . . . . . . . . . . . . . . . . . . 32

2.5.1 Recruitment . . . 32
2.5.2 Fishing mortality . . . 32
2.5.3 Movement . . . 32
2.5.4 Weight-at-age . . . 33
2.6 Reference Points . . . 33

**3 Specifications for the Pacific halibut MSE framework 34**

3.1 Management Procedures . . . 35
3.1.1 Data Generation . . . 35
3.1.2 Modelling length-at-age . . . 38
3.1.3 Estimation Model . . . 38
3.1.4 Harvest Rule . . . 40
3.2 Population structure . . . 40
3.2.1 Input population parameters . . . 40
3.2.2 Derived population parameters . . . 40
3.3 Structure of the fisheries . . . 40
3.3.1 Fishery parameters . . . 41

**Appendix A Parameters and notation 43**

**Appendix B Fishing mortality using exploitation rates: two approaches 46**

B.1 Fisheries are independent and do not effect each other . . . 46
B.2 Fisheries are sequential and earlier fisheries effect later ones . . . 49
B.3 Comparison . . . 51
B.4 A more complex example with three fisheries and discard mortality . . . 53

# Chapter 1

# Introduction

This technical document describes the Management Strategy Evaluation (MSE) framework and its elements, details specifications of the framework for the evaluation of scale and distribution management procedures, provides definition of terms used, and defines the technical details of the models and equations used within the framework. This is a working document that will be revised often as development of the MSE framework progresses. Therefore, this document is currently incomplete and will have occasional revisions.

## 1.1 Management Strategy Evaluation

MSE is a process to evaluate harvest strategies and develop a management procedure that is robust to uncertainty and meets defined objectives, and can be partitioned into four separate components that interact with each other (Figure 1.1). Management Procedures (MPs) are defined, often with input from stakeholders and managers but not necessarily, and evaluated against objectives which are determined with input from stakeholders and managers. Simulations of the various MPs are performed and evaluated against the objectives to identify the best performing MP to apply within a harvest strategy policy.

A harvest strategy policy can be implemented in a number of ways. Many fisheries are managed by applying the chosen management procedure each management cycle and implementing the results as management. Other agencies use the outcomes of the management procedure as a reference from which other considerations (e.g., socio-economic) are taken into account when determining a tactical decision of the management outcomes. This variability around the management procedure is called implementation variability and should be a part of the simulations and evaluation.

The four boxes shown in Figure 1.1 are all important component of an MSE. The objectives are the connection to stakeholders and managers. Performance metrics are derived from well defined objectives that are used in the evaluation. Management procedures are the link to a transparent management process and need to be clearly defined so that they are formulaic and can be written as computer code for the closed-loop simulations. The closed-loop simulations also consist of an operating model which simulates the population and produces the observations needed for the management procedure. Applying the best performing MP is the goal of MSE but is not the


**Figure 1.1:** An illustration of the closed-loop simulation within the MSE framework consisting of an operating model and a management procedure.

end. The MSE should be updated as additional observations and knowledge is gained from the population, fishery, or management process.

The engine of the MSE framework is the closed-loop simulation with the operating model (OM) and management procedure (Figure 1.2). The OM simulates the dynamics of the population and the fisheries that interact with it. The processes simulated by the OM can be thought of as processes that management does not, or chooses not, to control. For example, natural mortality is not a process that is not managed, and some aspects of the fisheries are not managed (e.g., specific daily decisions). These unmanaged processes result in variability that is normal to the system, referred to as 'natural variability' in this document, and is simulated by the OM.

The MP consists of elements that are managed and may include data collection and monitoring, estimation models, and the harvest rules that determine how the fisheries are managed. MSE can evaluate any of these elements including how changes in monitoring, and different estimation model, or various harvest rules affect the outcomes. This elements may be simple or complex.

The chapters in this document begin with a generalized operating model that can be specified for any fish population. The following chapter presents the specifications of the MSE for Pacific halibut fisheries, and the sections within that chapter follow the three boxes in Figure 1.1 labeled Goals & Objectives, Management Procedure, and Simulation.

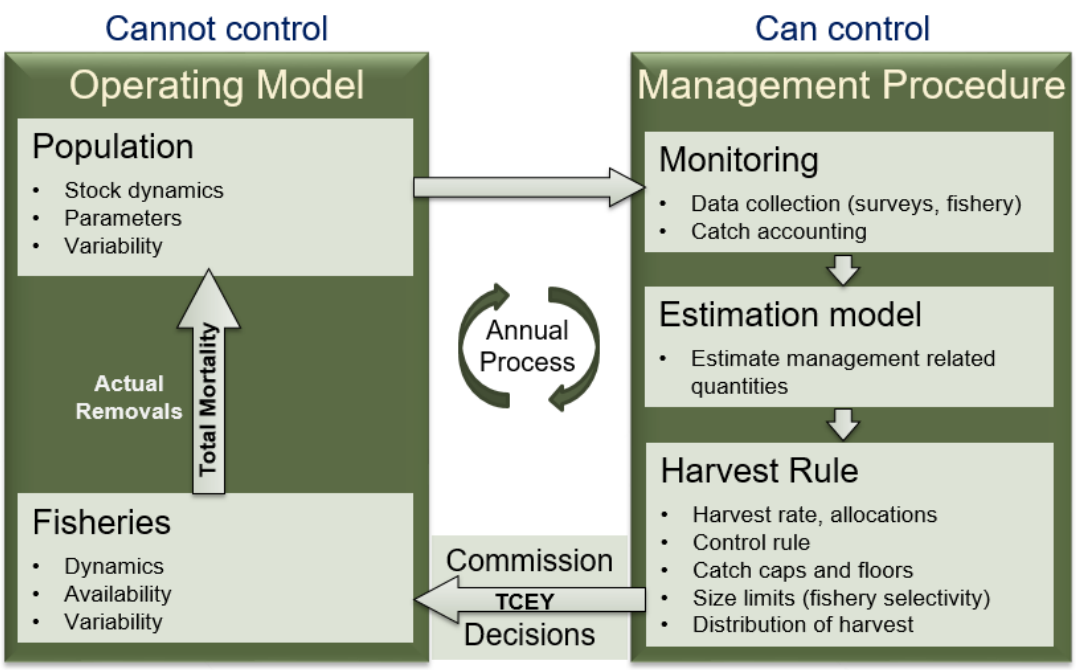



**Figure 1.2:** An illustration of the closed-loop simulation within the MSE framework consisting of an operating model and a management procedure.

# Chapter 2

# Operating model

In a management strategy evaluation (MSE), operating models (OM) simulate the population and fishery dynamics. It incorporates life-history processes such as recruitment, growth, migration, maturation, and mortality of the fish population, as well as fishery processes such as selectivity, availability, and catchability. Descriptions of the various processes are provided below along with the mathematical equations used to simulate those processes. Many of the details are drawn from the Hilborn and Walters (1992), Quinn and Deriso (1999), the CASAL manual Bull *et al.* (2012), Stock Synthesis technical details Methot and Wetzel (2013), and the Coleraine manual Hilborn *et al.* (2000).

There is uncertainty in the parameterization of the processes, natural variability in the processes, and multiple hypotheses about the mechanisms of the processes. These three sources of variability are introduced in three different ways.

1. Parameter uncertainty is introduced by conditioning the operating model to data, and determining the distribution of uncertainty for each parameter as well as correlation with other parameters. Parameter values for an individual simulated trajectory are randomly drawn from the multivariate estimated probability distribution. Therefore, each simulated trajectory uses a different set of parameters, thus including variability that represents the uncertainty in the parameters. This is described in Section 2.4.

2. Natural variability is introduced by defining a random process associated with various concepts. For example, recruitment varies naturally and is modelled by including random deviates applied annually to average recruitment. Other processes may have specific patterns such as changes in weight-at-age. This is described in Section 2.5.

3. Structural uncertainty is included by defining multiple hypotheses and implementing them as separate operating models. For example, growth may occur in different ways between models. Or, data may be structured in a different way when conditioning the model. Structural uncertainty captures the variability that can not be captured by the two methods above.

Parameters that will have uncertainty are defined (and those that are fixed are given fixed values), methods to include natural variability are defined, and potential areas of structural uncertainty are noted.

## 2.1 The state object

The state is the accounting of the population in numbers within an operating model and is contained in a state object with many dimensions. The state represents the intrinsic characteristics of the modeled population: age, maturity, and sex. This state is then evolved on a computational domain parameterized by time and space, which are extrinsic variables. Furthermore, sectors (fisheries and survey) interact with the state. Clarified this way, the state object contains a representation of the stock at a place and time and can be subsetted along any of these axes as needed to determine the state for any combination of these dimensions.

The dimensions are fixed inputs that are defined by the user, thus may be unique to any operating model. The different dimensions, and maximum ranges, are shown in Table 2.1. Maturity state (immature or mature) is not included as a dimension here (specifically for the Pacific halibut operating model) but may be a useful charactersitic to track for some stocks, depending on fishing intensity and the proportion maturing at age. Instead, the mature population is determined using the proportion mature at age, which can be applied to various dimensions of the population state (see Section 2.3).

**Table 2.1:** Partitions of the state object that are fixed inputs and the likely minimum and maximum input for each partition.

| | Dimension | | |
|---|---|---|---|
| Variable | Min | Max | Description |
| Age ($a$) | 1 | 251 | Age classes ranging from 0 to 250. Halibut will likely use 0 to 30 and age always starts at zero. A capital $A$ indicates the maximum age |
| Sex ($s$) | 1 | 3 | Sex, which includes female, male, and unsexed, in that order, labeled 1, 2, and 3. |
| Time ($t$) | 0 | $\infty$ | A minimum and maximum time-step (e.g., year) is input by user. The difference +1 determines the number of time-steps. These are not projected time-steps, but time-steps modelled to condition the OM. A time-step will typically be a year, but specific points in time (e.g., beginning, middle, or end of the year) may be noted in a superscript (see below). |
| Region ($r$) | 1 | $\infty$ | Number of spatial regions with migration between |
| Area within Region ($r_l$) | 1 | $\infty$ | Number of areas within a region. Migration is not modelled between areas. |
| Sector ($f$) | 1 | $\infty$ | Number of fishing-related sectors, which includes fisheries and surveys. Sectors typically will operate at the region level or a finer scale, but there may be a case where a sector operates across regions (which is unlikely for the Pacific halibut operating model). |

The state object is the key component of the population dynamics and must contain sufficient information to determine the population dynamics as well as any intermediate calculations, such as fishery catches. In this implementation, there are always six partitions, but some operating models may have a partition with only one element, effectively eliminating that dimension. For example, a single-sex, single-area model with no maturity partition would simply be a matrix of years and ages.

## 2.2 Notation

Notation of the variables in the operating model uses the concept of defining a quantity of the population (such as numbers or biomass), subscripted by various characteristics (intrinsic and extrinsic) and superscripted by specific concepts (such as spawning or exploitable). The subscripts reflect the intrinsic and extrinsic characteristics of the population by listing the intrinsic characteristics first (age and sex), followed by the extrinsic characteristics (time, region/area, and fishing sector). The possible subscripts are defined in Table 2.1 and are always subscripted in the order presented in those tables. For example, the numbers for age and sex in a year and region is $N_{a,s|y,r}$. When a subscript is not included, it is implied that the quantity is a summation over that index (or the index doesn't apply, as in the case of fishing sector) and ambiguity will be alleviated using the letter associated with the index when necessary (e.g., $N_{s=1|y=1}$ is the number of females in year 1 summed over all ages and regions).

Variables specific to a fishing sector ($f$) include a subscript for that sector at the end. For example, the catch-at-age for females from sector $f$ in year 1 and region 2 would be notated as $C_{a,1|1,2,f}$. Fishery sectors typically will operate at the region level or a finer scale, but the region subscript is retained for clarity and in case a sector does operate across regions (which is unlikely for the Pacific halibut operating model).

Finally, superscripts are used to notate specific concepts such as spawning biomass, which would be notated as $B^{sp}_{s=1|y=1}$ to represent the spawning biomass for females in year 1 over all regions. Additionally, a superscript that is a number between 0 and 1 indicates the time in the year that the quantity is calculated. For example, $B^{sp,0}$, $B^{sp,0.5}$, $B^{sp,1}$ would be the spawning biomass calculated at the beginning of the year, middle of the year, and end of the year, respectively. Possible superscripts and their definition are shown in Table 2.2.

**Table 2.2:** Superscripts for variable and their meaning.

| Variable | Description |
|---|---|
| ma | Mature |
| sp | Spawning. Most often used with $B^{sp}$ to represent spawning biomass. |
| sr | Selected and retained referring to the fish that are landed by a fishery sector. |
| n | Numbers. Indicates that a quantity, such as catch, is in numbers ($C^n$). Note that if a superscript is not used on catch, it is in weight. |
| $'$ | Denotes update made to numbers-at-age after partial timestep is complete, which includes the effect of movement but not mortality. |
| $''$ | Denotes update made to numbers-at-age at the end of the timestep. |
| Number 0-1 | A number between zero and 1 (inclusive) indicates the time within the year. For example, 0 indicates beginning of the year, 0.5 indicates middle of the year, and 1 indicates end of the year. |

## 2.3 Population dynamics

The population dynamics are modelled as an age-structured annual process accounting for changes in the numbers-at-age for each partition within the state (e.g., age and sex).

The sequence of processes from the start of the time-step (typically annual) is

1. *age increment*,
2. *recruitment (based on spawning biomass calculated at end of previous time-step or at the beginning of the current time-step)*,
3. *movement*,
4. *mortality*. The sequence of mortality from all sources is theoretically described below, but does not need to be specifically modelled as such because the mortality calculations will appropriately account for the sequence, as described in Section 2.3.4 and a later Appendix.
   (a) portion of natural mortality,
   (b) fishing mortality for one or more sectors,
   (c) portion of natural mortality,
   (d) fishing mortality for one or more sectors,
   (e) etc., until a full time-step of natural mortality has been applied
5. *spawning*.

The state object ($N_{a,s|t,r}$) is updated at three different points in the annual process, and superscripts note the time point.

| | | |
|---|---|---|
| $N$ | : | Beginning of the time-step after age increment and recruitment of age 0. |
| $N^{'}$ | : | After movement before mortality |
| $N^{''}$ | : | End of the time-step, after all natural and fishing mortality |

At any point in time, the biomass may be desired and can be calculated from numbers-at-age ($N_{a,s|t,r}$) and weight-at-age ($W_{a,s|t,r}$).

$$B_{a,s|t,r} = N_{a,s|t,r}W_{a,s|t,r} \tag{2.1}$$

Various partitions of biomass may be desired. For example, spawning biomass is the weight of spawning fish, and exploitable biomass is the weight of fish available to a specific sector. Biomass can also be calculated at specific points of time in the time-step. These various types of biomass will be defined in the sections below, and will be noted with a superscript. For example, spawning biomass is $B^{sp}_y$.

This section describes the technical specifications of the general population dynamics and how the historical population can be modelled given inputs such as catch and weight-at-age, as well as parameters that may be fixed or estimated from data. Conditioning the operating model is the process of determining the range of parameters and hypotheses that describe the observations, and is covered in Section 2.4. Projecting the population forward in time is discussed in Section 2.5, and involves defining random and fixed processes such as recruitment and changes in weight-at-age.

### 2.3.1 Age increment

The numbers-at-age at the beginning of the time-step with an annual time-step is obtained by incrementing the previous time-step's age class to one time-step older and calculating recruitment for age 0.

$$N_{a,s|t,r} = \begin{cases} R_{s|t,r} & a = 0 \\ N_{a-1,s|t-1,r} & 1 \leq a < A \\ N_{a-1,s|t-1,r} + N_{A,s|t-1,r} & a = A \end{cases} \tag{2.2}$$

### 2.3.2 Recruitment

Recruitment is a function of the spawning biomass calculated from the end of the previous time-step after all of the processes (movement and mortality) have occurred. See Section 2.3.6 for a description of spawning biomass.

$$R_{s|t,r} = p^R_{y,r} \times p^R_s \times f(B^{sp,1}_{s=1|t-1}) \times e^{(\varepsilon_{y,r} - b_y \frac{\sigma^2_R}{2})} \times e^{I_y \delta} \tag{2.3}$$

where $p_{y,r}$ is the proportion recruiting to region $r$ in time-step $t$, $p_s$ is the proportion of sex $s$ (typically 0.50), $f(B^{sp,1}_{s=1|t-1})$ is the equilibrium stock-recruit relationship using the end of the time-step spawning biomass (superscripts) for females from the previous time-step (subscripts), $e^{\epsilon}$ is the annual deviation in recruitment for time-step $t$, $b$ is a bias-correction multiplier, and $e^{I_y * \delta}$ is an overall adjustment for recruitment regime shift.

