IPHC Scientific Review Board (SRB014) – A Collection of Published Meeting Documents

26 – 28 June 2019, Seattle, WA

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INTERNATIONAL PACIFIC HALIBUT COMMISSION

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PROVISIONAL: AGENDA & SCHEDULE FOR THE 15th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB015)

Date: 24-26 September 2019
Location: Seattle, Washington, U.S.A.
Venue: IPHC Board Room, Salmon Bay
Time: 12:00-17:00 (24th), 09:00-17:00 (25th), 09:00-17:00 (26th)
Chairperson: Dr Sean Cox (Simon Fraser University)
Vice-Chairperson: Nil

1. OPENING OF THE SESSION

2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION

3. IPHC PROCESS
- 3.1. SRB annual workflow (D. Wilson)
- 3.2. Update on the actions arising from the 14th Session of the SRB (SRB014) (D. Wilson)
- 3.3. Outcomes of the 95th Session of the IPHC Annual Meeting (AM095) (D. Wilson)
- 3.4. Observer updates (e.g. Science Advisors)

4. INDEPENDENT EXTERNAL PEER REVIEW OF THE IPHC STOCK ASSESSMENT

5. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS)
- 5.1. Methods for spatial setline survey modelling – results to date for 2019 (R. Webster)

6. PACIFIC HALIBUT STOCK ASSESSMENT: 2019
- 6.1. Data source development (I. Stewart)
- 6.2. Modelling updates (I. Stewart)

7. MANAGEMENT STRATEGY EVALUATION: UPDATE
- 7.1. Updates to MSE framework and closed-loop simulations (A. Hicks)
- 7.2. MSAB Program of Work and delivery timeline for 2019-21 (A. Hicks)

8. BIOLOGICAL AND ECOSYSTEM SCIENCES RESEARCH UPDATES
- 8.1. Five-year research plan and management implications: Update (J. Planas)
- 8.2. Progress on ongoing research projects (J. Planas)

9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 15TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB015)

DRAFT: SCHEDULE FOR THE 15th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB015)

Tuesday, 24 September 2019		
Time	**Agenda item**	**Lead**
12:00-12:30	Arrival (light lunch provided)	
12:30-12:45	1. OPENING OF THE SESSION 2. ADOPTION OF THE AGENDA AND ARRANGEMENTS FOR THE SESSION	S. Cox & D. Wilson
12:45-13:00	3. IPHC PROCESS 3.1 SRB annual workflow (D. Wilson) 3.2 Update on the actions arising from the 14th Session of the SRB (SRB014) 3.3 Outcomes of the 95th Session of the IPHC Annual Meeting (AM095) 3.4 Observer updates (e.g. Science Advisors)	D. Wilson
13:00-14:15	4. INDEPENDENT EXTERNAL PEER REVIEW OF THE IPHC STOCK ASSESSMENT	K. Stokes
14:15-14:45	5. IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS) 5.1 Methods for spatial setline survey modelling – results to date for 2019	R. Webster
14:45-15:30	6. PACIFIC HALIBUT STOCK ASSESSMENT: 2019 6.1 Data source development 6.2 Modelling updates	I. Stewart
15:30-15:45	Break	
15:45-17:00	6. PACIFIC HALIBUT STOCK ASSESSMENT: 2019 (cont.)	I. Stewart
Wednesday, 25 September 2019		
Time	**Agenda item**	**Lead**
09:00-10:00	Review of Day 1 and discussion of SRB Recommendations	Chairperson
10:00-10:30	6. PACIFIC HALIBUT STOCK ASSESSMENT: 2019 (cont. as needed)	I. Stewart
10:30-10:45	Break	

10:45-12:30	7. MANAGEMENT STRATEGY EVALUATION: UPDATE 7.1 Updates to the MSE framework and closed-loop simulations 7.2 MSAB Program of Work and delivery timeline for 2019-21	A. Hicks
12:30-13:30	Lunch	
13:30-15:30	8. BIOLOGICAL AND ECOSYSTEM SCIENCES RESEARCH UPDATES 8.1 Five-year research plan and management implications: Update 8.2 Progress on ongoing research projects	J. Planas
15:30-15:45	Break	
15:45-16:30	8. BIOLOGICAL AND ECOSYSTEM SCIENCES RESEARCH UPDATES (cont.)	J. Planas
16:30-17:00	SRB drafting session	SRB members
Thursday, 26 September 2019		
Time	**Agenda item**	**Lead**
09:00-10:30	Review of Day 2 and discussion of SRB Recommendations	S. Cox
10:30-10:45	Break	
10:45-12:30	Revisit any remaining agenda topics or the Stock Assessment	SRB members
12:30-13:30	Lunch	
13:30-15:00	SRB drafting session	SRB members
15:00-17:00	9. REVIEW OF THE DRAFT AND ADOPTION OF THE REPORT OF THE 15th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB015)	S. Cox

LIST OF DOCUMENTS FOR THE 14th SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB014)

Document	Title	Availability
IPHC-2019-SRB014-01	DRAFT: Agenda & Schedule for the 14th Session of the Scientific Review Board (SRB014)	✓ 28 Mar 2019 ✓ 21 May 2019
IPHC-2019-SRB014-02	List of Documents for the 14th Session of the Scientific Review Board (SRB014)	✓ 21 May 2019 ✓ 24 May 2019
IPHC-2019-SRB014-03	Update on the actions arising from the 13th Session of the SRB (SRB013) (IPHC Secretariat)	✓ 21 May 2019
IPHC-2019-SRB014-04	Outcomes of the 95th Session of the IPHC Annual Meeting (AM095) (D. Wilson)	✓ 21 May 2019
IPHC-2019-SRB014-05 Rev_1	Methods for spatial survey modelling – program of work for 2019 (R. Webster)	✓ 24 May 2019 ✓ 20 Jun 2019
IPHC-2019-SRB014-06	Withdrawn	
IPHC-2019-SRB014-07	2019 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: Development (I. Stewart, A. Hicks)	✓ 23 May 2019
IPHC-2019-SRB014-08	An update on the IPHC Management Strategy Evaluation (MSE) process for SRB014 (A. Hicks, P. Carpi, S. Berukoff, & I. Stewart)	✓ 23 May 2019
IPHC-2019-SRB014-09	Report on current and future biological research activities (J. Planas, T. Loher, L. Sadorus, C. Dykstra, J. Forsberg)	✓ 24 May 2019
Information papers		
IPHC-2019-SRB014-INF01	Nil	

INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC-2019-SRB014-03

Last updated: 16 June 2019

UPDATE ON THE ACTIONS ARISING FROM THE 13TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB013)

PREPARED BY: IPHC SECRETARIAT (21 MAY, 16 JUNE 2019)

PURPOSE

To provide the Scientific Advisory Board (SRB) with an opportunity to consider the progress made during the intersessional period, on the recommendations/requests arising from the SRB013.

BACKGROUND

At the SRB013, the members recommended/requested a series of actions to be taken by the IPHC Secretariat staff, as detailed in the SRB013 meeting report (IPHC-2018-SRB013-R) available from the IPHC website, and as provided in Appendix A.

DISCUSSION

During the 14th Session of the SRB (SRB014), efforts will be made to ensure that any recommendations/requests for action are carefully constructed so that each contains the following elements:

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

RECOMMENDATION/S

That the SRB:

1) **NOTE** paper IPHC-2019-SRB014-03, which provided the SRB with an opportunity to consider the progress made during the inter-sessional period, in relation to the consolidated list of recommendations/requests arising from the previous SRB meeting (SRB013).
2) **AGREE** to consider and revise the actions as necessary, and to combine them with any new actions arising from SRB014.

APPENDICES

Appendix A: Update on actions arising from the 13th Session of the IPHC Scientific Review Board (SRB013)

APPENDIX A
Update on actions arising from the 13th Session of the IPHC Scientific Review Board (SRB013)

RECOMMENDATIONS

Action No.	Description	Update
SRB013–Rec.01 (para. 21)	***Pacific halibut stock assessment: 2018 - Modelling updates*** **NOTING** that the Commission has asked the IPHC Secretariat to develop a paper for consideration at the 94th Session of the IPHC Interim Meeting, that outlines both the current IPHC peer review process and areas for potential improvement, the SRB **RECOMMENDED** the following: a) Pacific halibut stock assessment and peer review cycle, noting that the intention is for the SRB to undertake annual peer review of stock assessment updates, and a peer review of the full stock assessment, independent of the SRB, occurs once every three years, that would then feed into the SRB process (Table 1). b) One option for the IPHC to consider would be for external reviewer(s) conduct a desktop review prior to SRB014 and send the review directly to the Commission. This would supplement the review from the SRB.	**Completed**. The Commission endorsed the stock assessment peer review cycle as detailed in Table 1 of the SRB013 report (IPHC-2018-SRB013-R) The Commission approved an external peer review of the IPHC Stock Assessment for 2019. The consultant hired will undertake a review throughout June-Aug. The SRB will be briefed on progress during SRB014.
SRB013–Rec.02 (para. 30)	***MSE Simulation results*** The SRB **RECOMMENDED** a clear separation between the current stock assessment process and MSE process, so that it is understood: a) these two processes, including statistics and performance metrics, are distinct and not comparable; b) the purpose of the current ensemble stock assessment approach is to develop a decision table to assist the Commission in setting an annual TCEY. This TCEY setting process lacks specificity and how decisions are made is unclear. Furthermore, repeated application of this process is difficult to evaluate relative to Commission objectives;	**Completed**. MSE results are provided for short-term, medium-term, and long-term timeframes, and presented separately from the stock assessment decision table. The MSAB and Commission have received explanations of the purpose of MSE and stock assessment, and that MSE is evaluating the consistent application of various management procedures.

Action No.	Description	Update
	c) the purpose of the MSE is to compare alternative management procedures against Commission objectives over a wide range of plausible uncertainties within the operating model and management procedures. Therefore, these procedures by definition must be specific and repeatable.	

REQUESTS

Action No.	Description	Update
SRB013–Req.01 (para. 26)	***Management Strategy Evaluation: update*** The SRB **REQUESTED** that the MSAB consider listing prioritized objectives used to guide the selection of a management procedure. These could include any combination of short, medium, and long-term objectives, provided Commission objectives be given highest priority. All performance metrics in the MSE must be computed from the operating model. See paragraph 30 for further clarification.	**Completed**. The Commission and MSAB have provided three prioritized objectives to evaluate coastwide MSE results. See paper ***IPHC-2019-SRB014-08***
SRB013–Req.02 (para. 29)	***Updates to MSE framework and closed-loop simulations*** The SRB **REQUESTED** that in future iterations of the MSE, the IPHC Secretariat and MSAB consider: a) the use of estimation error in the proxy assessment method with coefficients of variation equal to 0.15, a correlation of 0.5, and autocorrelation equal to 0.2 represents one plausible scenario. A larger error and autocorrelation could be considered in robustness tests or as alternative scenarios; b) a management procedure include a constraint on the TMq change to be consistent with the maximum change that has happened historically; c) the current conditioned operating model be used to simulate a coast-wide survey index and	**Completed**. The MSE simulations include estimation error and constrained management procedures have been evaluated by the Commission and MSAB. A survey-based management procedure has not been simulated using the current MSE operating model, but will be investigated in the current phase of the MSE analysis. See paper ***IPHC-2019-SRB014-08***

Action No.	Description	Update
	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).	
SRB013–Req.03 (para. 41)	***Biological research updates*** The SRB **REQUESTED** that specific research topics, analysis and results be addressed in depth at subsequent SRB meetings, and that at SRB014, a presentation focused on population genetics and migration as they relate to the stock assessment and MSE work be provided. For example, how does this work identify alternative hypotheses for movement and population structure that can be considered in the MSE process and the stock assessment.	**Completed**. The IPHC Secretariat will present (as a ppt) detailed information on selected research topics with emphasis on future studies on population genetics and migration that respond to specific management needs at SRB014. See also paper: ***IPHC-2019-SRB014-09***

OUTCOMES OF THE 95TH SESSION OF THE IPHC ANNUAL MEETING (AM095)

PREPARED BY: IPHC SECRETARIAT (D. WILSON, 21 MAY 2019)

PURPOSE

To provide the SRB with the outcomes of the 95th Session of the IPHC Annual Meeting (AM095) relevant to the mandate of the SRB.

BACKGROUND

The agenda of the Commission's Annual Meeting (AM095) included several agenda items relevant to the SRB:

6. STOCK STATUS OF PACIFIC HALIBUT (2018) & HARVEST DECISION TABLE (2019)
- *6.1 Fishery-Independent Setline Survey (FISS) design and implementation in 2018, including current and future expansions*
- *6.2 Space-time modelling of survey data (WPUE; FISS expansion results, etc.)*
- *6.3 Data overview and Stock assessment (2018), and draft harvest decision table (2019)*
- *6.4 Pacific halibut mortality projections – Using the IPHC mortality projection tool*

7. IPHC 5-YEAR RESEARCH PROGRAM
- *7.1 IPHC 5-year Biological & Ecosystem Sciences research program: update*

8. REPORT OF THE 19TH SESSION OF THE IPHC RESEARCH ADVISORY BOARD (RAB019)

9. REPORT OF THE 13TH SESSION OF THE IPHC SCIENTIFIC REVIEW BOARD (SRB013)

10. MANAGEMENT STRATEGY EVALUATION
- *10.1 IPHC Management Strategy Evaluation: update*
- *10.2 Report of the 12th Session of the IPHC Management Strategy Advisory Board (MSAB012)*

DISCUSSION

During the course of the 95th Session of the IPHC Annual Meeting (AM095) the Commission made a number of specific recommendations and requests for action regarding the stock assessment, MSE process, and 5-year research program. Relevant sections from the report of the meeting are provided in Appendix A for the SRB's consideration.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2019-SRB014-04 which details the outcomes of the 95th Session of the IPHC Annual Meeting (AM095) relevant to the mandate of the SRB.

APPENDICES

Appendix A: Excerpts from the 95th Session of the IPHC Annual Meeting (AM095) Report (IPHC-2019-AM095-R).

APPENDIX A
Excerpt from the 95th Session of the IPHC Annual Meeting (AM095) Report (IPHC-2019-AM095-R)

Recommendations and Requests

RECOMMENDATIONS

IPHC Management Strategy Evaluation

AM095–Rec.01 (para. 59c) The Commission **RECOMMENDED** the MSAB develop the following additional objective, as well as prioritize this objective in the evaluation of management procedures, for the Commission's consideration.

i. A conservation objective that meets a spawning biomass target.

Report of the 12th Session of the IPHC Management Strategy Advisory Board (MSAB012)

AM095–Rec.02 (para. 62) The Commission **RECOMMENDED** that the MSAB and IPHC Secretariat continue its program of work on the Management Procedure for the Scale portion of the harvest strategy, **NOTING** that Scale and Distribution components will be evaluated and presented no later than at AM097 in 2021, for potential adoption and subsequent implementation as a harvest strategy. The management procedure that best meets the primary objectives for coastwide scale is:

a) A target SPR of 40% with a fishery trigger of 30% and a fishery limit of 20% in the control rule;
b) An annual constraint of 15% from the previous year's mortality limit.

Fishery Limits (Sect. 4)

AM095–Rec.04 (para. 66) The Commission **RECOMMENDED** evaluating and redefining TCEY to include the U26 component of discard mortalities, including bycatch, as steps towards more comprehensive and responsible management of the resource, in coordination with the IPHC Secretariat and Contracting Parties. The intent is that each Contracting Party to the Treaty would be responsible for counting its U26 mortalities against its collective TCEY. This change would be intended to take effect for TCEYs established at the 2020 Annual Meeting.

AM095–Rec.05 (para. 67) The Commission **RECOMMENDED** that the IPHC Secretariat expand upon the analysis completed in IPHC-2019-AM095-INF08 "*Treatment and effects of Pacific halibut discard mortality (bycatch) in non-directed fisheries projected for 2019*", to be reviewed by the SRB at its next meeting. The objective of this work is to estimate lost yield from bycatch of Pacific halibut in non-directed fisheries for the years of 1991-2018.

Peer review process for IPHC science products

AM095–Rec.10 (para. 129) The Commission **RECOMMENDED** that the IPHC Secretariat develop terms of reference for a consultant to undertake a peer review of the IPHC Pacific halibut stock assessment, for implementation in early 2019. The terms of reference and budget shall be endorsed by the Commission inter-sessionally.

AM095–Rec.11 (para. 130) The Commission **RECOMMENDED** that the IPHC Secretariat finalise terms of reference for an expert/consultant to undertake a peer review of the IPHC Pacific halibut MSE, for implementation in early November 2019 and July 2020. The terms of reference and budget shall be endorsed by the Commission inter-sessionally.

REQUESTS

Space-time modelling of survey data (WPUE; FISS expansion results, etc.)

AM095–Req.03 (para. 23) **NOTING** that more FISS stations in the disputed area between Regulatory Areas 2B and 2C appear to be assigned to Regulatory Area 2C, and that the IPHC Secretariat indicated that this assignment is based on a 'compromise' boundary line previously developed, the Commission **REQUESTED** that this separation line be clarified and clearly marked on any future IPHC map to avoid confusion. The IPHC Secretariat shall develop such maps and distribute to the Commission in the coming weeks.

Methods for spatial survey modelling - program of work for 2019

PREPARED BY: IPHC SECRETARIAT (R. WEBSTER; 20 JUNE 2019)

PURPOSE

To propose methods for assessing options for a rationalised IPHC fishery-independent setline survey (FISS or "setline survey") following completion of the planned setline survey expansions in 2019.

BACKGROUND/INTRODUCTION

The IPHC has been undertaking a series of setline survey expansions, beginning with a 2011 pilot in IPHC Regulatory Area 2A, and continuing from 2014-19 as follows:

- 2014: Regulatory Areas 2A and 4A
- 2015: Regulatory Area 4CDE eastern Bering Sea flats
- 2016: Regulatory Area 4CDE shelf edge
- 2017: Regulatory Areas 2A and 4B
- 2018: Regulatory Areas 2B and 2C
- 2019: Regulatory Areas 3A and 3B

The purpose of the expansion program has been to fill in the often large gaps in the annually-fished setline survey to build a complete picture of Pacific halibut density throughout its range, and thereby reduce bias and improve precision in density indices and other quantities computed from the setline survey data.

With the planned expansions due for completion in 2019, the intention is to use our improved understanding of the Pacific halibut distribution to re-design the annual setline survey. As a result, it is likely that stations that were previously fished annually may require less frequent fishing, while it may be preferable to annually fish some expansion stations that have been surveyed just once to date. This report proposes criteria and methods for evaluating such a survey rationalisation, and uses Regulatory Area 4B as an example to demonstrate the application of our proposed approach. We envision the rationalisation as an ongoing process: as new data become available each year and relative costs change with time, future designs choices will be re-evaluated and modified to adapt to changing data needs.

Methods

The overall goal of the setline survey rationalisation is to maintain or enhance data quality (precision and bias) subject to the cost constraints of the FISS budget. Here we propose some precision targets, discuss an approach for reducing the chance of large biases, and note the importance of considering costs in any redesign.

Precision targets

At present, the IPHC Secretariat has an informal goal of maintaining a coefficient of variation (CV) of no more than 15% for mean WPUE for each IPHC Regulatory Area. Including all expansion data to date, this goal has been achieved in all areas from 2011, the year of the first pilot expansion (Table 1), except Regulatory Area 4B in 2011 and 2012 for O32 WPUE, and Regulatory Area 4A in 2018 (all sizes WPUE).

Table 1. Range of coefficients of variation for O32 and all sizes WPUE from 2011-18 by Regulatory Area.

Reg Area	O32 WPUE (2011-18)				All sizes WPUE (2011-18)			
	Lowest CV (%)	Year	Highest CV (%)	Year	Lowest CV (%)	Year	Highest CV (%)	Year
2A	9.9	2017*	11.7	2018	9.4	2014*	11.9	2018
2B	5.6	2018*	6.7	2012	5.8	2018*	6.7	2011
2C	5.6	2018*	6.3	2012	5.7	2018*	6.5	2011
3A	11.1	2016	12.0	2018	9.0	2016	9.7	2018
3B	10.3	2012	12.7	2015	9.3	2018	10.1	2015
4A	8.3	2014*	14.7	2018	9.3	2014*	16.3	2018
4B	9.5	2017*	16.1	2012	8.5	2017*	15.3	2012
4CDE	9.0	2017#	10.0	2013	5.2	2015*	5.9	2018

* Year of setline survey expansion in Reg Area. # Year of trawl survey expansion in Reg Area 4CDE.

Considering Biological Regions, CVs for WPUE in Region 2 were below 5% in all years from 2011 (Table 2), while we expect CVs to be reduced to similar levels in Region 3 following the 2019 expansion. Region 4 CVs for WPUE were below 10%, while the smallest region, Region 4B, has some years with CVs above 15% as noted previously. For all sizes NPUE (Table 3), CVs were above 10% in Region 3 only – again, we expect a reduction below 10% following the 2019 expansion. Based on this information, constraining the setline survey design to produce CVs of 10% or less for Regions 2-4 and 15% for Region 4B should allow for some reduced survey effort in the former regions, while maintaining low uncertainty in Region 4B.

Table 2. Range of coefficients of variation for O32 and all sizes WPUE from 2011-18 by Biological Region.

Region	WPUE (2011-18)				All sizes WPUE (2011-18)			
	Lowest CV (%)	Year	Highest CV (%)	Year	Lowest CV (%)	Year	Highest CV (%)	Year
2	3.8	2018*	4.4	2012	3.9	2018*	4.3	2013
3	8.7	2011	10.0	2018	6.9	2016	7.7	2018
4	7.2	2014*	8.1	2018	4.9	2014*	6.8	2018
4B	9.5	2017*	16.1	2012	8.5	2017*	15.3	2012

* Year of FISS expansion in at least part of the Region.

Table 3. Range of coefficients of variation for all sizes NPUE from 2011-18 by Biological Region.

Region	All sizes NPUE (2011-18)			
	Lowest CV (%)	Year	Highest CV (%)	Year
2	4.2	2018*	5.1	2012
3	12.5	2011	14.0	2017
4	4.6	2014*	6.3	2018
4B	9.0	2017*	17.0	2012

* Year of FISS expansion in at least part of the Region.

Finally, the CV of coastwide, all sizes NPUE (used in the stock assessment) is estimated to be from 6-10% for all years of estimation from 1993 to 2018, and can be expected to be reduced further following the 2019 expansions in Regulatory Areas 3A and 3B. This suggests a target of 10% for the CV of this index will ensure that uncertainty is maintained at a low level for this key stock assessment input.

In summary, in order to maintain the quality of the estimates used for the assessment, and for estimating stock distribution, we propose that a rationalised survey should be designed to meet the following precision targets:

- CVs below 15% for O32 and all sizes WPUE for all Regulatory Areas
- CVs below 10% for O32 WPUE, all sizes WPUE, and all sizes NPUE for Regions 2, 3 and 4
- CVs below 15% for O32 WPUE, all sizes WPUE, and all sizes NPUE for Region 4B
- CVs below 10% for the coastwide, all sizes NPUE index

Reducing the potential for bias

With these targets set, we can proceed to using the space-time modelling to evaluate different survey designs by IPHC Regulatory Area and Biological Region. However, sampling a subset of stations in any area or region brings with it the potential for bias, when trends in the unsurveyed portion of a management unit (Regulatory Area or Region) differ from the surveyed portion. To reduce the potential for bias, we also looked at how frequently part of an area or region (called a “subarea” here) should be surveyed in order to reduce the likelihood of appreciable bias. For this, we propose a threshold of a 10% absolute change in biomass share: how quickly can a subarea’s share of a Regulatory Area or Region’s biomass change by at least 10%? By sampling each subarea frequently enough to keep down the chance of its share changing by more than 10% between successive surveys of the subarea, we reduce the potential for appreciable bias in the Regulatory Area or Region’s indices as a whole.

Cost constraints

While there are financial benefits to sampling low-density waters less frequently, reduced sampling frequency in high-density waters will result in a loss of income generated from fish sales. Thus, there are constraints on the how the survey design can be modified in a given year. Consideration of the effect of survey operating costs and cost recovery will be part of the final analysis, and is likely to constrain options for reducing annual effort in high-density Regulatory Areas and limit the frequency of surveys in remote, low density regions. Any decisions on future survey designs must account for the relative costs of design options, and be subject to overall budget limitations.

Analytical methods

We propose examining the effect of subsampling a management unit on precision as follows:

- Identify subareas within each management unit and select priorities for future sampling
- Generate simulated data for all survey stations based on the output from the most recent space-time modelling
- Fit space-time models to the 1993-2018 observed data augmented with 1 to 3 additional years of data, where the design over those three years reflects the sampling priorities identified above

Extending the modelling beyond three years is not considered worthwhile, as we expect further evaluation undertaken following collection of data during the 1-3 year time period to influence design choice to subsequent years.

Ideally, a full simulation study with many replicate data sets would be used, but this is impractical for the computationally time-consuming spatio-temporal modelling. Instead, “simulated” sample data sets for the future years will be taken from the 2000 posterior samples from the most recent year’s modelling (i.e. 2018 for now). Each year’s simulated data will have to be added and modelled sequentially, as subsequent data can improve the precision of prior years’ estimates, meaning the terminal year is often the least precise (given a consistent design). If time allows, the process can be repeated with several simulated data sets to ensure consistency in results, although with large enough sample sizes (number of stations) in each year, we would expect even a single fit to be informative.

Example: IPHC Regulatory Area 4B

Regulatory Area 4B was chosen as an example for discussion as it is a relatively small area (and so models are quite quick to run), can be divided into fairly distinct subareas based on the 2017 expansion results, and is likely to benefit from a redesign as it has a high potential for exceeding CV targets and is costly to survey. We began by dividing Regulatory Area 4B into three subareas based on the results of the 2017 expanded survey (Figure 1):

1. West of Kiska Is. At present, a relatively low density subarea, but one that previously had much higher densities of Pacific halibut. (57 stations)
2. East of Kiska Is, and west of Amchitka Pass, including Bowers Ridge. Also at present a low density subarea, but one largely unsurveyed before 2017. (73 stations)
3. East of Amchitka Pass. Currently, a subarea of relatively high density and stability, although with higher density in the past. (73 stations)

In recent years, the bulk of the 4B stock (70-80%, Table 4) is estimated to have been in Subarea 3. With standard deviations typically increasing with the mean for this type of data, focusing survey effort on this subarea in future surveys may succeed in maintaining target CVs, while reducing net cost. However, Subarea 1’s share of the biomass can also change by relatively large amounts over short time frames, with changes of over 10% in its share of the 4B biomass frequently occurring over as little as 3-4 years (Table 5). This also should be accounted for in a three-year design plan.

We augmented the 1993-2018 data with simulated data sets for 2019-22. For 2019, the planned setline survey design was used, while the following designs were considered for subsequent years:

- 2019: Planned survey fished (standard 89-station 4B survey)
- 2020: Only Subarea 3 fished (73 stations)
- 2021: Only Subarea 3 fished (73 stations)
- 2022a: Only Subarea 3 fished (73 stations)
- 2022b: Only Subarea 1 fished (57 stations)
- 2022c: Subareas 1 and 2 fished (130 stations)

The three options for 2022 allow either a continuation of Subarea 3 only (2022a), Subarea 1 only to reduce the chance of bias due to changes in density in Subarea 1 over the three years since 2019 (2022b), and a third option (2022c) in case 2022b leads to CVs above the 15% target. The third option is also precautionary in that while there is apparent stability in Subarea 2’s share of the biomass (Tables 4 and 5), most of Subarea 2 has been surveyed just once, in the 2017 expansion. Therefore, this stability can be at least partly attributed to a lack of data reducing the potential for rapid change in its biomass share. As a precautionary approach, a more frequent survey for Subarea 2 than implied by the estimates in Table 2 could be implemented initially, with further evaluation once more data are available.

Table 4. Estimated share of biomass (%) in each subarea of Regulatory Area 4B by year.

Subarea	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
1	34	35	36	37	38	35	30	26	26	20	18	18	20
2	26	26	25	25	24	21	19	22	21	23	23	22	23
3	40	39	39	39	38	45	50	52	53	57	59	60	57
Subarea	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
1	25	26	29	30	22	22	17	12	9	9	9	11	15
2	20	17	16	16	16	17	18	18	16	14	12	10	11
3	55	57	55	54	63	61	65	70	75	77	79	78	74

Table 5. For each year, the number of years until at least a 10% absolute change in estimated biomass share is observed.

Subarea	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
1	9	8	7	4	3	4	3	13	12	7	5	4	4
2	17	21	20	19	18	19	–	16	16	14	13	12	11
3	6	5	4	3	2	4	11	10	11	11	10	9	8
Subarea	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
1	7	6	4	3	4	3	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–	–
3	6	6	4	3	4	3	3	–	–	–	–	–	–

Table 6 presents the estimated CVs for each of the space-time model inputs listed above for 2020-22, along with those from the 2018 model fit to observed 1993-2018 data only. The three fits based on surveying only Subarea 3 in 2020-22 (rows 3, 4 and 5 of Table 6) all lead to CVs below the 15% target. However, surveying only Subarea 1 instead of Subarea 3 in 2022 was insufficient to meet the target, with a CV of 17.0% estimated in 2022. Adding Subarea 2 brought the 2022 CV down to 14.2%, now below the target.

Table 6. Estimated coefficients of variation (%) by data input for Regulatory Area 4B. Proposed target CV is 15%.

Data input	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
1993-2018 data	9.5	13.7				
+ 2019-20 simulated data	9.4	12.6	12.4	10.2		
+ 2019-21 simulated data	9.6	12.6	12.7	11.2	12.3	
+ 2019-22a simulated data	9.5	12.2	11.9	10.1	12.1	14.0
+ 2019-22b simulated data	9.4	12.1	12.1	10.1	10.7	*17.0*
+ 2019-22c simulated data	8.8	11.0	10.7	8.7	8.7	14.2

The next step would be to calculate the relative costs of each option. Fishing both Subareas 1 and 2 in 2022 would be an expensive survey, with likely high vessel charter costs together with low catches offsetting those costs. It may be desirable to explore other options for 2022, such as pairing Subareas 1 and 3, and fishing Subarea 2 (probably together with Subarea 3) in a later year. Relative costs of different options for this example have yet to be discussed with relevant staff at the time of writing.

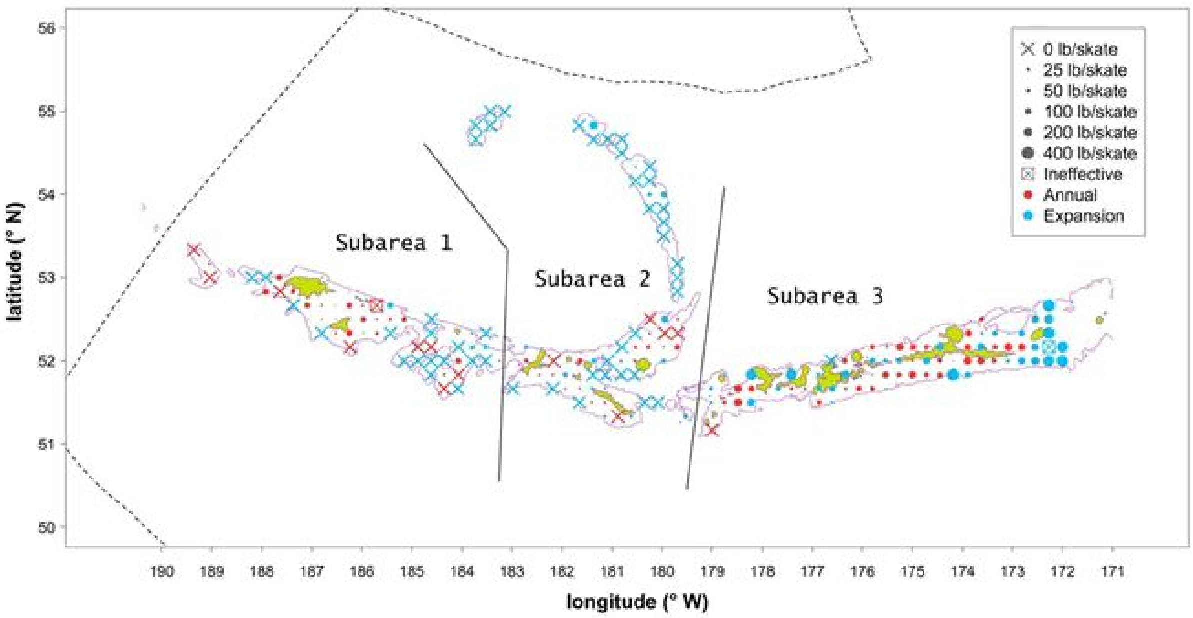

Figure 1. Map of 2017 the FISS expansion design in IPHC Regulatory Area 4B showing the subareas used in the analysis.

IPHC-2019-SRB014-07

2019 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: Development

PREPARED BY: IPHC SECRETARIAT (I. STEWART, A. HICKS; 23 MAY 2019)

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Summary

This document reports preliminary analyses in development of the 2019 Pacific halibut (*Hippoglossus stenolepis*) stock assessment. It follows the previous full stock assessment conducted in 2015 (Stewart and Martell 2016; Stewart et al. 2016), and subsequent updates to that assessment in 2016 (Stewart and Hicks 2017), 2017 (Stewart and Hicks 2018a), and 2018 (Stewart and Hicks 2019). Following the review of this document in June 2019 (external peer review and SRB014), requested revisions will be considered and presented for final review in October 2019 (SRB015). Updated data sources, including the results of the 2019 Fishery-Independent Setline Survey (FISS), logbook and biological data from the 2019 commercial fishery, and (potentially) sex-ratio information from the 2018 commercial landings-at-age will be included for the final 2019 analysis.