#### Density-dependent Recruitment

Density-dependence in the spawner-recruit relationship is modelled using a Beverton-Holt formulation.

$$f(B^{sp,1}_{s=1|t-1}) = \frac{B^{sp,1}_{s=1|t-1}}{a + bB^{sp,1}_{s=1|t-1}} \tag{2.4}$$

where the parameters $a$ and $b$ are determined from steepness ($h$), unfished equilibrium recruitment ($R_0$), and unfished equilibrium female spawning biomass ($B^{sp}_0$).

$$a = \frac{(1-h)B^{sp}_0}{4hR_0} \tag{2.5}$$

$$b = \frac{5h-1}{4hR_0} \tag{2.6}$$

Steepness ($h$) is a parameter noting the percentage of unfished equilibrium recruitment ($R_0$) that occurs when the female spawning biomass is 20% of unfished equilibrium female spawning biomass

($B_0^{sp}$). This can be shown using equations 2.4 and 2.5, and assuming that female spawning biomass is $\frac{1}{5}^{th}$ of unfished equilibrium female spawning biomass.

$$\begin{aligned} & \frac{1/5 B_0^{sp}}{\frac{(1-h)B_0^{sp}}{4hR_0} + \frac{5h-1}{4hR_0}(1/5 B_0^{sp})} \\ = & \frac{1/5}{\frac{1-h+1/5 5h-1/5}{4hR_0}} \\ = & \frac{4/5 hR_0}{4/5} \\ = & hR_0 \end{aligned}$$

The same method can be used to show that B0 results in R0. An example Beverton-Holt stock-recruit curve with a steepness of 0.70 is shown in Figure 2.1.

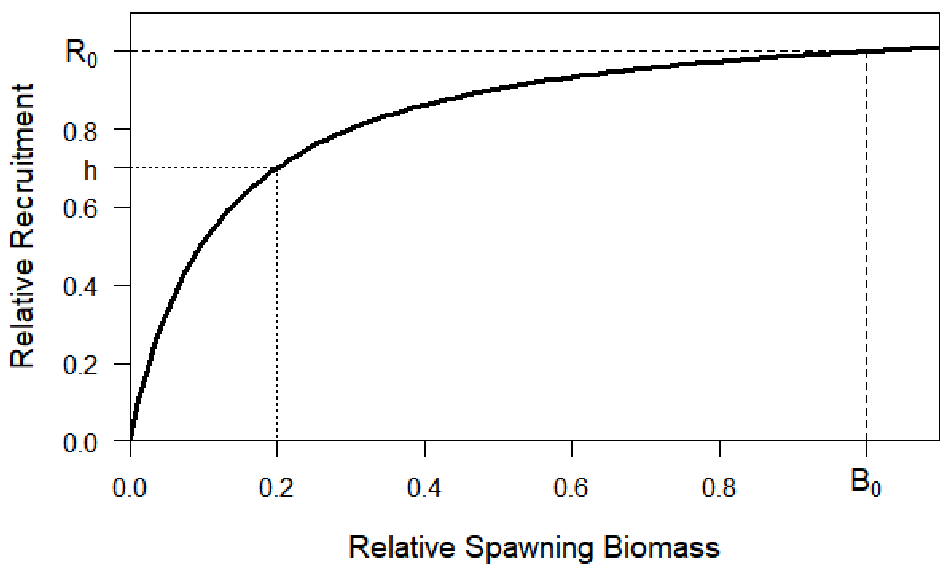



**Figure 2.1:** An example Beverton-Holt stock-recruit curve with a steepness ($h$) of 0.70.

The parameter for steepness is typically fixed because accurate estimation requires data informative of recruitment at low biomass levels and variability in recruitment often reduces the information content. The parameter $R_0$ is often estimated, and $B_0^{sp}$ can be calculated from $R_0$ and other life history parameters. Given those three parameters, $a$ and $b$ can be calculated.

### Recruitment Deviation

Recruitment varies around the stock-recruit curve, which is defined as mean recruitment. The distribution of recruitment is assumed to be lognormal and is parameterized using a Gaussian distributed deviate with an exponentiated mean of one and a variance notated as $\sigma_R^2$.

$$\varepsilon_{y,r}\ N(\mu = 0, \sigma_R^2) \qquad (2.7)$$

The arithmetic mean of the lognormal distribution is $e^{\mu+\sigma_R^2/2}$, and because $R_0$ is unfished equilibrium mean recruitment, a bias correction must be applied when simulating log deviates from a normal distribution with a mean/median equal to zero. As shown in equation 2.3, $e^{(\varepsilon_{y,r}-\sigma_R^2/2)}$ is used where the bias correction is $-\sigma_R^2/2$. This ensures that unfished equilibrium recruitment is, on average, $R0$ (e.g., the mean of the biased corrected exponentiated deviate is equal to 1). Figure 2.2 shows an example simulation without fishing when bias correcting and not bias correcting, and (Methot and Taylor 2011) present an analytical proof why bias correction is necessary.

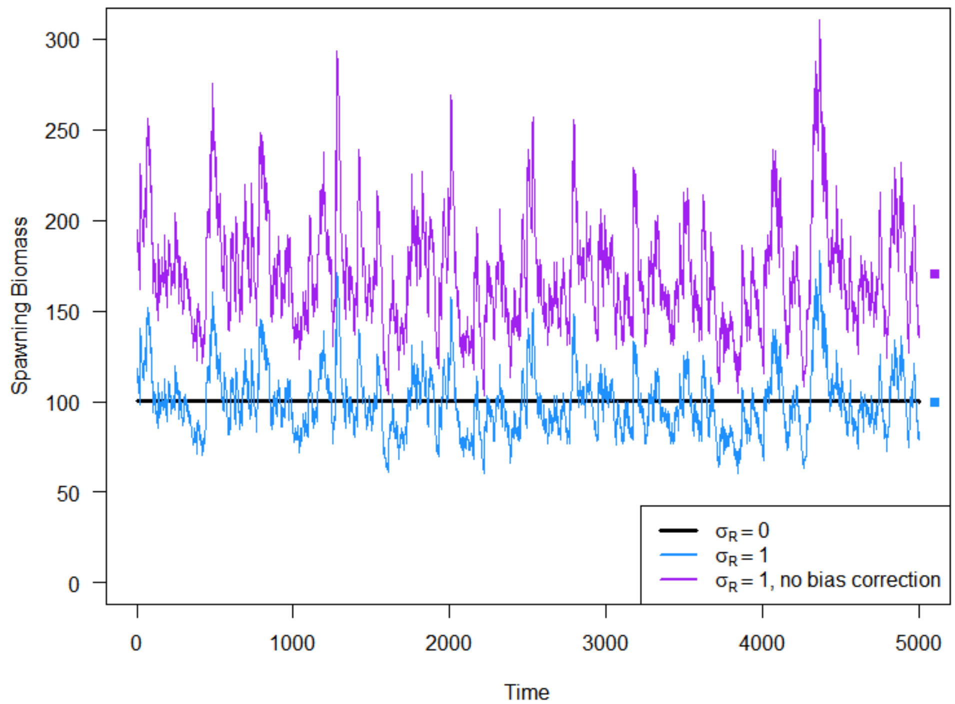



**Figure 2.2:** An example simulated projection of spawning biomass with no fishing mortality from an age-structured model with $\sigma_R = 1$ and bias-corrected recruitment deviates (blue line) and recruitment deviates not bias-corrected (purple line). A simulated trajectory with $\sigma_R = 0$ is shown by the flat black line, and the means of each simulated trajectory are shown by the appropriate colored square to the right.

Full bias-correction is necessary when simulating the fish population because the full lognormal distribution is used to simulate deviates, as shown in Figure 2.2. However, during estimation, information is reducing the uncertainty (i.e, distribution) around a deviation, and pulling it away from a value of zero. Therefore, a deviate without any information during estimation will be zero and not need bias correction, but a deviate that is fully informed (i.e., known exactly as in a simulation) will need full bias correction. In most estimation models, deviates are not often fully informed and a partial bias-correction is necessary. (Methot and Taylor 2011) provide a much more detailed discussion of this phenomenon. The parameter $b_y$ is included in equation 2.3 to allow for bias-correction if needed during estimation.

The recruitment process is a coastwide process with age-0 recruits distributed to regions. Therefore, the deviates may be region-specific, but it may be more appropriate to use a single coastwide deviate for each year and simulate region-specific variability across time-steps with the parameters representing the proportion recruiting to each region ($p^R_{y,r}$). Using region-specific deviates and proportion of recruits may be confounding.

#### Recruitment Distribution

Recruitment of age-0 fish to the population is determined from spawning biomass, and depending on the settlement process for a fish species and ocean dynamics, an age-0 fish may recruit a considerable distance from where spawning occurred. Furthermore, fish may migrate to spawning regions that are far from regions they occupied when not spawning. Therefore, the recruitment process is modelled assuming a coastwide spawning population (e.g., fish may spawn in regions where they are not present during the time of fishing) producing age-0 fish (recruits) throughout specified regions. The proportion of recruits in each region in each year is represented with the parameter $p^R_{y,r}$ as shown in equation 2.3, and $r-1$ parameters need to be specified for each time-step because the $r^{th}$ parameter is one minus the sum of the specified parameters (ie., $\sum_r p^R_{y,r} = 1$).

#### Recruitment Link to an Environmental Variable

Recruitment is modelled (equation 2.3) using a stock-recruit relationship (equation 2.4) that produces an average level of recruitment given current spawning biomass. Changes in the environment may change that average level of spawning biomass and is modelled using an environmental index ($I_y$) in equation 2.3 with the function $e^{I_y * \delta}$. The parameter $\delta$ is a covariate determining how the average recruitment is affected by the environmental index.

### 2.3.3 Movement

In its most simple form, movement (also called migration) is the proportion of individuals that move from region $j$ to region $k$ (individuals can only move among regions and movement among areas within regions is not explicitly modelled). The probability that the individual stays in its current region is equal to one minus the sum of the probabilities of moving out of the current region. Movement is specific to the partitions age, sex, time-step, and region.

One of the most common ways to model movement is using a transition matrix. Let $\Psi_{j\to k}$ be the instantaneous movement from region $j$ to region $k$ expressed as the proportion of the population in region $j$ moving to region $k$. The diagonal of the transition matrix will be the proportion that stay in region $j$ and the off-diagonals of $\Psi_{j\to k}$ will represent the proportions that move out of region $j$. The row of the matrix corresponds to $j$ (from) and $k$ corresponds to the column of the matrix (to). Each row of the transition matrix should sum to 1. Each dimension of the transition matrix will be equal to the number of regions. For example, let there be $n$ regions ($R = 1...n$), then the transition matrix for each age, sex, and time-step will look like:

$$\begin{bmatrix} \Psi_{R=1} & \Psi_{1\to 2} & \cdots & \Psi_{1\to n} \\ \Psi_{2\to 1} & \Psi_{R=2} & \cdots & \Psi_{2\to n} \\ \vdots & \vdots & \ddots & \vdots \\ \Psi_{n\to 1} & \Psi_{n\to 2} & \cdots & \Psi_{R=n} \end{bmatrix}$$

The numbers-at-age in region $j$ after movement, for a given age, sex, and time-step, is determined from the following equation.

$$\begin{aligned} N'_{a,s,|t,r=j} &= N_{|r=j} - N_{|r=j}\sum_{k\neq j}\Psi_{a,s|t,j\to k} + \sum_{k\neq j} N_{|r=k}\Psi_{a,s|t,k\to j} \\ &= N_{|r=j}\left(1-\sum_{k\neq j}\Psi_{a,s|t,j\to k}\right) + \sum_{k\neq j} N_{|r=k}\Psi_{a,s|t,k\to j} \\ &= N_{|r=j}\Psi_{a,s|t,j\to j} + \sum_{k\neq j} N_{|r=k}\Psi_{a,s|t,k\to j} \\ &= \sum_{k\in r} N_{|r=k}\Psi_{a,s|t,k\to j} \end{aligned} \tag{2.8}$$

**Movement parameters**

There are two options for the construction of the transition matrix:

1. entered as simple proportions in an array by time-step, age, sex, and region of origin, or
2. parameterize the proportions-at-age as a function of age and modify the parameters of the function for each time-step and sex.

A parameterized approach is implemented using functions called *constant* (Equation 2.9), *exponential* (Equation 2.10), or *double exponential* (Equation 2.11). Additionally, specific values for defined ages can be entered *Values* (Equation **??**)

$$\Psi_{a,s|t,k\to j} = \begin{cases} 0 & a \leq \psi_0 \\ \psi_c & a > \psi_0 \end{cases} \tag{2.9}$$

where, $\psi_0$ is the oldest age with a movement probability of zero before the first non-zero movement probability, and $\psi_c$ is a constant proportion for all ages greater than $\psi_0$.

$$\Psi_{a,s|t,k\to j} = \begin{cases} 0 & a \leq \psi_0 \\ \frac{e^{\psi}_{\lambda}(a-\psi_0+1)}{max(\Psi_{a,s|t,k\to j})} \times (\psi_{max} - \psi_{min}) & a > \psi_0 \end{cases} \tag{2.10}$$

where, $\psi_0$ is the oldest age with a movement probability of zero before the first non-zero movement probability, $\psi_\lambda$ is the slope parameter of the exponential function, $\psi_{min}$ is the minimum non-zero probability, and $psi_{max}$ is the maximum probability.

$$\Psi_{a,s|t,k\to j} = \begin{cases} 0 & a \leq \psi_0 \\ \frac{e^{\psi\lambda_L(a-\psi_0)-1}}{max(\Psi_{a,s|t,k\to j})}\psi_{max_L} & \psi_0 < a \leq \psi_{peak_L} \\ (\psi_{max_R} - \psi_a)e^{-\psi\lambda_R(a-\psi_0+1)} + \psi_a & a > \psi_{peak_L} \end{cases} \tag{2.11}$$

where, $\psi_0$ is the oldest age with a movement probability of zero before the first non-zero movement probability, $\psi_{\lambda_L}$ is the slope parameter of the exponential function for the left side of the function, $\psi_{\lambda_R}$ is the slope parameter of the exponential function for the right side of the function, $\psi_{max_L}$ is the maximum non-zero probability on the left side of the curve, , $\psi_{max_R}$ is the maximum non-zero probability on the right side of the curve, $\psi_{peak_L}$ is the age associated with the peak of the left curve.

$$\Psi_{a,s|t,k\to j} = \begin{cases} 0 & a \leq \psi_0 \\ \psi_{v_a} & a > \psi_0 \end{cases} \tag{2.12}$$

Overall, the followng are the possible parameters in the four functions described by equations 2.9 to 2.12 that may be specific to a sex, time, and region.

1. $\psi_0$: The oldest age with a movement probability of zero before the first non-zero movement probability. Therefore, all ages from age 0 to age $\psi_0$ do not move out the region they are in.
2. $\psi_c$: The constant non-zero probability of movement.
3. $\psi_\lambda$: The 'slope' of the exponential function in either the exponential function or associated with the left ($\lambda_L$) or right ($\lambda_R$) side of the double exponential.
4. $\psi_{min}$: The minimum non-zero probability of movement-at-age in the exponential function.
5. $\psi_{max}$: The maximum probability of the movement-at-age in the exponential function or for the left ($max_L$) or right ($max_R$) side of the double exponential function.
6. $\psi_{peak_L}$: The age at which the peak of the left ($peak_L$) side of the double exponential occurs. This is the transition between the left and right sides of the double exponential function. This parameter is an integer and the peak of the right side is one greater than $\psi_{peak_L}$.
7. $\psi_a$: The asymptote of the right side of the double exponential function.
8. $\psi_{v_a}$: Specific probability-at-age. Subsequent values after the last entered age are set to the last entered age.

### 2.3.4 Mortality

These operating models contain two types of mortality: natural mortality and fishing mortality. These are described below with definitions and mathematical equations. Total mortality, the summation of natural and fishing mortality, is noted as $Z$ and is often modelled using a differential equation describing the instantanous change with respect to a short period of time.

$$\frac{dN}{dt} = -Z \times N$$

Expanding to a single annual time step, the numbers in the next time-step, if mortality was the only process, are

$$N_{y+1} = N_y e^{-Z} \tag{2.13}$$

However, fishing mortality is often assumed to occur at a specific point in time.

$$N_{y+1} = N_y e^{-M} (1 - U_y) \tag{2.14}$$

where $U_y$ is an annual exploitation rate. This formulation makes the calculations simpler, faster, and easier to interpret. These equations are general mortality equations, and the specific equations related to natural and fishing mortality for the operating models are described below. We follow the FAO definition (`http://www.fao.org/3/a0212e/a0212e12.htm}`)and call the fishing mortality process in Equation 2.13 instantaneous and that in Equation 2.14 finite.

### Natural Mortality

Natural mortality represents mortality from all sources other than fishing (e.g., natural causes, predation, and emigration out of the area being modelled) and may reflect some processes that are not specifically accounted for in the model. Many fisheries models assume that natural mortality is constant over time, which will likely capture the general trend in abundance, but natural mortality likely varies from time-step to time-step. Therefore, the operating model allows for natural mortality that is age, sex, time-step, and region specific, but will likely assume a single value for natural mortality for each sex.