Creating robust, stable, and well-performing stock assessment models for the Pacific halibut stock has historically proven to be challenging due to the highly dynamic nature of the biology, distribution, and fisheries (Stewart and Martell 2014b). The stock assessment for Pacific halibut has evolved through many different modeling approaches over the last 30 years (Clark 2003). These changes have reflected improvements in fisheries analysis methods, changes in model assumptions, and responses to recurrent retrospective biases and other lack-of-fit metrics (Stewart and Martell 2014b). One solution to the endless search for a better stock assessment model is to recognize that all models are simple approximations to reality, and that the uncertainty in our analyses can be better captured through the explicit use of multiple models: the ensemble approach. The ensemble approach utilizes multiple models in the estimation of management quantities and therefore adds explicit accounting for structural uncertainty about these quantities (Stewart and Hicks 2018b, Stewart and Martell 2015). This reduces potential for abrupt changes in management quantities as improvements and additional data are added to individual models, and provides a more realistic perception of uncertainty than any single model, and therefore a stronger basis for risk assessment.

Development of the current ensemble of stock assessment models began in 2012 with a single model using three alternative fixed values of natural mortality (Stewart et al. 2013a). In subsequent years, ensemble development included exploration of highly varied model approaches, including a Virtual Population Analysis (VPA) and a simple biomass production model (Cox et al. 2014) and a spatially explicit model including migration rates and recruitment distribution (Cox et al. 2017). The treatment of the historical data through long and short modelled time-series, and the treatment of spatial patterns via coastwide aggregation of data and an Areas-As-Fleets (AAF) approach have emerged as two critically important axes over which to describe the uncertainty in both the scale and trends of the Pacific halibut stock and population dynamics. Therefore, recent ensembles have included four equally-weighted models representing a two-way cross of time-series length (short and long) and data aggregation (coastwide and by Biological Region).

Starting with the 2018 stock assessment data, models and results (Stewart and Hicks 2019; Stewart and Webster 2019), this analysis is sequentially updated to ‘bridge’ the changes toward

a preliminary assessment for 2019. This bridging analysis included a series of steps for which intermediate results and comparisons are provided. These steps included:

1) updating to the newest stock synthesis software (version 3.30.13; Methot et al. 2019),
2) adding newly available sex-ratio information from the 2017 commercial fishery landings,
3) extending the temporal length of the two short models to include the beginning of the available Fishery Independent Setline Survey (FISS) time series (1993),
4) updating the entire modelled FISS time series to include whale depredation criteria implemented in the survey in 2018, and
5) re-tuning the process and observation error components of these models to achieve internal consistency within each.

As documented in all recent analyses since 2013, a primary source of uncertainty has been the sex ratio of the commercial landings. The newly available data from 2017 allowed for a two-fold effect on this source of uncertainty: first, estimates of relative selectivity of males in the commercial fishery were decoupled from survey observations for the first time, second, this allowed improved overall fit to the various data sources and changes in the internally consistent levels of process and observation error within each model. In aggregate, the results of this preliminary assessment are consistent with those from recent assessments, but suggest a slightly higher absolute level of female spawning biomass, as well as a higher level of fishing intensity. Spawning biomass trends remain similar to recent analyses with large declines estimated from the late 1990s through around 2010, a brief period of stability and then gradual declines estimated since 2016. The uncertainty in stock dynamics also remains similar and high relative to that frequently reported for single-model or simple stock assessment analyses. This uncertainty will continue to be captured via the annual decision table, reporting the trade-offs between yield and various stock and fishery risks (i.e., Stewart and Hicks 2019).

Sensitivity and retrospective analyses were performed on all models contributing to the ensemble. Individual models showed differing sensitivity to specific important sources including the estimation of the steepness parameter, alternative values of female natural mortality (in the short models utilizing a fixed value of 0.15), and data weighting. Retrospective analyses suggested that these models are sensitive to new information, particularly the sex ratio information from 2017.

Given the challenges and uncertainties of the Pacific halibut population dynamics and stock assessment it is unlikely that some new future assessment model will provide substantially more precise and stable results. In light of the uncertainty and variability within which the Pacific halibut management occurs, the current effort to create and refine a robust management procedure through the IPHC's Management Strategy Evaluation (MSE) process (Hicks and Stewart 2019) may provide a much better prospect for future management success and stability than annual decisions based on annual stock assessment results.

Data sources

The Pacific halibut data sources are collected with sampling designs created to produce results first for each IPHC Regulatory Area, and then to be aggregated to Biological Regions and to the entire range of the species in U.S. and Canadian waters (FIGURE 1). This section provides a brief overview of the key types of data available for analysis. A more in-depth summary can be found in the annual overview of data sources created each year and most recently for the 2018 stock assessment (Stewart and Webster 2019). Where specific improvements to existing data sources have been included in this assessment (i.e., sex-ratios from the 2017 commercial landings and the revised modelled survey time-series) changes are described below.

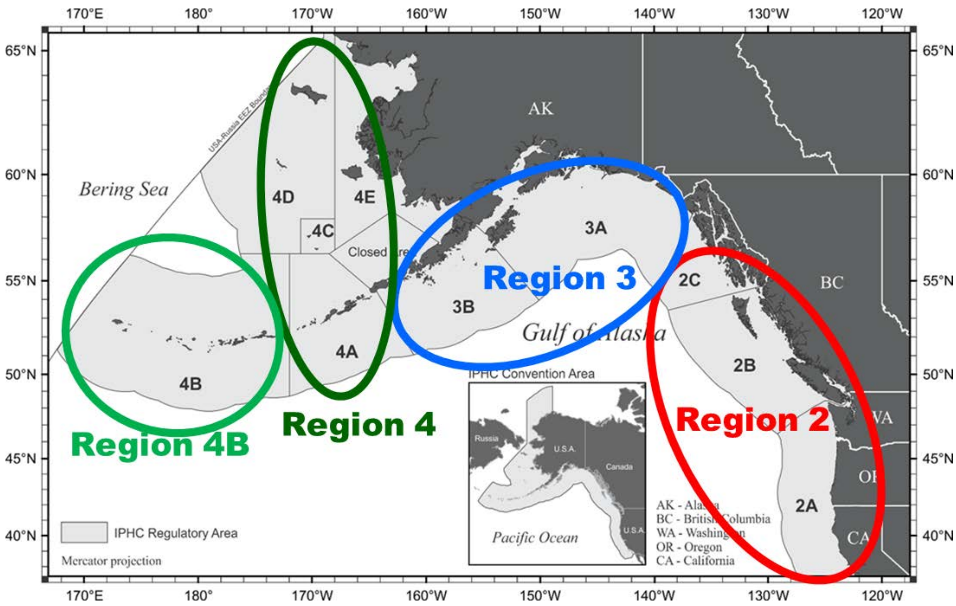


FIGURE 1. IPHC Regulatory Areas, Biological Regions, and the Pacific halibut geographical range within the territorial waters of Canada and the United States of America.

Overview of existing data

The time-series' of Pacific halibut data (Stewart and Webster 2019) provides a rich historical record including mortality estimates, abundance indices (CPUE) and age-composition data that extend back to the late 1800s and early 1900s (FIGURE 2). The IPHC's Fishery Independent Setline Survey (FISS; Erikson et al. 2019) provides the primary index of abundance and the most rich source of demographic information via individual weight, length and age data. The FISS includes Pacific halibut as young as 4-5 years old, on average several years prior to entry into the retained catch. In aggregate, 42% of the FISS catch comprises smaller fish below the IPHC's 32 inch (82 cm) minimum size limit. The FISS also provides identification of the sex of each fish sampled. Commercial data is sampled at the point of landing (Erikson 2019), so it does not contain biological or catch-rate information on younger, smaller fish below the IPHC's 32 inch (82 cm) minimum size limit (Stewart and Hicks 2018b). Annual mortality estimates are provided to the IPHC from a variety of sources (Erikson 2019) including the directed halibut fisheries (commercial, recreational and subsistence) as well as incidental mortality associated with discards in directed fisheries and bycatch mortality in fisheries that are not allowed to legally retain Pacific halibut. Each of these sources have differing levels of precision and likely accuracy associated with the estimates used for stock assessment.

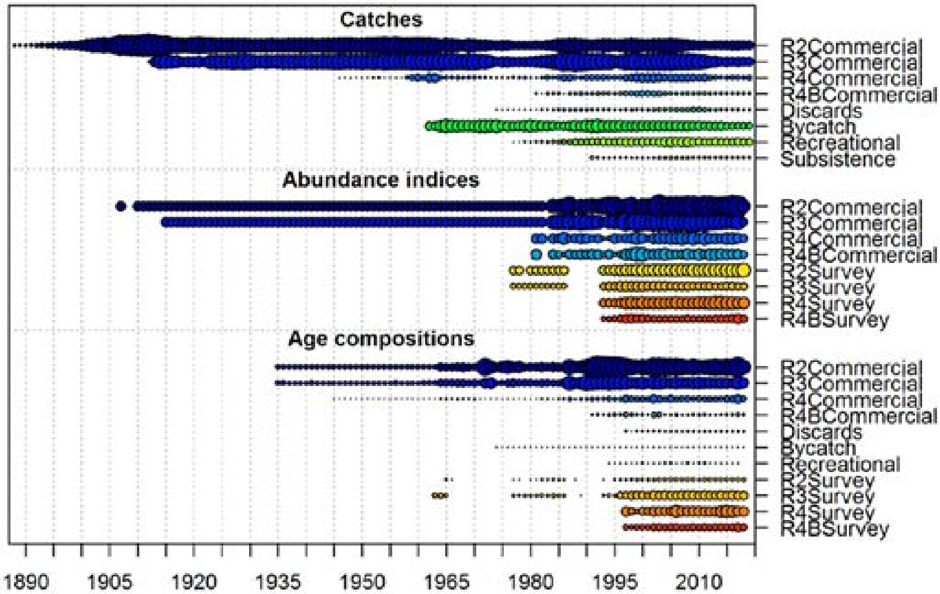


FIGURE 2. Data used in the stock assessment. Circle size is proportional to the magnitude of mortality (catches), inversely proportional to the variance (abundance indices) or proportional to the sample size (age-composition data).

Mortality

The industrial Pacific halibut fishery developed first off the west coast of the United States and Canada and sequentially moved to the north, only reaching full exploitation across all spatial areas in the last several decades (FIGURE 3). Mortality from bycatch in non-Pacific halibut directed fisheries increased rapidly with the arrival of foreign fleets into U.S. and Canadian waters in the 1960s. Recreational mortality has also increased over the time-series, although somewhat more gradually, since its initiation in the 1970s.

Index data

The IPHC's FISS (Erikson et al. 2019) comprises the primary index of recent abundance and the primary source of biological data for use in the stock assessment. Index values from 1993-present (TABLE 1) are reported and used in this assessment in numbers of halibut captured per unit effort (NPUE). The time-series is based on the output of the IPHC's space-time model (Webster 2019) which estimates the degree of spatial and temporal correlation among survey stations in order to predict trends in biomass and abundance across the entire range of Pacific halibut within the IPHC Convention Area. For the recent time period (1993-2018) this index provides relatively precise trend information by IPHC Regulatory Area. Estimates from the space-time model are weighted by the relative spatial bottom area in each IPHC Regulatory Area, when combined up to Biological Regions and coastwide indices. The variances are summed, accounting for the square of the weights, and converted to log(SE) for use in the assessment model assuming log-normal error (Stewart and Martell 2016). There were geographically limited surveys conducting during 1963-1989, with summarized catch rates, but no variance estimates available from 1977 (TABLE 1). For the period prior to 1993 where there are no variance estimates, twice the recent average value is used, and for the coastwide series where spatial coverage is incomplete values are doubled again.

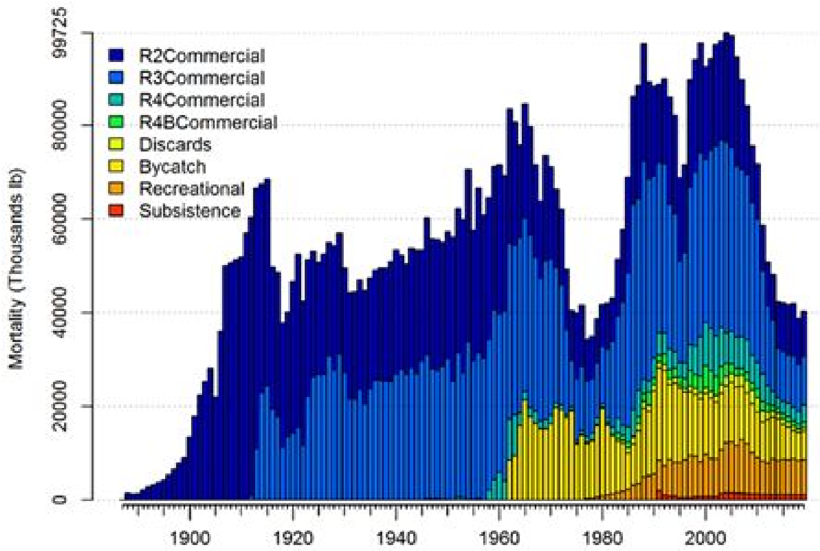


FIGURE 3. Time-series of mortality estimates used in the stock assessment. Commercial series is partitioned by Biological Regions, as in the Areas-As-Fleets models.

Commercial fishery landed Catch-Per-Unit-Effort (CPUE, generally referred to as Weight-Per-Unit-Effort or WPUE) is reported through mandatory logbooks (voluntary for vessels under 26 feet, 7.9 m, in length) collected by IPHC port samplers, and returned directly to the IPHC by mail. Commercial CPUE is available as far back as the early 1900s (Stewart and Webster 2019) providing a valuable historical record, but spanning a period of continuous fishery development and change, including an important transition to circle hooks in 1984 that substantially increased average catchability (TABLE 2-4).

TABLE 1. Modelled survey Numbers-Per-Unit-Effort (NPUE) 1993-2018, raw average observed NPUE 1977-1986 and estimated log(SE); assumed values in italics.

	Region 2		Region 3		Region 4		Region 4B		Coastwide	
Year	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)
1977	0.60	*0.124*	2.00	*0.246*	--	--	--	--	1.47	*0.322*
1978	0.80	*0.124*	1.30	*0.246*	--	--	--	--	1.11	*0.322*
1979	--	--	1.90	*0.246*	--	--	--	--	--	--
1980	1.20	*0.124*	2.50	*0.246*	--	--	--	--	2.01	*0.322*
1981	0.80	*0.124*	3.80	*0.246*	--	--	--	--	2.67	*0.322*
1982	1.85	*0.124*	3.80	*0.246*	--	--	--	--	2.88	*0.322*
1983	2.31	*0.124*	3.40	*0.246*	--	--	--	--	2.88	*0.322*
1984	6.75	*0.124*	11.60	*0.246*	--	--	--	--	9.31	*0.322*
1985	5.66	*0.124*	11.90	*0.246*	--	--	--	--	8.95	*0.322*
1986	4.55	*0.124*	7.80	*0.246*	--	--	--	--	6.26	*0.322*
1993	6.36	0.106	25.33	0.146	2.04	0.125	9.99	0.338	7.73	0.101
1994	7.66	0.112	25.14	0.124	2.12	0.116	10.22	0.268	7.96	0.083
1995	9.18	0.087	26.87	0.116	2.10	0.114	10.55	0.240	8.55	0.077
1996	8.14	0.075	27.44	0.096	2.36	0.096	10.76	0.187	8.66	0.064
1997	7.55	0.069	29.71	0.099	2.55	0.064	11.01	0.113	9.14	0.066
1998	6.35	0.071	25.21	0.091	2.70	0.062	11.13	0.112	8.15	0.059
1999	5.25	0.062	24.59	0.093	2.34	0.066	9.52	0.128	7.56	0.062
2000	5.79	0.062	26.66	0.093	2.49	0.061	8.70	0.141	8.11	0.063
2001	6.70	0.063	23.63	0.102	2.31	0.063	6.81	0.169	7.45	0.066
2002	6.71	0.059	26.25	0.106	2.19	0.063	4.95	0.202	7.81	0.072
2003	5.73	0.062	25.85	0.101	2.05	0.065	4.10	0.212	7.45	0.071
2004	5.26	0.060	29.17	0.107	2.02	0.066	3.81	0.207	8.00	0.079
2005	5.79	0.059	25.02	0.127	2.05	0.068	3.68	0.212	7.27	0.088
2006	5.70	0.056	23.82	0.126	2.09	0.059	4.29	0.194	7.08	0.085
2007	6.34	0.058	25.64	0.125	2.06	0.065	5.44	0.190	7.58	0.085
2008	6.32	0.058	23.31	0.124	2.41	0.067	5.25	0.179	7.31	0.080
2009	6.37	0.052	21.85	0.129	2.41	0.064	4.44	0.198	6.99	0.081
2010	6.35	0.053	22.10	0.129	2.28	0.060	4.18	0.209	6.94	0.083
2011	6.33	0.052	22.88	0.137	2.17	0.061	4.19	0.197	7.04	0.090
2012	7.42	0.051	23.75	0.143	2.21	0.053	3.77	0.201	7.38	0.092
2013	7.14	0.050	18.29	0.147	2.00	0.052	5.09	0.153	6.19	0.088
2014	7.38	0.049	21.64	0.147	2.07	0.050	4.54	0.153	6.91	0.093
2015	8.18	0.047	21.64	0.141	2.06	0.054	4.56	0.163	7.03	0.087
2016	8.26	0.048	21.54	0.137	1.87	0.057	5.02	0.137	6.93	0.086
2017	5.94	0.047	15.66	0.153	1.71	0.063	4.00	0.094	5.26	0.091
2018	5.04	0.045	14.65	0.160	1.59	0.066	4.03	0.146	4.85	0.097

TABLE 2. Commercial fishery Weight-Per-Unit-Effort (WPUE) 1907-1949 and estimated log(SE); assumed values in italics.

	Region 2		Region 3		Region 4		Region 4B		Coastwide	
Year	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)
1907	280.00	*0.100*	--	--	--	--	--	--	280.00	*0.100*
1910	271.00	*0.100*	--	--	--	--	--	--	271.00	*0.100*
1911	237.00	*0.100*	--	--	--	--	--	--	237.00	*0.100*
1912	176.00	*0.100*	--	--	--	--	--	--	176.00	*0.100*
1913	128.94	*0.100*	--	--	--	--	--	--	129.00	*0.100*
1914	124.13	*0.100*	--	--	--	--	--	--	124.00	*0.100*
1915	118.02	*0.100*	266.10	*0.100*	--	--	--	--	118.00	*0.100*
1916	114.60	*0.100*	202.80	*0.100*	--	--	--	--	137.00	*0.100*
1917	81.80	*0.100*	157.90	*0.100*	--	--	--	--	98.00	*0.100*
1918	87.50	*0.100*	125.40	*0.100*	--	--	--	--	96.00	*0.100*
1919	82.30	*0.100*	129.90	*0.100*	--	--	--	--	93.00	*0.100*
1920	84.10	*0.100*	147.90	*0.100*	--	--	--	--	96.00	*0.100*
1921	76.46	*0.100*	141.17	*0.100*	--	--	--	--	88.00	*0.100*
1922	62.44	*0.100*	133.79	*0.100*	--	--	--	--	73.00	*0.100*
1923	56.68	*0.100*	149.97	*0.100*	--	--	--	--	78.00	*0.100*
1924	55.39	*0.100*	109.13	*0.100*	--	--	--	--	74.00	*0.100*
1925	51.21	*0.100*	94.63	*0.100*	--	--	--	--	68.00	*0.100*
1926	51.67	*0.100*	93.73	*0.100*	--	--	--	--	67.00	*0.100*
1927	48.83	*0.100*	86.32	*0.100*	--	--	--	--	65.00	*0.100*
1928	47.27	*0.100*	72.34	*0.100*	--	--	--	--	58.00	*0.100*
1929	38.55	*0.100*	70.79	*0.100*	--	--	--	--	51.00	*0.100*
1930	34.44	*0.100*	65.91	*0.100*	--	--	--	--	46.00	*0.100*
1931	38.48	*0.100*	76.17	*0.100*	--	--	--	--	50.00	*0.100*
1932	47.50	*0.100*	83.49	*0.100*	--	--	--	--	60.00	*0.100*
1933	50.16	*0.100*	83.99	*0.100*	--	--	--	--	63.00	*0.100*
1934	54.07	*0.100*	74.97	*0.100*	--	--	--	--	62.00	*0.100*
1935	61.77	*0.100*	97.57	*0.100*	--	--	--	--	76.00	*0.100*
1936	54.66	*0.100*	96.70	*0.100*	--	--	--	--	71.00	*0.100*
1937	61.48	*0.100*	109.99	*0.100*	--	--	--	--	80.00	*0.100*
1938	70.33	*0.100*	114.29	*0.100*	--	--	--	--	88.00	*0.100*
1939	61.90	*0.100*	112.21	*0.100*	--	--	--	--	80.00	*0.100*
1940	61.71	*0.100*	116.38	*0.100*	--	--	--	--	81.00	*0.100*
1941	62.54	*0.100*	122.26	*0.100*	--	--	--	--	85.00	*0.100*
1942	65.43	*0.100*	132.54	*0.100*	--	--	--	--	90.00	*0.100*
1943	72.24	*0.100*	131.27	*0.100*	--	--	--	--	95.00	*0.100*
1944	86.84	*0.100*	149.23	*0.100*	--	--	--	--	110.00	*0.100*
1945	79.69	*0.100*	130.86	*0.100*	--	--	--	--	102.00	*0.100*
1946	83.78	*0.100*	123.82	*0.100*	--	--	--	--	101.00	*0.100*
1947	86.30	*0.100*	114.56	*0.100*	--	--	--	--	99.00	*0.100*
1948	88.61	*0.100*	112.20	*0.100*	--	--	--	--	99.00	*0.100*
1949	85.01	*0.100*	105.89	*0.100*	--	--	--	--	95.00	*0.100*

TABLE 3. Commercial fishery Weight-Per-Unit-Effort (WPUE) 1950-1991 and estimated log(SE); assumed values in italics.

	Region 2		Region 3		Region 4		Region 4B		Coastwide	
Year	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)
1950	87.66	*0.100*	103.60	*0.100*	--	--	--	--	95.00	*0.100*
1951	87.63	*0.100*	108.93	*0.100*	--	--	--	--	96.00	*0.100*
1952	95.58	*0.100*	128.86	*0.100*	--	--	--	--	110.00	*0.100*
1953	128.65	*0.100*	134.32	*0.100*	--	--	--	--	131.00	*0.100*
1954	137.97	*0.100*	127.43	*0.100*	--	--	--	--	133.00	*0.100*
1955	122.20	*0.100*	116.32	*0.100*	--	--	--	--	119.00	*0.100*
1956	132.02	*0.100*	126.05	*0.100*	--	--	--	--	129.00	*0.100*
1957	100.95	*0.100*	119.84	*0.100*	--	--	--	--	110.00	*0.100*
1958	101.96	*0.100*	139.96	*0.100*	--	--	--	--	121.00	*0.100*
1959	98.67	*0.100*	160.62	*0.100*	--	--	--	--	129.00	*0.100*
1960	105.02	*0.100*	156.08	*0.100*	--	--	--	--	132.00	*0.100*
1961	96.00	*0.100*	159.79	*0.100*	--	--	--	--	127.00	*0.100*
1962	84.76	*0.100*	136.89	*0.100*	--	--	--	--	115.00	*0.100*
1963	77.73	*0.100*	123.89	*0.100*	--	--	--	--	105.00	*0.100*
1964	75.27	*0.100*	120.10	*0.100*	--	--	--	--	100.00	*0.100*
1965	86.47	*0.100*	107.07	*0.100*	--	--	--	--	99.00	*0.100*
1966	82.59	*0.100*	112.72	*0.100*	--	--	--	--	100.00	*0.100*
1967	81.44	*0.100*	113.00	*0.100*	--	--	--	--	101.00	*0.100*
1968	86.58	*0.100*	111.62	*0.100*	--	--	--	--	103.00	*0.100*
1969	81.53	*0.100*	105.07	*0.100*	--	--	--	--	95.00	*0.100*
1970	73.62	*0.100*	103.67	*0.100*	--	--	--	--	91.00	*0.100*
1971	76.05	*0.100*	96.31	*0.100*	--	--	--	--	89.00	*0.100*
1972	69.47	*0.100*	82.87	*0.100*	--	--	--	--	78.00	*0.100*
1973	64.41	*0.100*	62.13	*0.100*	--	--	--	--	63.00	*0.100*
1974	60.88	*0.100*	61.95	*0.100*	--	--	--	--	61.00	*0.100*
1975	61.85	*0.100*	66.76	*0.100*	--	--	--	--	61.00	*0.100*
1976	44.37	*0.100*	61.91	*0.100*	--	--	--	--	55.00	*0.100*
1977	64.14	*0.100*	65.57	*0.100*	--	--	--	--	63.00	*0.100*
1978	54.05	*0.100*	68.47	*0.100*	--	--	--	--	71.00	*0.100*
1979	55.84	*0.100*	67.33	*0.100*	--	--	--	--	75.00	*0.100*
1980	59.56	*0.100*	116.09	*0.100*	--	--	--	--	94.00	*0.100*
1981	73.95	*0.100*	148.86	*0.100*	137.27	*0.100*	99.00	0.078	111.00	*0.100*
1982	71.95	*0.100*	181.34	*0.100*	97.82	*0.100*	--	--	127.00	*0.100*
1984	152.14	0.045	491.33	0.046	350.30	*0.100*	161.00	0.103	291.00	*0.100*
1985	161.87	0.051	535.06	0.039	441.49	0.103	234.00	0.160	351.00	0.034
1986	137.49	0.035	506.00	0.042	325.84	0.059	238.00	0.372	315.00	0.041
1987	135.71	0.027	490.38	0.036	353.58	0.162	220.00	0.111	316.00	0.038
1988	168.60	0.054	560.55	0.042	405.68	0.105	224.00	0.122	363.00	0.036
1989	155.08	0.042	507.69	0.031	379.25	0.080	268.00	0.094	353.00	0.025
1990	194.77	0.043	403.54	0.036	362.91	0.097	209.00	0.103	315.00	0.029
1991	170.73	0.039	375.02	0.041	365.84	0.157	329.00	0.085	314.00	0.038

TABLE 4. Commercial fishery Weight-Per-Unit-Effort (WPUE) 1992-2018 and estimated log(SE).

	Region 2		Region 3		Region 4		Region 4B		Coastwide	
Year	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)	Index	log(SE)
1992	167.74	0.040	413.39	0.048	324.01	0.117	280.00	0.095	315.00	0.035
1993	200.10	0.031	439.11	0.096	400.28	0.447	218.00	0.220	369.00	0.100
1994	175.72	0.027	362.77	0.049	343.14	0.333	197.00	0.101	302.00	0.069
1995	190.75	0.025	439.48	0.043	330.22	0.100	189.00	0.336	326.00	0.037
1996	208.83	0.042	505.01	0.046	427.58	0.138	269.00	0.185	387.00	0.039
1997	237.52	0.035	498.02	0.026	432.94	0.103	275.00	0.064	400.00	0.025
1998	221.23	0.029	512.59	0.036	433.49	0.084	287.00	0.058	403.00	0.025
1999	249.46	0.079	475.49	0.024	406.86	0.058	310.00	0.045	390.00	0.023
2000	229.96	0.036	494.83	0.026	415.81	0.082	320.00	0.048	399.00	0.023
2001	202.80	0.039	454.52	0.029	365.44	0.212	270.00	0.076	358.00	0.042
2002	214.84	0.032	466.46	0.025	303.90	0.080	245.00	0.081	356.00	0.020
2003	208.97	0.018	439.27	0.024	254.79	0.071	196.00	0.068	325.00	0.018
2004	192.93	0.028	425.79	0.026	242.57	0.070	202.00	0.061	315.00	0.019
2005	178.99	0.024	387.69	0.023	219.59	0.063	238.00	0.093	293.00	0.017
2006	180.18	0.024	360.70	0.022	174.18	0.066	218.00	0.111	267.00	0.019
2007	158.09	0.023	344.27	0.026	150.17	0.057	230.00	0.108	249.00	0.020
2008	138.82	0.020	318.17	0.024	162.55	0.071	193.00	0.069	229.00	0.017
2009	152.91	0.020	277.22	0.020	175.25	0.054	189.00	0.097	220.00	0.018
2010	185.13	0.037	242.32	0.024	141.52	0.081	142.00	0.063	202.00	0.020
2011	179.87	0.020	226.65	0.025	141.21	0.057	165.00	0.103	196.00	0.015
2012	193.90	0.020	213.46	0.032	136.03	0.081	149.00	0.066	193.00	0.021
2013	192.72	0.026	189.98	0.033	117.39	0.075	127.00	0.064	178.00	0.017
2014	210.33	0.026	182.93	0.039	108.29	0.098	146.00	0.070	183.00	0.022
2015	217.26	0.024	224.46	0.045	132.77	0.066	149.00	0.076	202.00	0.025
2016	212.58	0.019	216.22	0.044	126.67	0.067	123.00	0.083	196.00	0.020
2017	213.73	0.020	219.60	0.037	116.34	0.087	120.00	0.082	202.00	0.020
2018	204.55	*0.055*	191.36	*0.134*	104.87	*0.135*	133.00	*0.148*	180.00	*0.061*

Age data

Otoliths are sampled randomly from all stations FISS catches at variable rates across IPHC Regulatory areas, with a target of 1500 per Area. The number of stations contributing to the annual age information varies considerably over the time-series, with Biological Region 3 the most heavily sampled, followed by Region 2, Region 4 and far fewer samples collected in Region 4B (TABLE 5). There are also a small number of geographically limited surveys from the period 1963-1966 for which there are age samples, but no corresponding index. Otoliths from the commercial fishery landings are also sampled in proportion to the weight of the catch with different rates by IPHC Regulatory Area. This has led to a relatively larger number of commercial trips sampled in Biological Region 2 over most of the historical period, with Region 3, Region 4, and Region 4B each contributing fewer samples (TABLE 6-7).

TABLE 5. Number of stations contributing to survey age data (1963-2018).

Year	Region 2	Region 3	Region 4	Region 4B	Coastwide
1963	--	236	--	--	236
1964	--	305	--	--	305
1965	121	146	--	--	267
1966	66	--	--	--	66
1977	58	100	--	--	158
1978	62	98	--	--	160
1979	--	104	--	--	104
1980	80	101	--	--	181
1981	72	102	--	--	174
1982	154	148	--	--	302
1983	192	101	--	--	293
1984	241	198	--	--	439
1985	166	103	--	--	269
1986	178	97	--	--	275
1988	72	--	--	--	72
1989	--	33	--	--	33
1993	66	70	--	--	136
1994	--	147	--	--	161
1995	103	120	--	--	223
1996	200	424	--	--	624
1997	212	429	221	74	936
1998	228	507	100	42	877
1999	332	556	61	82	1031
2000	242	553	153	83	1031
2001	334	522	148	83	1087
2002	313	558	154	82	1107
2003	323	518	153	82	1076
2004	330	527	148	71	1076
2005	342	509	152	83	1086
2006	321	529	243	84	1177
2007	330	540	181	74	1125
2008	339	552	184	76	1151
2009	336	559	179	84	1158
2010	336	533	182	78	1129
2011	365	554	172	79	1170
2012	361	524	174	72	1131
2013	368	537	170	80	1155
2014	386	567	247	77	1277
2015	365	540	248	82	1235
2016	352	549	230	78	1209
2017	374	527	175	124	1200
2018	467	538	168	77	1250

TABLE 6. Number of commercial fishing trips contributing to fishery age data (1935-1982); historical values in italics are assumed.

Year	Region 2	Region 3	Region 4	Region 4B	Coastwide
1935	*50*	*50*	--	--	*100*
1936	*50*	*50*	--	--	*100*
1937	*50*	*50*	--	--	*100*
1938	*50*	*50*	--	--	*100*
1939	*50*	*50*	--	--	*100*
1940	*50*	*50*	--	--	*100*
1941	*50*	*50*	--	--	*100*
1942	*50*	*50*	--	--	*100*
1943	*50*	*50*	--	--	*100*
1944	*50*	*50*	--	--	*100*
1945	*50*	*50*	*5*	--	*100*
1946	*50*	*50*	*5*	--	*100*
1947	*50*	*50*	*5*	--	*100*
1948	*50*	*50*	*5*	--	*100*
1949	*50*	*50*	*5*	--	*100*
1950	*50*	*50*	*5*	--	*100*
1951	*50*	*50*	*5*	--	*100*
1952	*50*	*50*	*5*	--	*100*
1953	*50*	*50*	*5*	--	*100*
1954	*50*	*50*	*5*	--	*100*
1955	*50*	*50*	*5*	--	*100*
1956	*50*	*50*	*5*	--	*100*
1957	*50*	*50*	*5*	--	*100*
1958	*50*	*50*	*5*	--	*100*
1959	*50*	*50*	*5*	--	*100*
1960	*50*	*50*	*5*	--	*100*
1961	*50*	*50*	*5*	--	*100*
1962	*50*	*50*	*5*	--	*100*
1963	*50*	*50*	*5*	--	*100*
1964	116	100	14	--	230
1965	118	106	12	--	238
1966	102	113	12	--	228
1967	125	133	20	--	278
1968	135	132	14	--	282
1969	113	102	12	--	227
1970	97	125	18	--	241
1971	82	77	9	--	168
1972	552	196	3	--	752
1973	311	262	5	--	578
1974	153	68	3	--	226
1975	234	76	7	--	320
1976	332	135	7	--	476
1977	247	138	7	--	401
1978	241	120	4	--	377
1979	125	101	6	--	244
1980	140	113	1	--	262
1981	146	90	7	--	248
1982	168	137	11	--	316

TABLE 7. Number of commercial fishing trips contributing to fishery age data (1983-2018).

Year	Region 2	Region 3	Region 4	Region 4B	Coastwide
1983	133	106	23	--	268
1984	170	90	9	--	282
1985	171	99	14	--	286
1986	158	152	34	--	345
1987	531	498	76	--	1117
1988	278	258	19	--	571
1989	318	371	39	--	752
1990	491	560	50	--	1104
1991	718	496	62	12	1288
1992	1027	478	61	20	1586
1993	959	471	65	11	1506
1994	896	474	89	31	1490
1995	887	468	72	37	1464
1996	859	437	76	27	1399
1997	676	429	183	58	1346
1998	515	277	127	47	966
1999	454	303	118	24	899
2000	512	358	119	27	1016
2001	505	233	117	13	868
2002	561	284	163	53	1061
2003	545	266	118	49	978
2004	491	200	75	9	775
2005	461	193	125	13	792
2006	483	256	81	22	842
2007	429	218	95	12	754
2008	385	221	98	11	715
2009	432	240	68	14	754
2010	354	260	97	25	736
2011	383	224	83	14	704
2012	421	217	81	13	732
2013	455	196	73	14	738
2014	426	221	64	8	719
2015	476	192	119	15	802
2016	466	164	112	15	757
2017	325	152	100	15	592
2018	319	164	100	16	599

As has been the case since the 2015 stock assessment (Stewart and Martell 2016), all age data used in the stock assessment is aggregated into bins of ages from age-2 to age-25, with age 2 representing a ‘minus’ group including all fish of age 2 and younger, and age 25 representing a ‘plus’ group including all fish age 25 and older. For years prior to 2002 (except the survey ages from 1998 which were re-aged in 2013), surface ages were the standard method, replaced by break-and-bake in recent years. Because surface ages are known to be biased at older ages, the age data are aggregated at a lower ‘plus’ group, age 20+, for all years where this was the primary method.

Other biological and fishery information

There are several other sources of information contributing to the stock assessment models. These include:

1) the time-series of the Pacific Decadal Oscillation (PDO) index
2) the maturity schedule
3) fecundity information
4) weight-at-age
5) length-weight relationship
6) ageing error (bias and imprecision)
7) data based ‘priors’ on bycatch, discard, and recreational selectivity

There have been no significant changes to the treatment of these sources of information since the 2015 stock assessment (Stewart and Martell 2016), and they are updated (where appropriate) and described each year in the annual overview of data sources (Stewart and Webster 2019). For convenience, the treatment of each is briefly summarized in TABLE 8.

Sex-ratio of the commercial landings

A major source of uncertainty in the IPHC’s historical datasets is the sex-ratio of the commercial landings. Because Pacific halibut are legally required to be dressed at sea, port samplers are unable to easily determine the sex of fish at the time of landing. The sensitivity of the stock assessment to the relative selectivity of male and female Pacific halibut has been highlighted since the 2013 analysis (Stewart and Martell 2014a). Through consultation with the Scientific Review Board (SRB), several pilot studies were conducted to explore having fishermen identify the sex and voluntarily mark individual fish at sea (McCarthy 2015). The IPHC ultimately opted to use a genetic test that could be conducted in a cost efficient manner using tissue samples (Drinan et al. 2018). Beginning in 2017, fin clips were collected from all Pacific halibut sampled for length, weight, and age from the commercial fishery landings (Erikson and Kong 2018).

These data are available for this preliminary 2019 stock assessment, and were compiled in an identical manner to the standard fishery age data, but delineating males and females through the weighting and aggregation up to Biological Regions and coastwide. Although not yet published, the data suggest a very high fraction of the commercial landings are female Pacific halibut (82% coastwide), with Biological Regions ranging from 65% female in Region 4B to 92% female in Region 4 (FIGURE 4). The differences among Biological Regions are most pronounced for ages-13 and greater (FIGURE 5). The effects of these new data on the stock assessment results are discussed as part of the bridging analysis described below.

TABLE 8. Summary of other information sources contributing directly to stock assessment input files (Stewart and Webster 2019).

Input	Summary	Key assumptions
Pacific Decadal Oscillation index	Monthly values (http://jisao.washington.edu/pdo/) averaged and compiled into a binary index for each year based on assignment to ‘positive’ and ‘negative’ phases	Only used as a binary indicator rather than annually varying values.
Maturity	Trimmed logistic from Clark and Hare (2006); 50% female maturity at 11.6 years old.	Based on visual assessments, treated as age-based and time-invariant.
Fecundity	Assumed to be proportional to body weight.	Temporal variability only via changes in weight-at-age.
Weight-at-age	Reconstructed from survey and fishery information by Biological Region.	Temporal variability has been similar for female and male Pacific halibut.
Length-weight relationship	Not used directly in the assessment, most of the historical data relies on a constant average length-weight relationship.	Relationship has been shown to differ over space and time (Webster and Erikson 2017)and so may not provide an accurate translation from numbers to weight in some circumstances.
Ageing error	Pacific halibut are relatively easy to age accurately and with a high degree of precision using the break-and-bake method (Clark 2004a, 2004b; Clark and Hare 2006; Piner and Wischnioski 2004). Surface ages are biased and less precise (Stewart 2014).	Multi-decadal comparison suggest that accuracy and precision have not changed appreciably over the entire historical record (Forsberg and Stewart 2015).
Bycatch selectivity prior	Age-distributions are created from weighted and aggregated length frequencies from a variety of sources and age-length keys from trawl surveys.	Due to incomplete sampling, poor data quality in many years, and other uncertainties data are considered unreliable for estimation of recruitment.
Discard selectivity prior	Age-distributions of sub-legal (<32 inch) Pacific Halibut captured by the FISS are used as a proxy for poorly sampled directed commercial fishery discards.	Survey data may not be representative of commercial fishing behavior, but are currently the only source of information on the age range of discarded fish.
Recreational selectivity prior	Weighted age-frequency data from the IPHC Regulatory Area 3A recreational fishery are the only comprehensive source available.	These data may not be representative of all recreational mortality, but provide the best information currently available.

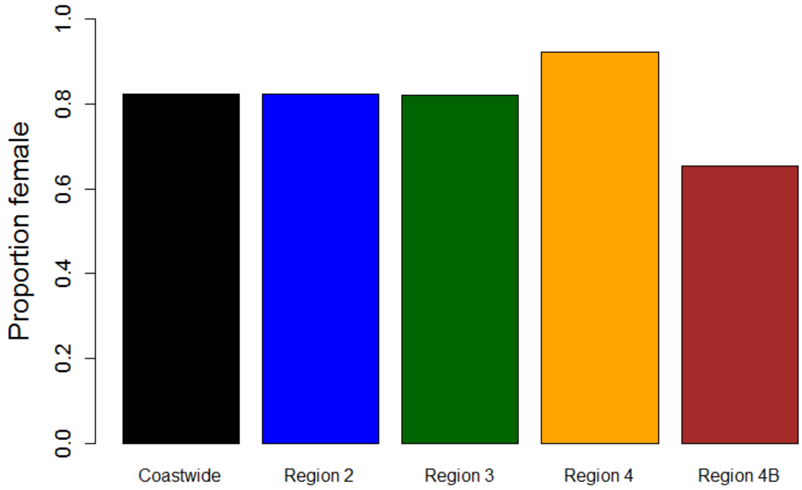


FIGURE 4. Estimates of the proportion female of the commercial landings (numbers of fish) by Biological Region.

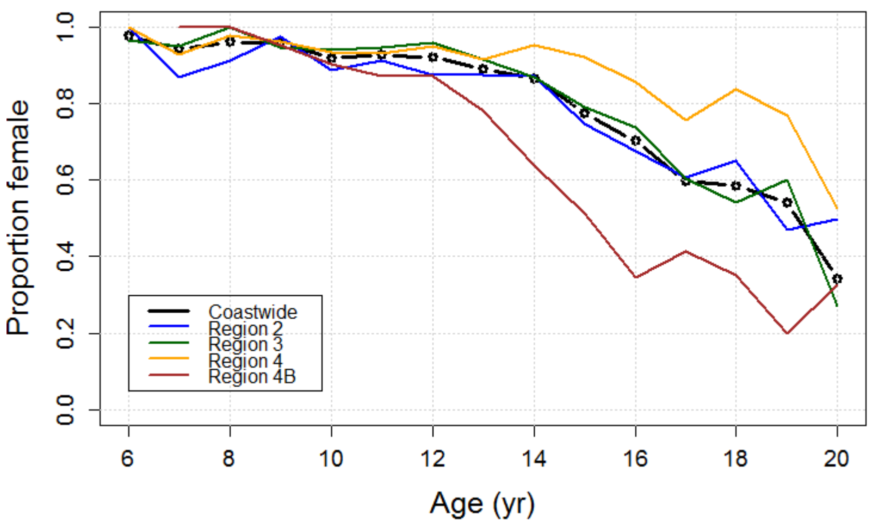


FIGURE 5. Estimates of the proportion of the commercial landings (numbers of fish) by Biological Region and age; data are aggregated at below age-six and above age-20 due to small sample sizes.

Revised Fishery-Independent Setline Survey (FISS) time-series

In 2017, the IPHC Secretariat reviewed historical criteria for determining when a FISS station had experienced whale depredation. Concerns that low levels of depredation and/or cryptic indications of whale activity on the gear might lead to unidentified depredation and therefore negatively biased catch rates led to a revision of the criteria for the 2018 FISS sampling season (Erikson et al. 2019). In order to retroactively apply these criteria to the historical time-series of FISS sampling (Soderlund et al. 2012), specifically including 1993-2017 (the years that are currently included in the space-time model), original field logs and other information had to be retrieved from the IPHC archives and inspected record-by-record. This effort was completed in February, 2019 and provided for this preliminary stock assessment analysis.

The annual station-by-station results, including type of whale interaction and station assignment are publicly available via the IPHCs interactive website (https://www.iphc.int/data/fiss-performance). Briefly, there were only a few geographical areas where enough stations were retroactively assigned as 'ineffective' to make an appreciable change to the modelled time-series. These were largely located in IPHC Regulatory Area 4A, and did not effect the 2018 estimate, because the revised criteria had already been applied to the 2018 data. In IPHC Regulatory Area 4A the variance increased slightly, and the index between 2004 and 2017 increased slightly due to removal of negatively biased catch-rates associated with now identified whale depredation (FIGURE 6). At the scale of Biological Regions and coastwide there was little change in the time-series estimates, and only a very small increase in the variance (FIGURE 7). The effects of these data on the stock assessment results are discussed as part of the bridging analysis described below.

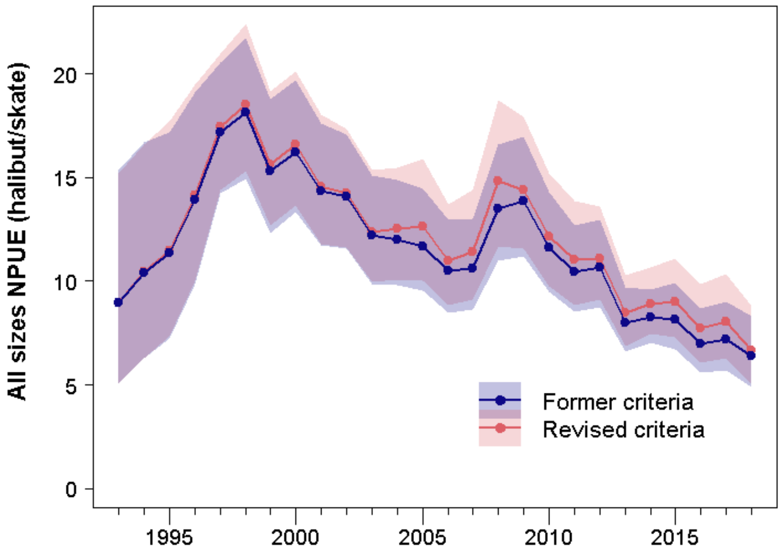


FIGURE 6. Comparison of modelled survey time series for Regulatory Area 4A with the old (former) and new (revised) whale depredation criteria applied to determine station effectiveness.

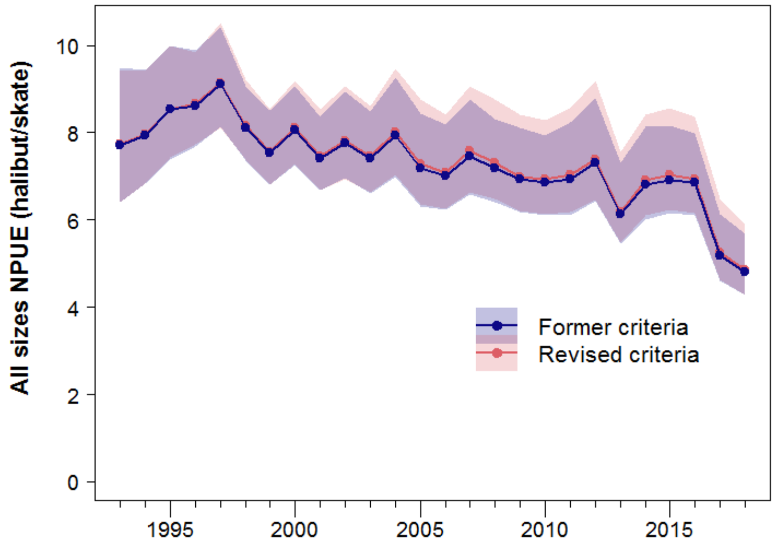


FIGURE 7. Comparison of modelled survey coastwide time series with the old (former) and new (revised) whale depredation criteria applied to determine station effectiveness.

Model development

Multimodel approach

Creating robust, stable, and well-performing stock assessment models for the Pacific halibut stock has proven extremely challenging due to the highly dynamic nature of the biology, distribution, and fisheries (Stewart and Martell 2014b). The stock assessment for Pacific halibut has evolved through many different modeling approaches over the last 30 years (Clark 2003; Clark and Hare 2006). These changes have reflected improvements in fisheries analysis methods, changes in model assumptions, and responses to recurrent retrospective biases and other lack-of-fit metrics (Stewart and Martell 2014b). Perhaps the most influential of these changes was the transition from separate IPHC Regulatory Area-specific assessment models to a coastwide model in 2006, as the understanding of adult movement among areas was substantially updated by the results of the IPHC's extensive PIT-tagging experiment in 2003-2009 (Clark and Hare 2006; Webster et al. 2013). Some simulation studies have found that dividing a migratory population into several discrete assessment units tends to overestimate the total biomass (e.g., Li et al. 2014; McGilliard et al. 2014).

Although recent modelling efforts have created some new alternatives, no single model satisfactorily approximates all aspects of the available data and scientific understanding. Building on simpler approaches in 2012 and 2013, in 2014, the current ensemble of four stock assessment models, representing a two-way cross of short vs. long time series', and aggregated coastwide vs. Areas-As-Fleets (AAF) models was developed for the most recent full assessment analysis and review in 2015 (Stewart and Martell 2016). AAF models are commonly applied when biological or sampling differences among geographical areas make coastwide summary of data sources problematic (Waterhouse et al. 2014). AAF models continue to treat the population dynamics as a single aggregate stock, but fit to each of the spatial datasets individually, allowing for differences in selectivity and catchability of the fishery and survey among regions. In addition, AAF models more easily accommodate temporal and spatial trends in where and how data have been collected, and fishery catches have occurred. This is achieved through explicitly, accounting for missing information in some years, rather than making assumptions to expand incomplete observations to the aggregate coastwide level. Both aggregating the data into a single series and approximating spatial dynamics via AAF approaches may be useful under some circumstances; however, there is no clear best-performing configuration under all conditions. Not surprisingly, models that most closely match the biology, which is only known under simulated conditions, tend to perform the best (Punt et al. 2015).

To capture the structural uncertainty inherent among the Pacific halibut stock assessment models, it is necessary to use multi-model inference, here referred to as an ‘ensemble’ of models (e.g., Ianelli et al. 2016; Karp et al. 2018; Stewart and Martell 2015). The ensemble approach, applied in many fields in addition to fisheries (Du 2014; Hamill et al. 2012), recognizes that there is no “perfect” assessment model, and that a robust risk assessment can be best achieved via the inclusion of multiple models in the estimation of management quantities and the uncertainty about these quantities (Stewart and Martell 2015). This stock assessment is based on the approximate probability distributions derived from an ensemble of models, thereby incorporating the uncertainty within each model as well as the uncertainty among models. This approach reduces potential for abrupt changes in management quantities as improvements and additional data are added to individual models (Stewart and Hicks 2018c), and provides a more realistic perception of uncertainty than any single model, and therefore a stronger basis for risk assessment.

The current ensemble explicitly captures two critically important dimensions of uncertainty: how the time-series data are used via short and long models, and how the spatial information is treated in the models via data aggregation to the level of Biological Regions treated as separate fleets (AAF) or to the coastwide level. Inclusion of these sources of structural uncertainty results in wider confidence intervals than are commonly seen in single-model stock assessments (Stewart and Hicks 2019). More detail on how the models are integrated can be found in the Ensemble section below.

Structural rationale

Consistent with the analyses from 2015-17, this stock assessment is implemented using the generalized software stock synthesis (Methot and Wetzel 2013b), a widely used modeling platform developed at the National Marine Fisheries Service. This platform allows for a wide range of structural choices with regard to biology and growth, catchability, selectivity, spatial processes, stock-recruitment dynamics as well as error distributions and integrated projections. A benefit of using this code is that it is well documented (Methot and Wetzel 2013a; Methot et al. 2019), and the inputs and output formats are standardized, regardless of model configuration, allowing easy interpretation of model files and rapid evaluation of the results without re-running the fitting algorithm using the r4ss package in R (https://cran.r-project.org/).

A primary structural stock assessment model choice is whether or not to model growth explicitly (and often parametrically) or empirically. Many stock assessments assert/estimate a growth function of some type and rely on this growth function to translate between numbers and biomass for model calculations. This approach has the benefit of allowing direct fitting to observed length observations, as well as interpolating and/or extrapolating predictions for years where direct observations may be missing, as well as direct inclusion of the potential effects of selectivity at length on the observed data. The cost of such an approach is that growth can be an extremely complex process, varying over time, space and by cohort (via density dependence). When there is appreciable growth variability, a great deal of complexity may be required to adequately model this population process, even before sampling and selectivity issues have been addressed. Failure to account for this type of variability can lead to poor fits to composition data, potentially biasing the assessment results (Maunder et al. 2015, and subsequent special issue papers).

The Pacific halibut stock assessment models, like many other stock assessments with relatively complete age and size information, take a simpler approach to growth by using empirically derived weights-at-age. The empirical weight-at-age approach has the benefit of reducing complexity with regard to growth modelling, but has several costs in other modelling areas. These include the need for more complexity in modelling selectivity, particularly where some of the selectivity process may be a function of size rather than age alone. This is the case for Pacific halibut, where the interaction of changes in size-at-age, gear selectivity that is likely at least partially a function of fish size, and minimum size limits thus requires the treatment of selectivity-at-age as a time-varying process (Stewart and Martell 2014). However, the treatment of selectivity as time-varying appears to be a necessity for Pacific halibut even if treated as a function of size; static selectivity for a spatially aggregated model in the face of changes in availability was identified as a primary contributor to severe historical retrospective patterns (Stewart and Martell 2014).

There are relatively few examples of stock assessments used for management purposes that are explicitly spatial: modelling movement among areas, distributing recruitment events, and tracking spatial variability in biological characteristics. Most assessments either aggregate the available data across spatial heterogeneity (preferably weighting appropriately such that the aggregate information reflects the underlying distribution), or retain separate data series representing spatial areas, but fit to them in the context of a single instantaneously-mixing population model (the AAF approach). These methods for dealing implicitly with spatial dynamics are by necessity gross approximations, with performance properties that are unknown, and almost certainly depend on the true underlying processes. Simulation studies have shown that fisheries operating in different areas with differing selectivity schedules can be reasonably approximated by an AAF approach (e.g., Waterhouse 2014). Other studies have found acceptable performance of AAFs when simulating actual spatial variability (e.g., Hurtado et al. 2014, McGilliard et al. 2014); however additional studies have found that combining spatial data into weighted-aggregates also performs acceptably, and may be more stable than more complex AAF approaches (Punt et al. 2015, Li et al. 2015). A primary conclusion from simulation-based studies is that if the true underlying process is well-represented, then models reflecting these dynamics tend to perform well (Goethel and Berger 2017). Unfortunately, in the case of Pacific halibut it is not clear whether aggregated or AAF models might be the best choice as neither approach accurately represents the complex spatial dynamics.

The choice of how long a time-series to model generally represents a compromise among: data availability, data quality, model complexity, and technical convenience (e.g., data preparation and model convergence times). As assessment model time series' are extended to include more historical data, commonly the quality of those data becomes increasingly lower as standardization of sampling programs has a greater likelihood of having changed appreciably. In the case of Pacific halibut, fishery-independent survey information has been reasonably comprehensive since approximately 1997, and sufficient to support the recently developed geostatistical model since 1993 (Webster 2018). Current fishery sampling approaches have also not changed dramatically over the same period. The completeness of this time period with regard to data availability was one of the primary incentives for stock assessment models used by the IPHC since 2006 to begin the modelled period in 1996. Notable differences prior to that period included the transition in the survey and fishery from "J" to circle hooks, variable and much less comprehensive survey coverage, lack of access to raw historical fishery data (ages, catch rates, etc.), and many others. The costs of using only a relatively short time-series include a lack of integration between harvest strategy calculations derived from full historical period, a lack of perspective on recent trends, the need for careful treatment of initial model conditions, and increased sensitivity to additional data, as each year represents a greater fraction of the total information available in the model. These trade-offs prompted the development of a long time-series model in 2013, with the recognition that neither the short or long time-series approach was clearly superior, and that differences in the results reflected a meaningful source of uncertainty in the assessment results.

All of the halibut models considered here treat male and female halibut separately. Like many broadcast spawning fishes, there is a basic assumption that spawning is likely to be limited primarily by female spawning output and not by male abundance over a reasonable range of sex-ratios). If the sex-ratio could be expected to be stable over time, it might be reasonable to structure assessment models without regard to sex and/or just assume half of the mature biomass represented females. However, for Pacific halibut, highly dimorphic growth interacting with a fishery in which there are strong incentives to target the larger females (due to the minimum size limit and graduated price structure) results in sex-ratios of the catch skewed largely toward females. Historical modelling suggesting lower natural mortality for males and changing size-at-age all lead to the potential for a static assumption regarding sex-ratio to lead to a highly biased interpretation of stock status unless females and males are modelled separately.

In aggregate, these considerations led to the choice of four stock assessment models during the 2014 assessment process: a two-way cross of: coastwide vs. AAF data structuring, and long vs. short time-series. Each of these models explicitly treated male and female halibut separately and employed empirical weight-at-age rather than an explicit growth function. All models fit to both fishery and survey index trends and age compositions, and allowed for temporal variability in selectivity and catchability. Additional alternative modelling approaches were considered, including a simple surplus production model and a Virtual Population Analysis model. Both of these approaches suggested that recent removals and stock trends were on a similar scale to the four models included in that assessment (Stewart and Martell 2015), but presented sufficiently substantial issues in interpretation or application to the management process that they were not formally included in the final risk-assessment.

General model configuration

There are a number of basic technical settings and features that are common to all four stock assessment models described here. This section provides an overview, which is supplemented by a description of specific individual model details below.

The stock synthesis software separates inputs into several files read in prior to model estimation including the primary data file, the primary control file (including parameter setup and estimation switches), the weight-at-age file, the forecast file (including settings for reference point calculations), and the starter file (including some general estimation and reporting switches and settings). Each of these input files for each of the four stock assessment models described here are included in the background documents, along with the primary report file of estimated and derived quantities and the directory of summary and diagnostic figures created by r4ss (see Appendix A).

These models were configured to make use of relatively standard population structuring. There were no seasonal dynamics, and catches were assumed to be removed halfway through the year via Pope's approximation. This approach does not require estimation of fleet- and year-specific fishing mortality rate parameters, and should reasonably approximate the dynamics unless fishing mortality rates are extremely high. Catches were input in thousands of pounds (net weight; head-off and gutted, approximately 75% of round weight), so that the weight-at-age inputs were in pounds and the numbers-at-age tracked in thousands of individuals. Population dynamics contain ages 0-30, and female and male halibut are tracked separately in the dynamics.

The input data were partitioned via a fleet structure of: the directed fishery (by area in the AAF models), discards from the directed fishery, bycatch, recreational, subsistence, and survey (by area in the AAF models). TABLE 9 summarizes the data and key features of each model. Age data were partitioned by sex (the vectors for each year contain females, then males), where this information was available and assigned the appropriate ageing method in the data file (see section above). Where few fish contribute to the 'tails' of the age distributions for each fleet and year combination, the model was set to automatically aggregate observations and predictions representing proportions less than 0.1%. This choice avoid large vectors of zeroes in the multinomial calculations. The model was also set up to add a very small constant (0.0001) to all age proportions in order to stabilize the computation.

TABLE 9. Comparison of structural assumptions among models.

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Modelled period[1]	1992-2020	1888-2020	1992-2020	1888-2020
Data partitions	N/A	N/A	Regions 2, 3, 4, 4B	Regions 2, 3, 4, 4B
Directed Fishery fleets	1	1	4	4
Other fishing fleets	4	4	4	4
Survey fleets	1	1	4	4
Fishery CPUE (weight)	1992+	1907+	1992+	1907+, 1915+, 1981+, 1981+
Fishery age data years	1992+	1935+	1992+	1935+, 1935+, 1945+, 1991+
Survey CPUE (numbers)	1993+	1977+	1993+, 1993+, 1997+, 1997+	1977+, 1977+, 1997+, 1997+
Survey age data years	1993+	1963+	1993+, 1993+, 1997+, 1997+	1965+, 1963+, 1997+, 1997+
Weight-at-age	Aggregate	Aggregate	Areas 2, 3, 4	Areas 2, 3, 4
Female M	Fixed at 0.15	Estimated	Fixed at 0.15	Estimated
Male M	Estimated	Estimated	Estimated	Estimated
Stock-recruit relationship	B-H	B-H	B-H	B-H
Initial conditions estimated	R_1, *N*-at-age: 1-19	R_0, *N*-at-age: 1-29	R_1, *N*-at-age: 1-19	R_0, *N*-at-age: 1-29
Environmental regime effects on recruitment	No	Estimated	No	Estimated
Steepness (*h*)	0.75	0.75	0.75	0.75
$\sigma_{\text{recruitment deviations}}$	1.0	0.55	0.75	0.5
Survey selectivity	Asymptotic, by sex	Asymptotic, by sex	Domed, by sex (R2, R3) Asymptotic, by sex (R4, R4B)	Domed (R2, R3), Asymptotic (R4, R4B)
Fishery selectivity	Asymptotic, by sex	Asymptotic, by sex	Domed, by sex (R2, R3) Asymptotic, by sex (R4, R4B)	Domed, by sex (R2, R3) Asymptotic, by sex (R4, R4B)
Scale of male fishery selectivity	Estimated, time-varying	Estimated	Estimated	Estimated
Bycatch selectivity	Domed	Asymptotic	Domed	Domed
Recreational selectivity	Domed	Domed	Domed	Domed
Discard selectivity	Domed, by sex	Domed, by sex	Domed, by sex	Domed, by sex
Personal use selectivity	Mirrored to recreational	Mirrored to recreational	Mirrored to recreational	Mirrored to recreational

[1]Mortality estimates for 2020 were projected based on adopted IPHC limits.

All growth specifications in the control file were bypassed in order to use the empirical weight-at-age approach; therefore the settings in the control file and the results included in model outputs related to these settings are not meaningful (this includes length-at-age, weight-at-length, and maturity-at-length; these are all integrated directly in the weight-at-age inputs). The weight-at-age file also included a matrix of spawning output-at-age representing the product of annual weight-at-age (a matrix) and the static vector of maturity-at-age (Stewart and Webster 2019).

For all estimated parameters (except temporal deviations), uniform priors were implemented, with bounds sufficiently wide to avoid maximum likelihood estimates falling on or very near a bound, unless the bound was structurally logical. TABLE 10 summarizes the counts of estimated parameters in each model. Natural mortality was allowed to differ by sex, with the value for male halibut estimated in all four models, and the value for females in the two long time-series models. Treatment of both the stock-recruitment relationship and the initial conditions at the start of the modelled time-series differed among the four models and are described below.

The double-normal selectivity parameterization is used in all four models, as it represents a flexible, but still parametric approach that can easily be made time-varying via just one or two parameters with annual deviations. There are more flexible nonparametric selectivity options, but these generally require all the parameters to vary over time, creating a substantial increase in complexity. The double-normal selectivity can be easily configured to be either asymptotic or dome-shaped, by adjusting the width of the peak and/or descending slope and final selectivity parameters. It also includes an option for male selectivity to be offset from female selectivity, based directly on the parameters of the selectivity curve (females from males), such that time-varying selectivity for one sex can be mapped into variability for both sexes without estimating a second set of parameters. The double-normal was implemented for all model fleets, with at least the ascending limb of selectivity (ascending width and peak parameters) allowed to vary over time for all four models (described further below).

As has been the case in all recent halibut models, the catch-per-unit-effort index derived from the directed halibut fishery is included in each of the models, but the catchability is allowed to vary over time, except in a few cases where there was no improvement in model fit by allowing temporal variability. In principle, there are many factors which can create changes in the proportionality of the catch-rate in a fishery with the underlying population. The most obvious of these are abrupt changes in fishing methods, such as the change from “J” to circle-hooks in 1984. This type of change was accommodated (in the long time-series models) via an unconstrained deviation on catchability in that year (effectively a separate q for the two parts of the time series). Beyond abrupt changes, there are many factors that can ‘drift’ over time, but may not be so obvious, including technological improvements, changes in spatial areas or times of year being fished, etc. This type of change suggests a random walk in catchability, which was the approach taken in all four models here. To implement this, a catchability parameter was estimated for the first year for which index data were available, and then a deviation (from the previous year’s value, not the mean) was estimated for each subsequent year of the time-series. The annual deviations were constrained by a single σ for each fleet. The iterative tuning algorithm for identifying the internally consistent values for each σ is described below along with other changes for 2019.

TABLE 10. Comparison of estimated parameter counts among models.

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Static				
Female M	--	1	--	1
Male M	1	1	1	1
Log(R_0)	1	1	1	1
Initial R_0 offset	1	--	1	--
Environmental link coefficient	--	1	--	1
Fishery catchability	1	1	4	4
Survey catchability	1	4	--	4
Fishery selectivity	5	5	20	18
Discard selectivity	6	7	5	6
Bycatch selectivity	4	2	4	3
Recreational selectivity	4	3	3	4
Survey selectivity	5	5	21	18
Total static	29	31	60	61
Time-varying				
Recruitment deviations[1]	51	165	51	165
Fishery catchability deviations	--	108	52	212
Fishery selectivity deviations	76	166	208	532
Survey selectivity deviations	75	84	182	236
Total deviations	202	523	493	1,145
Total	231	554	553	1,206

[1]Includes initial age structure and four forecast years (the latter only included here such that counts will match model output).

In all models, fit to the age data used a multinomial likelihood with initial input sample sizes representing the number of fishery trips or survey stations contributing to that observation, subsequently adjusted down via a multiplicative scalar for each fleet in the control file (more discussion below). Indices of abundance from both the setline survey and commercial fishery (by area in the AAF models) were fit using a log-normal likelihood and input log(*SE*)s. Survey indices were fit in numbers of fish to avoid converting numbers to weights in the data and then weights back to numbers in the model predictions (as recommended by the Scientific Review Board in 2014). Weight-per-unit-effort is the native scale for the fishery indices.

As developed for the 2015 assessment, discard mortality, bycatch and recreational selectivity are estimated, but the age composition data are downweighted to avoid imparting any significant information on recruitment strengths from these uncertain and likely non-representative data sets. Discards in the directed commercial fishery are treated as a separate fleet in each model. This approach was taken for several reasons: discard rates may be a function of spatial fishing effort and not simply contact selectivity as is often assumed to be the case, and there has been little relationship between the magnitude of discards and the magnitude of commercial landings when this has been evaluated for previous reviews. Sex-specific selectivity curves were estimated in each model informed by the observations from the sublegal fish captured by the setline survey. The selectivity was configured to be a double normal, with female halibut offset from male halibut to account for the dimorphic growth (the opposite of all other fleets), and the relative scale of females to males estimated directly. Both sexes were allowed to be dome-shaped, with differing descending limbs. Because the sublegal survey age data were already included in the likelihood as part of the survey age compositions, it would be a misrepresentation of the uncertainty to naively fit them again equally as part of the discard data set. Instead, previous analyses showed that down-weighting these data such that they had a very small input sample size had no appreciable effect on the model results but still allowed for the direct estimation of selectivity. This approach propagates uncertainty in the estimated selectivity, and lends itself to direct inclusion of observer data on discarded halibut when it becomes available.