### Fishing Mortality

Fishing mortality can be modelled using the Baranov catch equation (an instantaneous formulation as with natural mortality), but it is simpler, faster, and more interpretable to model fishing mortality as a finite exploitation rate (also called Pope's approximation). This assumes that fishing occurs at a specific point in time, which will be an important assumption to consider when the fishery operates year round and at high mortality rates. For most applications, especially Pacific halibut with relatively low fishing mortality rates and a defined season, the exploitation rate is a useful approximation.

$$U_{|t,r,f} = \frac{C_{|t,r,f}}{B^{sr,p_f}_{|t,r,f}} \tag{2.15}$$

where $C_{|t,r,f}$ is the catch in time-step $t$ and region $r$ for sector $f$, and $B^{sr}_{|t,r,f}$ is the selected-and-retained biomass for that fishery. The time-point is the proportion of the time-step, $p_f$, at which the fishery occurs, and is commonly defined as 0.5. The fishing sectors typically operate at a scale finer than region, but region is used in the equations for fishing mortality because a single Pacific halibut may be available to any of the sectors in a region throughout an annual time step. Therefore, sectors are tracked at the region level, but may represent fishing in a particular area within a region (through selectivity and fishery timing, $p_f$). If a sector operates at a greater scale than region, that sector should be divided into region-specific sectors. In other words, a sector only operates within a region. Therefore, the region and sector subscripts are redundant, but retained.

Selectivity represents the probability that a fish of a particular age will be caught by the sector. This is a combination of gear selection (e.g., the size of the hook or the width of mesh in a net) and availability (are fish of that age in the area being fished). We do not separate these components and instead model them as a single probability. The selected proportions at age generally increase from young ages to older ages, but may also decline at the oldest ages. This is referred to as dome-shaped selectivity and may occur because older fish move out of the fishing area and become less available to the fishery, older fish may be able to avoid or escape the fishing gear, etc. Selectivity in this model is forced to asymptote at one (and not greater) for at least one age. Therefore, the exploitation rate refers to the proportion of a fully selected age-class of fish removed from the population.

The proportion selected at age can be entered specifically for each age, modelled using a logistic formulation to asymptote at one (equation 2.16),

$$S_{a,s|t,r,f} = \frac{\zeta_{max,s|t,r,f}}{1+19^{(\zeta_{a50,s|t,r,f}-age)/(\zeta_{a95,s|t,r,f}-\zeta_{a50,s|t,r,f})}} \tag{2.16}$$

or modelled using a double-normal function to allow for dome-shaped selectivity (equation 2.17).

$$S_{a,s|t,r,f} = \begin{cases} \zeta_{max,s|t,r,f}\dfrac{e^{-(a-\zeta_{peak,s|t,r,f})^2}}{2\zeta_{\sigma_L,s|t,r,f}} & age < \zeta_{peak,s|t,r,f} \\ \mathrm{Max}\left[\zeta_{max,s|t,r,f}\dfrac{e^{-(a-\zeta_{peak,s|t,r,f})^2}}{2\zeta_{\sigma_R,s|t,r,f}},\ \zeta_{final,s|t,r,f}\right] & age \geq \zeta_{peak,s|t,r,f} \end{cases} \tag{2.17}$$

Parameters are described below. Examples of these two parameterizations are shown in Figure 2.3. Additional parameterizations may be introduced in the future. An option for all selectivity parameterizations is to define the age at which selectivity is zero for that age and all lower ages. This parameter is $\zeta_{zero,s|t,r,f}$.

There are three parameters in the logistic function for selectivity.

1. $\zeta_{a50,s|t,r}$: The age at which the probability of selection is 50% for sex $s$, at time $t$, for sector $f$.
2. $\zeta_{a95,s|t,r}$: The age at which the probability of selection is 95% for sex $s$, at time $t$, for sector $f$.
3. $\zeta_{max,s|t,r}$: The maximum probability of selection (asymptote) for sex $s$, at time $t$, for sector $f$.

There are five parameters in the double normal function for selectivity.

1. $\zeta_{peak,s|t,r}$: The age at which the probability of selection is at its maximum for sex $s$, at time $t$, for sector $f$. This is the division between the left and right sides of the function.
2. $\zeta_{\sigma_L,s|t,r}$: The standard deviation of the normal distribution for ages younger than the peak age ($\zeta_{peak,s|t,r}$). This side of the selection curve is referred to as the left side or ascending limb.

3. $\zeta_{\sigma_R,s|t,r}$: The standard deviation of the normal distribution for ages older than the peak age ($\zeta_{peak,s|t,r}$). This side of the selection curve is referred to as the right side or descending limb. To create an asymptotic selectivity ogive with the double normal this parameter would be fixed at a sufficiently large value.

4. $\zeta_{max,s|t,r}$: The probability at the age associated with the peak. This must be set at 1.0 for one of the sexes, but may be less than 1.0 for the other sex.

5. $\zeta_{final,s|t,r}$: The lowest value of the function on the right side of the function. The probability for ages that would be calculated less than this value are fixed at this value.

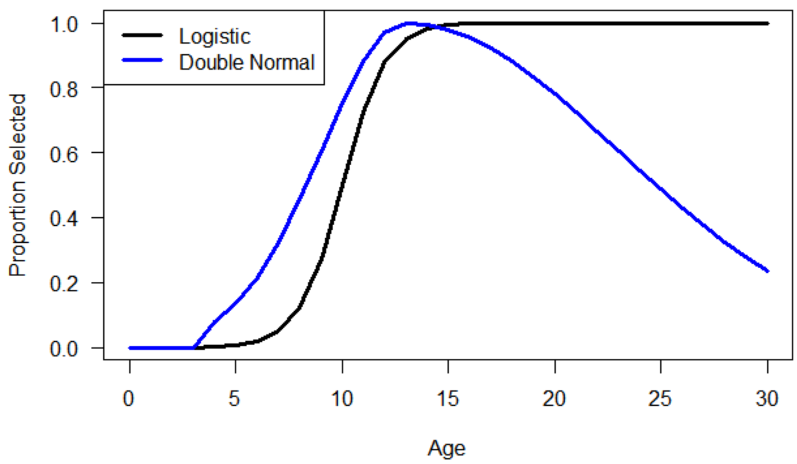



**Figure 2.3:** Examples of the logistic and double-normal parameterizations for selectivity.

The availability of fish to a sector changes from year to year and changes may be made to gear for efficiency or to meet changes in regulation. Therefore, selectivity likely varies over time, hence the time subscript on the parameters and selectivity-at-age. Time-varying selectivity-at-age can be implemented by adjusting the parameters across time according to the methods described in section 2.3.9.

Specific terms are used to refer to fishery related quantities. Landings are the fish that are landed and quantified. These include commercial landings of O32 Pacific halibut at processing plants and Pacific halibut kept in the recreational fishery. Captured fish refers to fish that are captured by fishing gear, of which some may subsequently survive if released. Some sources may refer to that as catch, but **the term catch in this document is synonymous with landings**. Of the captured fish that are subsequently released, some may die; this is called discard mortality. The sum of catch (i.e., landings) and discard mortality is the total fishing mortality. To model total fishing mortality an exploitation rate, selectivity curve, and retention curve are needed.

Retention-at-age represents the probability that a captured fish is retained. This curve typically increases from lower probabilities at younger ages and nearing one at older ages, but often does not reach exactly one at its peak to represent the occasional discarding or loss of older/larger fish in that fishery. Low retention of young fish may represnet a minimum size limit or high-grading for larger/older fish. Low retentions of older fish may represent a maximum size limit or high-grading for smaller/younger fish. It is important to use retention because it can be used to calculate the proportion of fish-at-age that are released and may suffer discard mortality.

Retention is parameterized using the same options as selectivity (direct input by age, logistic, or double-normal) The retention parameters are

1. $\eta_{a50,s|t,r}$: The age at which the probability of retention is 50% for sex $s$, at time $t$, for sector $f$.
2. $\eta_{a95,s|t,r}$: The age at which the probability of retention is 95% for sex $s$, at time $t$, for sector $f$.
3. $\eta_{max,s|t,r}$: The asymptote or maximum probability of retention at any age (ranges from 0 to 1).

There are five parameters in the double normal function for selectivity and one optional parameter.

1. $\eta_{peak,s|t,r}$: (Required) The age at which the probability of retention is at its maximum for sex $s$, at time $t$, for sector $f$.
2. $\eta_{\sigma_L,s|t,r}$: (Required) The standard deviation of the normal distribution for ages younger than the peak age ($\eta_{peak,s|t,r}$). This side of the retention curve is referred to as the left side or ascending limb.
3. $\eta_{\sigma_R,s|t,r}$: (Required) The standard deviation of the normal distribution for ages older than the peak age ($\eta_{peak,s|t,r}$). This side of the retention curve is referred to as the right side or descending limb. To create an asymptotic retention ogive with the double normal this parameter would be fixed at a sufficiently large value.
4. $\eta_{max,s|t,r}$: The asymptote or maximum probability of retention at any age (ranges from 0 to 1).
5. $\eta_{final,s|t,r}$: The lowest value of the function on the right side of the function. The probability for ages that would be calculated less than this value are fixed at this value.

The logistic function for retention is

$$R_{a,s|t,r,f} = \frac{\eta_{max,s|t,r}}{1 + 19^{(\eta_{a50,s|t,r,f} - age)/(\eta_{a50,s|t,r,f} - \eta_{a95,s|t,r,f})}} \tag{2.18}$$

and the double-normal function for retention is

$$R_{a,s|t,r,f} = \begin{cases} \eta_{max,s|t,r,f} \dfrac{e^{-(a-\eta_{peak,s|t,r,f})^2}}{2\eta_{\sigma_L,s|t,r,f}} & age < \eta_{peak,s|t,r,f} \\ Max\left[\eta_{max,s|t,r,f} \dfrac{e^{-(a-\eta_{peak,s|t,r,f})^2}}{2\eta_{\sigma_R,s|t,r,f}},\ \eta_{final,s|t,r,f}\right] & age \geq \eta_{peak,s|t,r,f} \end{cases} \tag{2.19}$$

It is important to not confuse retention with selectivity. For fisheries that retain all fish, the retention curve would be one across all ages because selectivity accounts for the sector not catching younger fish. The resulting product of retention and selectivity is called the keep curve and represents the probabilities-at-age of fish that are captured and retained, thus kept and landed. Figure 2.4 shows examples of selectivity and retention curves, and the resulting keep curve.

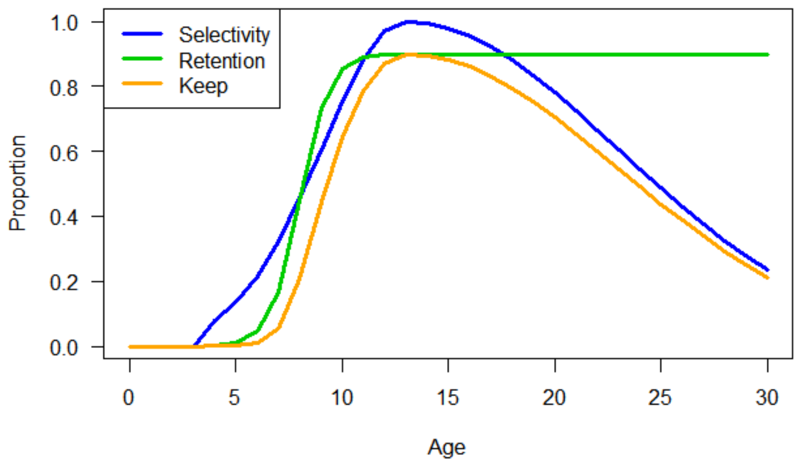



**Figure 2.4:** Examples of the double-normal parameterization for selectivity, a logistic parameterization for retention, and the resulting keep curve.

The sectors are assumed to operate at a very specific point of time defined as the proportion of the time-step ($p_f$). Some sectors will operate before others and will affect the abundance available later in the time-step. Therefore, the sequential operation of the sectors is accounted for by applying the probability that a fish survives sectors that occurred previously (catch and discard mortality). This necessitates determining only those sectors that occurred before the sector of interest.

Catch at age and sex in numbers ($C^n$) or weight ($C$) for a sector in an area can be determined from the numbers-at-age ($N_a$), natural mortality rate ($M$), exploitation rate ($U_f$), selectivity ($S$), proportion that are subsequently retained ($R$), mean weight-at-age ($W$), and the mortality from fisheries that occurred before the sector of interest. Appendix B presents details of this method as well as a method that does not take the sequence into account.

We notate the numbers-at-age and the biomass-at-age at a particular point in time in a time-step as $N^p_{a,s|t,r}$ and $B^p_{a,s|t,r}$, respectively, where the superscript indicates the proportion of the time-step. Given this notation, the catch for a particular sector is

$$\begin{aligned} C^n_{a,s|t,r,f} &= N^p_{a,s|t,r} U_{|t,r,f} S_{a,s|t,r,f} R_{a,s|t,r,f} \\ C_{a,s|t,r,f} &= N^p_{a,s|t,r} W_{a,s,|t,r,f} U_{|t,r,f} S_{a,s|t,r,f} R_{a,s|t,r,f} \end{aligned}$$

and the total catch for a sector is

$$C^n_{|t,r,f} = \sum_{a=0}^{A} \sum_{s} C^n_{a,s|t,r,f} \tag{2.20}$$

$$C_{|t,r,f} = \sum_{a=0}^{A} \sum_{s} C_{a,s|t,r,f} = U_{|t,r,f} B^{sr,p}_{|t,r,f} \tag{2.21}$$

where $B^{sr,p}_{|t,r,f}$ is the selected and retained biomass for sector $f$, and will be discussed later.

Discarded fish-at-age (fish caught but not retained) that suffer mortality after release (discard mortality) are an additional source of fishing mortality not accounted for in the retained catch. Discard mortality is calculated as

$$\begin{aligned} D^n_{a,s|t,r,f} &= N^p_{a,s|t,r} U_{|t,r,f} S_{a,s|t,r,f} \left(1 - R_{a,s|t,r,f}\right) d_{a,s|t,r,f} \\ D_{a,s|t,r,f} &= N^p_{a,s|t,r} W_{a,s,|t,r,f} U_{|t,r,f} S_{a,s|t,r,f} \left(1 - R_{a,s|t,r,f}\right) d_{a,s|t,r,f} \end{aligned}$$

where $d_{a,s|t,r,f}$ is the discard mortality rate (DMR) and $(1 - R_{y,a,s,f})\, d_{y,a,s,r,f}$ is the proportion of selected fish that are released and do not survive. The summation of catch ($C_{|t,r,f}$) and discarded fish that die ($D_{|t,r,f}$) is the total mortality for sector $f$.

$$TM_{|t,r,f} = C_{|t,r,f} + D_{|t,r,f} \tag{2.22}$$

When modelling multiple fisheries occurring at different times, the calculation of $N^p$ incorporates the mortality from fisheries that occurred previous to the sector of interest. The code may divide a time-step into sub-time-steps, but a more efficient method can be done using the probability that a fish survives an earlier sector in that time-step. The reader is referred to Appendix B for the details. The catch for a sector is

$$\begin{aligned} C^n_{a,s|t,r,f} = & N_{a,s|t,r} e^{-p_f M_{a,s|t,r}} \times \\ & \prod_{i \in p_j < p_f} \left\{1 - U_{|t,r,i} S_{a,s|t,r,i} \left[R_{a,s|t,r,i} + (1 - R_{a,s|t,r,i}) d_{a,s|t,r,i}\right]\right\} \times \\ & U_{|t,r,f} S_{a,s|t,r,f} R_{a,s|t,r,f} \end{aligned} \tag{2.23}$$

$$C_{a,s|t,r,f} = C^n_{a,s|t,r,f} W_{a,s|t,r} \tag{2.24}$$

where

$$N^p_{a,s|t,r} = N_{a,s|t,r} e^{-p_f M_{a,s|t,r}} \prod_{i \in p_j < p_f} \left\{1 - U_{|t,r,i} S_{a,s|t,r,i} \left[R_{a,s|t,r,i} + (1 - R_{a,s|t,r,i}) d_{a,s|t,r,i}\right]\right\}$$

and incorporates the product of the probabilities-at-age of surviving fisheries that occurred prior to the sector of interest ($f$). The total predicted catch for a sector in a region is shown in equation B.3.