Bycatch and recreational selectivity curves were also allowed to be dome-shaped given the relative frequency of younger halibut in the observed distributions. Where descending limb parameters were estimated to be at the upper bounds, these parameters were fixed (making the curves asymptotic) to avoid any negative behavior during minimization and approximation of the variance in model quantities via the Hessian matrix. Because of the down-weighting of the data for these series, and the unknown or potentially poorly spatially representative nature of the data themselves, no attempt was made to allow these selectivity curves to vary over time.

The presence of both observation error (in the indices and age composition data) and process error (in fishery catchability and selectivity for the survey and fishery) creates a challenge for standard weighting and tuning practices employed in many assessment models. Specifically, if process error is not modelled (and/or a fixed value is asserted), the input sample sizes (and sometimes index variances) can be relatively easily iteratively tuned or estimated (Maunder 2011). This approach is useful for reducing the potential effects of outliers, lack-of-fit, or model misspecification with regard to composition data (Francis 2011). At the other extreme, if the observation error is assumed to be known (and assigned a fixed value), then the degree process error can be estimated via random effects, or iteratively tuned using a maximum likelihood-based approximation (the ‘Thompson and Lauth method’; Annex 2.1.1 in Thompson and Lauth 2012). Recent work has shown that under some circumstances both components can be iteratively (or by other more statistically rigorous means) estimated simultaneously (Thorson 2018; Thorson et al. 2016).

The general goal for the treatment of process error in selectivity and catchability and observation error in the data is to first reduce clear signs of bias to the degree possible and then to achieve internal consistency among error distributions and sample sizes/variances. In all four models developed here, the initial input sample sizes, derived from the number of survey sets and fishery trips (and not the number of individual fish measured, which would be much larger), were considerably larger than commonly applied weighting for stock assessment models would suggest (TABLE 5-7). These values were iteratively reduced based on evaluation of three considerations: the relative magnitude of the standardized residuals, comparison of the input value for each fleet with the harmonic mean effective sample size which is an unbiased estimator for a set of independent multinomial samples (Stewart and Hamel 2014), and the scaling suggested by the Francis (2011) method (as implemented in the r4ss package). For almost all fleets and all models, this approach led to a substantial reduction from initial sample sizes. In no cases were the input values increased from those derived from the number of trips or stations represented in the data.

Starting from a small value for the input σ for each fleet and parameter combination where temporal variability was allowed, process error was increased until the tuned value was consistent with the degree of variability observed among the deviations (SE_{devs}^2) and the average uncertainty of the deviations themselves $\bar{\sigma}_{dev}{}^2$. This approach is very close to that outlined by Thompson and Lauth (2012) and is consistent with the preferred method for tuning this and other types of process error (such as recruitment deviations) in stock synthesis (Methot and Taylor 2011; Methot et al. 2019):

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

In addition to providing internal consistency, this approach makes intuitive sense: under perfect information the average variance of the deviations will be zero and the variability among the deviations will exactly match the process error, conversely under no information the variance of the deviations will be the input constraint. After initial process error tuning input sample sizes were adjusted downward until the weights suggested by the fit to the mean age over the time series were approximately equivalent to the input values (the “Francis method’; Francis 2011). There were only minor changes to the tuned σ values required after iteration of the input sample sizes, suggesting the two processes were relatively separable and stable, and an improvement on the similar but simpler approach employed in the 2015 stock assessment.

As a final model-building step, models were regularized via adjusting parameterizations through removing and/or fixing parameters that consistently remain stuck to bounds or are not contributing to the likelihood in a meaningful way (<1% correlation with other model parameters). This does not include forecast recruitment deviations, which are expected to be uncorrelated with other model parameters (and the objective function), but are ‘estimated’ in order to appropriately propagate the uncertainty in recent recruitments into forecasts.

The tuning approach for the stock-recruitment relationship was very similar, ensuring that the input σ governing recruitment variability was consistent with the observed variability and variance estimates; the automated calculation for this is automated in the r4ss package and does not require external calculations. The output of that calculation was used as a guide for the scale of the bias correction, including ramps to and from the peak value consistent with the information content of the data and variability in the deviations observed in the output. This step is important for recruitment variability as it also provides for a better approximation for the bias correction in recruitment deviations (Methot and Taylor 2011) in the ‘main’ or best informed period of the time-series of recruitments. Again here, after initial tuning, little change was observed across alternative models, except where the central tendency of the stock-recruitment relationship was changed (e.g., sensitivity analyses estimating steepness).

In the end, this tuning process provides a model that is internally consistent: the error distributions are commensurate with the fit to the data and the degree of process error is consistent with the signal (information content) in the data. Importantly, accounting for process error in selectivity was the primary solution for historically observed retrospective patterns in the Pacific halibut stock assessment models (Stewart and Martell 2014b). Tuning diagnostics and results specific to each model are provided below.

In order to provide for direct transparent comparisons from this preliminary stock assessment through the final results for 2019, the initial step in this analysis was to extend the modelled time-series to 2020, using the projected mortality associated with the limits set by the IPHC for 2019 (IPHC 2019). Weight-at-age was assumed to remain constant from 2018 to 2019 (it will be updated when new data become available) and no other information was needed for this single year projection.

Coastwide short

The initial conditions for a model starting after an extensive historical fishery and appreciable recruitment variability must be structured to avoid simple assumptions that may have strong effects on the subsequent time-series. For the coastwide short model the initial conditions included estimating the population numbers at age 1-19 in the first year of the model (1992 after extension of the time-series; see below). Since the age data available for the initial year were aggregated at age-20 (due to the historical use of the surface ageing method), there was no specific information on additional individual year-classes. To accommodate a non-equilibrium value in the plus group, an offset to initial equilibrium recruitment (via a single time 'block') was also estimated. The effect of these two approaches was to essentially decouple the numbers-at-age at the beginning of the time-series from any equilibrium assumptions.

The coastwide short model employed a Beverton-Holt stock recruitment relationship (a change from 2015, as described below) with estimated equilibrium recruitment level (R_0) setting the scale of the stock-recruit relationship. Steepness (*h*) was fixed at a value of 0.75 for this and all other models (see sensitivity analyses). Fixing steepness, but iteratively solving for the internally consistent level of recruitment variability generally does not have a large effect on year-class strengths where data are informative, but does have very strong effects on estimates of Maximum Sustainable Yield (Mangel et al. 2013); however, this quantity is not of specific interest for the Pacific halibut assessment. A summary of the number of estimated parameters contributing to each aspect of the model is provided in TABLE 10.

Age-based selectivity for female halibut in both the setline survey and commercial fishery was estimated using the double normal, forced to be asymptotic once it reached peak selectivity. This required two parameters: the ascending width of the curve and the age at which the peak selectivity is reached. Both parameters are allowed to vary over time with a random walk of annual deviations. These deviations were initiated in the first year for which age composition data were available, and no deviation was estimated for the terminal year (2019), because there were no data yet in the model. This means that the actual mortality in 2019 may have a different effect on the projections when updated from projections and removed via an informed selectivity schedule in the final assessment. Male selectivity for the survey was estimated via offsets to the female ascending width and peak parameters, and a third parameter defining the scale of male selectivity relative to that for females. In the coastwide short model, with fixed female natural mortality and direct overlap between all years of fishery and survey age data, the male offset parameters for the fishery have been estimated in recent assessments. These parameters have been informed by the weak information on sex-ratio included the sex-aggregated age data. In aggregate, there were five estimated base parameters each for the survey and fishery and annual deviations on the ascending limb parameters (TABLE 10).

As in the 2015 assessment, the scale of male selectivity for both the survey and fishery were allowed to vary over time as a random walk. With only sex-aggregated commercial fishery age compositions (except in 2017; see below), it is not clear how strongly the temporal variability in the scale of male selectivity is informed (and potentially how correlated it would be with female natural mortality, which is fixed in this model). However, the addition of time-varying deviations on the scale parameters was found to improve the residual patterns in the fit to the fishery age-data, and did not show signs of erratic estimation over sensitivity and alternative model runs.

Coastwide long

Initial conditions for the coastwide long time-series model were represented simply as the equilibrium stock condition, as the model period began well before (1888) the first age data were available (1935), and therefore there was a substantial ‘burn in’ for recruitment variability. The treatment of the stock-recruitment function in the coastwide long model was substantially different from that of the coastwide short model. Consistent with historical IPHC analyses (Clark and Hare 2002a, 2006), the coastwide long model allowed for the possibility that recruitment variability is correlated with the regimes of the Pacific Decadal Oscillation (PDO). To implement this approach, a Beverton-Holt relationship was used, parameterized with an estimated value for the equilibrium recruitment level (R_0) parameter, and a fixed value of steepness (h) of 0.75. The annual average of the PDO index was converted to a binary indicator (PDO_{regime}) where productive regimes (e.g., 1977-2006) were assigned a value of 1.0, and poor regimes a value of 0.0. These regimes were linked to the scale of the stock-recruit function via an adjusted equilibrium level of recruits (R_0’) based on an estimated coefficient (β) creating an offset to the unadjusted value:

$$R_0{}' = R_0 * e^{\beta * PDO_{regime}}$$

The adjusted equilibrium recruitment value was then used in the stock-recruit function with bias-corrected annual deviations:

$$R_y = f\left(SB_y, R_0{}', SB_0, h\right) * e^{r_y - \frac{\sigma^2}{2}}$$

Although the specific parameterization changed in the newest version of stock synthesis (Methot et al. 2019), it was possible to configure the control file to achieve an algebraically identical approach to that used since 2015. This parameterization allows for the β parameter to be estimated at a value of 0.0 if there is no correlation between the putative environmental index and underlying mean recruitment; in that case R_0' is simply equal to R_0. As was the case for the coastwide short time-series model, fixing steepness precludes the naïve use of *MSY* estimates.

The approach to selectivity in the coastwide long model was identical to that in the coastwide short model, except that the scale of male selectivity was only estimable after adding the sex-ratio information from 2017 (see below) and was highly unstable when those data were removed (consistent with the 2015 assessment results). Therefore, no attempt was made at present to allow this parameter to vary over time. Selectivity deviations on the ascending limb parameters of the fishery and survey series were initiated in the first year for which age composition data were available for both the fishery (1935) and the survey (1963).

AAF short
The AAF short model was configured very similarly to the coastwide short model. The most notable difference was in the treatment of selectivity for the survey and fishery in Regions 2 and 3: these were allowed to be dome-shaped relative to the coastwide population dynamics. Implementing dome-shaped selectivity for these four model fleets requires the addition of a third selectivity parameter defining the width of the descending limb. This additional parameter was not allowed to vary over time, although this could be investigated in future modelling efforts.

The second difference between the short time-series models was in the treatment of the scale of male selectivity for the fishing fleets in each of the four areas. Similar to the coastwide long model, the three parameters defining the male offset to female selectivity for the commercial fishery in each area were only estimable after the addition of the 2017 sex-ratio data. Temporal variability in selectivity parameters occurred over a slightly longer range of years in the AAF short model, as there were Region-specific survey data available for the entire time-series from Regions 2 and 3.

AAF long
The only structural differences between the AAF long and AAF short models were the years over which deviations in recruitment, selectivity and catchability are estimated. The AAF long model treated the stock-recruitment function in the same manner as the coastwide long model, including the PDO as an estimated covariate to equilibrium recruitment.

Convergence criteria
Over the past four years, hundreds of alternative model runs for these four model configurations have been evaluated for evidence of lack of convergence. Tools employed have included monitoring of the maximum gradient component, alternative phasing and initial values (including the use of overdispersed starting points – 'jitter analyses') as well as likelihood profiles, and a limited amount of Bayesian integration (see section below).

For this preliminary 2019 assessment, all individual models all had a maximum gradient component < 0.003. A series of preliminary and intermediate runs did not indicate any signs that the estimates reported here represented a local minima, nor did the models have difficulty converging and producing a positive definite Hessian matrix under the broad range of alternative and sensitivity analyses (some presented in this document, but many used only for development).

Wherever parameters were hitting bounds either the bounds were adjusted (if biologically plausible) or the parameters were fixed. For example, the descending limb of the 4B commercial fishery (where there were a high fraction of males in 2017 and presumably throughout the time series) was estimated to be at the bound of 1.0, and so was fixed at this value. This approach reduces the likelihood that variances calculations will be (undesirably) effected by parameters stuck to bounds, but does require periodic revisitation to ensure that the signal for parameters hitting bounds remains, and that fixing those parameters does not have an appreciable effect on the maximum likelihood solution.

Changes from 2018

In the intervening period between the last full stock assessment analysis and review (conducted in 2015) and this preliminary analysis for 2019 a number of important data sources have been changed or added. These changes have been documented and their effects evaluated singly in each year (Stewart and Hicks 2018a, 2019; Stewart and Hicks 2017); however, the cumulative effects on data weighting, parameter estimability, and the tuning of process error in selectivity and recruitment variation has not been fully evaluated. Key changes to the data sources since the full assessment in 2015 include:

- A 44% increase in the number of years of FISS index observations from 1997-2014 to 1993-2018, including the addition of newly collected data and the extension of the time series to include 1993+ in 2017.
- FISS expansions in 2015-2018 supplementing historical gaps in sampling with an effect on both the time-series values and uncertainty.
- Addition of age data from non-standard FISS stations not previously included (2017).
- Design- to space-time model-based survey time series, with changes in the values and uncertainty (generally reduced).
- Use of measured commercial fishery individual fish weights instead of predictions from the length-weight relationship L-W predictions beginning with the 2015 data.

These changes, in tandem with the specific changes described below, result in changes to estimates for a number of model parameters, and the relative tuning of sample sizes and process error variances. These results are described sequentially below, via the ‘bridging’ analysis.

Software version update

Prior to 2019, this stock assessment has used stock synthesis version 3.24 (Methot 2015; Methot and Wetzel 2013b). For 2019, all of the features used in the Pacific halibut stock assessment models have been implemented in stock synthesis version 3.30.13 (Methot et al. 2019). Although some options have been reparameterized (e.g., the treatment of initial model conditions relative to the stock-recruitment curve), in all cases near perfect back-compatibility was retained. The estimated spawning biomass time series and uncertainty intervals for the coastwide and AAF short models were essentially unchanged after updating all of the input files and parameterizations (FIGURE 8). The two long time-series models differed slightly, mainly in the initial conditions, likely as a function of recoding those calculations in the newest version (FIGURE 9). The results from the updated software version were separated from the rest of the bridging analysis to more easily identify these minor differences; all subsequent comparisons were made using the version 3.30 results.

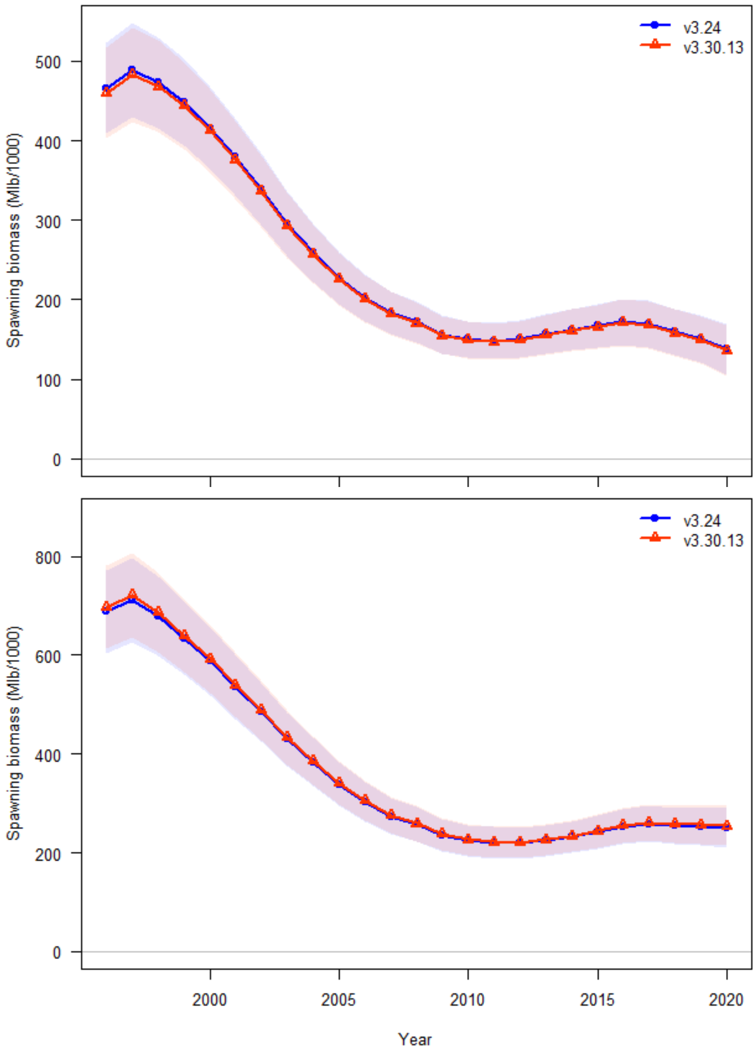


FIGURE 8. Comparison of estimated biomass time series for the coastwide (upper panel) and Areas-as-fleets (lower panel) short models before and after updating to the newest version of stock synthesis.

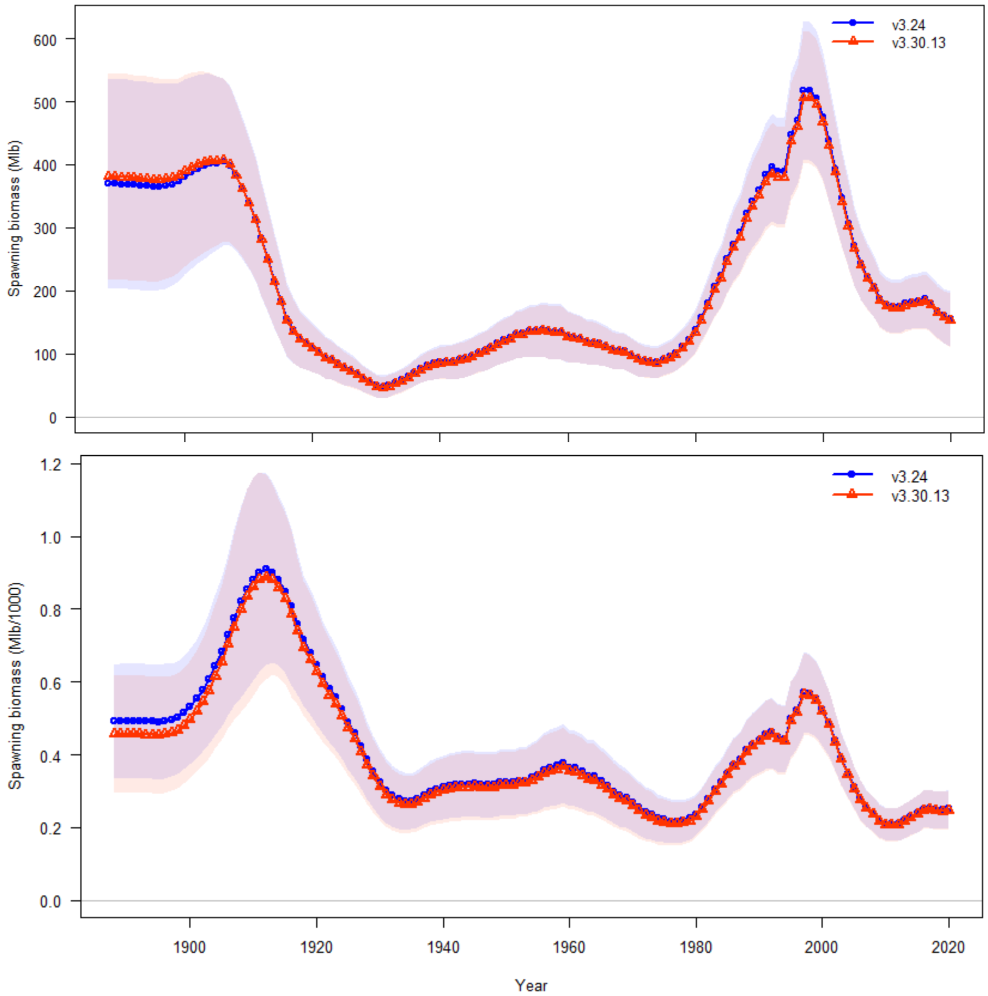


FIGURE 9. Comparison of estimated biomass time series for the coastwide (upper panel) and Areas-as-fleets (lower panel) long models before and after updating to the newest version of stock synthesis.

Updated data sources

There were four steps taken to update from the 2018 stock assessment (implemented in the newest version of stock synthesis) to the preliminary results for 2019:

1) Add the newly available sex-ratio data from the 2017 commercial fishery landings and estimate male selectivity scale parameters.
2) Extend the time series (for the two short models) from 1996 to 1992 and add a stock-recruitment function to these models.
3) Replace the modelled FISS time-series with the series corrected for whale depredation.
4) Regularize and tune each model to be reliable and internally consistent given all the changes that had been made.

The results of each of these steps is reported sequentially for each of the four stock assessment models.

Adding the sex-ratio data to the coastwide short model had no appreciable effect on the trend, but changed the scale slightly, estimating a somewhat larger spawning biomass throughout the modelled period (FIGURE 10). Extending the time-series to include the entire time series of available modelled FISS data and adding a stock-recruitment relationship also increased the spawning biomass estimates slightly and steepened the downward trend over the last several years. The new data also substantially increased the level of recruitment estimated for 1995 and 1994. The modelled FISS time-series including stricter criteria for whale depredation had no visible effect on the results of the short coastwide model. Regularizing and tuning the final configuration including all of the new data also had very little effect on the results.

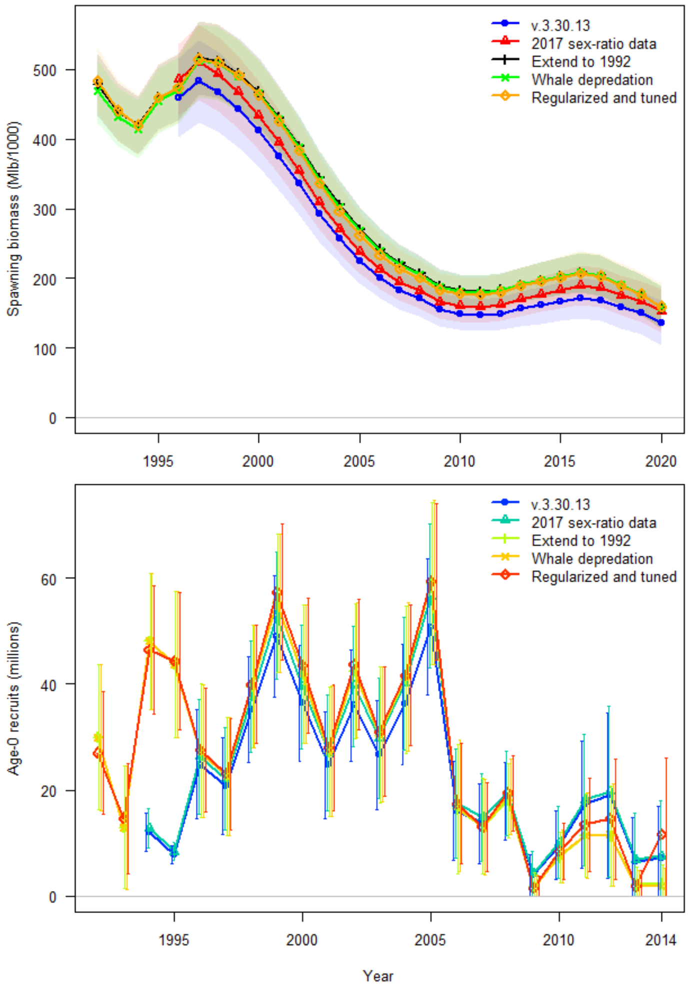


FIGURE 10. Comparison of estimated biomass (upper panel) and recruitment time series (lower panel) over sequential changes from the 2018 to preliminary 2019 coastwide short models.

Adding the sex-ratio data to the coastwide long model and estimating the scale of the male selectivity (rather than assigning the value estimated for the survey as was done in previous assessments) had little effect on the recent spawning biomass trend (FIGURE 11). However, it did increase the scale of the estimated spawning biomass over most of the time-series, as it suggested fewer male halibut in the commercial landings than in the survey (and therefore previously assumed). The modelled FISS time-series including stricter criteria for whale depredation again had no visible effect on the results of the long coastwide model. Regularizing and tuning the final configuration including all of the new data also increased the scale of the spawning biomass at the end of the time series, and had small but variable effects on the rest of the results.

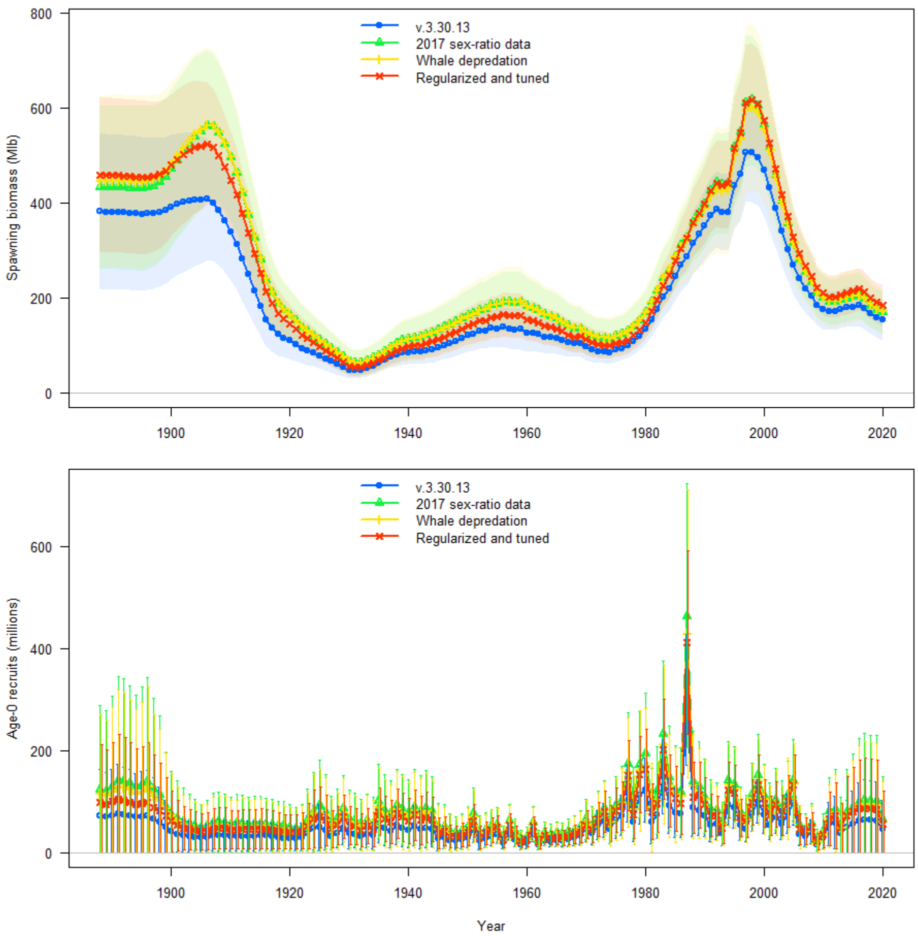


FIGURE 11. Comparison of estimated biomass (upper panel) and recruitment time series (lower panel) over sequential changes from the 2018 to preliminary 2019 coastwide long models.

Adding the sex-ratio data to the AAF short model and estimating the scale of the male selectivity for each Region (rather than assigning the values estimated for the survey in each Region) again increased the scale of the estimated spawning biomass substantially, suggesting fewer male halibut in the commercial landings than in the survey (FIGURE 12). Extending the time-series increased the scale of the spawning biomass estimates at the end of the modelled period, and adjusted upward the 1994-1995 year-class strengths. As in the other models, the modelled FISS time-series including stricter criteria for whale depredation again had no visible effect on the results of the short AAF model. Regularizing and tuning the final configuration including all of the new data produced a noticeably flatter trend at the end of the modelled period.

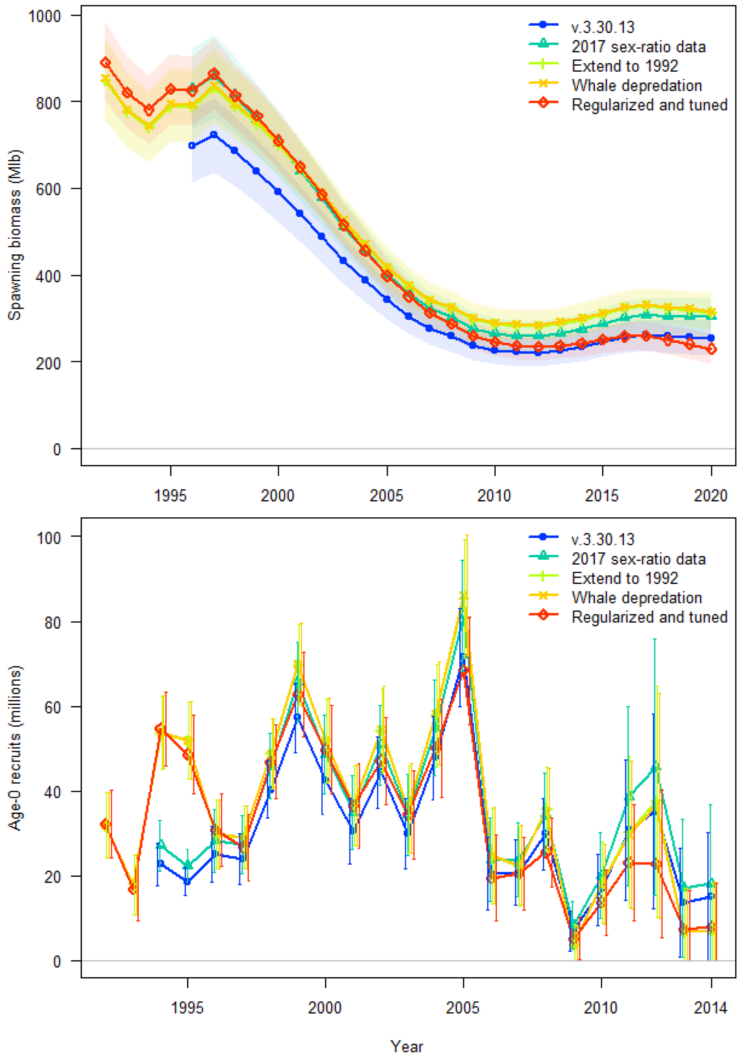


FIGURE 12. Comparison of estimated biomass (upper panel) and recruitment time series (lower panel) over sequential changes from the 2018 to preliminary 2019 AAF short models.

Adding the sex-ratio data to the AAF long model and estimating the scale of the male selectivity for each Region (rather than assigning the values estimated for the survey in each Region) again increased the scale of the estimated spawning biomass substantially, suggesting fewer male halibut in the commercial landings than in the survey (FIGURE 13). A very large peak in the historical recruitment series, prior to the information content of the age data (beginning in 1935) appeared in this model where the 2018 assessment had estimated a short period of higher recruitment rather than a single large annual deviation. Again for the AAF long model, the modelled FISS time-series including stricter criteria for whale depredation had no visible effect on the results. Regularizing and tuning the final configuration including all of the new data revised the historical trends substantially, decreasing historical stock sizes before about 1960 (and eliminating the single large recruitment that appeared in the first bridging model) and increasing stock sizes from 1960through the mid-2000s. Despite these changes, the scale and trend at the very end of the time-series was similar to that from the 2018 stock assessment.

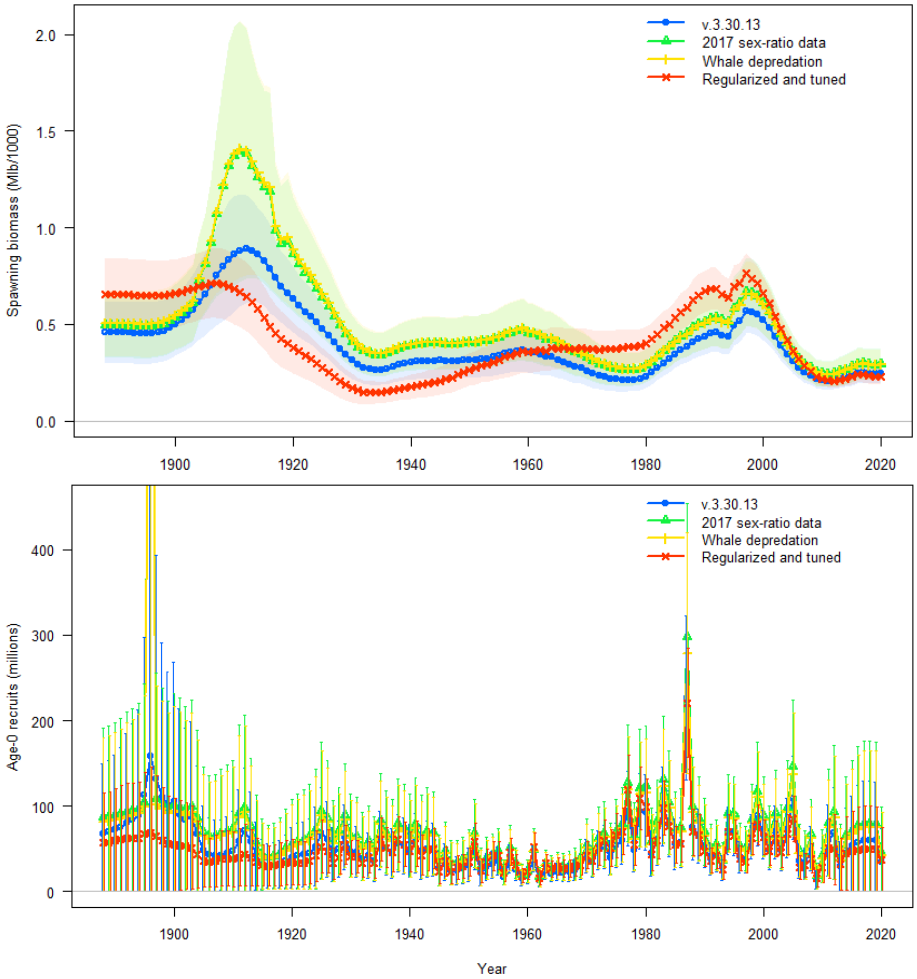


FIGURE 13. Comparison of estimated biomass (upper panel) and recruitment time series (lower panel) over sequential changes from the 2018 to preliminary 2019 AAF long models.

Overall, the inclusion of sex-ratio data resulted in higher spawning biomass for all models, and the updated whale depredation data made little difference. Extending the time-series back in the short models resulted in higher estimates of recruitment for 1994 and 1995. Regularizing and tuning the series had different effects on each model.

Individual model diagnostics and results

This section provides more detail on the specific diagnostics and results of each of the four assessment models. It is not intended to report the fit and residuals to every data component, but to summarize the basic performance of the model and specifically highlight areas of deficiency. Figures showing comprehensive diagnostics and results and the full report files, as output directly from stock synthesis, are provided electronically as described in Appendix A. Each model section finishes with a brief summary of the pros and cons of each model.

Coastwide short

Predictions of both the fishery and survey indices of abundance fit the observed data very well in the coastwide short model (FIGURE 14). In the 2018 assessment, a small amount of process error was allowed on fishery catchability. In this preliminary assessment, the iterative tuning of the annual deviations suggested it as no longer needed, and was therefore removed from the model. The predicted aggregate age distributions also matched the observed distributions quite well, for both the fishery and survey indicating that the selectivity approach was generally capturing differences in both the age-structure (and sex-ratio for the survey; FIGURE 15). The 2017 sex-ratio specific commercial data were not tuned separately from the remainder of the data, and it the model did not fit this information as closely as the rest of the series. Some lack of fit was also evident in the aggregate age composition data for the discard fleet; due to the downweighting of these data, several parameters were highly correlated and were fixed in the final model. Average input sample size by fleet (after adjustments) was substantially below the harmonic mean effective sample sizes for both the survey and fishery and the fishery data were weighted relatively less to achieve consistency with Francis weights (TABLE 11) which likely contributed to the very tight fit to the index time-series.

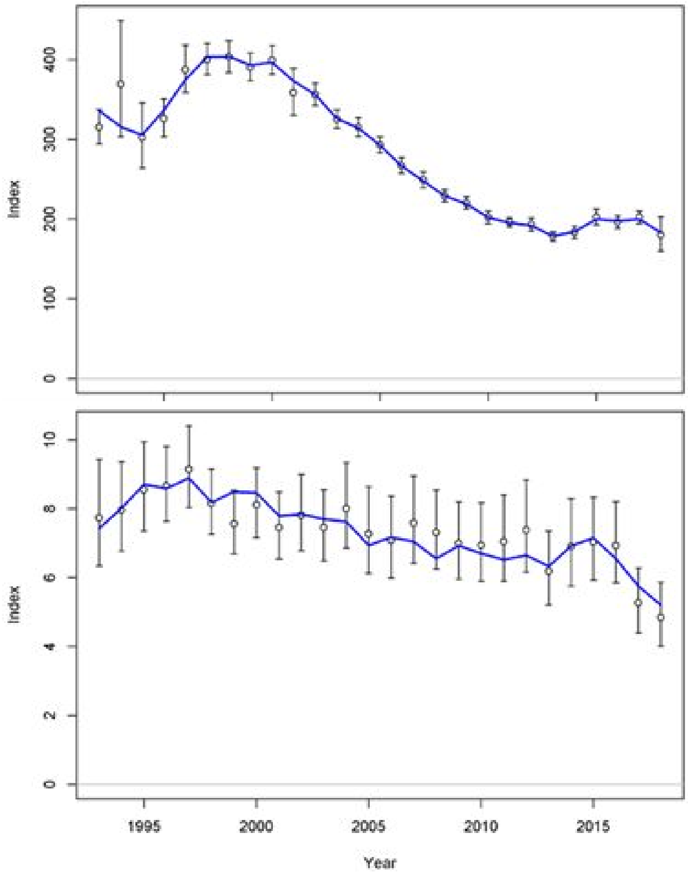


FIGURE 14. Fit to fishery (upper panel) and survey (lower panel) indices of abundance in the coastwide short model; note that the scale of the y-axes differ appreciably.

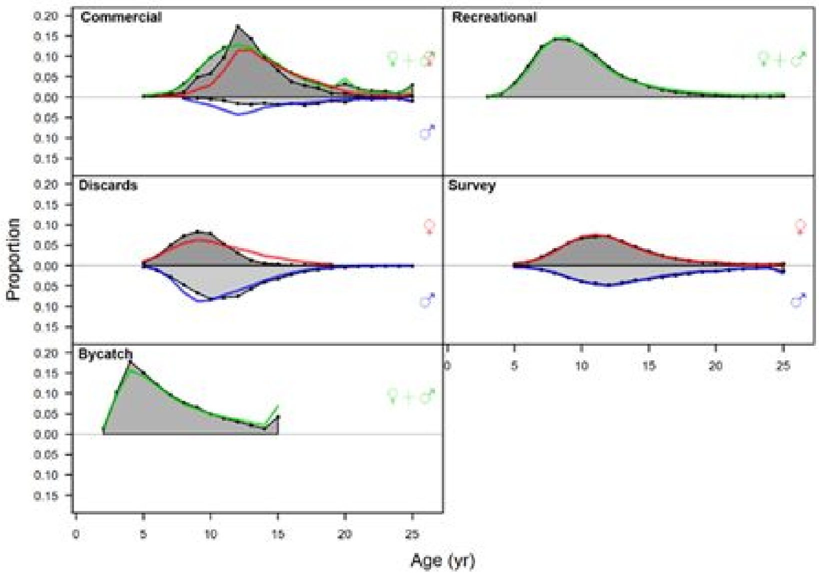


FIGURE 15. Aggregate fit to all age data by model fleet in the coastwide short model; sex-specific distributions for the commercial fishery represent only 2017.

Fit to the annual setline survey age compositions were good (FIGURE 16), although some patterning was visible in the standardized residuals (FIGURE 17). Specifically, there was a pattern of negative residuals in the plus group for male halibut; however, this was almost imperceptible in the fits themselves. The fits to the annual fishery data were also acceptable (FIGURE 18). Additional diagnostics and diagnostic figures (such as fits to the down-weighted annual compositions for the discard, bycatch, and recreational fleets) are included in the in the background materials.

TABLE 11. Post-iteration sample size diagnostics for age-composition data by model and fleet.

	Average iterated input	Harmonic mean effective	Francis weight samples	Maximum Pearson residual
Coastwide short				
Fishery	37	244	37	1.58
Discards[1]	9	126	79	0.89
Bycatch[1]	5	56	49	1.65
Sport[1]	5	109	35	0.93
Survey	372	724	372	2.48
Coastwide long				
Fishery	140	391	148	4.15
Discards[1]	6	234	118	0.58
Bycatch[1]	2.5	37	5	1.38
Sport[1]	2.5	118	23	0.72
Survey	125	196	125	3.81
AAF short				
Region 2 Fishery[2]	136	591	218	3.97
Region 3 Fishery[2]	127	570	229	2.20
Region 4 Fishery	40	64	40	3.80
Region 4B Fishery[2]	23	114	55	1.69
Discards[1]	6	216	134	0.73
Bycatch[1]	5	51	65	1.10
Sport[1]	5	117	27	0.70
Region 2 Survey	185	411	187	1.14
Region 3 Survey	240	575	235	1.93
Region 4 Survey	87	195	90	2.98
Region 4B Survey	40	188	40	1.34
AAF long				
Region 2 Fishery[2]	270	347	513	3.72
Region 3 Fishery[2]	167	347	334	3.76
Region 4 Fishery	30	61	30	5.28
Region 4B Fishery[2]	22	104	57	1.81
Discards[1]	6	222	95	3.82
Bycatch[1]	2.5	45	7	1.26
Sport[1]	5	132	24	0.68
Region 2 Survey	9	101	9	1.30
Region 3 Survey	43	154	43	1.85
Region 4 Survey	82	198	87	3.45
Region 4B Survey	40	192	42	1.56

[1]Inputs downweighted, and not iteratively reweighted – see text.
[2]Sample size equal to maximum (input based on number of samples).

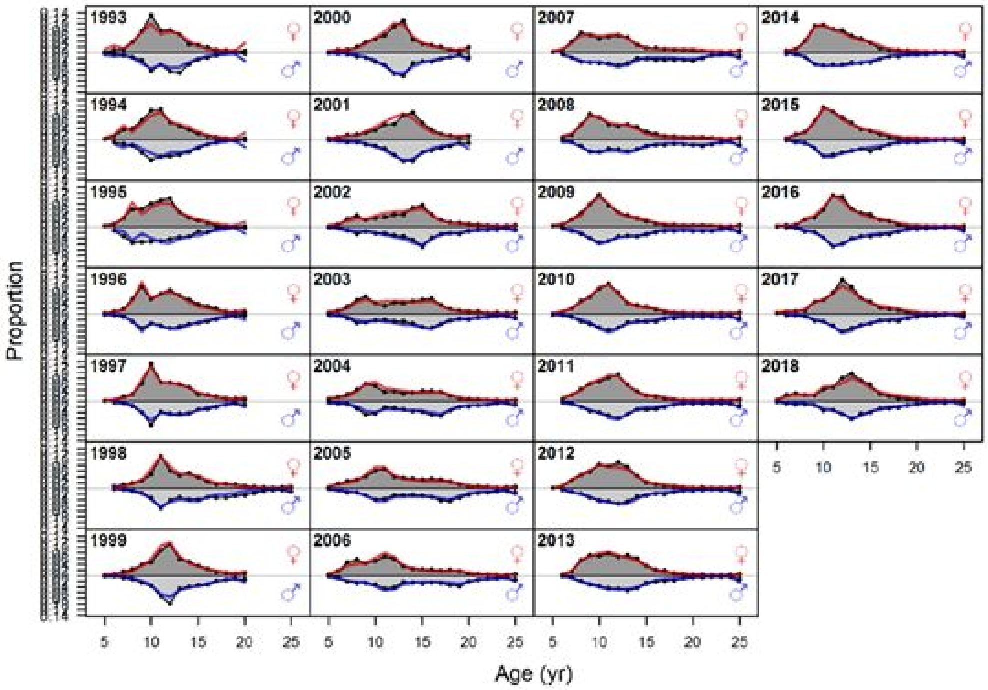


FIGURE 16. Fit to annual age data from the FISS survey in the coastwide short model.

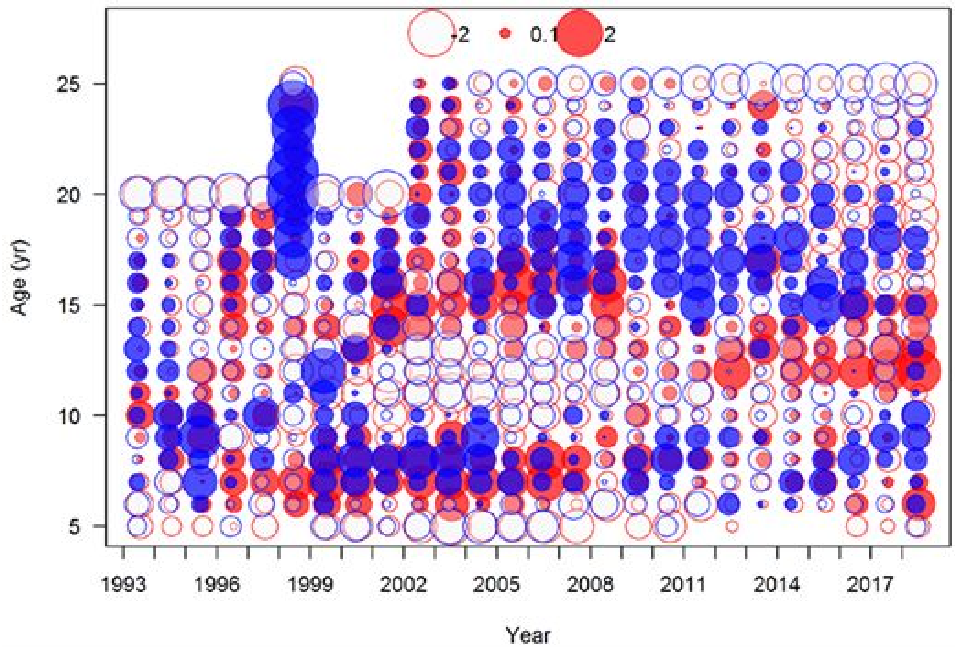
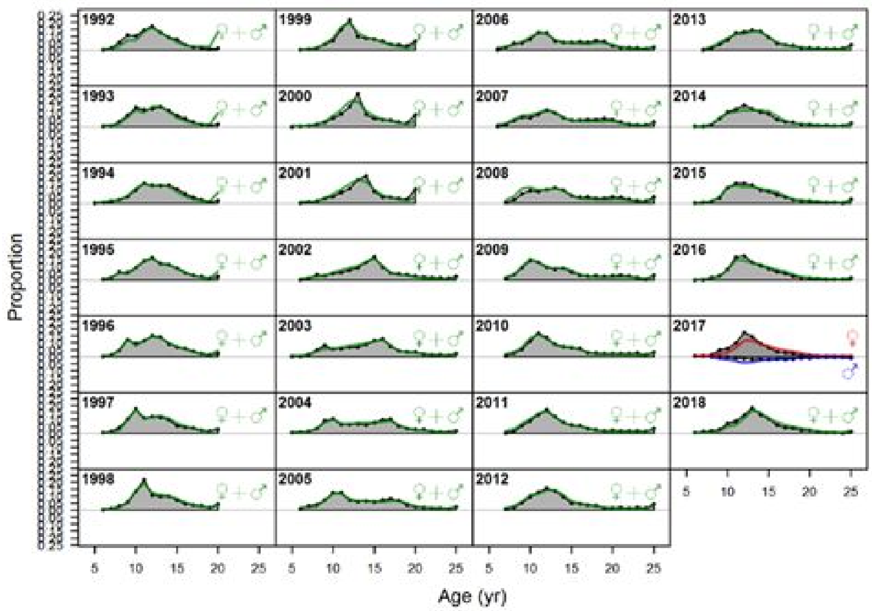


FIGURE 17. Pearson residuals for fit to annual age data from the FISS survey in the coastwide short model; red circles denote female residuals, and blue circles denote male residuals.



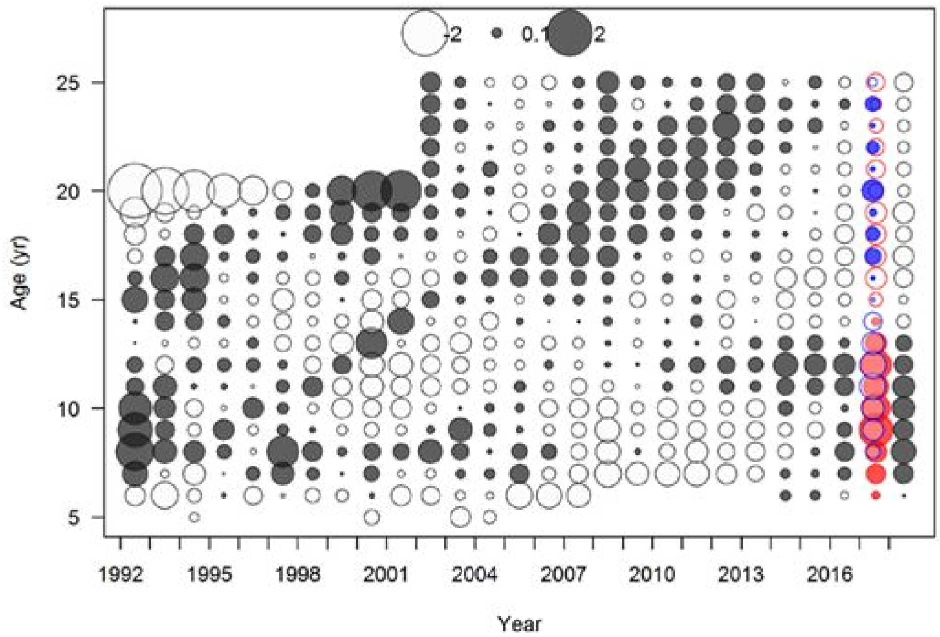
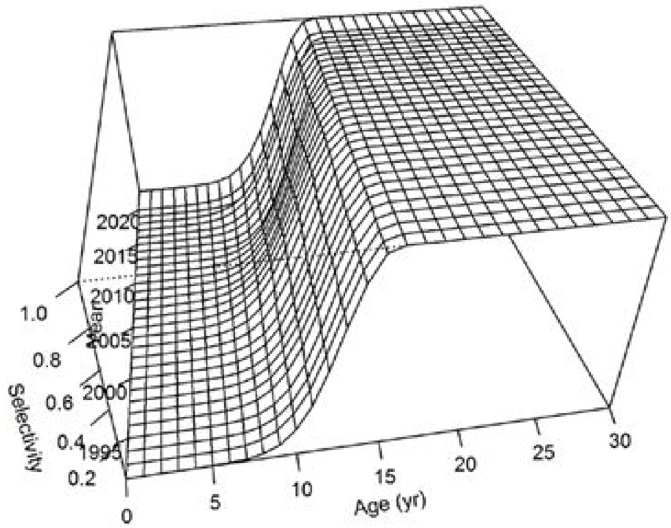


FIGURE 18. Fit (upper panel) and Pearson residuals (lower panel) for fit to annual age data from the commercial fishery landings in the coastwide short model; grey circles denote unsexed residuals, red circles denote female residuals, and blue circles denote male residuals.

Neither the survey nor the fishery selectivity was estimated to have a highly variable ascending limb over the short time-series (FIGURE 19). The estimated fishery selectivity showed a trend toward increasing selection of males in recent years (FIGURE 20), perhaps a function of the catch distribution shifting toward the Eastern side of the stock where fast-growing males are much more common, as well as the decline in the strong cohorts from the 1980s which produced an abundance of older females. The survey estimates did not show this trend, but selected a much larger relative fraction of females.



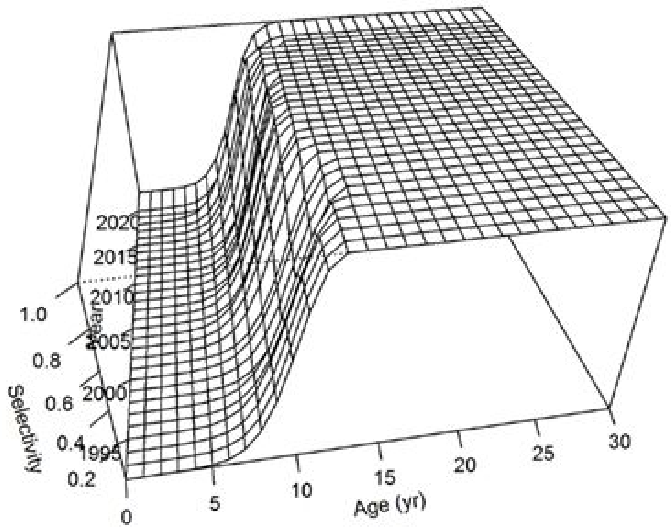


FIGURE 19. Estimated time-varying female selectivity curves for the commercial fishery landings (upper panel) and FISS survey (lower panel).

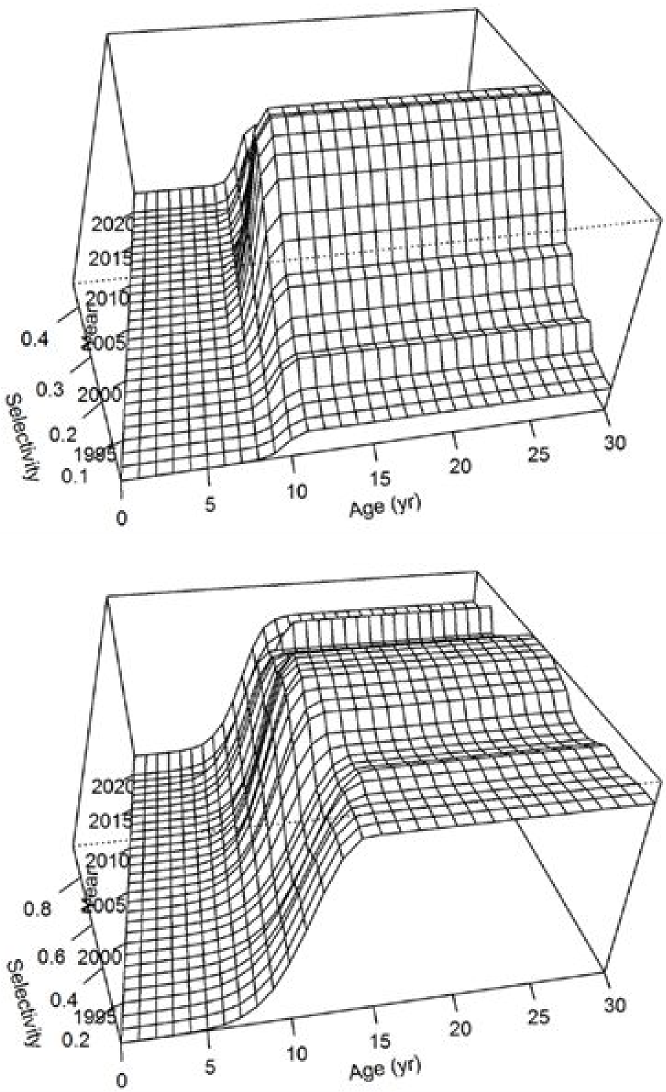


FIGURE 20. Estimated time-varying male selectivity curves for the commercial fishery landings (upper panel) and FISS survey (lower panel).

Estimated selectivity for the discard fleet selected fewer males than females (FIGURE 21). Estimated selectivity for the bycatch fleet showed a peak at age-4 and a domed relationship. Recreational selectivity was shifted to the left of the commercial fishery discards (and therefore the survey), reflecting the increased numbers of halibut age-7 and younger in the data from the Gulf of Alaska.

Male natural mortality was estimated to be slightly higher (0.155) than the fixed value assumed for females of 0.15 (TABLE 12), which differed from the slightly lower value estimated in the previous assessment (although still inside the 95% interval).

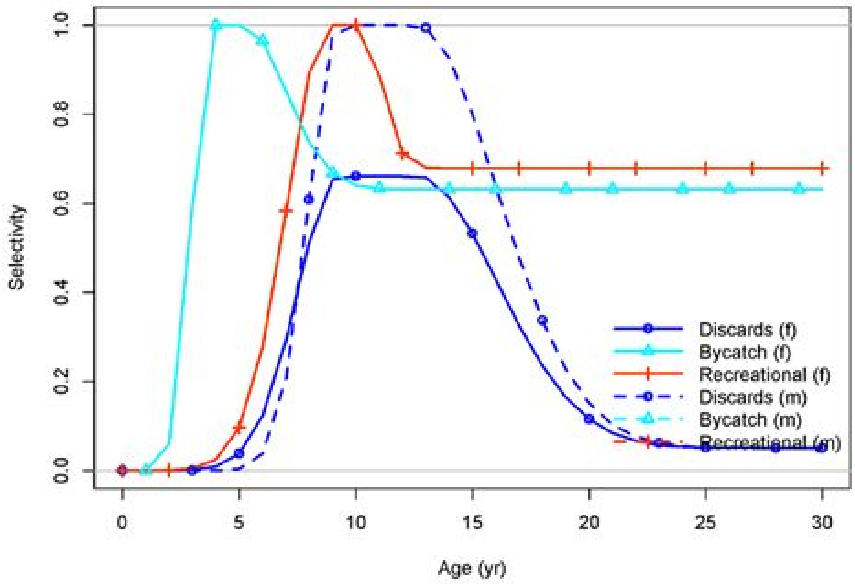


FIGURE 21. Estimated selectivity curves for discard, bycatch and recreational fleets in the coastwide short model.

Summary of pros and cons for the coastwide short model:

Pros:

- Lowest technical overhead (complexity) of the four models in the ensemble
- Fits the fishery and survey indices very well
- Fits the survey age data (males and females) relatively well
- Allows for changes in sex-ratio of the commercial landings over time
- Parameter estimates are derived from the most recent time period
- Internally consistent data weighting

Cons:

- Does not include uncertainty in female natural mortality
- Does not include extensive historical data
- May lose Region-specific trends and biological patterns due to aggregation
- Does not use environmental information to inform recruitment
- Commercial age data is not heavily weighted and there are therefore residual patterns despite allowing for process error in selectivity

TABLE 12. Select parameter estimates (maximum likelihood value and approximate 95% confidence interval) by model and Region (where applicable).

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Biological				
Female *M*	0.150 (Fixed)	0.213 (0.188-0.238)	0.150 (Fixed)	0.173 (0.157-0.189)
Male *M*	0.155 (0.143-0.167)	0.199 (0.184-0.214)	0.140 (0.134-0.147)	0.155 (0.145-0.165)
Log(R_0)	10.63 (10.45-10.81)	11.06 (10.72-11.40)	10.68 (10.53-10.82)	10.66 (10.35-10.96)
Initial R_0 offset	-1.274 (-1.474--1.075)	NA	-0.659 (-0.833--0.485)	NA
Environmental Link (β)	NA	0.398 (0.167-0.629)	NA	0.293 (0.078-0.508)
Survey Log(q) Δ1984 (transition to circle hooks)	NA	0.943 (0.011-1.874)	NA	R2:1.209 (0.863-1.554) R3:2.100 (1.825-2.375)
Fishery Log(q) Δ1984	NA	0.654 (0.493-0.816)	NA	R2:0.573 (0.387-0.758) R3:0.934 (0.734-1.135) R4:0.784 (0.591-0.977) R4B:0.446 (0.263-0.629)
Scale of male survey selectivity (max value relative to females)	Time-varying	0.501 (0.354-0.648)	R2: 0.308 (0.196-0.419) R3: 0.604 (0.516-0.692) R4: 0.414 (0.340-0.488) R4B: 1.000 (Fixed at bound)	R2: 0.315 (0.222-0.408) R3: 0.494 (0.402-0.586) R4: 0.371 (0.310-0.432) R4B: 1.000 (Fixed at bound)
Scale of male fishery selectivity (max value relative to females)	Time-varying	0.362 (0.263-0.461)	R2: 0.113 (0.079-0.147) R3: 0.234 (0.171-0.298) R4: 0.086 (-0.002-0.174) R4B: 0.856 (0.455-1.000)	R2: 0.106 (0.074-0.139) R3: 0.220 (0.160-0.279) R4: 0.088 (0.033-0.143) R4B: 1.000 (Fixed at bound)

Coastwide long

Both the fishery and survey indices were fit well (FIGURE 22), with breaks in catchability to accommodate the change from “J” to circle hooks which were very conspicuous in both series (TABLE 12). In aggregate, the predicted age compositions matched the observed data well (FIGURE 23); however, there were notable differences among years within the time-series. Fits to the setline survey were quite poor in the early portion of the time series, improving where the data became more comprehensive in the mid-1990s, and quite good in the most recent years (FIGURE 24). Fishery data fit reasonably well for the entire time-series (FIGURE 25), with patterns in the residuals corresponding to relatively small differences with observed distributions. Harmonic mean effective sample sizes were much larger than adjusted inputs when Francis weights were close to 1.0 (TABLE 11).

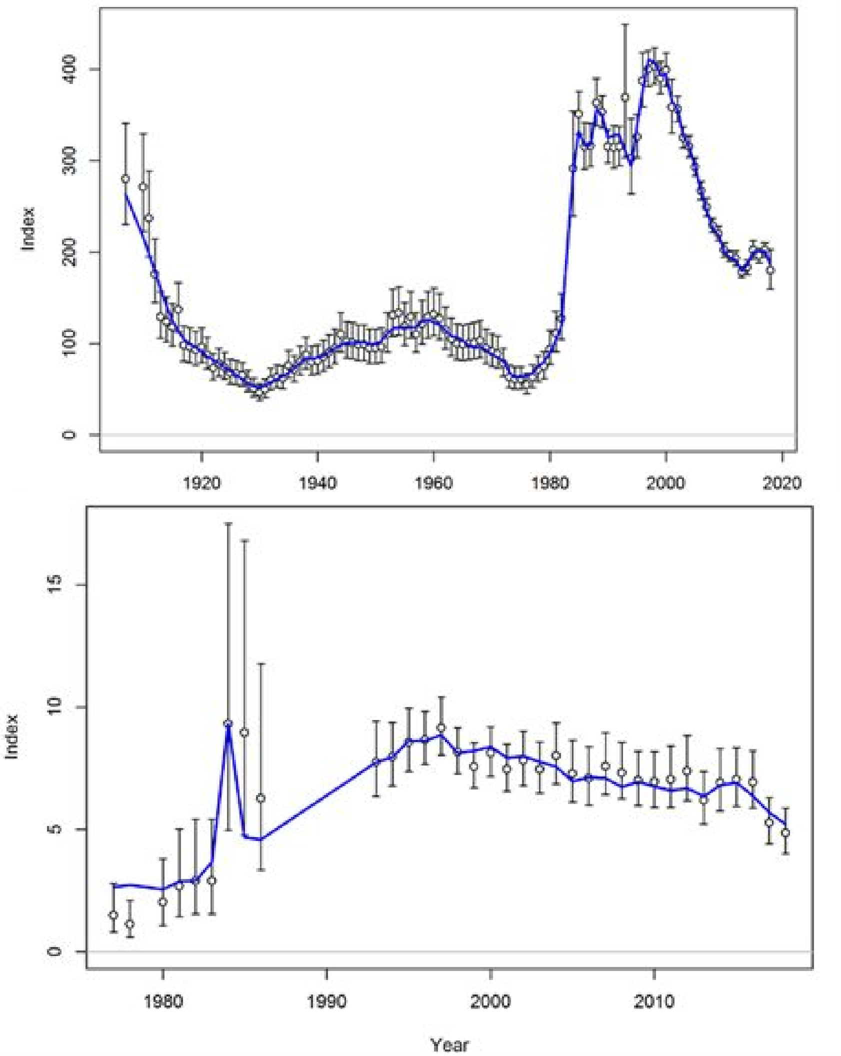


FIGURE 22. Fit to fishery (upper panel) and survey (lower panel) indices in the coastwide long model.

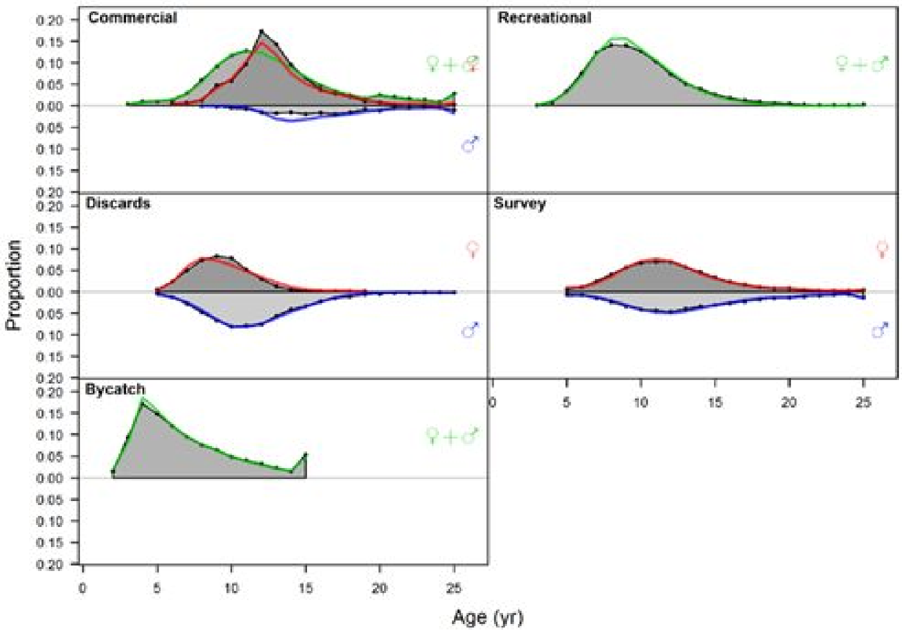


FIGURE 23. Aggregate fit to all age data by model fleet in the coastwide long model; sex-specific distributions for the commercial fishery represent only 2017.