Discarded fish-at-age (fish caught but not retained) that suffer mortality after release (discard mortality) is calculated in a similar manner.

$$\begin{aligned} D^n_{a,s|t,r,f} = & N_{a,s|t,r} e^{-p_f M_{a,s|t,r}} \times \\ & \prod_{i \in p_j < p_f} \left\{1 - U_{|t,r,i} S_{a,s|t,r,i} \left[R_{a,s|t,r,i} + (1 - R_{a,s|t,r,i}) d_{a,s|t,r,i}\right]\right\} \times \\ & U_{|t,r,f} S_{a,s|t,r,f} \left(1 - R_{a,s|t,r,f}\right) d_{a,s|t,r,f} \end{aligned} \tag{2.25}$$

$$D_{a,s|t,r,f} = D^n_{a,s|t,r,f} W_{a,s|t,r,f} \tag{2.26}$$

where $d_{a,s|t,r,f}$ is the discard mortality rate (DMR) and $(1 - R_{y,a,s,f})\, d_{y,a,s,r,f}$ is the proportion of selected fish that are released and do not survive. The summation of catch ($C_{|t,r,f}$) and discarded fish that die ($D_{|t,r,f}$) is the total mortality for sector $f$ (equation 2.22) and can be written as

$$
\begin{aligned}
(2.27) \qquad TM^{n}_{|t,r,f} &= \sum_{a=0}^{A}\sum_{s} N_{a,s|t,r} e^{-p_f M_{a,s|t,r}} \times \\
&\prod_{i \in p_j < p_f} \left\{1 - U_{|t,r,i} S_{a,s|t,r,i} \left[R_{a,s|t,r,i} + (1 - R_{a,s|t,r,i}) d_{a,s|t,r,i}\right]\right\} \times \\
&S_{a,s|t,r,f} \left[R_{a,s|t,r,f} + \left(1 - R_{a,s|t,r,f}\right) d_{a,s|t,r,f}\right] \\
(2.28) \qquad TM_{t,r,f} &= \sum_{a=0}^{A}\sum_{s} N_{a,s|t,r} e^{-p_f M_{a,s|t,r}} \times \\
&\prod_{i \in p_j < p_f} \left\{1 - U_{|t,r,i} S_{a,s|t,r,i} \left[R_{a,s|t,r,i} + (1 - R_{a,s|t,r,i}) d_{a,s|t,r,i}\right]\right\} \times \\
&S_{a,s|t,r,f} \left[R_{a,s|t,r,f} + \left(1 - R_{a,s|t,r,f}\right) d_{a,s|t,r,f}\right] W_{a,s|t,r,f}
\end{aligned}
$$

The selected-and-retained biomass for sector $f$ in the population is simply the catch divided by the exploitation rate, but catch is an input and selected-at-retained biomass must be calculated from selectivity ($S$), proportion retained ($R$), and mean weight-at-age ($W$) to determine the exploitation rate $U_f$ (equation B.11).

$$
\begin{aligned}
(2.29) \qquad B^{sr,p}_{|t,r,f} &= \frac{C_{a,s|t,r,f}}{U_{|t,r,f}} \\
&= \sum_{a=0}^{A}\sum_{s} N_{a,s|t,r} e^{-p_f M_{a,s|t,r}} \times \\
&\prod_{i \in p_j < p_f} \left\{1 - U_{|t,r,i} S_{a,s|t,r,i} \left[R_{a,s|t,r,i} + (1 - R_{a,s|t,r,i}) d_{a,s|t,r,i}\right]\right\} \times \\
&S_{a,s|t,r,f} R_{a,s|t,r,f} W_{a,s|t,r,f}
\end{aligned}
$$

Therefore, natural and fishing mortality can be accounted for simultaneously, and the numbers-at-age in the next time-step, accounting for all mortality, are

$$
(2.30) \quad N''_{a,s|t,r} = N'_{a,s|t,r} e^{-M_{a,s|t,r}} \prod_{f} \left\{1 - U_{|t,r,i} S_{a,s|t,r,i} \left[R_{a,s|t,r,i} + (1 - R_{a,s|t,r,i}) d_{a,s|t,r,i}\right]\right\}
$$

See Appendix B for details.

The exploitation rate is defined to be between zero and one, but it is possible that the explotation rate may exceed one if the calculated exploitable biomass is less than the fixed input catch for a sector. If the exploitation rate for a specific sector exceeds 1, a negative population size may occur. Therefore, a maximum exploitation rate ($U_{max}$) must be specified, which is realistically less than one. If the exploitation rate for a sector exceeds the defined maximum, the exploitation rate for that sector should be set to the defined maximum. When this adjustment occurs, the predicted catch will be different than the input catch, and a penalty should be applied since catches are considered observed inputs (not data with error). This penalty will be discussed in a later section on conditioning.

### 2.3.5 Maturity

Maturity and spawning may be separated into two separate states with maturity being a part of the state object, and the numbers of mature fish specifically tracked as part of the state. However, this operating model does not partition maturity in the state, but instead simply determines the numbers of mature fish from mature proportions-at-age (called the maturity curve).

$$N^{ma}_{a,s|t,r} = N''_{a,s|t,r}\Omega_{a,s|t,r} \tag{2.31}$$

#### Maturity functional forms and parameters

The maturity curve ($\Omega$) may be an empirical vector of proportions input by the user from externally estimated data. Alternatively, the vector or proportions may be determined from a functional form, such as a logistic equation, with appropriate parameters defined.

$$\Omega_{a,s|t,r} = \frac{\omega_{max,s|t,r}}{1 + 19^{(\omega_{a50,s|t,r} - age)/(\omega_{a95,s|t,r} - \omega_{a50,s|t,r})}} \tag{2.32}$$

There are three parameters in this asymmetric logistic function.

1. $\omega_{max,s|t,r}$: The asymptote or maximum proportion mature at any age (ranges from 0 to 1).
2. $\omega_{a50,s|t,r}$: The age at which the proportion mature equals 50% of the asymptote for sex $s$, at time $t$, and in region $r$.
3. $\omega_{a95,s|t,r}$: The age at which the proportion mature is 95% of the asymptote for sex $s$, at time $t$, and in region $r$. Must be greater than $\omega_{a50,s|t,r}$.

### 2.3.6 Spawning biomass

The number of spawning individuals is the number that are mature at age times the proportion spawning at age. This allows for the accounting of individuals that are mature (able to produce gametes) but are not actively spawning in that time-step (e.g., skip spawning), and those that are mature and actively spawning in that time-step.

$$N^{sp}_{a,s|t,r} = N^{ma}_{a,s|t,r}\Phi_{a,s|t,r} \tag{2.33}$$

The spawning biomass ($B^{sp}$) is calculated as follows.

$$B^{sp}_{|t,r} = \sum_{a=0}^{A}\sum_{s} N^{sp}_{a,s|t,r}W^{1}_{a,s|t,r} \tag{2.34}$$

where $W^{1}_{a,s|t,r}$ is the weight-at-age for that age, sex, time-step, and region at the end of the time-step.

Most sex-specific stock assessments account for only the female spawning biomass, which would simply be

$$B^{sp}_{s=1|t,r} = \sum_{a=0}^{A} N^{sp}_{a,s=1|t,r} W^{1}_{a,s=1|t,r} \tag{2.35}$$

**Spawning proportion parameters**

The proportions spawning ($\Phi$) is a vector of proportions-at-age input by the user from externally estimated data. Typically, this vector contains a value of 1 for all ages because there is currently a paucity of information for many fish stocks.

### 2.3.7 Size-at-age

Growth is not modelled specifically (e.g, length-at-age), but weight-at-age is used to calculate biomass-at-age from numbers-at-age. Mean weight-at-age, sex, and region for a particular time-step and sector ($W_{a,s|t,r,f}$, which will simply be referred to as weight-at-age regardless of the various partitions), is input by the user. Sector-specific weight-at-age are used because selectivity may operate on the larger fish of a certain age, resulting in a larger weight-at-age than in the population.

Projecting variability in weight-at-age is discussed in Section 2.5.

### 2.3.8 Initial population

The initial population is the partitioned population numbers at the start of the first modelled time-step, and is based on unfished equilibrium recruitment ($R_0$) with three potential adjustments.

1. An overall adjustment ($e^{\delta_{|I}}$) that changes $R_0$ (i.e., the overall scale of recruitment) and could mimic a different regime that influenced the initial population.
2. Cohort ($a$) specific adjustments to account for recruitment variability ($\varepsilon_{a|I}$).
3. Adjustments by age to account for an average level of fishing that occurred before the initial time-step: $\prod_f \left\{1 - U_{|t,r,f} S_{a,s|t,r,f} \left[R_{a,s|t,r,f} + (1 - R_{a,s|t,r,f}) d_{a,s|t,r,f}\right]\right\}$.

Calculating the initial equilibrium population size is not a simple calculation when region is in the partition and initial recruitment deviations are used. It is easiest to build up the population sequentially by each cohort that makes up the initial population using the sequence of processes described in Section 2.3: recruitment, movement, and mortality. This will be time-consuming, but only has to be done while an operating model is being conditioned.

The numbers at age 0 for the cohort that is age $a$ in the initial time-step ($I$) for each sex and region is

$$N_{0,s|I-a,r} = p_s\; p_{a|I,r}\; e^{\delta_{|I}} R_0\; e^{\left(\varepsilon_{a|I}-\frac{\sigma_R^2}{2}\right)} \prod_f \left\{1 - U_{|I,r,f} S_{0,s|I,r,f}\left[R_{0,s|I,r,f} + (1-R_{0,s|I,r,f}) d_{0,s|I,r,f}\right]\right\} \tag{2.36}$$

where $p_s$ is the proportion of sex $s$ at birth ($\sum_s p_s = 1$) and $p_{a|I,r}$ is the proportion of cohort $a$ recruiting to region $r$ in the initial time-step ($\sum_r p_{|I,a,r} = 1$). It is assumed that there is a single selectivity curve for the initial time period that applies equally to all cohorts and a constant exploitation rate for all cohorts over their life-span before the initial time-step.

Equation 2.36 calculates the number for each cohort when they were age 0 prior to the initial time-step. To calculate the numbers-at-age in the initial time-step, the annual process for each cohort is iterated up to the age that each cohort would be in the initial time-step. For example, to calculate the cohort that is age 3 in the initial population, Equation 2.36 would first determine the number of that cohort that were born into the population three time-steps prior. Then, the population dynamics would apply to that cohort for three iterations (0 to 1, 1 to 2, and 2 to 3) to determine the numbers in that cohort at age 3 in the initial time-step. Therefore, the annual process for the cohort that is age $a$ in the initial time-step is iterated from $i = a \dots 1$ in the following equations. It begins by incrementing the annual process.

$$N_{a-i+1,s|I-i+1,r} = N_{a-i,s|I-i,r} \tag{2.37}$$

Then, movement from region $j$ to $k$ is applied. The subscripts for age, sex, and time-step are dropped for clarity in the derivation below, but are noted in the final equation. Also note that the movement-at-age, $Psi$, does not change in time-steps prior to the initial time-step.

$$\begin{aligned}
N'_{a-i+1,s|I-i+1,j} &= N_{|j} - N_{|j}\sum_{k\neq j}\Psi_{|j\to k} + \sum_{k\neq j} N_{|k}\Psi_{|k\to j} \\
&= N_{|j}\left(1 - \sum_{k\neq j}\Psi_{|j\to k}\right) + \sum_{k\neq j} N_{|k}\Psi_{|k\to j} \\
&= N_{|j}\Psi_{|j\to j} + \sum_{k\neq j} N_{|k}\Psi_{|k\to j} \\
&= \sum_{k\in r} N_{a-i+1,s|I-i+1,k}\Psi_{a-i+1,s|I,k\to j} \qquad (2.38)
\end{aligned}$$

Finally, natural and fishing mortality is applied. Subscripts for age, sex, and time-step are dropped for clarity, but are the same as in the left side of the equation unless indicated (e.g., $M$, $U$, $S$, $R$, and $d$).

$$N''_{a-i+1,s|I-i+1,r} = N'_{|r} e^{(-M_{|I,r})} \prod_f \left\{1 - U_{|I,r,f} S_{|I,r,f}\left[R_{|I,r,f} + (1-R_{|I,r,f}) d_{|I,r,f}\right]\right\} \tag{2.39}$$

Graphically, the process will look like:

$U_{t=I-\{5...0\}}$

| $Sel$ | $I-5$ | $I-4$ | $I-3$ | $I-2$ | $I-1$ | $I$ |
|---|---|---|---|---|---|---|
| $S_0$ | $coh5_{a=0}$ | $coh4_{a=0}$ | $coh3_{a=0}$ | $coh2_{a=0}$ | $coh1_{a=0}$ | $coh0_{a=0}$ |
| $S_1$ | | $coh5_{a=1}$ | $\cdots$ | $\cdots$ | $\cdots$ | $coh1_{a=1}$ |
| $S_2$ | | | $coh5_{a=2}$ | $\cdots$ | $\cdots$ | $coh2_{a=2}$ |
| $S_3$ | | | | $coh5_{a=3}$ | $\cdots$ | $coh3_{a=3}$ |
| $S_4$ | | | | | $coh5_{a=4}$ | $coh4_{a=4}$ |
| $S_5$ | | | | | | $coh5_{a=5}$ |

**Table 2.3**

| | Years before Initial | | | | | | |
|---|---|---|---|---|---|---|---|
| | ... | I-5 | I-4 | I-3 | I-2 | I-1 | I |
| Cohort | | | | | | | $coh0_{a=0}$ |
| | | | | | | $coh1_{a=0}$ | $coh1_{a=1}$ |
| | | | | | $coh2_{a=0}$ | $coh2_{a=1}$ | $coh2_{a=2}$ |
| | | | | $coh3_{a=0}$ | $coh3_{a=1}$ | $coh3_{a=2}$ | $coh3_{a=3}$ |
| | | | $coh4_{a=0}$ | $coh4_{a=1}$ | $coh4_{a=2}$ | $coh4_{a=3}$ | $coh4_{a=4}$ |
| | | $coh5_{a=0}$ | $coh5_{a=1}$ | $coh5_{a=2}$ | $coh5_{a=3}$ | $coh5_{a=4}$ | $coh5_{a=5}$ |
| | ... | ... | ... | ... | ... | ... | ... |

### Summary of initial population numbers

To summarize how the initial numbers in the partitions are completed, psuedo code is provided below.

1. Determine the inital number of age zero ($i = 0$) fish for the cohort ("*coh*" in the schematic representation above) of age $a$ from Equation 2.36, where $a = 0, 1, 2, \ldots, nA$. The $n$ is a multiplier on the plus group age $A$ to simulate beyond the plus group to ensure the dynamics of the plus group are correct.

2. Loop over $a = 1, 2, \ldots, nA$. For each $a$,
   (a) loop over $i = a, a-1, \ldots, 2, 1$ applying Equations 2.37, 2.38, and 2.39 to build up the initial numbers for each cohort at age $a$.
3. sum numbers over $a = A, A+1, \ldots, nA$ to create the plus group ($A$).

A value of 3 is typically used for $n$, but it depends on the plus group age and the time willing to spend iterating over ages.

### Calculation of other initial population values

Initial spawning biomass is calculated after the initial numbers-at-age are completed.

$$B^{sp}_{|I,r} = \sum_{a=0}^{A} \sum_{s} N''_{a,s|I,r} \Omega_{a,s|I,r} \Phi_{a,s|I,r} W^{1}_{y,a,s,r} \tag{2.40}$$

**Population Dynamics**

The sequence

1. *age increment*,
2. *spawning (or may occur at end)*,
3. *recruitment*,
4. *movement*,
5. *mortality*, and
6. *spawning (or may occur at beginning)*.

The notation

| | | |
|---|---|---|
| $N$ | : | Beginning of the time-step after age increment and recruitment. |
| $N'$ | : | After movement before mortality |
| $N''$ | : | End of the time-step, after natural and fishing mortality |

The equations

$$N_{y,a,s,r,m} = \begin{cases} R_{s|t,r} & a = 0 \\ N_{a-1,s|t-1,r} & 1 \le a < A \\ N_{a-1,s|t-1,r} + N_{a,s|t-1,r} & a = A \end{cases}$$

$$N'_{a,s|t,r} = \sum_{k \in r} N_{a,s|t,k} \Psi_{a,s|t,k \to r}$$

$$N''_{a,s|t,r} = N'_{a,s|t,r} e^{-M_{a,s|t,r}} \prod_{f} \left\{ 1 - U_{|I,r,f} S_{|I,r,f} \left[ R_{|I,r,f} + (1 - R_{|I,r,f}) d_{|I,r,f} \right] \right\}$$

#### 2.3.9 Parameter evolution through time

A description of deviations applied to parameters.

### 2.4 Conditioning the Operating Models

#### 2.4.1 Observations and Data

The current assessment used eight categories of observations and data in the modelling and fitting process (IPHC-2020-SA-01, https://iphc.int/uploads/pdf/sa/2020/iphc-2020-sa-01.pdf). A detailed description of the various data used in the stock assessment and related data sets are provided in IPHC-2020-SA-02 (https://iphc.int/uploads/pdf/sa/2020/iphc-2020-sa-02.pdf). Below is a description of the categories of data/observations and what may be available for use in conditioning the multi-area operating model, including data that may not currently be used in the stock assessment.

**Fishing mortality**

The mortality of Pacific halibut due to fishing (i.e., landings and discard mortality) are not treated as data in the stock assessment because they are entered as fixed, known values without error (empirical observations). Fishing mortality is a very important driver of the population dynamics.

Sectors

**FISS Indices**

These data are an annual relative index of abundance or biomass. They represent changes in abundance or biomass from year to year, but do not represent the absolute scale. Fishery-Independent Setline Survey (FISS) numbers-per-unit-effort (NPUE), survey weight-per-unit-effort (WPUE), and fishery catch-per-unit-effort in weight (CPUE) are available for Pacific halibut. The survey index in numbers-per-unit-effort (NPUE) is available coastwide, by Biological Region, or by IPHC Regulatory Area.