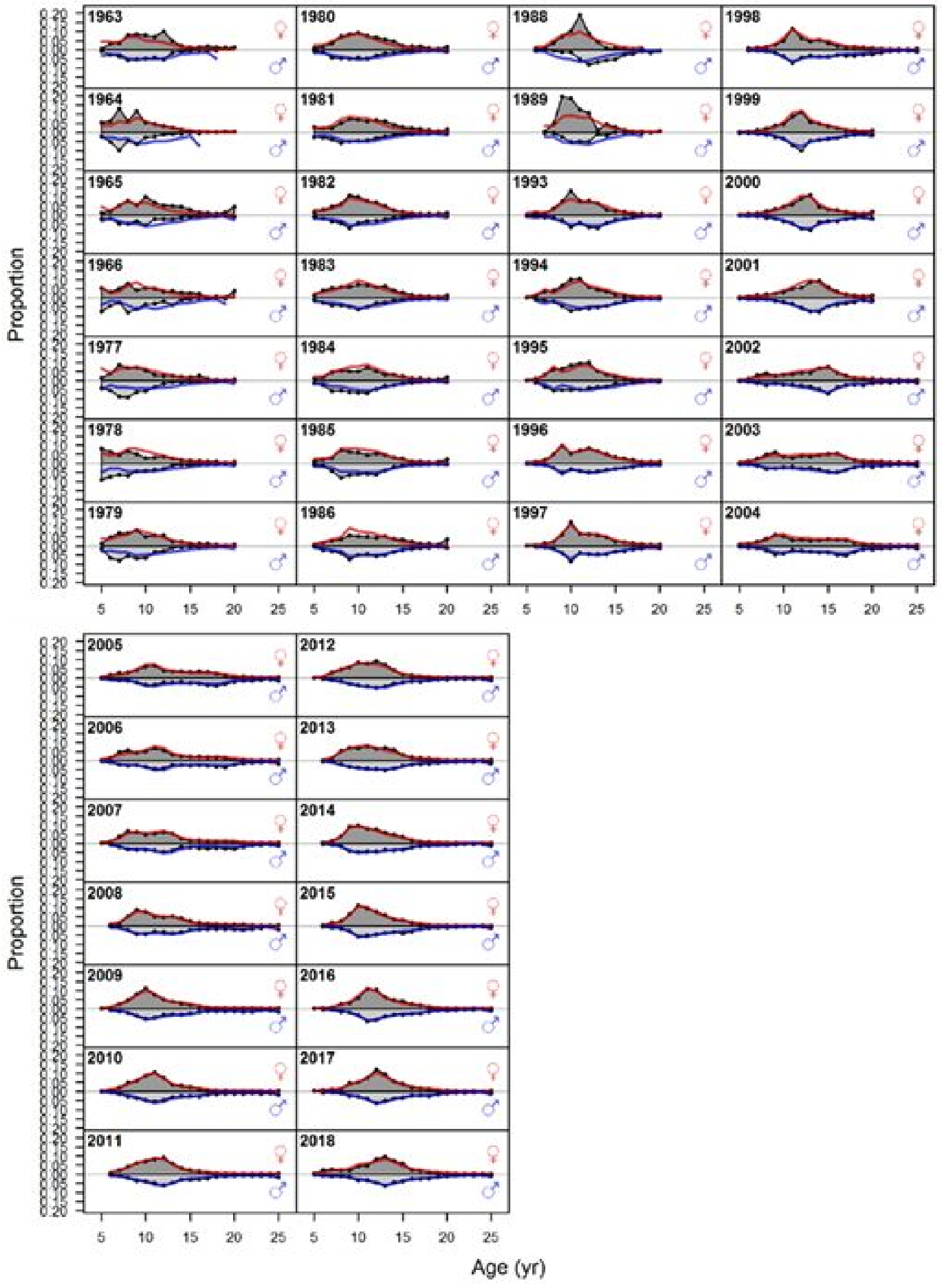


FIGURE 24. Fit to survey age data in the coastwide long model.

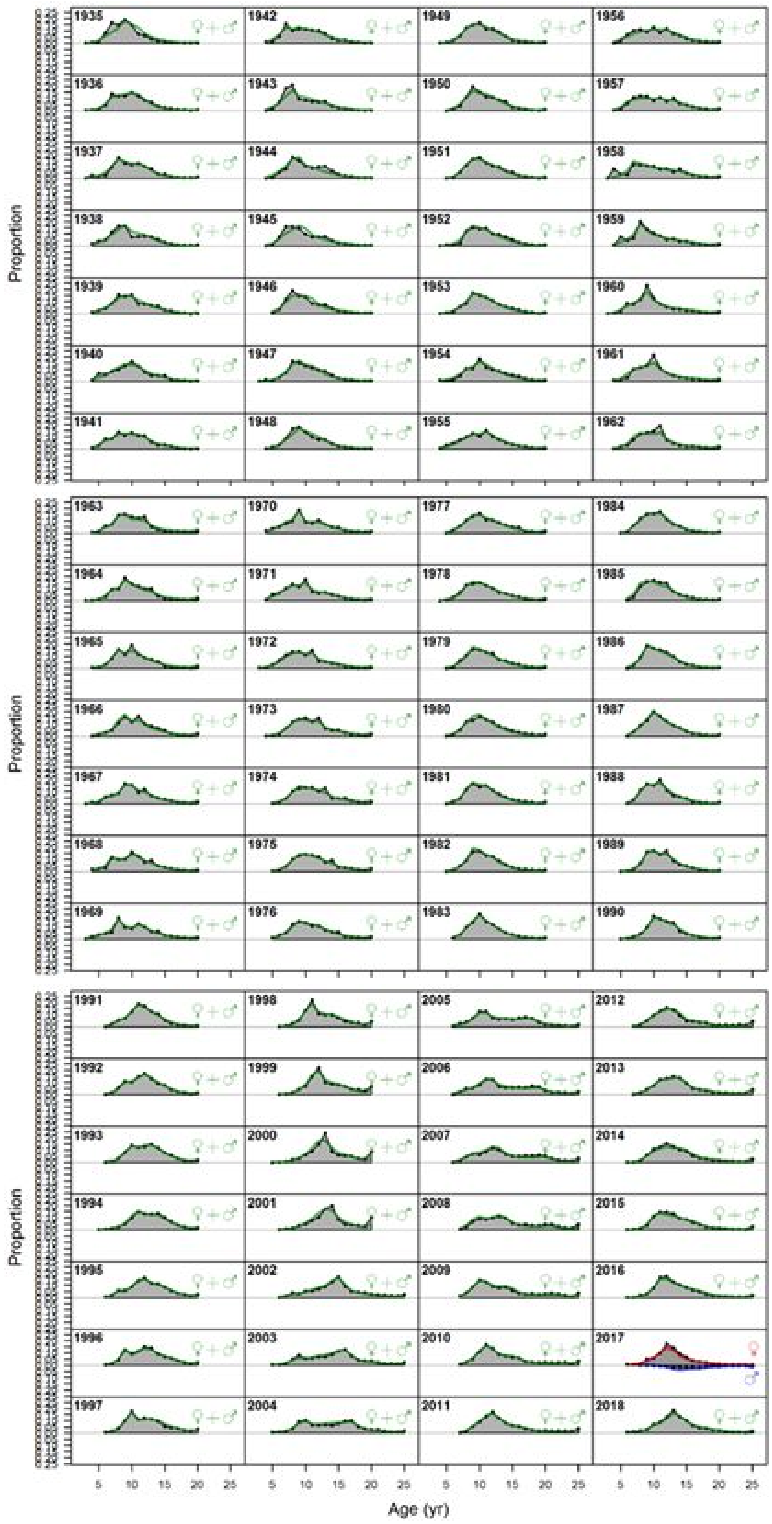


FIGURE 25. Fit to fishery age data in the coastwide long model.

Fishery selectivity generally showed a pattern toward selecting fewer younger fish in the latter half of the time series, but a similar trend to the setline survey in the most recent years (FIGURE 26). This may be consistent with changes in both the age-structure of the stock and the spatial distribution. Fishery catchability showed a very large (unconstrained) increase associated with the change from “J” to circle hooks (TABLE 12, FIGURE 27). Older halibut were more represented in the bycatch age data prior to 1992, and therefore the estimated selectivity was asymptotic. Recreational and discard selectivity estimates were relatively similar to those from the coastwide short model.

Female natural mortality in the coastwide long model was estimated to be higher (0.213) than for males although the 95% intervals overlap (0.199; TABLE 12, FIGURE 28). The environmental link parameter (β) was estimated to be positive (0.398), with no density below a value of 0.0 (TABLE 12, FIGURE 29). However, the time series of estimated recruitment deviates (FIGURE 30) suggested that some residual effect and/or mismatch in the relationship might still be present, as the poor PDO period from 1947-1977 and the positive phase from 1978-2006 generally correspond to negative and positive deviations, respectively (FIGURE 31).

Summary of pros and cons for the coastwide long model:

Pros:

- Includes uncertainty in female natural mortality
- Includes extensive historical data
- Uses environmental information to inform recruitment
- Modest technical overhead (complexity)
- Fits the fishery and survey indices well
- Fits both the survey and fishery age data well
- Internally consistent data weighting

Cons:

- May lose Region-specific trends and biological patterns due to aggregation
- Relies heavily on only fishery trends over the historical period
- Implicitly assumes stationarity in some processes (e.g., the stock-recruitment function, natural mortality) over long historical period (beyond environmental effects)

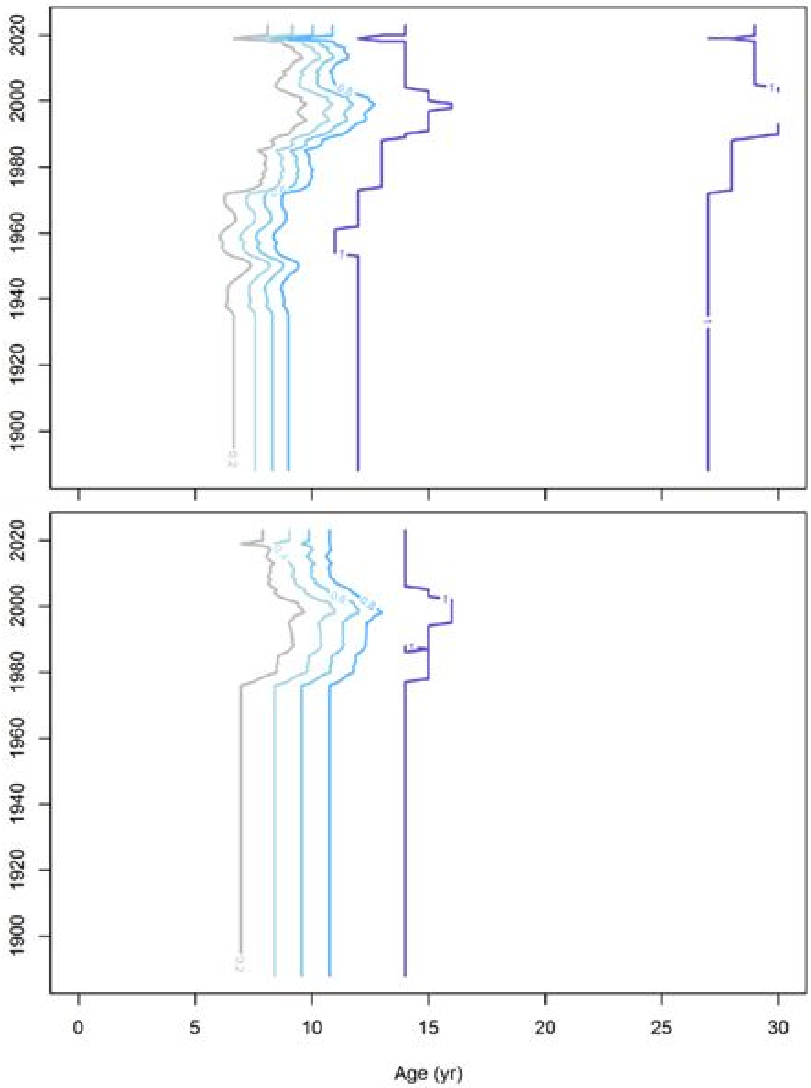


FIGURE 26. Estimated selectivity for females in the commercial fishery landings (upper panel) and survey (lower panel) in the coastwide long model; note that the apparent dip near the end of the time-series just corresponds to the fixed deviation in that year where there are not yet any data.

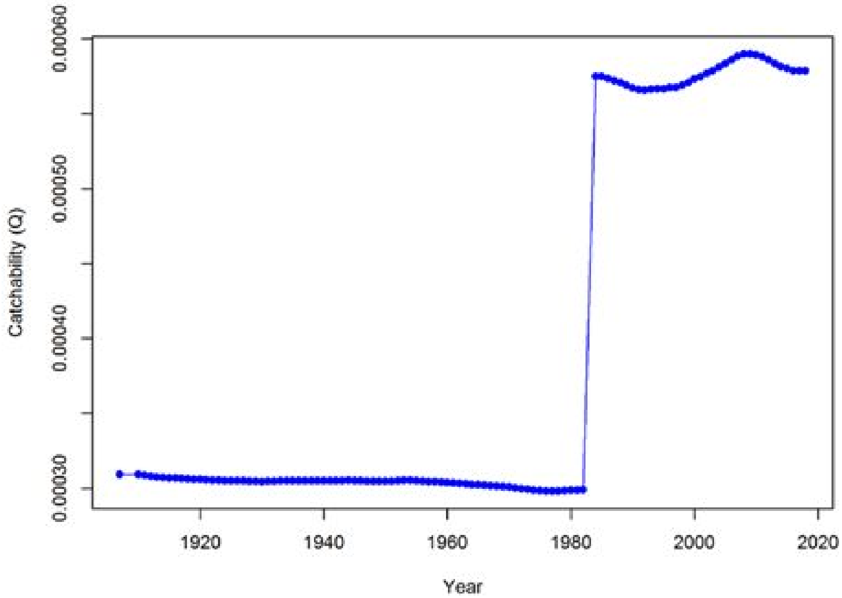


FIGURE 27. Time-varying fishery catchability in the coastwide long model.

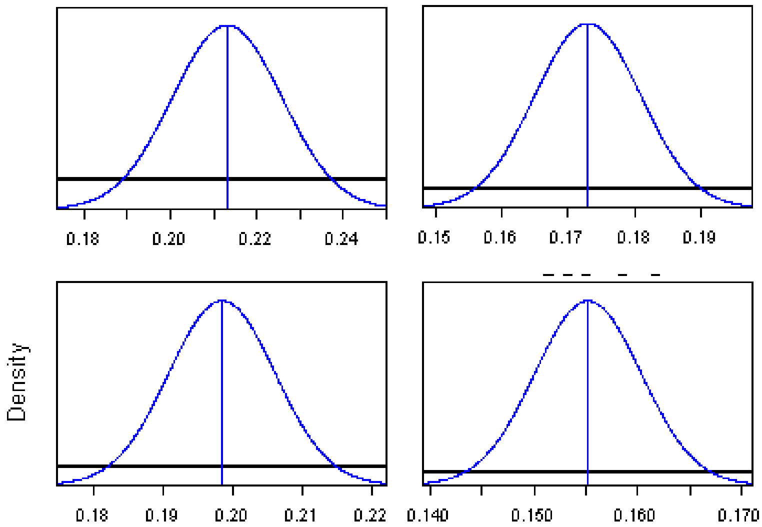


FIGURE 28. Estimated parameter distributions for female (upper panels) and male (lower panels) natural mortality from the coastwide long model (left panels) and the AAF long model (right panels); horizontal lines indicate uniform priors, vertical lines the maximum likelihood value.

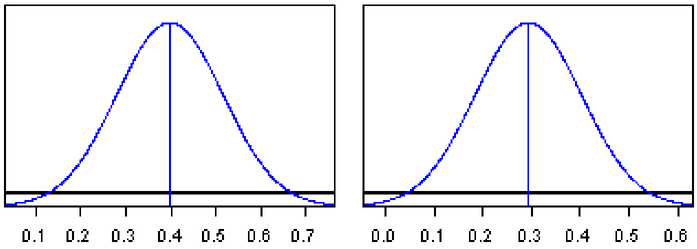


FIGURE 29. Estimated parameter distributions for the environmental regime parameters from the coastwide long model (left panel) and the AAF long model (right panel); horizontal lines indicate uniform priors, vertical lines the maximum likelihood value.

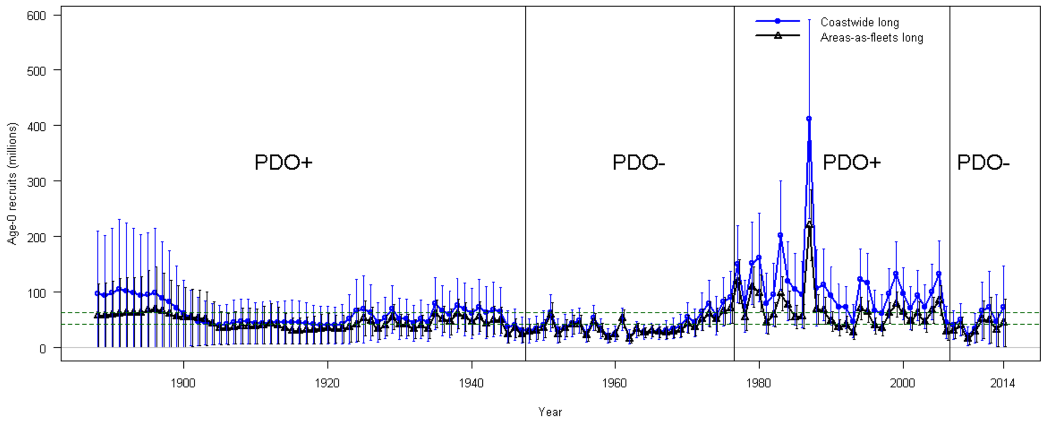


FIGURE 30. Estimated recruitments and assumed PDO regimes from the coastwide long and AAF long models (right panel); horizontal lines indicate equilibrium values.

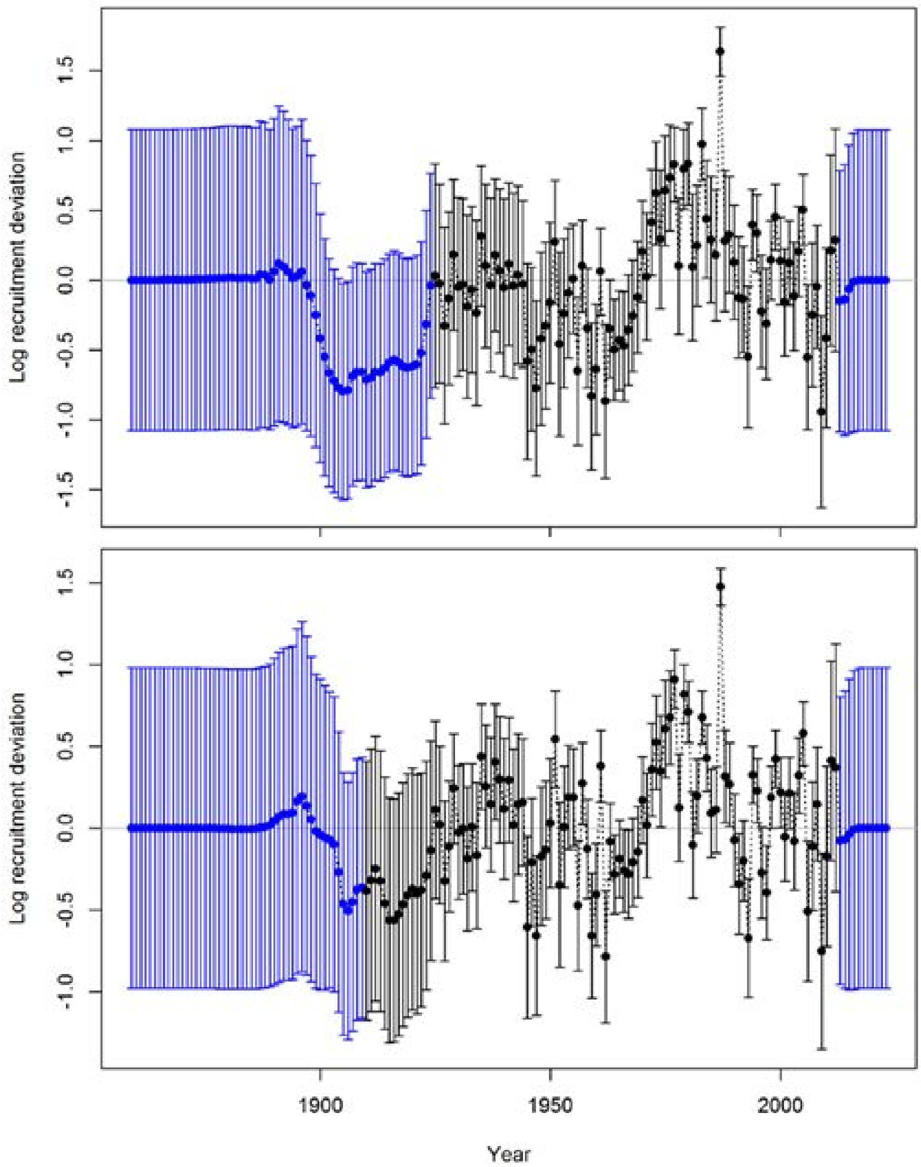


FIGURE 31. Estimated recruitment deviations coastwide long (upper panel) and AAF long (lower panel) models; horizontal lines indicate expected values based only on the stock-recruitment functions.

AAF short

The AAF short model fit the observed trends in all fishery and survey indices relatively well (FIGURE 32-33). These fits were somewhat better than those from the 2015 stock assessment, particularly for Regions 2 and 3 (Stewart and Martell 2016). Fit to the aggregate age data for each model fleet clearly illustrated the differences in age structure (FIGURE 34). The biggest differences between female and male halibut occurred in the Region 3 survey, and generally Regions 4 and 4B were predicted (and observed) to have the greatest fraction of older halibut, particularly males. The fit to the annual survey age data generally captured these patterns, with the worst fit in Region 2 (FIGURE 35); the Francis weight still suggested a relatively high weighting for the Region 2 survey despite these patterns (TABLE 11). Although showing a reasonably good aggregate fit, the fit to annual commercial fishery landings in Regions 4 and 4B (FIGURE 36) did not capture the strong peaks created by the 1987 year-class in the late 1990s and early 2000s; however of these fleets only the Region 4 data were downweighted from the number of samples collected based on the Francis weighting (TABLE 11). No model configurations evaluated during model development were able to fit the peak observations of this cohort observed in Regions 4 and 4B, which may be a reflection of the spatial nature of the dynamics not well approximated by an AAF approach.

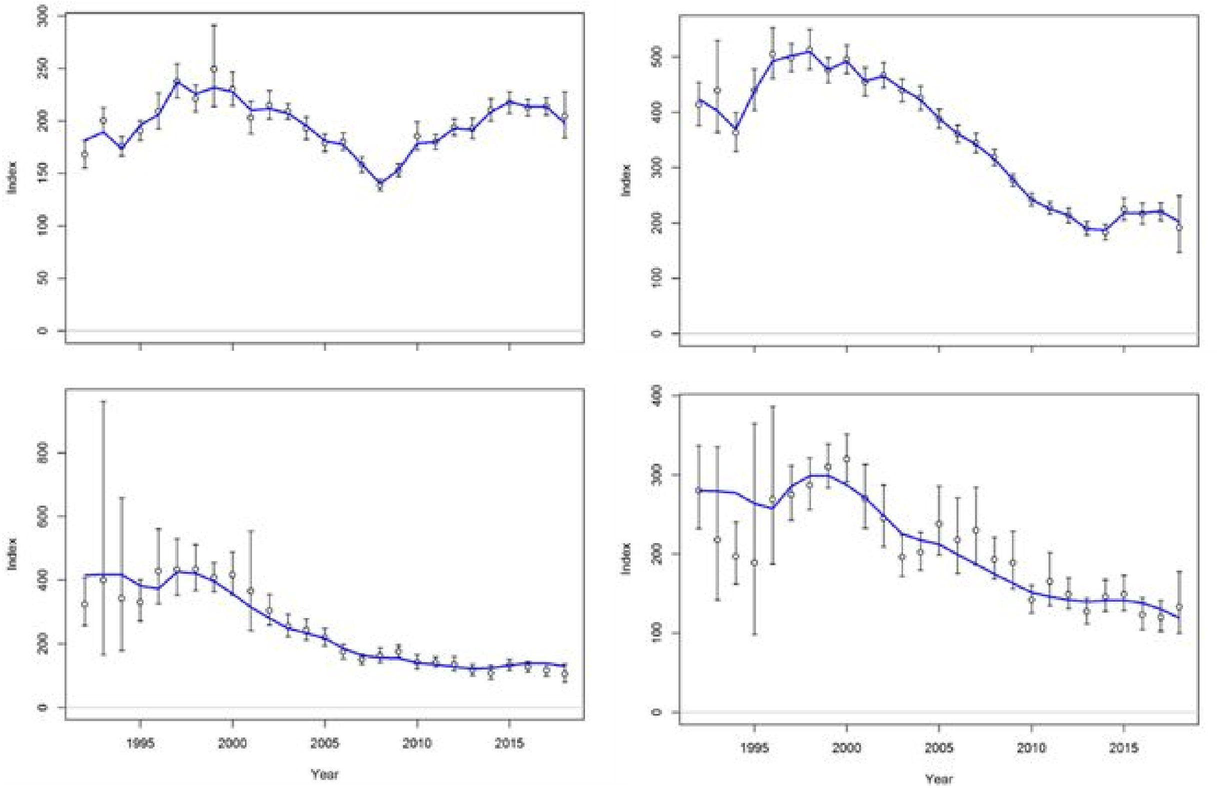


FIGURE 32. Fit to fishery trends in Regions 2, 3, 4, and 4B (top left to bottom right) in the AAF short model.

Male selectivity was estimated to be much less (0.31-0.6) relative to female selectivity for the survey in all Regions except 4B, where both were estimated to be fully selected and have a similar ascending limb (TABLE 12). Fishery selectivity was estimated to be shifted to the right of survey selectivity, and males were estimated to achieve a lower full selection relative to females in all Regions (0.086-0.856; TABLE 12). Bycatch, sport and discard selectivity estimates were similar to those from the coastwide short model.

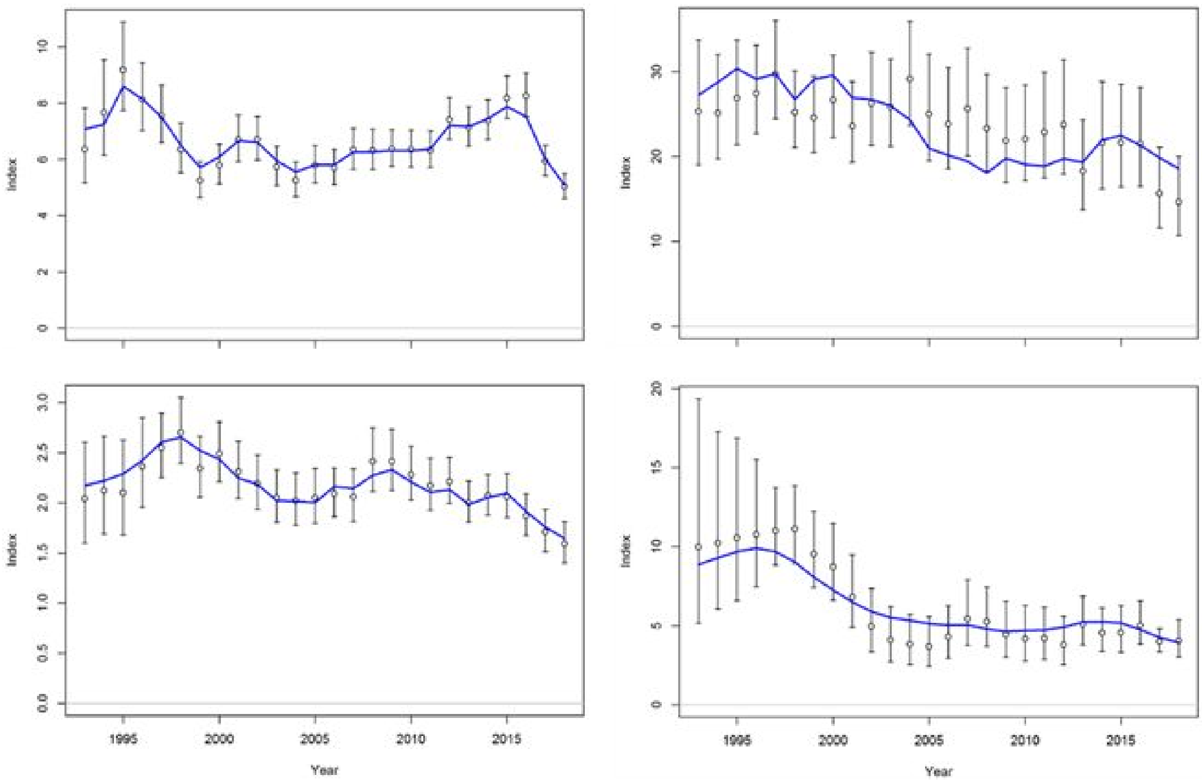


FIGURE 33. Fit to survey trends in Regions 2, 3, 4, and 4B (top left to bottom right) in the AAF short model.

Estimated fishery catchability showed differing temporal patterns and scale in Regions 2 and 3, with neither obviously showing a large amount of interannual variability (FIGURE 37). Although explored, tuning of process error deviations in catchability did not suggest retaining time-varying catchability for the Regions 4 and 4B fishery, and the fit to the indices remained consistent with the variance associated with the observations (FIGURE 32).

The estimate of male natural mortality in the AAF short model (0.14) was slightly lower than in the coastwide short model (TABLE 12) and the 95% intervals did not overlap that estimate. This result likely indicates the trade-off between the assumption of asymptotic selectivity in the coastwide model and domed selectivity for most Regions in the AAF models.

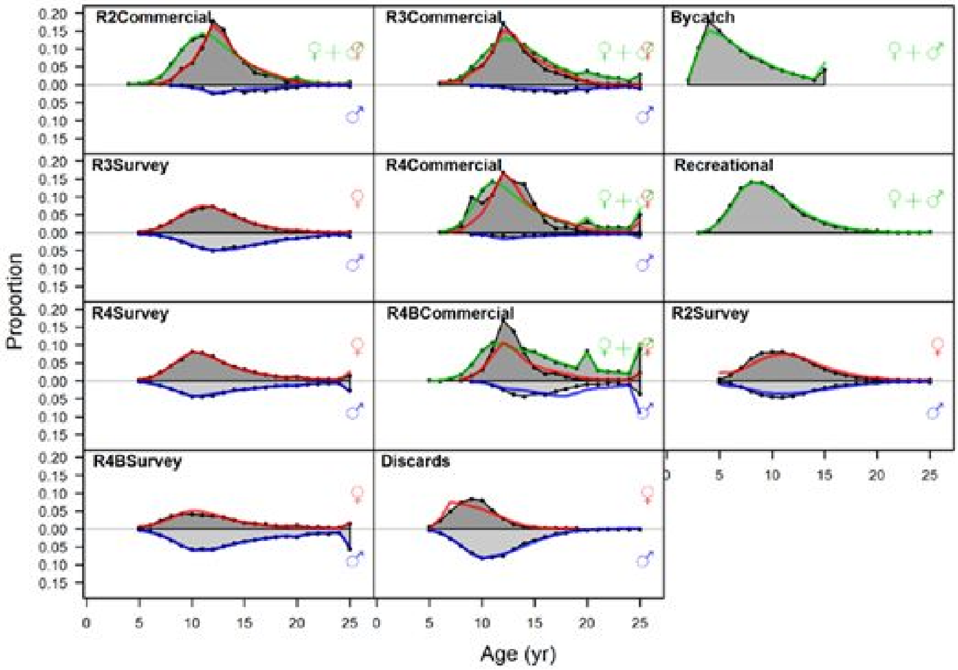


FIGURE 34. Aggregate fit to age data for each model fleet in the AAF short model; sex-specific distributions for the commercial fishery represent only 2017.