**FISS Age Compositions**

These data are the numbers-at-age of Pacific halibut (commonly in proportions) in the survey catches and fishery catches. Survey observations are available for each sex and two years of separate sex data are currently available for fishery landings (2017 and 2018). Differences in sex ratios inform differences in selectivity, availability, and potentially movement between areas.

### Fishery CPUE

These data are an annual relative index of abundance or biomass. They represent changes in abundance or biomass from year to year, but do not represent the absolute scale. Fishery-Independent Setline Survey (FISS) numbers-per-unit-effort (NPUE), survey weight-per-unit-effort (WPUE), and fishery catch-per-unit-effort in weight (CPUE) are available for Pacific halibut.

### Fishery Age Compositions

These data are the numbers-at-age of Pacific halibut (commonly in proportions) in the survey catches and fishery catches. Survey observations are available for each sex and two years of separate sex data are currently available for fishery landings (2017 and 2018). Differences in sex ratios inform differences in selectivity, availability, and potentially movement between areas.

### Weight-at-age

These data are the weight-at-age of Pacific halibut observed from various sources and are commonly summarized as the average weight-at-age. They are entered as empirical data in the stock assessment and are not involved in the fitting process.

### Maturity-at-age

There are limited data on maturity-at-age for Pacific halibut and a single ogive representing the probability of being mature at each age is used to calculate fecundity and entered as empirical data.

### Environmental Observations

The Pacific halibut stock assessment uses an index linked to average recruitment (high or low) that is developed from the Pacific Decadal Oscillation (PDO).

Additional environmental observatiosn may be useful to condition the multi-area operating model. These may be ocean temperatures or prey abundance, for example.

### Other Surveys

There are many other surveys that catch Pacific halibut, including NMFS trawl and longline surveys. These data may inform abundances of various cohorts in specific areas.

**Lengths**

Length data are not used in the age-structured stock assessment model but more samples are available coastwide than age data. They may be useful to investigate differences between areas.

**Stock distribution**

The stock distribution estimated from FISS data are available by IPHC Regulatory Area and by Biological Region. Changes in this distribution over time may indicate differences in fishing pressure between areas and may also inform movement.

**Tag returns**

Tagging data are useful to inform movement, migration, and mortality. There are many years of tag releases and returns for Pacific halibut, which are mostly informative of movement between specific areas. The synthesis of this information over amny years can provide an insight into the movement of Pacific halibut.

### 2.4.2 Predictions from the stock assessment

The stock assessment integrates various data sources to predict population quantities as well as uncertainty in those quantities. Four inidividual models are combined in an ensemble to account for structural and parameter uncertainty. Two of the individual models incorporate a short time-series starting in 1993, thus only predictions from 1993 onward can be supplied by the ensemble.

## 2.5 Projecting the Operating Models

### 2.5.1 Recruitment

See IPHC-2018-MSAB012-07. Discuss regimes, PDO, and recruitment variability.

### 2.5.2 Fishing mortality

Based on the management procedure. Mimic catch sharing plans by IPHC Regulatory Area to determine allocation across sectors. Selectivity deviations for commercial fishery and survey.

### 2.5.3 Movement

Annual variability in movement yet to be determined.

### 2.5.4 Weight-at-age

Projected values of weight-at-age are modelled using a random walk to introduce inter-annual variability. Done by region with some synchrony.

## 2.6 Reference Points

Unfished, equilibrium spawning biomass at the start of the year was found using weight-at-age, maturity-at-age, natural mortality, and unfished, equilibrium recruitment ($R_0$).

$$B_0 = R_0 \left[ \sum_{a=1}^{A-1} e^{-M(a-1)} \overline{w}_a m_a + \frac{e^{-M(A-1)} \overline{w}_A m_A}{1 - e^{-M}} \right] \tag{2.41}$$

Unfished equilibrium spawning biomass (i.e., $B_0$) requires the definition of many parameters (e.g., weight-at-age) that are likely time-varying, thus the spawning biomass will fluctuate without fishing. Therefore, dynamic calculations of unfished equilibrium spawning biomass are calculated using information from recent years. This is a measure of the stock size if fishing had not occurred and is useful to calculate a stock status that is reflective of the effect of fishing and not the environment.

Dynamic unfished quantities are calculated by simulating a ‘shadow’ state alongside the fished state. All parameters (including deviations) are the same, except that the ‘shadow’ state does not have any fishing mortality. The additional processing time is minimal because the ‘shadow’ state is entirely processed in memory with almost negligible additional reading or writing to disk and the fishing processes are not called, which are typically a large part of the processing time.

The calculation of Total Mortality based on SPR...

# Chapter 3

# Specifications for the Pacific halibut MSE framework

The Management Strategy Evaluation for Pacific halibut is currently being used to investigate management procedures to set the coastwide mortality limit (coastwide scale) and determine catch limits for each IPHC Regulatory Area (distribution of mortality limits, Figure 3.1). This requires a multi-area operating model with fleets represented within IPHC Regulatory Areas. The specifications for this MSE are provided below.

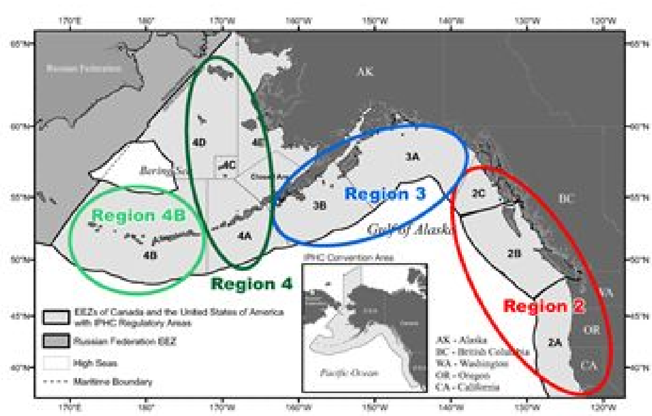



**Figure 3.1:** IPHC Regulatory Areas (grey shaded areas) and Biological Regions (colored circles).

There are many parameters that make up the Operating Model including population parameters and fishery parameters. Some of the parameters are simply a set parameter that drives the population, and are called input parameters. Derived parameters are calculated from parameters, inputs, and outputs. An example is that natural mortality ($M$) is an input parameter that in combination with other parameters results in the spawning biomass (a derived parameter). Parameters are described below.

## 3.1 Management Procedures

### 3.1.1 Data Generation

The OM provides outputs that can be used to generate data from the Pacific halibut stock. In particular, for each year in the simulation the model provides numbers-at-age in the stock by sex and region, numbers-at-age in the catch by sex, region and fishery sector, numbers-at-age available to each fishery at a specific point in time, selectivity-at-age by fishery sector, and weight-at-age by sex, region and fishery sector. From these outputs it would be possible to obtain all the inputs currently used in the stock assessment. To maintain consistency between the various elements needed by the Estimation Model (EM) and with the way data are collected in reality, all quantities are first generated at an IPHC Regulatory Area level and then aggregated to a coastwide level.

**Coastwide total mortality** The total mortality (TM) for a fishery is set equal to the TCEY resulting from the application of the harvest control rule, but may be modified in the OM to account for implementation error. Therefore, the coastwide total mortality required by the assessment is obtained by summing the total mortality from each fishery.

**Proportion at age in the catch and in the survey.** Proportion-at-age in the catch by fishery sector are derived from the numbers-at-age available to each fishery sector at a specific point in time times the selectivity-at-age for each specific fishery sector. From this exploitable abundance-at-age the proportions-at-age are calculated.

$$pNAA_{a,s|t,r} = \frac{(N_{a,s|t,r} \times S_{a,s|t,f})}{\sum_{a=0}^{A} N_{a,s|t,r}} \tag{3.1}$$

where $N_{a,s|t,r}$ are the numbers-at-age in the population available to a specific fishery sector $f$, $S_{a,s|t,f}$ is the selectivity by age and sex for each year and fishery sector $f$. Observation error is implemented by means of a Dirichlet distribution, using a sample size (3.1.1) as scale parameter. The generated proportion-at-age by fishery sector are then multiplied by the fishery sector total mortality in number, to calculate catch-at-age in numbers per each fishery sector. These catch-at-age are aggregated to a coastwide level, and the proportions-at-age by sector are re-calculated to be used in the EM.

**Sample size** The number of fish aged for each fishery (sample size) is used as the scale parameter for the Dirchlet distribution. The total coastwide number of fish aged in a specific year is also an input of the estimation model. Two options are suggested for the calculation of the sample size:

1. the sample size by Biological Region is generated from the sample size by Biological Region used in the long coastwide assessment model: in particular, the sample size is randomly drawn from the sample size available historically for each fishery sector.

2. the sample size by Biological Region is generated directly using a fixed proportion of the total mortality by fishery sector or total abundance by Biological Region:

   - sample size for the directed commercial, non-directed commercial discard mortality, recreational and subsistence sectors: for each sector, the sample size is calculated using a fixed proportion of the total mortality by Biological Region and sector.
   - sample size for survey and directed commercial discard mortality sectors: for each sector, the sample size is calculated using a fixed proportion of the available numbers-at-age by region.

   The proportion chosen could be an average derived from observations on the historical data.

**Survey NPUE and commercial WPUE.** The Fishery Independent Setline Survey (FISS) NPUE ($I^{sur}_{t,r}$) and the commercial WPUE ($I^{comm}_{t,r}$) are needed for the EM at a coastwide level, and for the MP at a Biological Region or IPHC Regulatory Area level. The OM produce the numbers-at-age available to the survey and the numbers-at-age available to the directed commercial sectors: from these values, the exploitable abundance and biomass are calculated at a Biological Region level. These are then multiplied by the catchability for each specific Biological Region.

$$I^{sur}_{t,r} = q^{sur}_{t,r} \sum_{a=0}^{A} N_{a,s|t,r,f} \times S_{a,s|t,f} \tag{3.2}$$

$$I^{comm}_{t,r} = q^{comm}_{t,r} \times \sum_{a=0}^{A} N_{a,s|t,r,f} \times S_{a,s|t,f} \times W_{a,s|t,f} \tag{3.3}$$

Some of the harvest control rules require the provision of the over 32 inches (O32) stock distribution at biological region and regulatory area level. In this case, the numbers-at-age are multiplied by the probability of each age to be 32 inches or bigger (see section **??**):

$$I^{sur}_{t,r} = q^{sur}_{t,r} \sum_{a=0}^{A} N_{a,s|t,r,f} \times O32prob_{a,s} \times S_{a,s|t,f} \tag{3.4}$$

(3.5)

Regional $q$ is specified as a relative $q$ by region (i.e. Biological Region 3 will have $q = 1$, and the other regional $q$ will be relative to this one) whose weighted mean (where the weight is the survey bottom area and the commercial catch for the NPUE and WPUE respectively) will equal the coastwide $q$. The proportion of each regional $q$ relative to $q$ in Biological Region 3 was arbitrarly fixed to the average of the last 20 years (Fig 3.2)

To derive the indices at the IPHC Regulatory Area level, as required by some of the MPs, the exploitable abundance and biomass are partitioned to each IPHC Regulatory Area using an average of the historical stock distribution from the modelled FISS survey (Fig 3.3). The catchability is assumed to be equal for each IPHC Regulatory Area in a Biological Region.

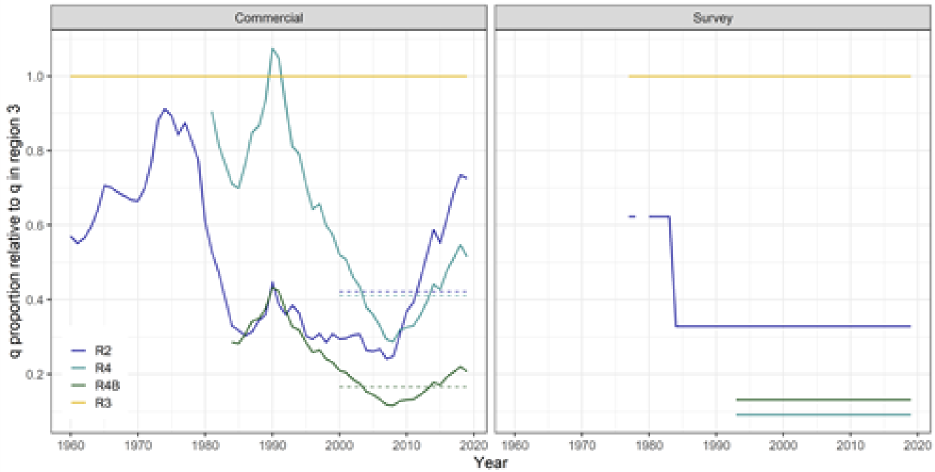



**Figure 3.2:** Proportion of each regional q relative to Biological Region 3 for the commercial WPUE (left) and the survey NPUE (right). The average of the years 2000 to 2019 is shown as a dotted line.

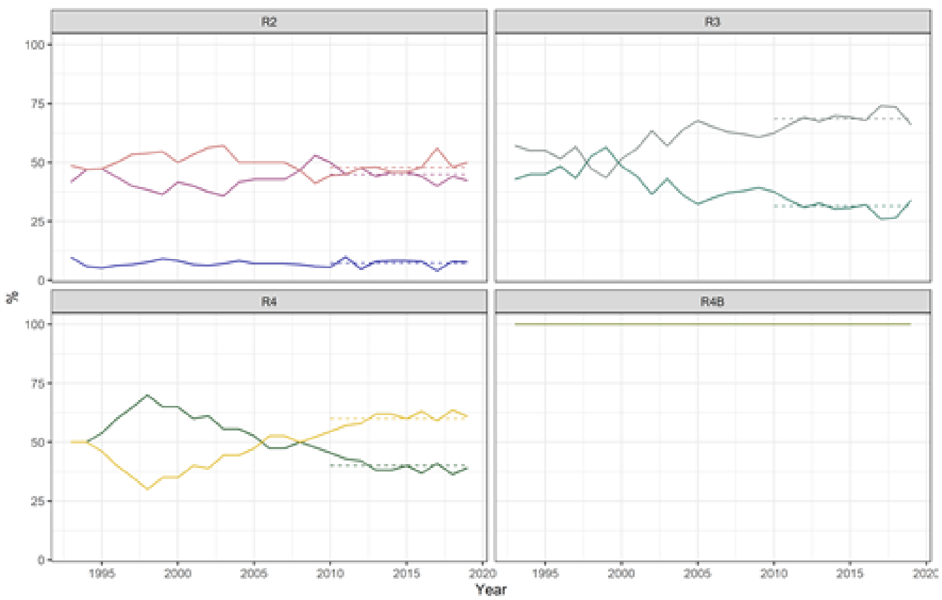


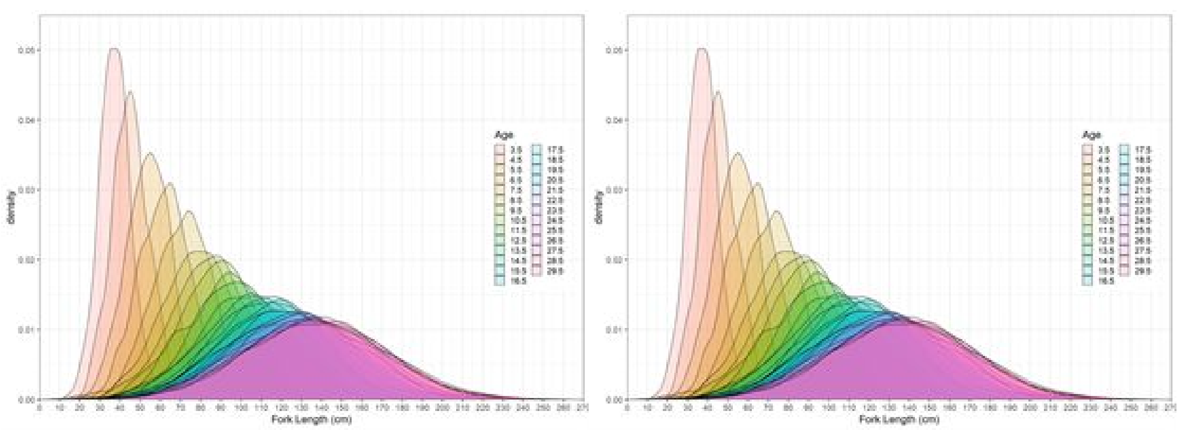

**Figure 3.3:** Proportion of stock distribution in each IPHC Regulatory Area by Biological Region from the modelled FISS survey. The 10 year average is shown as a dotted line.

In the base case the catchability coefficient is time invariant. Alternative scenarios will test a time variant catchability parameter modeled as a random walk of the coastwide $q$ or of the regional $q$ as a function of the abundance in each Biological Region.

The coastwide NPUE and WPUE will be calculated as the weighted average of the indices for each Biological Region. The weights are the survey bottom area and the commercial catch for the NPUE and WPUE, respectively.

### 3.1.2 Modelling length-at-age

Fish have different lengths within age groups and this variability was modelled using probability distributions. The data used to inform the model are the length-at-age distribution resulting from the long coastwide SS model used in the ensemble for Pacific halibut (section `Biology_at_age_in_endyr_with_CV` of the report file). One-thousand randomly generated values with mean equal to the average length-at-age-and standard deviation of length-at-age were drawn from a normal distribution for males and females separately (Figure 3.4).




**(a)** Females **(b)** Males

**Figure 3.4:** Length distribution at ages 3 to 25 for females and males of Pacific halibut

For each age group, the proportion of fish within each lenght bin $l$ for age $a$ and gender $s$ is equal to:

$$\Phi_{s,a,l} = \begin{cases} \Phi\frac{L'_m in - \widetilde{L}_{s,a}}{\sigma_{s,a}} & l = 1 \\ \Phi\frac{L'_{l+1} - \widetilde{L}_{s,a}}{\sigma_{s,a}} - \Phi\frac{L'_l - \widetilde{L}_{s,a}}{\sigma_{s,a}} & 1 < l < A_l \\ 1 - \Phi\frac{L'_m ax - \widetilde{L}_{s,a}}{\sigma_{s,a}} & l = A_l \end{cases} \quad (3.6)$$

where $\Phi$ is the standard normal cumulative density function, $L'_l$ is the lower limit of the smallest bin, $L'_l$ is the lower limit of the length bin $l$, $L'_m ax$ is the lower limit of the largest bin.

The proportion of fish in each age class above 32 inches are then summed up (Fig 3.5).

### 3.1.3 Estimation Model

To simulate estimation error of management quantities an ensemble of estimation models is used, which is analogous to the stock assessment. This approach uses the data generated with error from

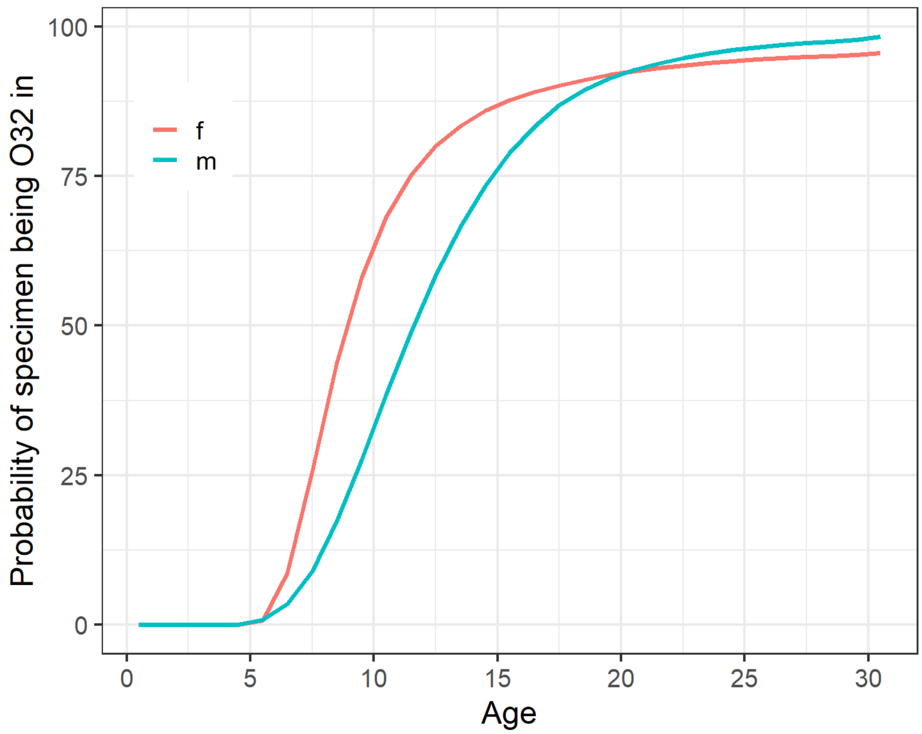



**Figure 3.5:** Proportion of fish above 32 inches by sex

the OM and then estimates management quantities using two estimation models to mimic the stock assessment ensemble. This approach aims at capturing the correlated error and potential biases in the estimated management quantities.

The estimation model chosen for Pacific halibut uses two stock synthesis (v. 3.30.13) models mimicking the short coastwide and long coastwide models in the stock assessment. This approach aims at capturing the correlated error and potential biases in the estimated management quantities. The two stock synthesis models are averaged to represent a simplified version of the stock assessment ensemble currently used for Pacific halibut. The coastwide models (long and short coastwide) were chosen from the four currently used in the stock assessment ensemble and were streamlined to increase efficiency and to reduce the time of the MSE simulations, yet retain the complexity and uncertainty captured by the full stock assessment ensemble. The short and long coastwide models represent the uncertainty in natural mortality rates (estimated in the long time-series but fixed for females in the short time-series), the environmental effect on recruitment (estimated only in the long time-series), as well as other structural and parameter assumptions.

The streamlining of the coastwide models consisted of:

- Reducing the amount of data included (e.g. fewer years with age composition, long coastwide model starting from 1935, etc.)
- Using the optimized version of stock Synthesis (SS 3.30.13)
- Fixing annual deviations in selectivity parameters for the historical time series, and estimate only the deviations for the most recent 10 years.

- Using the ss.par file from the original assessment model for the starting parameters values

To speed up the estimation time, the hessian is not estimated, the estimation of parameters start after the last phase (so all parameters are estimated at the same time), and screen outputs are reduced to a minimum.

See IPHC-2020-SRB-08 for more description.

### 3.1.4 Harvest Rule

The harvest rule is the defined procedure that uses outputs from data generation and the estimation models to determine mortality limits for each fishery. Currently, this uses a fishing mortality rate based on SPR, a control rule to reduce the fishing intensity below specified stock sizes, and a distribution procedure to distribute the coastwide TCEY to each IPHC Regulatory Areas and then to each fishery. Different specifications of the harvest rule are the main focus for investigation of management procedures for Pacific halibut.

## 3.2 Population structure

To simulate the distribution of mortality and determine how management procedures meet objectives specific to IPHC Regulatory Areas and fisheries, the operating model will have to include multiple regions with migration between them. Biological Regions (Figure 3.1) have been defined based on current knowledge of movement as well as biological understanding. A Biological Region is larger than an IPHC Regulatory Area (Figure 3.1), but fisheries operate at the level of the IPHC Regulatory Area or finer. Movement will not be specifically modelled between areas within a region, but movement will always be modelled between regions. Even though the computer program for the operating model allows flexibility to define any arrangement of regions and areas, with movement modelled between Biological Regions, it would be moot to model movement within a Biological Region on an annual time-step because it is assumed that a fish may be anywhere within the region within a year. The modelling of fisheries in separate areas is described below. Additionally, the detailed understanding of movement within a Biological Region is not well understood and would be difficult to parameterize.

### 3.2.1 Input population parameters

### 3.2.2 Derived population parameters

## 3.3 Structure of the fisheries

The annual mortality limits determined for various fishery sectors occur at the level of IPHC Regulatory Areas (Figure 3.1). However, some fisheries for Pacific halibut may operate at a finer scale than an IPHC Regulatory Area. The best definition of fishery areas was determined from the objectives defined for the MSE, input from stakeholders, as well as the availability of knowledge to parameterize the fisheries for simulation, which is likely at the IPHC Regulatory Area level. This can be done when modelling the population at larger Biological Regions by defining separate sectors within a region, and using separate selectivity curves and exploitation rates to account for the availability of Pacific halibut to a particular sector (see Section **??**). This assumes that each fishery within a Biological Region operates on the same pool of fish, but each fishery encounters those fish differently.

See IPHC-2020-SRB016-08 for a description of the fisheries included in the OM.

### 3.3.1 Fishery parameters

Parameters for each fishery were determined from the 2019 long AAF assessment model. Selectivity for the directed commercial and survey fisheries were made asymptotic because movement should account for at least some of the differences in availability between Biological Regions.

# Bibliography


Bull B, Francis RICC, Dunn A, McKenzie A, Gilbert DJ, Smith MH, Bian R, Fu D. 2012. CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v 2.30–2012/03/21. NIWA Technical Report 135. 282 pp.

Hilborn R, Maunder M, Parma A, Ernst B, Payne J, Starr PJ. 2000. Documentation for a general age-structured Bayesian stock assessment model: code named Coleraine. Fisheries Research Institute, University of Washington. FRI/UW 00/01. 54 pp.

Hilborn R, Walters CJ. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York, 570 pp.

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

Methot RD Jr, Wetzel CR. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142:86–99.

Quinn, Deriso. 1999. Quantitative Fish Dynamics. Biological Resource Management Series. Oxford University Press, New York.

# Appendix A

# Parameters and notation

**Table A.1:** Dimension and partition notation in the operating models (used as subscripts).

| Parameter | Description |
|---|---|
| $y$ | Year. |
| $a$ | Age. A capital $A$ indicates the maximum age. |
| $s$ | Sex, which includes female, male, and unsexed, in that order, labeled 1, 2, and 3. |
| $r$ | Region with movement occurring between regions. |
| $r_l$ | Area within region. Movement is not modelled between areas. |
| $im$ | Immature state of the maturity partition. |
| $ma$ | Mature state of the maturity partition. |
| $sp$ | Spawning state calculated from the maturity partition. Note that this is not a specific partition in the state object. |
| $f$ | Fishery sector. |
| $I$ | Initial, meaning the starting time-step. |

**Table A.2:** Parameters in the operating models.

| Parameter | Description |
|---|---|
| *Population dynamics parameters* | |
| $N_{y,a,s,r,m}$ | Numbers for year, age, sex, region, and maturity |
| $B_0$ | Unfished equilibrium biomass |
| $R_0$ | Unfished equilibrium recruitment |
| $B_{y,a,s,r,m}$ | Biomass at the beginning of year $y$ (and possibly other partitions as noted) |
| $B^M_{y,a,s,r,m}$ | Mature biomass at the beginning of year $y$ |
| $B^S_{y,a,s,r,m}$ | Spawning biomass at the beginning of year $y$ |
| $B^R_{y,r,f}$ | Biomass selected and retained by sector $f$ in year $y$ |
| $M_{y,a,s,r}$ | Natural mortality |
| $W_{y,a,s,r}$ | Mean weight-at-age in year $y$ (and possibly other partitions) |
| $\Omega$ | Proportion of mature individual at age, or the proportion transitioning from immature to mature at age, depending on partioning maturity in the state object. |
| $\Phi$ | Proportion of spawning individuals at age |
| $\Psi_{j \to k}$ | Movement rate from area j to area k |
| $\rho_1$ | Parameter for Type II functional response of movement from area 1 to area 2 |
| $\rho_2$ | Parameter for Type II functional response of movement from area 1 to area 2 |
| $p_s$ | Proportion of females at birth. |
| $p_{y,r}$ | Proportion of recruitment in region $r$ in year $y$. Sums to one over regions. |
| $p_f$ | Proportion of natural mortality that occurs before exploitation from sector $f$ occurs. |

Table A.2 continued.

| Parameter | Description |
|---|---|
| *Fishing mortality related parameters* | |
| $C_{y,a,s,r,f}$ | Catch (in weight) for year, age, sex, region, and sector. Catch summed over age and sex ($C_{y,r,f}$) is typically an input to the model. |
| $C^N_{y,a,s,r,f}$ | Catch (in numbers) for year, region, and sector. |
| $U_{y,r,f}$ | Exploitation rate for sector $f$ |
| $S_{a,f}$ | Selectivity-at-age for sector $f$ |
| $R_{a,f}$ | Proportion retained-at-age for sector $f$ |
| *Survey parameters* | |
| $Z_j$ | Survey index for year $j$ |
| $q$ | Survey catchability |
| $\tau_j$ | Error in year $j$ for the survey series |
| $\sigma^2_{\tau_j}$ | Total variability of the survey in year $j$ |
| *CPUE parameters* | |
| $U_{u,i}$ | CPUE for year $i$ |
| $\alpha$ | Multiplier in relationship between CPUE and abundance for the CPUE series |
| $\beta$ | Nonlinearity parameter in relationship between CPUE and abundance |
| $\nu_i$ | Error in year $i$ for CPUE series |
| $\sigma^2_{\nu_i}$ | Total variability of the CPUE series in year $i$ |

# Appendix B

# Fishing mortality using exploitation rates: two approaches

This appendix presents two methods to determine catch and exploitation rates when modelling the fisheries with an exploitation rate (finite or Pope's approximation) instead of the instantaneous formulation (i.e. Baranov equation). The benefit of using an exploitation rate is that the code does not have to iterate to find the fishing mortality rate (i.e., there is not closed-form solution for the Baranov formulation). This will speed up the simulation time.

These equations have been simplified to show the concept. For example, retention and discard mortality are not considered, and sex and region subscripts have been ommitted. The subscripts remaining are $a$ for age, $t$ for time-step, and $f$ for fleet/fishery. Superscripts are used to indicate specific about the quantity, such as $n$ for numbers and $sr$ for selected-retained (i.e., exploitable by a particular fleet), as well as the timing within the time-step (e.g., 0.25 would be one-quarter of the natural mortality in that time-step occurred).

## B.1 Fisheries are independent and do not effect each other

To make things simpler, in a sense, we may make the assumption that the fisheries are independent of each other or they occur at exactly the same time. That means that the sequential nature of the fisheries does not have to be tracked, making the equations and accounting simpler. However, an additional complication is introduced in making sure that the total exploitation rate (sum over all fisheries) does not exceed a defined maximum (or a value of one).

Fishing mortality is parameterized with an exploitation rate and is assumed to occur at a specific point in time after a proportion of the mortality ($p_{|f}$) has occurred. The proportion may be equal for all fleets, and if not then it is assumed that the removals from a fleet operating before other fleets does not affect the biomass available to subsequent fleets (may be OK with small exploitation rates).

Catch at age and sex in numbers ($C^n$) or weight ($C$) for a sector in an area can be determined from the exploitation rate ($U$), selectivity ($S$), and mean weight-at-age ($W$). Note that retention is not listed to simplify the examples shown here.

$$C^n_{a|t,f} = U_{|t,f} N_{a|t} S_{a|t,f} e^{-p_f M_{a|t}} \tag{B.1}$$

$$C_{a|t,f} = U_{|t,f} N_{a|t} S_{a|t,f} W_{a|t,f} e^{-p_f M_{a|t}} \tag{B.2}$$

and the total predicted catch for a sector in a region is

$$C^n_{|t,f} = \sum_{a=0}^{A} C^n_{a|t,f} \tag{B.3}$$

$$C_{|t,f} = \sum_{a=0}^{A} C_{a|t,f} = U_{|t,f} B^{sr,p}_{|t,f} \tag{B.4}$$

Natural and fishing mortality can be accounted for simultaneously, and the numbers-at-age in the next time-step, after all mortality, can be simply determined with a single equation. Let's assume there are two fleets with the mortality from fleet 1 occurring after three fifths of the natural mortality ($p_{|1} = 0.6$) and the mortality from fleet 2 occurring after one-quarter of the natural mortality ($p_{|2} = 0.25$). The catch (in numbers) for each fleet is

$$C^n_{a|t,f=1} = N_{a|t} U_{|t,f=1} S_{a|t,f=1} e^{-0.6M_a} \tag{B.5}$$

$$C^n_{a|t,f=2} = N_{a|t} U_{|t,f=2} S_{a|t,f=2} e^{-0.25M_a} \tag{B.6}$$

The numbers-at-age in the next year, accounting for fishing mortality by removing the catch at the appropriate time, is

$$N_{a|t+1} = \left[\left[N_{t,a}e^{-0.25M_a} - C^N_{a|f=2}\right]e^{-(0.6-0.25)M_a} - C^N_{a|f=1}\right]e^{-(1-0.6)M_a} \tag{B.7}$$

Converting the catch ($C^n$) to exploitation rates using equation B.5 and simplifying produces the equation for N in the next time-step.

$$\begin{aligned}
N_{a|t+1} &= \left[\left[N_{t,a}e^{-0.25M_a} - N_{a|t}U_{|t,f=2}S_{a|t,f=2}e^{-0.25M_a}\right]e^{-(0.6-0.25)M_a} - \right. \\
&\quad \left. N_{a|t}U_{|t,f=1}S_{a|t,f=1}e^{-0.6M_a}\right]e^{-(1-0.6)M_a} \\
&= \left[N_{t,a}e^{-0.25M_a}e^{-0.35M_a}(1-U_{|t,f=2}S_{a|t,f=2}) - N_{a|t}U_{|t,f=1}S_{a|t,f=1}e^{-0.6M_a}\right]e^{-0.4M_a} \\
&= \left[N_{t,a}e^{-0.6M_a}(1-U_{|t,f=2}S_{a|t,f=2}) - N_{a|t}U_{|t,f=1}S_{a|t,f=1}e^{-0.6M_a}\right]e^{-0.4M_a} \\
&= \left[N_{t,a}e^{-0.6M_a}(1-U_{|t,f=2}S_{a|t,f=2} - U_{|t,f=1}S_{a|t,f=1})\right]e^{-0.4M_a} \\
&= N_{t,a}e^{-M_a}(1-\sum_f U_{|t,f}S_{a|t,f}) \qquad \text{(B.8)}
\end{aligned}$$

This can be generalized to any set of $p_{|f}$ as long as the proportions are sorted from smallest to largest in the derivation. The sequential nature of the fleets does not need to be accounted for in the calculations.