Summary of pros and cons for the AAF short model:

Pros:

- Parameter estimates are derived from the most recent time period
- Avoids aggregating data over Regions with differing trends and biological patterns
- Fits the Regional fishery and survey indices well
- Fits Region 2 and 3 fishery and Region 3 survey age data well
- Internally consistent data weighting

Cons:

- Does not includes uncertainty in female natural mortality
- Does not include environmental information to inform recruitment
- Modest technical overhead (complexity)
- Residual patterns in Region 4 and 4B fishery and survey age data
- Fits Region 2 survey age data poorly
- Does not include extensive historical data

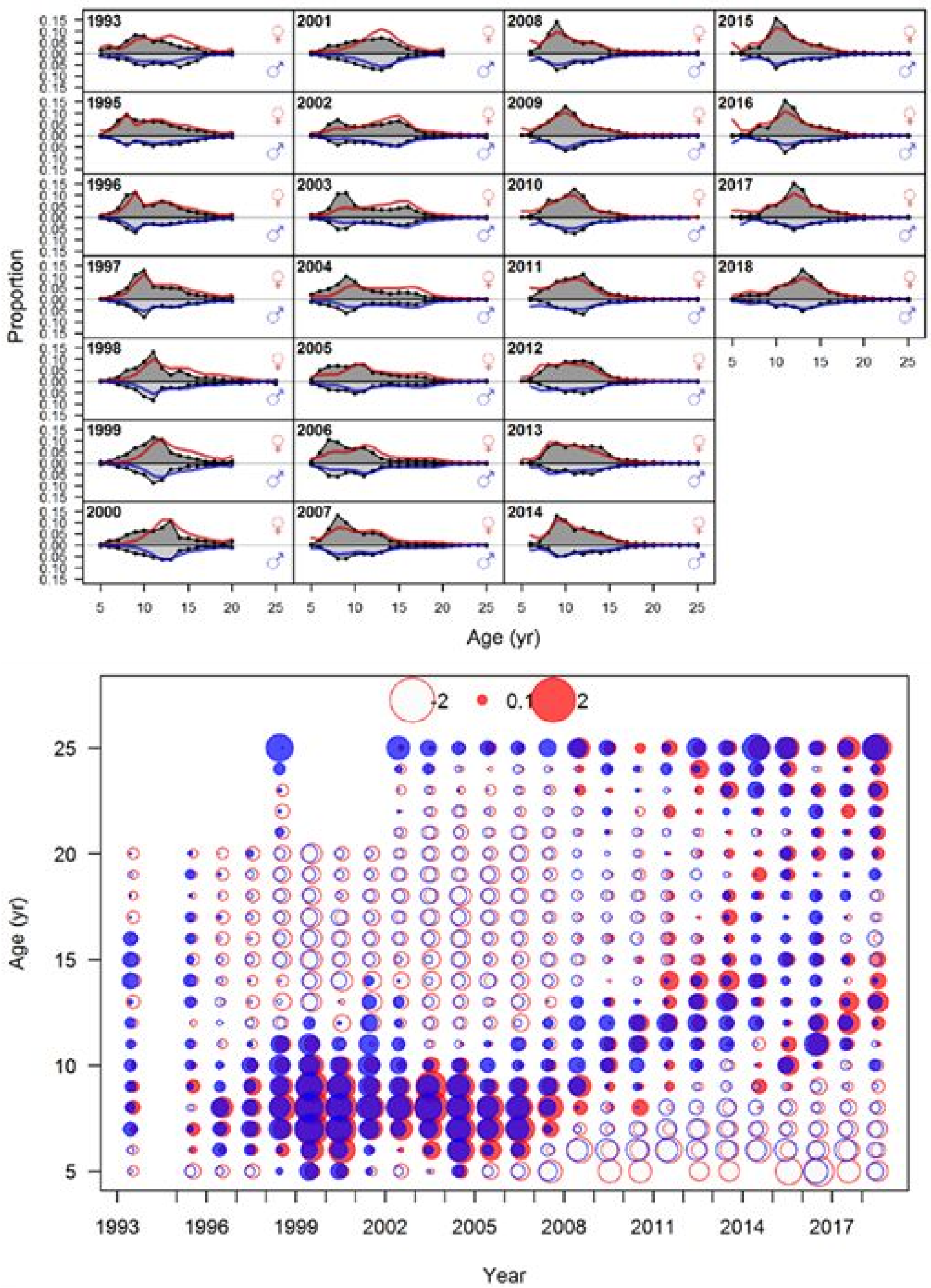


FIGURE 35. Fit to age data (upper panel) and Pearson residuals (lower panel) from the Region 2 survey in the AAF short model; red circles denote female residuals, and blue circles denote male residuals.

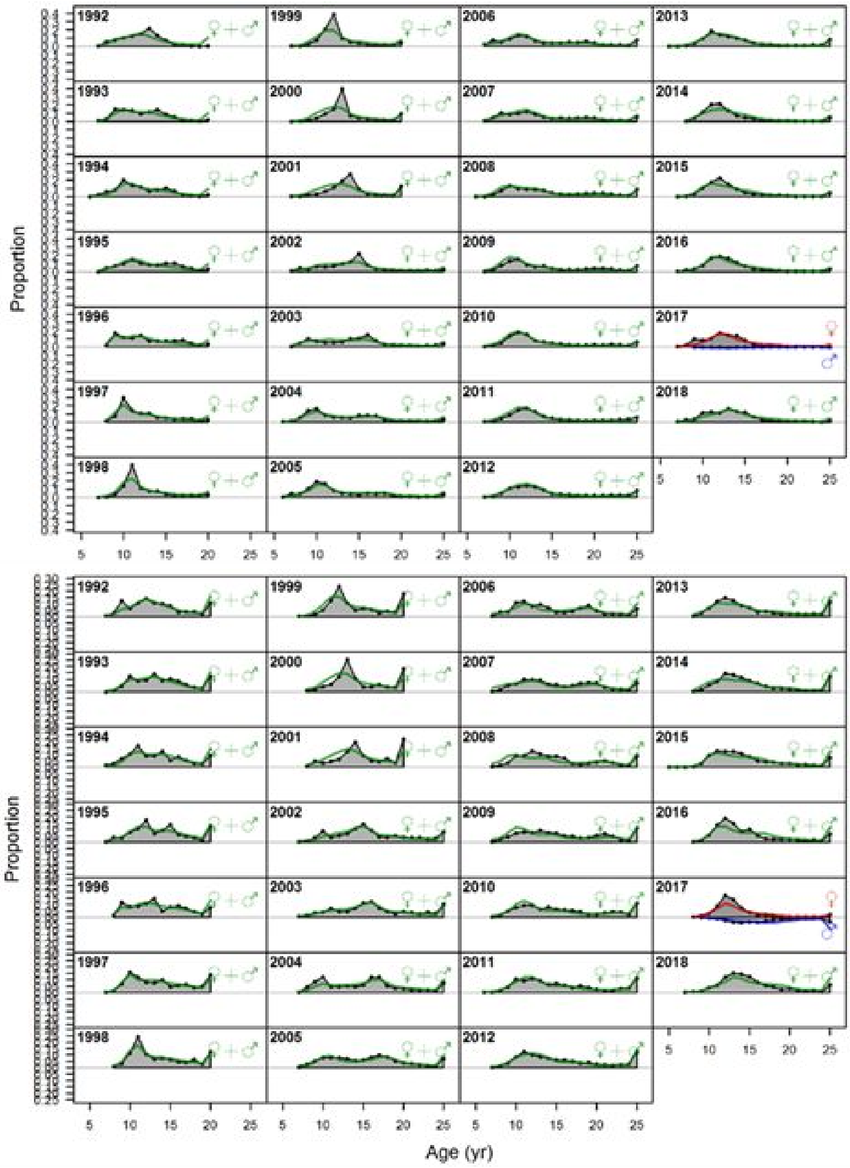


FIGURE 36. Fit to age data from the Region 4 (upper panel) and Region 4B (lower panel) commercial fishery landings in the AAF short model.

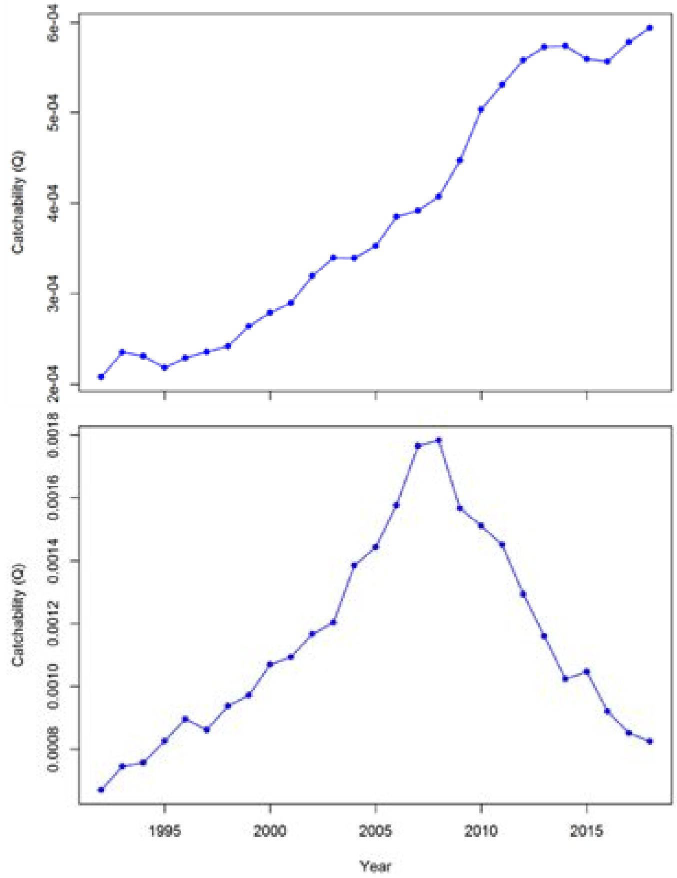


FIGURE 37. Estimated trends in the Region 2 (upper panel) and Region 3 (lower panel) commercial fishery catchbility in the AAF short model.

AAF long

Like the AAF short model, the AAF long model fit both the fishery and survey trends relatively well (FIGURE 38-39). Aggregate fits to the survey age composition data showed similar patterns to those observed in the AAF short model (FIGURE 40). Generally, the fit to the survey age data improved over the time series. The Region 2 survey age data was relatively downweighted in order to achieve consistency with the Francis weighting TABLE 11, and this resulted in the worst fit by fleet (FIGURE 41). Lack of fit to the Region 3 survey data occurred primarily in the early part of the time-series. Among the fishery fleets, only the Region 4 data were downweighted from the number of samples TABLE 11. Generally, as a function of the iterative weighting and the separation of commercial male selectivity (from the strong assumption in previous models that peak male selectivity was equal to that in the survey) the fits to the age data in this preliminary assessment were improved over previous analyses.

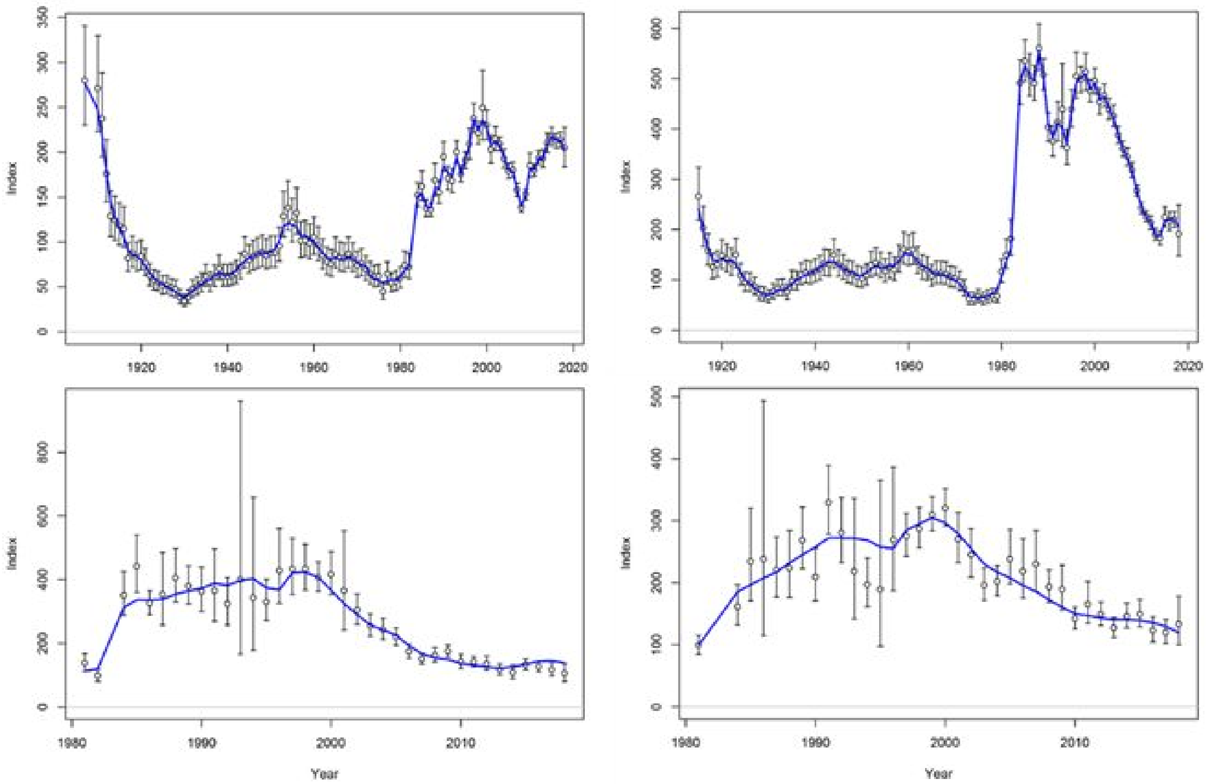


FIGURE 38. Fit to fishery trends in Regions 2, 3, 4, and 4B (top left to bottom right) in the AAF long model.

Similar to the AAF short model, peak male survey selectivity was estimated to be asymptotic only for Region 4B, ranging from 0.32-0.49 among the other Regions (TABLE 12). Peak male selectivity in the commercial fishery landings was estimated to be much less (0.09-0.22), except in Region 4B where it was also asymptotic. Fishery catchability was estimated to be strongly increasing in Region 2 and decreasing in Area 3 at the end of the time series (FIGURE 43). As in the AAF short model, tuning eliminated time-varying catchability for the Region 4 and 4B commercial fisheries. All fleets with data extending past the transition from J to circle hooks in 1984 showed a strong offset in the unconstrained deviation in catchability for that year (TABLE 12). Discard and recreational selectivity estimates were similar in the AAF long model to those estimated in the coastwide long model. Bycatch selectivity was estimated to be domed, again illustrating the trade-off between domed fleets in the AAF models and asymptotic selectivity over the entire time-series in the coastwide models. This likely interacts with the estimation of natural mortality, producing slightly lower values in the AAF long model (0.173 for females, and 0.155 for males) than in the coastwide long model (TABLE 12).

The environmental link coefficient was estimated to be slightly weaker (0.293) than in the coastwide long model, although the 95% interval did not contain zero (TABLE 12, FIGURE 29)

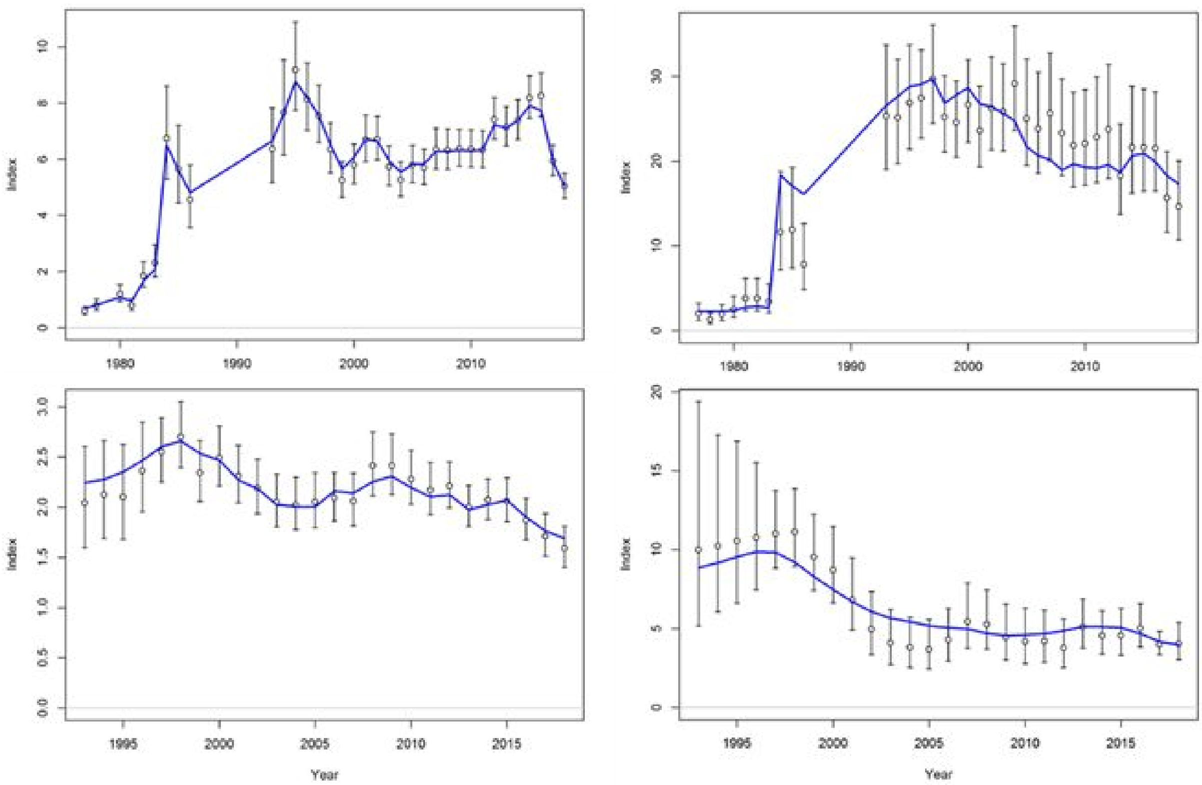


FIGURE 39. Fit to survey trends in Regions 2, 3, 4, and 4B (top left to bottom right) in the AAF long model.

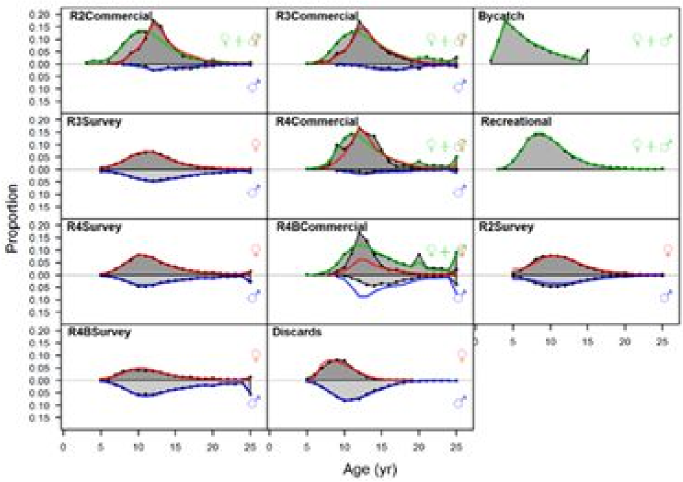


FIGURE 40. Aggregate fit to age data for each model fleet in the AAF long model; sex-specific distributions for the commercial fishery represent only 2017.

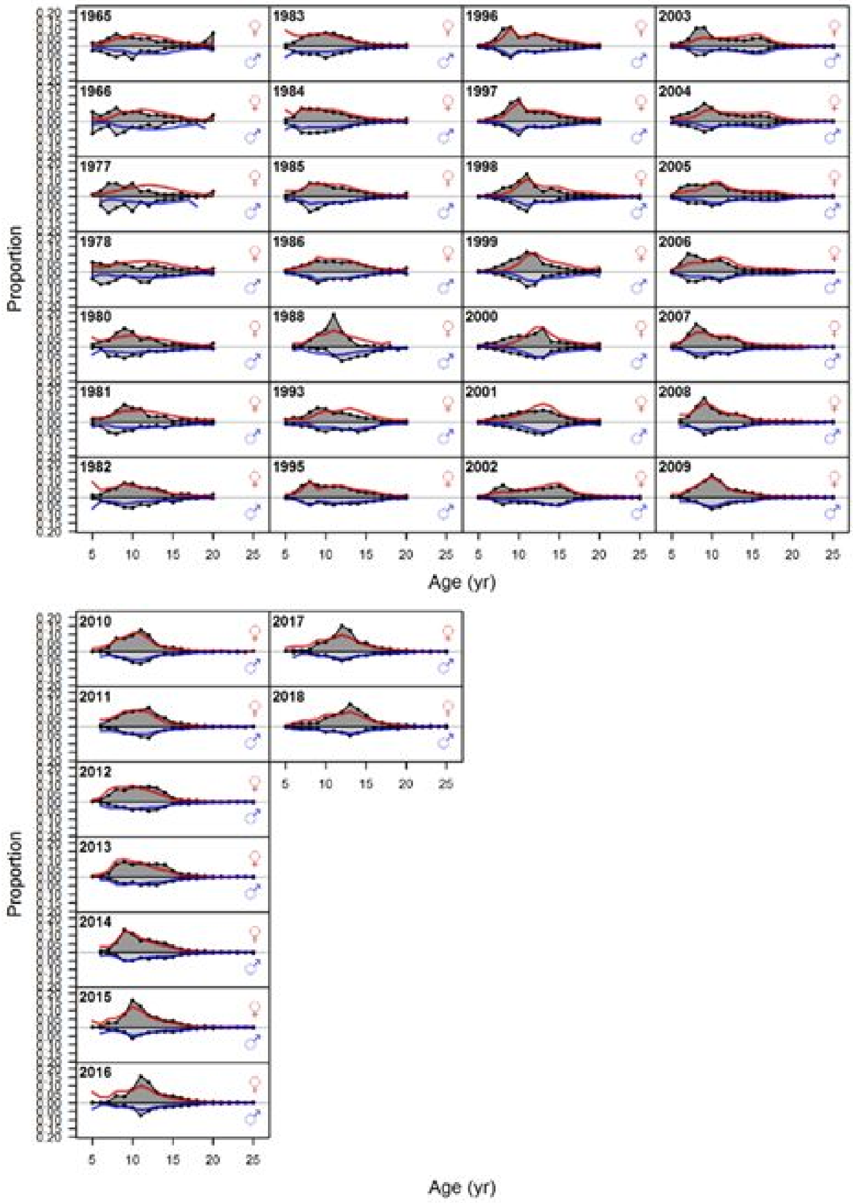


FIGURE 41. Fit to age data from the Region 2 survey in the AAF long model.

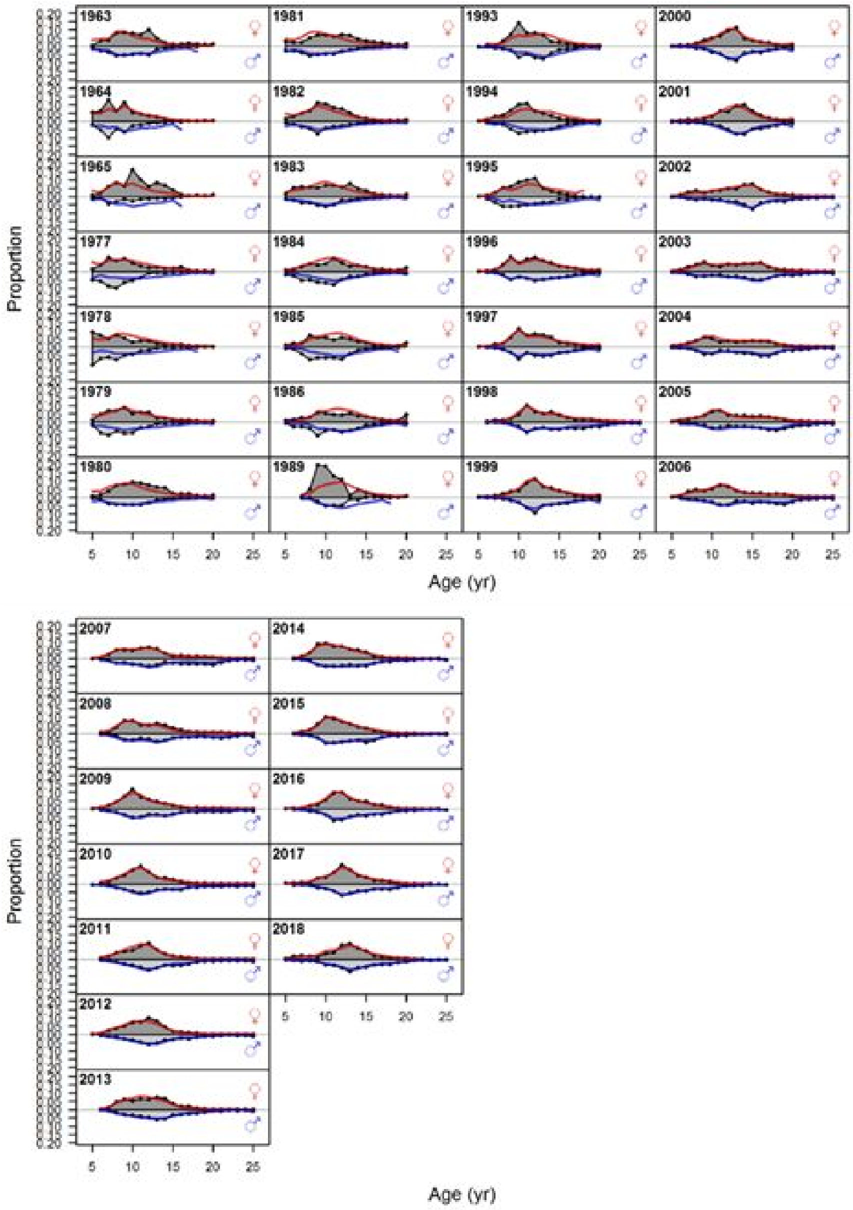


FIGURE 42. Fit to age data from the Region 3 survey in the AAF long model.

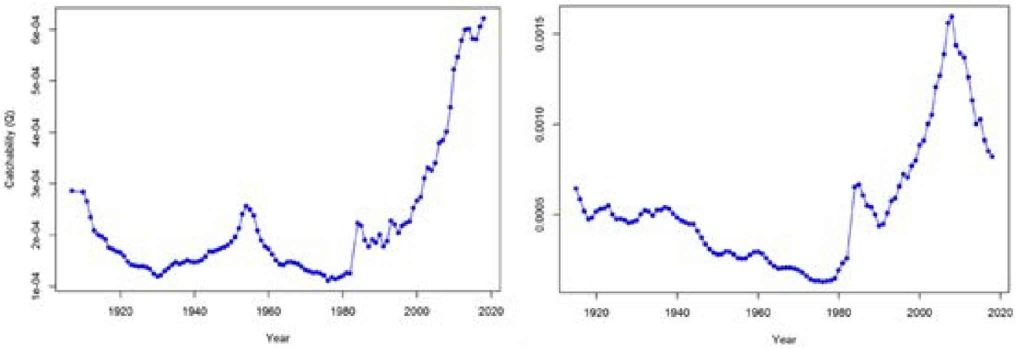


FIGURE 43. Estimated trends in the Region 2 (upper panel) and Region 3 (lower panel) commercial fishery catchability in the AAF long model.

Summary of pros and cons for the AAF long model:

Pros:

- Includes uncertainty in female natural mortality
- Includes extensive historical data
- Uses environmental information to inform recruitment
- Fits the fishery and survey indices well
- Fits both the Regions 2, 3 and 4B fishery age data well
- Fits Region 4 and 4B survey age data well
- Internally consistent data weighting

Cons:

- Highest technical overhead (complexity) of the four models
- Relies heavily on only fishery trends over the historical period
- Implicitly assumes stationarity in some processes (e.g., the stock-recruitment function, natural mortality) over long historical period (beyond modelled environmental effects)
- Residual patterns in Region 4 fishery age data
- Fits Region 2 and 3 survey age data poorly

Sources of uncertainty

The four models evaluated here represent significant sources of uncertainty in how to treat the data (partitioning by fleets or aggregating to a single series), as well as how to treat the time-series (emphasizing the recent dynamics or including more historical information). Further, the differing assumptions of fixed vs. estimated female natural mortality rate is also embedded in the differences observed among the model results. These factors lead to differences in both scale and trend. In aggregate, the four models together reflected much more uncertainty than any single model, while still showing a similar basic trend over the recent time-series' of both spawning biomass and recruitment.

Sensitivity analyses

Many alternative model configurations were evaluated during model development, but only a subset of these is reported here. These results were selected to try to highlight the features of each of the four models to which there appeared to be the strongest response in stock size and trend estimates, or to illustrate the effect of specific model features of specific interest.

The large differences in the scale of the spawning biomass in the historical period between the two long time series models represent the range of assumptions about the connectivity of the stock via spatial availability (FIGURE 44). Specifically, domed selectivity for Region 2 and Region 3 in the long AAF model implicitly assumes that older fish (located in northern and western areas) were historically less available and therefore less mobile. Conversely, in the coastwide long model the assumption of asymptotic selectivity implies a high degree of availability and therefore connectivity between all geographic components in the population. Sensitivity analyses in the 2015 assessment indicted that these two models could be made much more similar by adjusting the degree of domed selectivity (Stewart and Martell 2016). The use of both of these models encompasses the range of uncertainty that exists over this aspect of the historical population dynamics, thus the primary sensitivity in the stock assessment is included in the ensemble results.

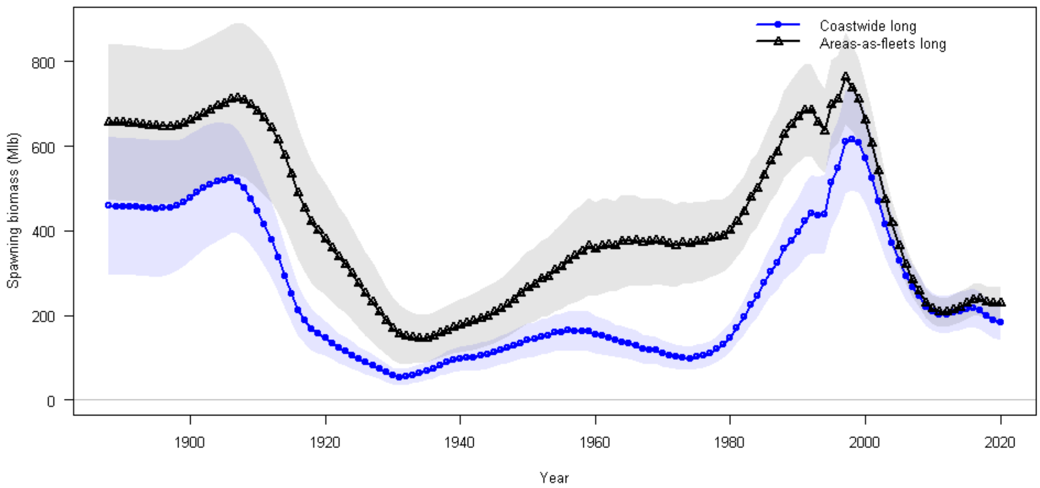


FIGURE 44. Comparison of the spawning biomass for the long coastwide and AAF models.

Steepness of the stock-recruitment relationship was fixed at a value of 0.75 for all four models. Exploratory model runs revealed that when estimated, steepness was either very imprecisely informed or maximum likelihood values occurred at the upper bound of 1.0. The effects of estimating steepness on the spawning biomass time series varied among the four models. The two short time-series models showed little difference in the estimated time series when steepness was estimated (FIGURE 45), likely due to the flexible initial conditions and the full information content of the entire series directly informing all recruitment deviations. The long AAF model also showed little difference when steepness was estimated (FIGURE 46), and was the only model where steepness did not go to a value of 1.0 (however the 95% interval did contain 1.0). In contrast, the coastwide long model showed an increase in the scale of both the spawning biomass and recruitment estimates across the entire time-series when steepness was estimated (FIGURE 47). This is likely due to an interaction between the very low relative stock sizes estimated during the historical period and the relatively small value of the σ constraining recruitment deviations (0.55; TABLE 9), and the higher estimated natural mortality in this model. This sensitivity was not investigated further to determine whether retuning the recruitment σ would result in a smaller difference in the overall results.

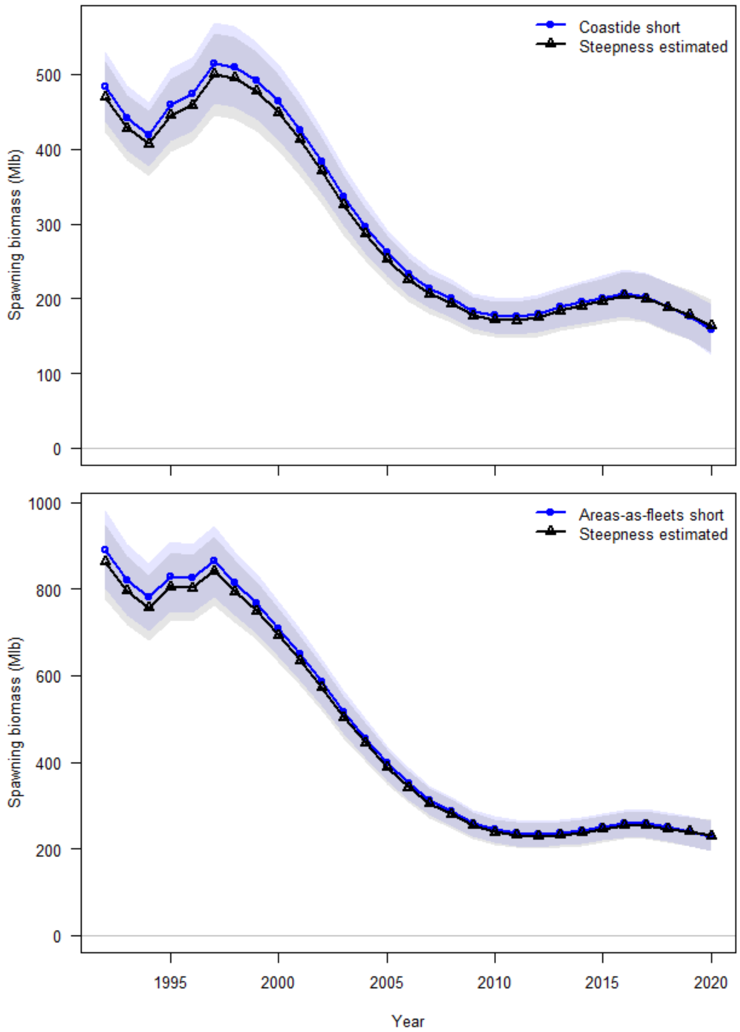


FIGURE 45. Effect of freely estimating steepness (*h*) in the coastwide short model (upper panel) and in the AAF short model (lower panel).