However, a potential problem is that the sum of the exploitation rates in equation B.14 may exceed a value of one (or some defined maximum), which is theoretically impossible. Therefore, a maximum exploitation rate ($U_{max}$) must be specified, which is realistically less than one. To determine if the overall exploitation rate is greater than $U_{max}$, the partition-specific exploitation rates (e.g., age, sex, region, and fleet) for a time-step are summed across fleets within a region, and the maximum rate within a region over the partions are determined. This is called $U_y^{maxObs}$.

$$U_{|t}^{maxObs} = max_a\left(\sum_f S_{a|t,f}U_{|t,f}\right) \tag{B.9}$$

If $U_y^{maxObs} > U_{max}$, then

$$U_{|t,f} = \frac{U_{max}}{U_{|t}^{maxObs}}\frac{C_{|t,f}}{B^{sr,p}_{|t,f}} \tag{B.10}$$

which is simply an adjustment to the original exploitation rate ($U_{|t,f}$). When this adjustment occurs, the predicted catch will be different than the input catch, and a penalty should be applied since catches are considered observed inputs (not data with error).

Catch is an input and biomass is calculated as part of the modelling process, so the exploitation rate is calculated as the ratio between catch and exploitable biomass for a particular fleet.

$$U_{|t,f} = \frac{C_{|t,f}}{B^{sr,p}_{|t,f}} \tag{B.11}$$

where $C_{|t,r,f}$ is the catch in time-step $t$ and region $r$ for sector $f$, and $B^{sr}_{|t,r,f}$ is the selected-and-retained (exploitable) biomass for that fishery.

The exploitable biomass is calculated from the numbers-at-age ($N$), selectivity ($S$), and mean weight-at-age ($W$).

$$B^{sr,p}_{|t,f} = \sum_{a=0}^{A} N_{a|t} S_{a|t,f} W_{a|t,f} e^{-p_{|f} M_{a|t}} \tag{B.12}$$

## B.2 Fisheries are sequential and earlier fisheries effect later ones

The more appropriate way to model the fisheries, but more complex in terms of accounting, is to account for the decline in the population from fisheries occuring before later fisheries. For example, as above, let's assume there are two fleets with the mortality from fleet 1 occurring after three fifths of the natural mortality ($p_{|1} = 0.6$) and the mortality from fleet 2 occurring after one-quarter of the natural mortality ($p_{|2} = 0.25$). The "pulse" fishing activity of fleet 2 causes a reduction in the population by the time fleet 1 operates its fishery, and the catch (in numbers) for each fleet would be calculated as follows.

$$\begin{aligned}
C^n_{a|t,f=2} &= N_{a|t} e^{-p_2 M_{a|t}} U_{|t,2} S_{a|t,2} \\
C^n_{a|t,f=1} &= \left( N_{a|t} e^{-p_2 M_{a|t}} - C^n_{a|t,f=2} \right) U_{|t,1} S_{a|t,1} e^{-(p_1 - p_2) M_{a|t}} \\
&= \left( N_{a|t} e^{-p_2 M_{a|t}} - U_{|t,2} S_{a|t,2} e^{-p_2 M_{a|t}} N_{a|t} \right) U_{|t,1} S_{a|t,1} e^{-(p_1 - p_2) M_{a|t}} \\
&= N_{a|t} e^{-p_2 M_{a|t}} \left( 1 - U_{|t,2} S_{a|t,2} \right) U_{|t,1} S_{a|t,1} e^{-(p_1 - p_2) M_{a|t}} \\
&= N_{a|t} e^{-p_1 M_{a|t}} \left( 1 - U_{|t,2} S_{a|t,2} \right) U_{|t,1} S_{a|t,1}
\end{aligned}$$

Generally,

$$C^n_{a|t,f} = U_{|t,f} S_{a|t,f} e^{-p_f M_{a|t}} N_{a|t} \prod_{f' \in p_{j \neq f} < p_f} \left( 1 - U_j S_{a|t,f'} \right) \tag{B.13}$$

where $(1 - U_j S_{a|t,f'})$ is the probability of surviving a fishery that occurs before the fishery for fleet $f$. This requires some additional logic to determine which fisheries have occurred before the fishery of interest to properly account for that preceeding mortality.

The numbers-at-age in the next time-step can be derived in a similar manner as above, except using the newly defined catch equations.

$$N_{a|t+1} = \left[\left[N_{t,a} e^{-0.25M_a} - C^N_{a|f=2}\right] e^{-(0.6-0.25)M_a} - C^N_{a|f=1}\right] e^{-(1-0.6)M_a} \tag{B.14}$$

Converting the catch $(C^N)$ to exploitation rates using equation B.13 and simplifying produces the equation for N in the next time-step.

$$\begin{aligned}
N_{a|t+1} &= \Big[\big[N_{a|t} e^{-0.25M_a} - N_{a|t} U_{|t,f=2} S_{a|t,f=2} e^{-0.25M_a}\big] e^{-(0.6-0.25)M_a} - \\
&\quad N_{a|t} U_{|t,f=1} S_{a|t,f=1} e^{-0.6M_a} (1 - U_{|t,f=2} S_{a|t,f=2})\Big] e^{-(1-0.6)M_a} \\
&= \big[N_{a|t} e^{-0.6M_a} (1 - U_{|t,f=2} S_{a|t,f=2}) - N_{a|t} U_{|t,f=1} S_{a|t,f=1} e^{-0.6M_a} (1 - U_{|t,f=2} S_{a|t,f=2})\big] e^{-0.4M_a} \\
&= \big[N_{a|t} e^{-0.6M_a} (1 - U_{|t,f=2} S_{a|t,f=2})(1 - U_{|t,f=1} S_{a|t,f=1})\big] e^{-0.4M_a} \\
&= N_{a|t} e^{-M_a} \prod_f (1 - U_{|t,f} S_{a|t,f}) \qquad \text{(B.15)}
\end{aligned}$$

This is simply the numbers-at-age in the current time-step times the survival from natural causes times the survival from each fishery. With this formulation, adjusting for a maximum exploitation rate is not necessary, other than ensuring that each fleet-specific exploitation rate does not exceed a value of one (or a defined maximum).

Catch is an input and biomass is calculated as part of the modelling process, so the exploitation rate is calculated as the ratio between catch and exploitable biomass for a particular fleet, as shown in B.11.

The exploitable biomass is calculated from the numbers-at-age $(N)$, selectivity $(S)$, and mean weight-at-age $(W)$, and accounts for the decrease in abundance due to fisheries that occurred previously.

$$
\begin{aligned}
\text{(B.16)} \quad B^{sr,p}_{|t,f=2} &= \sum_{a=0}^{A} N_{a|t} S_{a|t,2} W_{a|t,2} e^{-p_{|2} M_{a|t}} \\
\text{(B.17)} \quad B^{sr,p}_{|t,f=1} &= \sum_{a=0}^{A} \left( N_{a|t} e^{-p_{|2} M_{a|t}} - C^{n}_{a|t,2} \right) S_{a|t,1} W_{a|t,1} e^{-(p_{|1}-p_{|2}) M_{a|t}} \\
\text{(B.18)} \quad &= \sum_{a=0}^{A} \left( N_{a|t} e^{-p_{|2} M_{a|t}} - U_{|t,2} S_{a|t,2} e^{-p_{2} M_{a|t}} N_{a|t} \right) S_{a|t,1} W_{a|t,1} e^{-(p_{|1}-p_{|2}) M_{a|t}} \\
\text{(B.19)} \quad &= \sum_{a=0}^{A} N_{a|t} e^{-p_{|2} M_{a|t}} \left( 1 - U_{|t,2} S_{a|t,2} \right) S_{a|t,1} W_{a|t,1} e^{-(p_{|1}-p_{|2}) M_{a|t}} \\
\text{(B.20)} \quad &= \sum_{a=0}^{A} N_{a|t} e^{-p_{|1} M_{a|t}} \left( 1 - U_{|t,2} S_{a|t,2} \right) S_{a|t,1} W_{a|t,1} \\
\text{(B.21)} \quad &
\end{aligned}
$$

which is the same result if using the equation $C = U \times B$.

## B.3 Comparison

It can be shown that these two assumptions produce the exact same results when only one fishery is considered. When two or more fisheries occur at exactly the same time, the catch is exactly the same (i.e., one fishery does not occur before another, thus they operate on the same biomass), but the equation for $N_{t+1}$ is slightly different between the two formulations. Say that two fisheries operate $\frac{3}{5}^{ths}$ of the way through the time-step, each with an exploitation rate of 0.5. If they operated independently and each took half of the exploitable biomass, then all of the exploitable biomass would be removed since the sum of the two exploitation rates is 1. The real issue comes in when the sum of the exploitation rates is greater than 1, which is theoretically impossible.

Using the above two fishieries occurring at exactly the same time, let's assume that the exploitation rates were 0.3 and 0.4, which is still quite high for a marine commercial fishery. That is a combined exploitation rate 0.7 (assuming selectivity equals 1) and the equations for abundance in the next year (equations B.14 and B.15) are

$$
\begin{aligned}
\text{Independent fisheries} &= N_{a|t} e^{-M_a} [1 - (0.3 + 0.4)] = N_{a|t} e^{-M_a} (0.3) \\
\text{Sequential fisheries} &= N_{a|t} e^{-M_a} (1 - 0.3)(1 - 0.4) = N_{a|t} e^{-M_a} (0.42)
\end{aligned}
$$

Therefore, the number-at-age is 1.4 times greater for the sequential fishery compared to the independent fisheries. This occurs because of the product of the two exploitation rates is added back in, when expanded.

$$\begin{aligned} \text{Independent fisheries} &= [1-(U_1+U_2)] = (1-U_1-U_2) \\ \text{Sequential fisheries} &= (1-U_1)(1-U_2) = (1-U_1-U_2+U_1U_2) \end{aligned}$$

This is especially useful when the exploitation rate is high because it never allows the exploitation rate to exceed one. For example, when U=1 (the theoretcial maximum) the independent fisheries equation results in a multiplier of -1, while the sequential fisheries equation results in a multiplier of 0. When exploitation rates are 0.2 for two fisheries, the difference between the two methods is small (i.e., $0.2 \times 0.2 = 0.04$ and 1.07 times greater for the sequential fisheries). Additionally, exploitation rates in the sequential method are more interpretable as exploitation rates and do not need adjustments to make them remain below the theoretical maximum of one. Figure B.1 shows that are small exploitation rates, the difference in survival between the two methods is small.

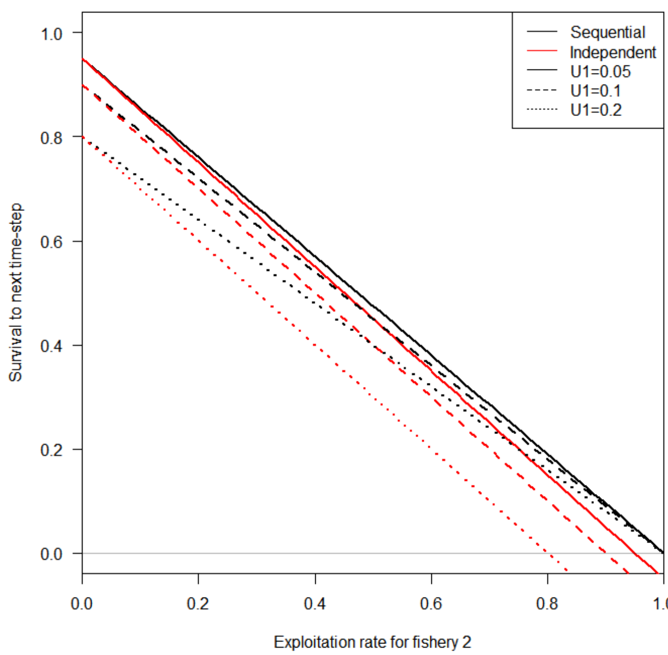



**Figure B.1:** A comparison of survival to the next-time step for the sequential (black) and independent (red) methods assuming exploitation rates ($U$) of 0.05, 0.1, and 0.2 for fishery 1, and a range of exploitation rates for fishery 2.

It is unlikely that two fisheries operate independently when exploitation rates are high and it may be more prudent to treat them in a sequential nature, calculating the exploitation rates for each from the sequential exploitable biomass (or splitting them up into many catch events and switching back and forth between the two, which is overly complicated). We propose to use the equations under the sequential fisheries, and when two or more fisheries operate at the exact same time, the fishery operates in a sequence in order of the size of their catch for that time-step (smallest to largest).

## B.4 A more complex example with three fisheries and discard mortality

It is worth working through the concept of sequential fisheries when three fisheries occur and each has discard mortality. Let's assume there are three fleets with the mortality from fleet 1 occurring after one-fifth of the time-step ($p_{|1} = 0.2$), the mortality from fleet 2 occurring after two-fifths of the time-step ($p_{|2} = 0.4$), and the mortality from fleet 3 occurring after four-fifths of the time-step ($p_{|2} = 0.8$). The total mortality (in numbers) includes catch and discard mortality for each fleet and would be calculated as follows (with the current time-step subscript ($t$) removed for simplicity).

$$
\begin{aligned}
TM^n_{a|f=1} &= C^n_{a|1} + D^n_{a|1} \\
&= N_a e^{-p_1 M_a} U_{|1} S_{a|1} R_{a|1} + N_a e^{-p_1 M_a} U_{|1} S_{a|1} (1 - R_{a|1}) d_{a|1} \\
&= N_a e^{-p_1 M_a} U_{|1} S_{a|1} \left[ R_{a|1} + (1 - R_{a|1}) d_{a|1} \right] \\
TM^n_{a|f=2} &= \left( N_a e^{-p_1 M_a} - TM^n_{a|1} \right) U_2 S_{a|2} \left[ R_{a|2} + (1 - R_{a|2}) d_{a|2} \right] e^{-(p_2 - p_1) M_a} \\
&= N_a e^{-p_2 M_a} U_2 S_{a|2} \left[ R_{a|2} + (1 - R_{a|2}) d_{a|2} \right] \left[ 1 - U_1 S_{a|1} \left[ R_{a|1} + (1 - R_{a|1}) d_{a|1} \right] \right] \\
TM^n_{a|f=3} &= \left[ \left( N_a e^{-p_1 M_a} - TM^n_{a|1} \right) e^{-(p_2 - p_1)} - TM^n_{a|2} \right] U_3 S_{a|3} \left[ R_{a|3} + (1 - R_{a|3}) d_{a|3} \right] e^{-(p_3 - p_2) M_a} \\
&= N_a e^{-p_3 M_a} U_3 S_{a|3} \left[ R_{a|3} + (1 - R_{a|3}) d_{a|3} \right] \prod_{i=1}^{2} \left\{ 1 - U_i S_{a|i} \left[ R_{a|i} + (1 - R_{a|i}) d_{a|i} \right] \right\}
\end{aligned}
$$

Generally,

$$TM^n_{a|f} = N_a e^{-p_f M_a} U_f S_{a|f} \left[R_{a|f} + (1 - R_{a|f}) d_{a|f}\right] \times \prod_{i \in p_j < p_f} \left\{1 - U_i S_{a|i} \left[R_{a|i} + (1 - R_{a|i}) d_{a|i}\right]\right\} \quad \text{(B.22)}$$

where $j$ is over all fleets. In essence, the total mortality is determined from the numbers-at-age that survived naturally to that point and survived the probability of fishing mortality (retained or discarded and died) from all fleets up to that point in the time-step.

# Independent peer review of the 2020 IPHC Management Strategy Evaluation process

Trevor A. Branch
Associate Professor, School of Aquatic and Fishery Sciences, University of Washington
Final report, 24 September 2020

## Summary

The management strategy evaluation (MSE) of IPHC is intended to simulation test rules for setting allowable catch for Pacific halibut and the allocation of catch and bycatch among IPHC Regulatory Areas. In my judgment the MSE is technically sound. Furthermore, the MSE team led by Allan Hicks was praised by all interviewed participants involved in the process for their technical work, collaboration with stakeholders in developing harvest control rules, and communication of results to stakeholders. However, the following issues need to be resolved to ensure the continued success and accuracy of MSE simulations for IPHC: (1) decide soon on the future of the MSE process beyond January 2021 and allocate necessary funding; (2) treat the MSE framework as an ongoing process that will be used over many years alongside the stock assessment, to test the effectiveness of data gathering, stock assessment assumptions, and catch-setting in IPHC; (3) require the Commission to codify the rules they used to adjust catch levels within each Regulatory Area after the harvest control rule is applied, so that the MSE framework accurately evaluates risk to the stock and catches within each such Area. Additional discussion, points, and thoughts are presented in full below.

## Acronyms and terms used

HCR: harvest control rule
MSAB: management strategy advisory board
MSE: management strategy evaluation
SRB: scientific review board
TCEY: total constant exploitation yield

## Background

Development of a management strategy evaluation (MSE) was started in 2013 at the IPHC, but progress has generally been slow until the most recent 2-3 years with the formation of the current MSE team comprising Allan Hicks, Piera Carpi, and Steve Berukoff. A key MSE milestone was the testing of different harvest control rules (HCRs) for setting coastwide allowable catch (Total Constant Exploitation Yield, or TCEY), presented in multiple documents during 2019 and 2020 (e.g. Hicks et al. 2020). This year, the MSE has focused on modeling the allocation of the TCEY among the IPHC Regulatory Areas. Preliminary results were presented at an informational meeting in August, with further results expected at the 22-24 September 2020 session of the Scientific Review Board (SRB) and 19–22 October 2020 meeting of the Management Strategy Advisory Board (MSAB). A final report has been requested by the Commission on MSE development testing rules for allocating the TCEY among IPHC Regulatory Areas for the 97$^{th}$ Annual Meeting of the IPHC in 25–29 January 2021.

## Terms of reference

This review is intended to provide advice on and contribute to a subset of the following topics, both in terms of peer review and technical contribution:

1. Review the goals and objectives used to evaluate management procedures
2. Review the IPHC MSE closed-loop simulation framework

3. Review and advise on the operating model and how it is conditioned to mimic the Pacific halibut population
4. Review tools and methods used to communicate simulation results for the evaluation of management procedures.
5. Evaluate the process of soliciting objectives from stakeholders and managers and creating performance metrics from those objectives.
6. Assist with developing and defining reference points and management procedures
7. Advise on methods to communicate results of the simulations, the trade-offs between various management procedures, and the ranking of management procedures.

This report is a succinct written review of the IPHC MSE process, evaluating results, and any other aspects identified, including recommendations for the simulation framework and other aspects of the MSE framework.

## Information gathering

In the process of writing this report, I reviewed documents and decisions from recent IPHC meetings (2019-20) including MSAB, SRB, and Commission meetings, including the independent peer review of the IPHC stock assessment, the second performance review of the IPHC, and the main stock assessment and MSE documents. I attended the August informational meeting presenting preliminary MSE results to members of the MSAB; conducted a series of informal conversations with a diverse array of MSAB members including the MSE team, scientists, managers, and industry representatives; and presented interim recommendations to the SRB meeting in September for feedback.

## Findings

The MSE model framework was implemented according to international guidelines and standards for the evaluation of harvest control rules (e.g. Butterworth 2007, Plagányi et al. 2007, Punt et al. 2016), and comprises a simulated model of truth (the operating model), a simulation of the stock assessment process (estimation model) and a simulation of the catch setting and catch allocation process (the harvest control rule).

In my review and examination of the model structure and implementation, I did not identify any major technical issues or flaws, although some of the technical documentation of the MSE (Hicks et al. 2019) was incomplete. MSEs are notorious for the long time they take to run, but the IPHC addressed this known bottleneck by coding the operating model in C++ and the estimation model in AD Model Builder, both well known for their speed, by using parallelization, and accessing fast processors. In this way, the MSE simulations could be conducted relatively rapidly and be responsive in addressing topical questions. Statistical software R was used for reporting and visualization, as is standard practice.

The suite of performance metrics covers all aspects usually considered important in other MSEs: ensuring that biomass does not fall below some minimum level; examining spawning biomass relative to a target level; maximizing catches; and limiting catch variability from one year to the next. Additional metrics report the proportion of the total catch taken in each of the Biological Areas or Regulatory Area. Many metrics are computed and reported in addition to the core list, and the suite of performance metrics is comprehensive, was developed with extensive stakeholder input, and meets the needs of the MSE process.

The presentation of the results through reports follows standard practice, although it could additionally use some refinement to ensure that each scenario can be compared in as little space as possible (perhaps on a single page in a dashboard format). The use of the online visualization of results using the R Shiny app is encouraged, as it allows stakeholders to interact more directly with the results and understand the implications of changes to key model parameters, although the Shiny application would achieve broader uptake among stakeholders with more extensive instructional and example materials.

Overall, the science capability of the IPHC MSE team is strong, and trusted by all participants that I spoke to, often resulting in unsolicited comments praising the leadership from Allan Hicks and others on the team. In my experience, grudging acceptance is a more common reaction than open praise, which speaks highly to the work conducted by the MSE team over the last two years, both technically and in ensuring widespread participation and acceptance of the process among stakeholders.

The effectiveness of the Management Strategy Advisory Board is a particularly strong feature of the MSE process at IPHC. Despite diverse representation from multiple sectors, the overwhelming impression I received from interviews and participating in the informational meeting, was that the MSAB members are clearly committed to ensuring the best science possible, are motivated to participate fully, and have in-depth knowledge of the MSE models and the process around the models. It helps that many of the members have been attending meetings for several years, and that the meetings have been regular (twice a year or more often). A key step to ensuring well-functioning MSAB meetings was appointing two co-chairs who are not part of the MSE science team to facilitate discussions, which should be continued. Efforts should however be made to ensure that all sectors are represented in the MSAB, including crew, communities, and NGOs or environmental organizations, to ensure that any management changes arising from the MSE process are accepted by all parties benefiting from the halibut fishery. MSAB members also need time to report back to, and consult with, the stakeholder groups that they represent to ensure that all stakeholders accept decisions coming out of the MSE process.

The current MSE timeline is strict, with a final deadline for the MSE process being set for the January 2021 Annual Meeting of the IPHC. This strict deadline may arise from the long period from 2013 to the present over which the MSE process has developed, although it is only in the past 2-3 years with the expansion of the MSE team that rapid progress has been made. Given the amount of time needed to run the MSEs, and their complexity, I expect that results examining allocation of catches among Regulatory Areas, to be presented in January, will need one more round of modification before being finalized and ready for management implementation. For these reasons, it is likely that recommendations from the MSE process will need to be run in parallel with the current process for setting and allocating catches for 1-2 years, before any new rules replace current rules.

There is considerable uncertainty over the future role of the MSE process in the management of Pacific halibut. Two members of the science team (Carpi, Berukoff) are on short-term contracts, which would need to be extended to retain their expertise, but it was not clear what plans have been made by the Commission for ongoing MSE work beyond January 2021. The Commission needs to clearly delineate the amount of resources to be devoted to MSE work after January 2021 and, if deemed essential, act to retain personnel required to conduct future MSE simulations.

MSE simulations can be used in a wide variety of ways to provide advice useful to management. In some fisheries, the sole aim of MSEs is to identify a harvest control rule (HCR) that will be used to set annual catches in a more-or-less automatic manner: each year, data are collected, an assessment is conducted, and the results are fed into the HCR to set the catch limit for the next year. This automated process is often touted as the most valuable feature of the MSE process: avoiding the annual haggling over catch-setting (e.g. Butterworth 2007). It is key to outline so-called "exceptional circumstances" that would allow managers to change the HCR from the rules tested by the MSE. In other words, the role of the MSE process is to ensure that the HCR is robust, and allows a good balance between sustainability and catches to meet the objectives of the management body. Thus far, this is how the MSE process at IPHC has been conducted, with the exception that the Commission retains the ability to make final adjustments to catch levels and allocations instead of these being set in an automated manner.

Increasingly, however, MSE simulations are being used in much more varied ways than just deciding on a harvest control rule for catch setting. MSEs can be used to assess the impact of changing survey frequency, altered effort on each survey, different frequency of stock assessments, and different structural models of the truth. For example, MSEs can assess whether different migration models will affect long-term sustainability, the impact of bycatch in other fisheries, and whether some Russian catches should be included in the stock assessment. MSEs can evaluate the consequences of making incorrect assumptions in the model about natural mortality, steepness, or trends in weight-at-age. For IPHC-specific problems, MSEs could be used to assess whether four stock assessment models are needed, and if so, how to weight them; whether Bayesian methods would improve management; how to tune the models to fit to age composition data vs. surveys; and the impact of changes in size limits and bycatch management. Finally, MSEs can be used to identify areas of research that should be prioritized by IPHC in the future though a cost-benefit analysis that weighs research cost against the benefits of more precise stock assessments (e.g. Muradian et al. 2019).

Given the potential array of applications of the MSE process, the IPHC should think of MSE as a tool for evaluating the long-term sustainability of Pacific halibut and the fishery under a variety of scenarios, rather than just a tool for deciding on a harvest control rule. In other words, MSE should be treated as an integral part of the assessment and management cycle to better predict long-term consequences of decisions about the stock assessment, data gathering, and management processes. This path is the one followed by the Pacific Hake/Whiting Treaty organization, where every year a different suite of questions are answered by MSE simulations. This requires a stable team and sufficient in-house expertise to ensure that the MSE models can be applied to new questions each year.

One of the trickier aspects of the MSE process in IPHC is the inherent tension between testing harvest control rules, and Commission flexibility in deviating from any specific control rule. One of the core assumptions of MSE is that it captures the key rules used to (1) gather data, (2) conduct an assessment, and (3) set catches (e.g. Punt et al. 2016). Only then can it accurately evaluate the long-term consequences of an entire management system. In other jurisdictions, considerable time is spent ensuring that every aspect of these rules is included in the MSE process. However, in IPHC, there is an additional step not included in the MSE simulations, which involves the Commission adjusting catches in each Regulatory Area to account for other objectives (social, economic, etc.). In the EU, this kind of final tinkering step has led to decades of overfishing—politicians there set catches 20% higher than scientific advice during 2001–15 (Carpenter et al. 2016). Elsewhere, notably for the Commission for the Conservation of Southern Bluefin Tuna (e.g. Hillary et al. 2016), and in South African fisheries (e.g. Plagányi et al. 2007), the MSE process was carefully designed to replace annual haggling over catch limits with an automated and transparent process. For the IPHC, the impacts of such policy adjustments have not recently been evaluated, but in 2013-16, adopted mortality limits were higher than the recommended "blue line" catches. A careful analysis (ideally using the MSE process itself) is needed to determine the long-term impacts of Commission discretion in setting final mortality limits that differ from those recommended by a prescribed harvest control rule. While this is flagged here by me, I should also note that MSAB participants are in favor of retaining Commission discretion in modifying final mortality limits in each Regulatory Area, and this aspect of management was not currently regarded as problematic.

In the MSE evaluation of harvest control rules, "exceptional circumstances" rules are currently missing from the discussion. Such rules are invoked when circumstances in the fishery, surveys, data gathering, or stock assessment fall outside those modelled in the MSE process (e.g. Hillary et al. 2016). For example, if large levels of unreported catch are discovered, then exceptional circumstances could be invoked. When exceptional circumstances are invoked, a new MSE should be conducted to replace the current harvest control rule with a new (and hopefully better) harvest control rule for the changed circumstances. Rules governing exceptional circumstances need to be pre-specified so that the harvest control rule is not arbitrarily overruled in setting catches.

## Priority recommendations

1. I recommend that the Commission plans ahead for the future of the MSE process beyond January 2021, and allocates required funding and personnel accordingly.
2. The MSE process will be most useful to IPHC in the future if it is considered to be an ongoing process that is used each year alongside the stock assessment itself, to test different features of the data gathering, stock assessment, and catch-setting components of Pacific halibut.
3. Analysis is needed of the impact of the Commission modifying catch levels in each Regulatory Area after the TCEY recommendation from the harvest control rule. Preferably such analysis should be conducted using the MSE process and be based empirically on past Commission modifications. Since catch-setting is an integral part of the MSE, the MSE framework will be most accurate when it accurately models the decision-making process of the Commission.

## Additional recommendations

1. MSAB membership could be expanded to include representatives for crew members, fishing communities, and environmental organizations.
2. The current documentation of technical details of the IPHC MSE framework (Hicks et al. 2019) is described as a working document that will be revised often. As it stands, it is incomplete. To ensure the methods can be repeated, a full description of the methods used to obtain the results presented in January 2021 should be presented at the same time as the results.

## References

Butterworth DS (2007) Why a management procedure? Some positives and negatives. ICES Journal of Marine Science 64:613-617

Carpenter G, Kleinjas R, Villasante S, O'Leary BC (2016). Landing the blame: the influence of EU Member States on quota setting. Marine Policy 64:9-15.

Hicks A, Carpi P, Berukoff S (2019) Technical details of the IPHC MSE framework. IPHC-2019-MSAB014-INF02

Hicks A, Carpi P, Berukoff S, Stewart I (2020) IPHC Management Strategy Evaluation (MSE): update. IPHC-2020-AM096-12

Hillary RM, Preece AL, Davies CR, Kurota H, Sakai O, Itoh T, Parma AM, Butterworth DS, Ianelli J, Branch TA (2016) A scientific alternative to moratoria for rebuilding depleted international tuna stocks. Fish and Fisheries 17:469-482

Muradian ML, Branch TA, Punt AE (2019) A framework for assessing which sampling programs provide the best trade-off between accuracy and cost of data in stock assessments. ICES Journal of Marine Science 76:2102-2113

Plagányi ÉE, Rademeyer RA, Butterworth DS, Cunningham CL, Johnston SJ (2007) Making management procedures operational - innovations implemented in South Africa. ICES Journal of Marine Science 64:626-632

Punt AE, Butterworth DS, de Moor CL, De Oliveira JAA, Haddon M (2016) Management strategy evaluation: best practices. Fish and Fisheries 17:303-334

**DESCRIPTION OF MANAGEMENT PROCEDURES PROPOSED FROM MSAB015**

**PREPARED BY: IPHC SECRETARIAT (A. HICKS & P. CARPI, 19 OCTOBER 2020)**

**ALSO SEE IM096 PAPER: [HTTPS://WWW.IPHC.INT/UPLOADS/PDF/IM/IM096/IPHC-2020-IM096-11.PDF](https://www.iphc.int/uploads/pdf/im/im096/iphc-2020-im096-11.pdf)**

## DESCRIPTION OF MANAGEMENT PROCEDURES PROPOSED FROM MSAB015

The proposed management procedures from the 15th Session of the Management Strategy Advisory Board (MSAB015) are described here. Each management procedure has a coastwide component and a distribution component (Appendix II of IPHC-2020-MSAB016-07). The distribution component can distribute directly to IPHC Regulatory Areas or distribute to Biological Regions first.

For all the MPs considered, the coastwide component sees the application of a coastwide SPR and of a 30:20 control rule. The 30:20 harvest control rule adjusts the reference SPR if the estimated stock status falls below the 30% trigger value. Specifically, the fishing intensity is reduced linearly if the stock status falls below 30% of unfished spawning stock biomass to a value of zero at and below an estimated status of 20% of unfished spawning stock biomass.

**MP15-A**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%.

**MP15-B**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory

Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%.

**MP15-C**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to Biological Regions using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to Biological Regions such that the relative harvest rate in Biological Regions 4 and 4B is 0.75 and the relative harvest rate in Biological Regions 2 and 3 is 1.0. The regional TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%.

**MP15-D** this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible) and a percentage allocation for IPHC Regulatory Area 2B calculated from a 30% weight on the current interim management procedure's target TCEY distribution (i.e., O32 stock distribution and relative harvest rates) and 70% weight to 20%. These 2A and 2B adjustments are made by adding to the total coastwide TCEY, rather than reallocating among IPHC Regulatory Areas (as in other MPs). Once this last step is complete, the sum of the distributed TCEY is compared with the TCEY corresponding to a SPR value of 36% (maximum fishing intensity). If the sum of the distributed TCEY is higher than the TCEY corresponding to the maximum fishing intensity, IPHC Regulatory Areas 2A and 2B are adjusted so that the sum of the distributed TCEY is equal to the TCEY corresponding to the maximum fishing intensity. If the sum of the distributed TCEY is lower than the TCEY corresponding to the maximum fishing intensity, no further adjustments are made.

**MP15-E**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0. Further adjustments are applied to the distributed TCEY, to assign a fixed 1.65 million pounds for IPHC Regulatory Area 2A (when possible).

**MP15-F**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. A National Share of 20% is then applied to IPHC Regulatory Area 2B and the remaining 80% is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

**MP15-G**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

**MP15-H**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in IPHC Regulatory Area 4B is 0.75 and the relative harvest rate in all other IPHC Regulatory Areas is 1.0.

**MP15-I:** this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the 'all-sizes' stock distribution, which is determined from the biomass of all sizes of Pacific halibut caught in the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

**MP15-J**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using a 5 year moving average of the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS. A proportional relative harvest rate is applied to IPHC Regulatory Areas such that the relative harvest rate in the western areas (i.e. 3B, 4A, 4CDE, and 4B) is 0.75 and the relative harvest rate in eastern areas (i.e. 2A, 2B, 2C, 3A) is 1.0.

**MP15-K**: this MP applies a coastwide SPR and the 30:20 harvest control rule to obtain a coastwide TCEY. A 15% constraint is then applied to not allow the coastwide TCEY to increase or decrease by more than 15% from the previous year's limit. The coastwide TCEY is then distributed to IPHC Regulatory Areas using the previous 5-year average of the O32 stock distribution (i.e. biomass of fish over 32 inches) from the FISS, calculated only every $5^{th}$ year.