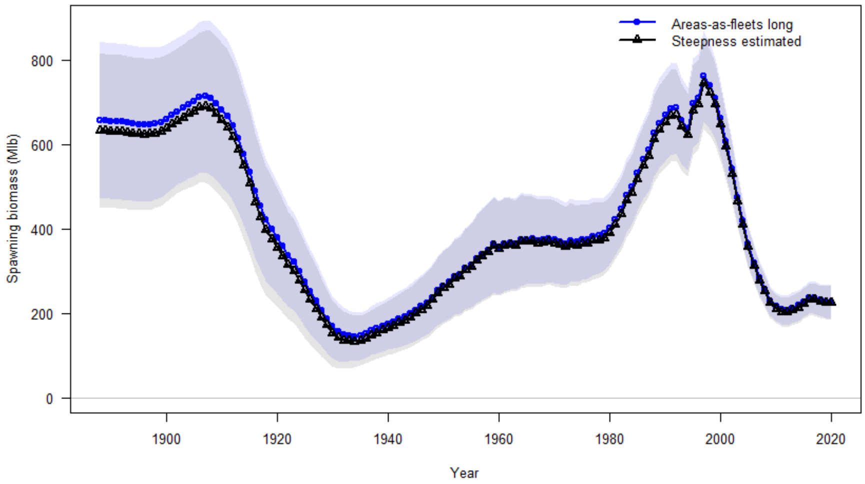


FIGURE 46. Effect of freely estimating steepness (*h*) in the AAF long model.

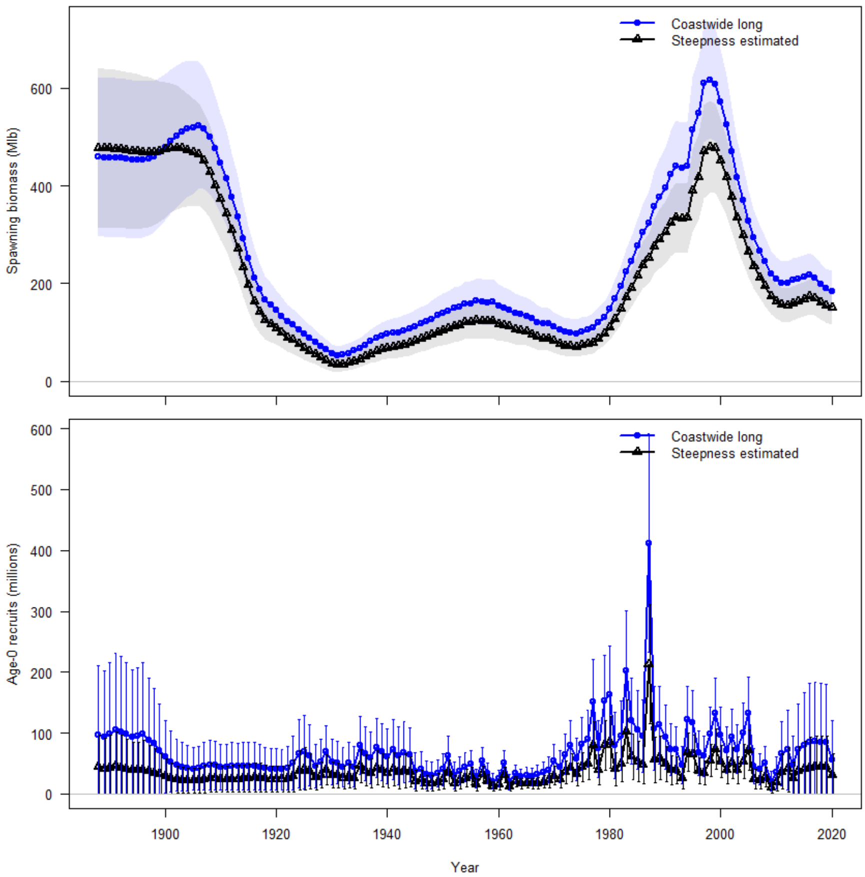


FIGURE 47. Effect of freely estimating steepness (*h*) on spawning biomass (upper panel) and recruitment estimates (lower panel) in the coastwide long model.

Female natural mortality (*M*) is fixed at 0.15 in the two short time-series models, representing a very strong assumption about the scale and productivity of the estimated population. In exploratory analyses, the values of female and male natural mortality were not jointly estimable with only the short time-series of data to inform them given the other estimated processes in these models. To evaluate the degree of uncertainty missing from these models, lower and higher values were constructed based approximately on the width of the intervals from the two long models where female natural mortality is freely estimated. Centered on the fixed value of 0.15, models with a lower value of 0.13 and a higher value of 0.17 were run. The results were consistent with previous sensitivity analyses: female natural mortality is a direct scalar on the scale of spawning biomass and recruitment in both the coastwide and AAF short models (FIGURE 48-49). Higher values of natural mortality corresponded to larger stock sizes and age-0 recruitment estimates; however, the trends in both series were nearly identical to those from the model assuming female natural mortality was 0.15.

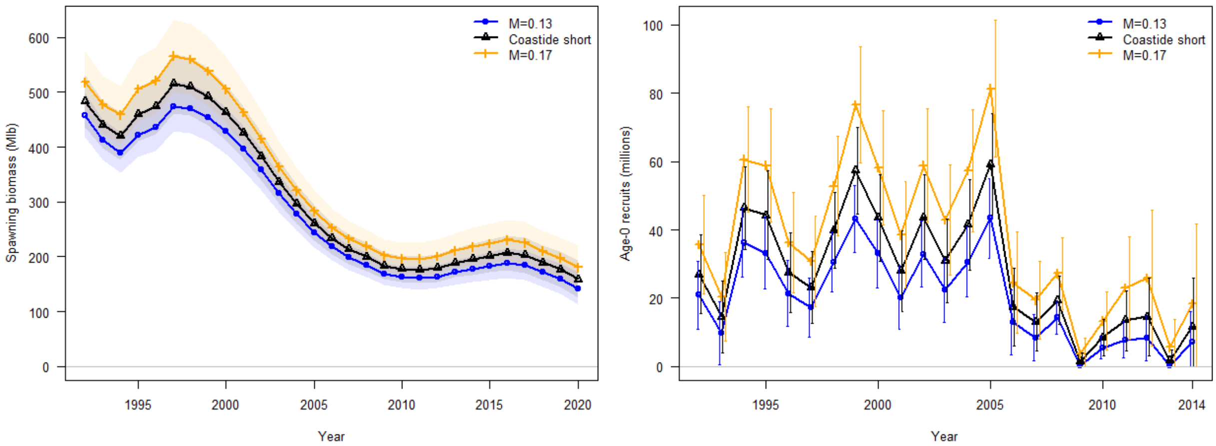


FIGURE 48. Effect of alternative fixed values of natural mortality relative to the base value (0.15) in the coastwide short model.

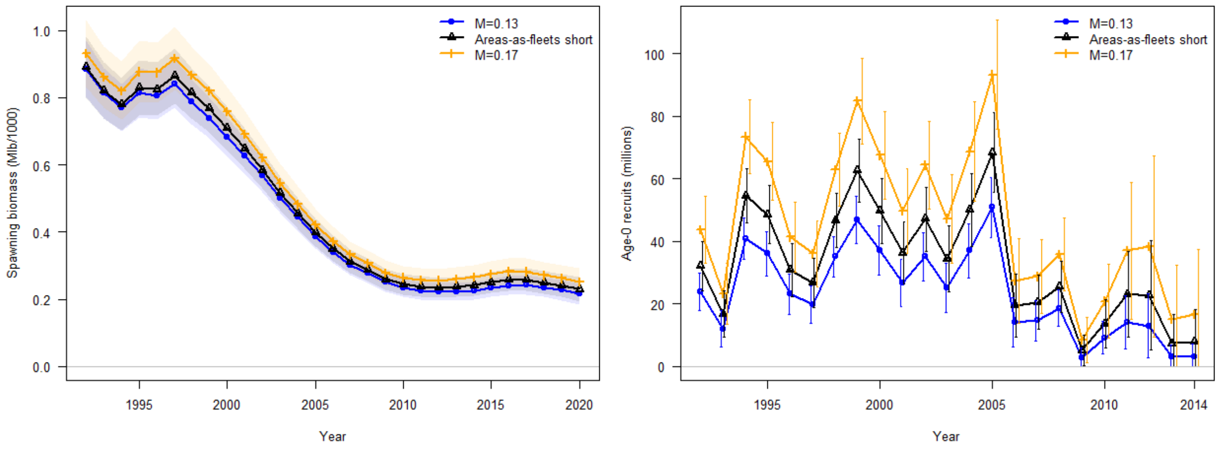


FIGURE 49. Effect of alternative fixed values of natural mortality relative to the base value (0.15) in the AAF short model.

For each of the models where one or more sources of age data were relatively weighted much less than the others a sensitivity was conducted to determine if this weighting consistently effected the biomass in one direction and how strongly. To conduct these sensitivity analyses, the lowest weighted age data (depending on the model) was increased to be roughly consistent in input sample size with other sources without making any other changes (i.e., retuning process and observation error) in that model. Increasing the weight of the commercial fishery age data in the coastwide short model led to a reduction in the scale of the estimated spawning biomass (FIGURE 50). Conversely, increasing the weight of the survey age data had a positive effect on the scale and trend of the spawning biomass time-series in both the AAF short (FIGURE 51) and long models (FIGURE 52). These results suggest that it may be worthwhile to explore reparameterizing the selectivity curves and process error (time-varying parameters) for fleets receiving lower weighting, in order to search for an approach that could fit these data better, but still retain internal consistency. It is unclear whether similar effects of the biomass time-series would be realized, but this sensitivity analysis underscores the importance of internally consistent data weighting, and the relative sensitivity of three of these models for Pacific halibut to the conflicting signals in the data. The degree to which these conflicting signals may be a result of unmodelled spatial processes is unknown, but there may not be a dramatic improvement using only nonspatially-explicit approach for these population dynamics.

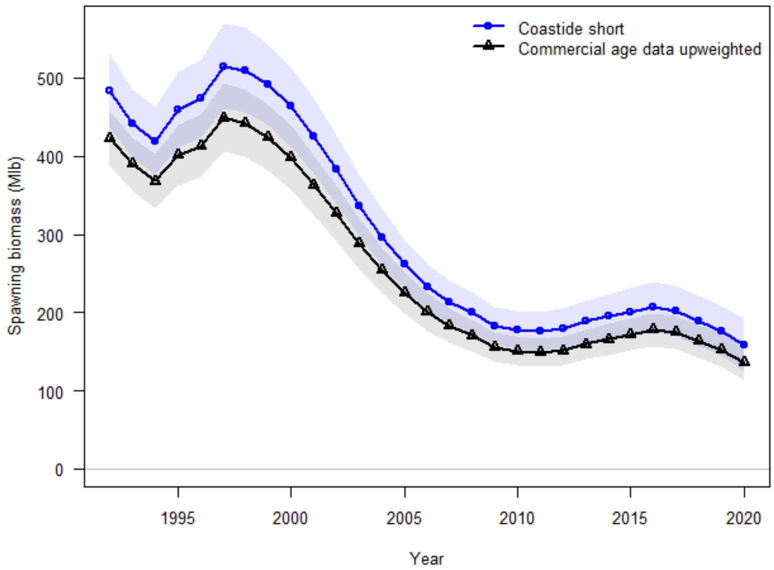


FIGURE 50. Effect of upweighting the commercial fishery age data in the coastwide short model.

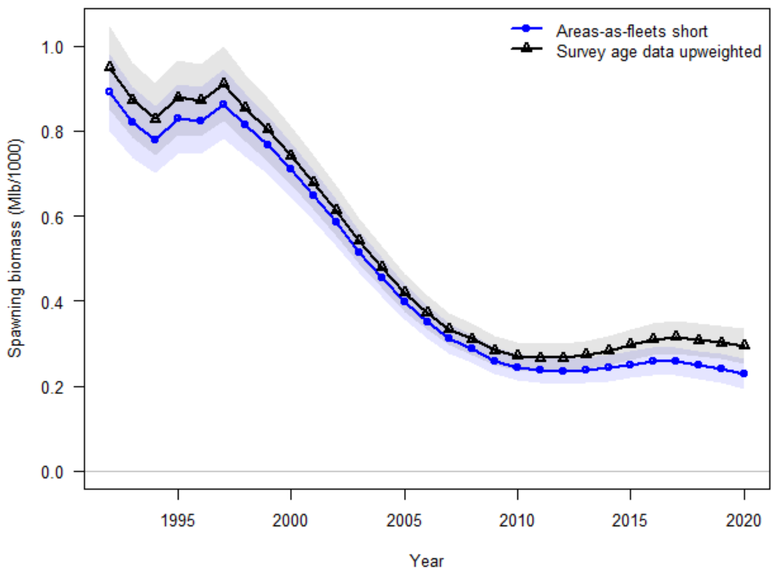


FIGURE 51. Effect of upweighting the survey age data in the AAF short model.

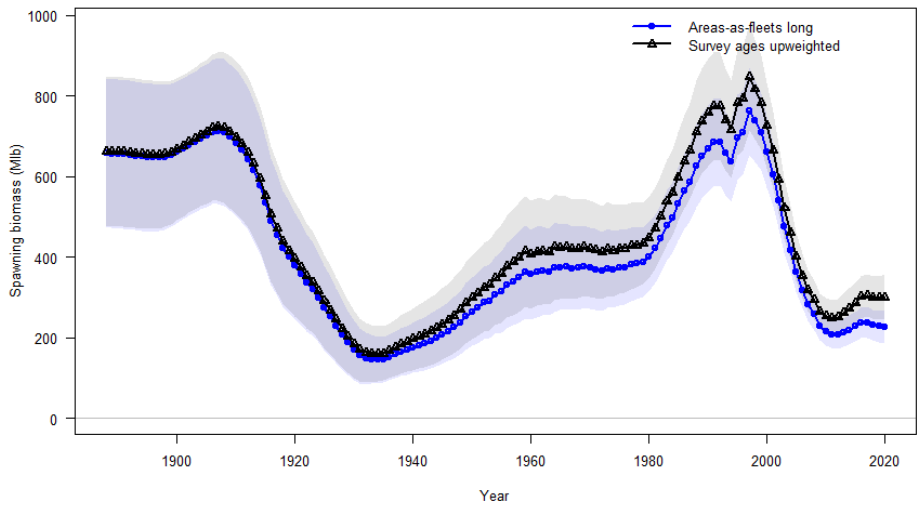


FIGURE 52. Effect of upweighting the survey age data in the AAF long model.

Retrospective analyses

The halibut model used from 2006 until 2011 was plagued by a very strong retrospective pattern, both in the scale of the most recent stock size estimates as well as the trend in those estimates (Stewart and Martell 2014b; Stewart et al. 2013a). The solution to this problem was additional flexibility for process error (temporal variability) in the selectivity curves for both the fishery and survey representing not just gear (or 'contact') selectivity but also spatial availability.

Retropective analyses were conducted for these preliminary 2019 models by sequentially removing the terminal six years from the model (a five-year retrospective, since the terminal year currently contains no information other than mortality projections). Both the coastwide and AAF short models showed variability in the scale of the spawning biomass estimates, with the only apparent trend (increasing) occurring in the AAF short model after the important sex-ratio data from the 2017 commercial fishery landings were removed in the third year of the retrospective (FIGURE 53-54). The coastwide long time series model was also sensitive to the retrospective removal of data, again particularly so after the sex-ratio data from 2017 had been removed and fits to the data and parameter estimates became unreliable (FIGURE 55). A slightly increasing trend was observed in the AAF long model, although retrospective estimates remained inside the 95% intervals from the base model (FIGURE 56).

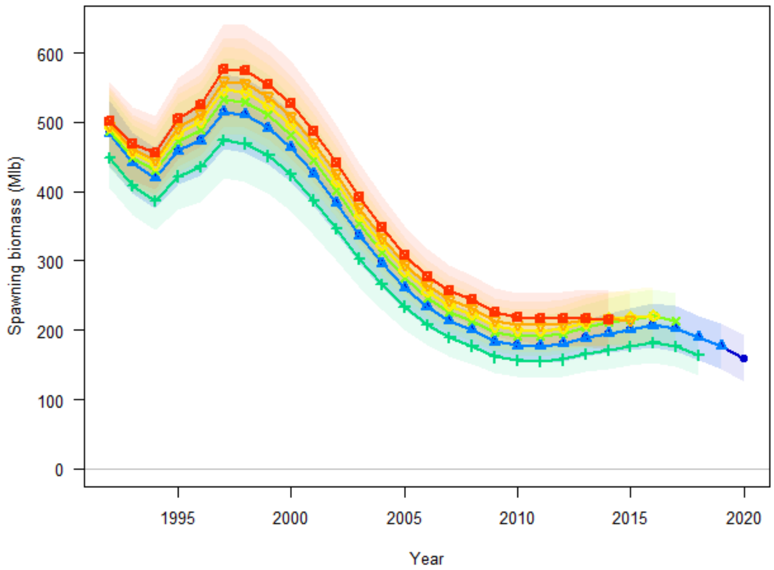


FIGURE 53. Six-year retrospective analysis of spawning biomass (1st year is a projection with no data) based on the coastwide short model.

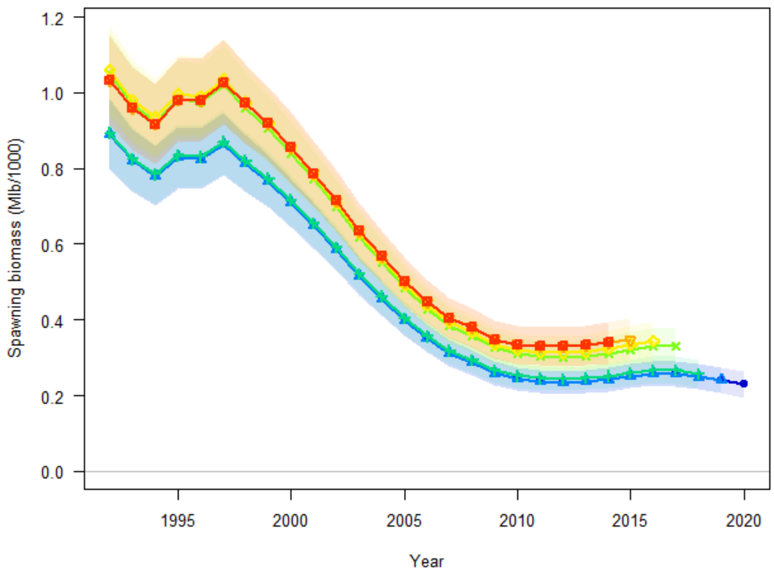


FIGURE 54. Six-year retrospective analysis of spawning biomass (1st year is a projection with no data) based on the AAF short model.

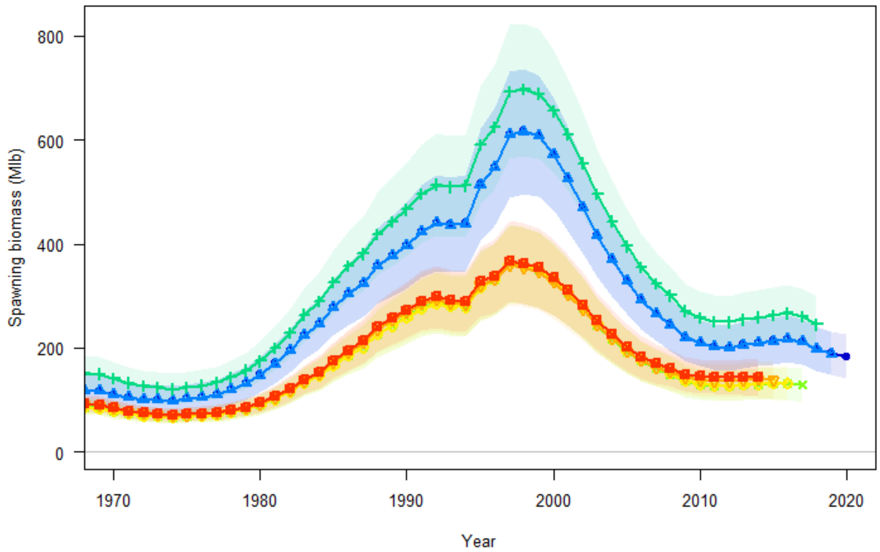


FIGURE 55. Six-year retrospective analysis of spawning biomass (1st year is a projection with no data) based on the coastwide long model.

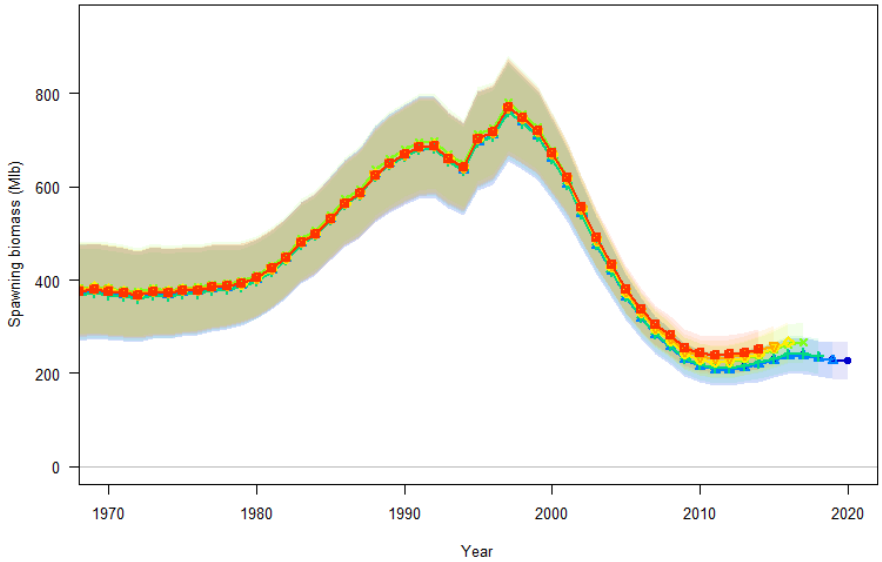


FIGURE 56. Six-year retrospective analysis of spawning biomass (1st year is a projection with no data) based on the AAF long model. Time-series is truncated in 1972 so that differences in the terminal years are more visible.

In order to better understand the interaction between the retrospective analysis and the important change in information content provided by the 2017 sex-ratio information (allowing for the estimation of the scale of male selectivity in the commercial fisheries), a second series of retrospective analyses were conducted for the short AAF, and two long time-series models. This set of retrospective analyses fixed the scale of male selectivity at the estimates from the base models, and then sequentially removed each year of data as above. The results indicated little difference in the retrospective patterns for the AAF short (FIGURE 57) and AAF long models (FIGURE 58). In contrast, the coastwide long model showed very little retrospective pattern when the scale of the male selectivity was fixed at the base estimate, illustrating the sensitivity to, and importance of this piece of information to the current stock assessment (FIGURE 59).

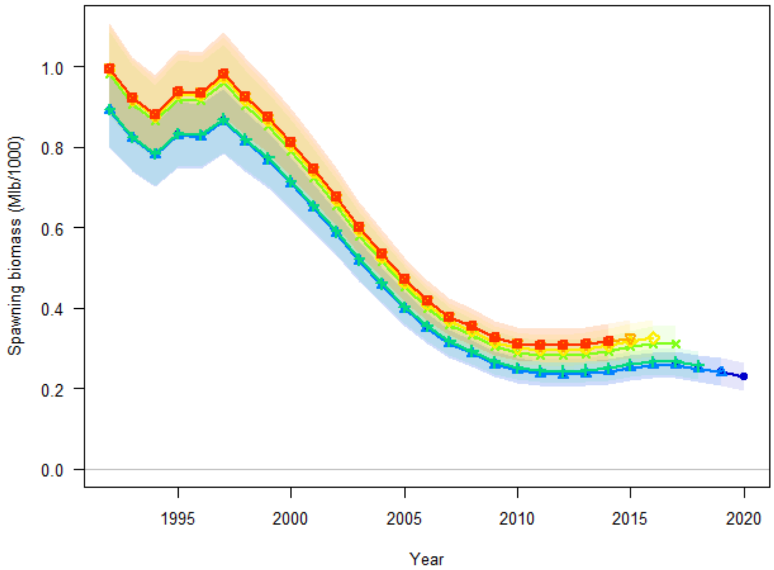


FIGURE 57. Alternative six-year retrospective analysis of spawning biomass (1st year is a projection with no data) holding commercial male selectivity scale constant based on the AAF short model.

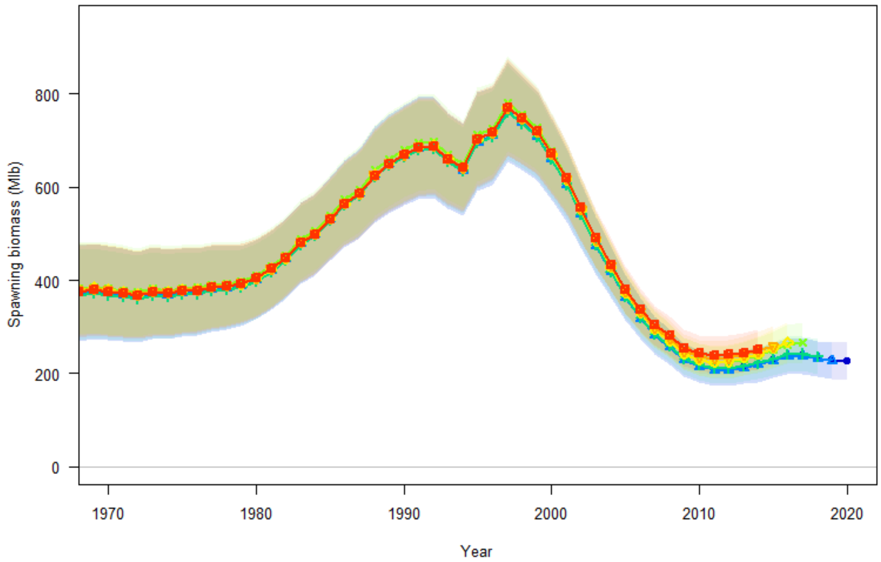


FIGURE 58. Alternative six-year retrospective analysis of spawning biomass (1st year is a projection with no data) holding commercial male selectivity scale constant based on the AAF long model.

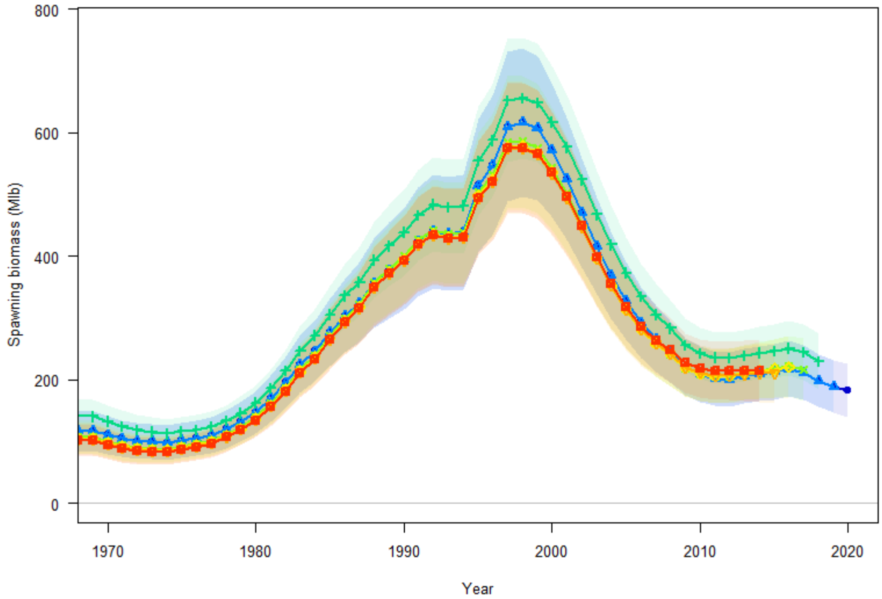


FIGURE 59. Alternative six-year retrospective analysis of spawning biomass (1st year is a projection with no data) holding commercial male selectivity scale constant based on the coastwide long model.

Bayesian analysis

Like most fisheries analyses, the models used for the Pacific halibut stock assessment have always been based on Maximum Likelihood Estimates (MLEs) and asymptotic approximations to the variance about these estimates (Fournier et al. 2012). However there are a number of potential benefits to using an explicitly Bayesian approach, including better characterization of uncertainty (Magnusson et al. 2012) and a more directly interpretable characterization of the probability distributions. There is also the potential for differences in the results of Bayesian analyses due to the right-skewed nature of some distributions in complex fisheries models (Stewart et al. 2013b).

Recent work by Cole Monnahan, who contributed to the 2015 stock assessment (Stewart et al. 2016), has demonstrated the potential for new methods to dramatically increase the computational efficiency of Bayesian models implemented in AD Model builder (Monnahan and Kristensen 2018). Similar, but not identical, results were reported for a regularized and simplified Bayesian assessment model based on the 2015 coastwide short Pacific halibut model as part of a larger evaluation of these new methods (Monnahan et al. 2019).

Previous reviews have not placed a high priority on the refinement of the models contributing to the Pacific halibut stock assessment toward a fully Bayesian implementation, but have noted some interest. For this preliminary assessment, we investigated the coastwide short time series model (the fastest running of the four) in a Bayesian context. We followed the iterative approach suggested by Monnahan et al. (2019; https://github.com/colemonnahan/bayes_assess/blob/master/demo.R) of first identifying highly correlated parameters with slow mixing during short pilot chains using the Random Walk Metropolis (RWM) algorithm in AD Model Builder, and then simplifying the model to reduce these posterior correlations. After this initial regularization, a two-step approach was used to run several parallel chains of the No-U-Turn-Sampler (NUTS) algorithm based first on the Hessian created during minimization, and then re-running longer parallel NUTS chains using a mass-matrix updated by the earlier run. Results were integrated using the 'sample_admb' function in R and diagnosed using the 'launch_shinyadmb' function.

For the coastwide short model, a small number of selectivity parameters (primarily highly correlated deviations) were removed from the model during regularization which had a very small (<3%) effect on the maximum likelihood estimate of spawning biomass, but dramatically sped up the mixing of the posterior sampling chains. Computation time for the iterative approach was approximately: 70 seconds for minimization and calculation of the Hessian matrix, 20 minutes per RWM chain, 12-14 hours for each set of preliminary NUTS chains, and 3-4 days for final NUTS chains. To compare with maximum likelihood results, seven parallel chains were run for 3000 iterations each. There were no divergences, and despite remaining parameter correlations and broad (weakly informed) posteriors for some deviation and selectivity parameters, the effective sample size was 1,217, and maximum 'Rhat' was 1.004 for the least well-mixed parameter. Therefore, these results appeared sufficient to draw inference on parameter distributions and quantities of management interest. These results were obtained much more quickly than previous attempts using the RWM algorithm, which still showed very low effective sample sizes after days of integration.

The short coastwide model results indicated that posterior distributions for primary scaling parameters were very close to maximum likelihood estimates (FIGURE 60). Both the female spawning biomass time-series and the recruitment time-series posteriors were also nearly identical to the asymptotic distributions with only a very slight asymmetry in the uncertainty intervals (FIGURE 61). This result suggests that the asymptotic distributions are a reasonable approximation for the full posterior distributions in this model, and also that the process of regularizing the selectivity parameters, and removing some deviations prior to integration did not having an appreciable effect on the solution. This is generally consistent with studies of process error where overparameterizing (adding the capability for variation when it wasn't present) was generally found to be unbiased, and therefore preferable to underparameterizing when temporal variability was present (e.g., Stewart and Monnahan 2017).

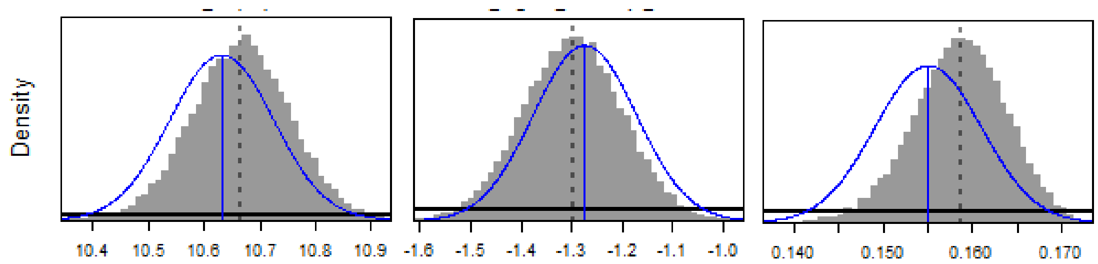


FIGURE 60. Distributions for select model parameters for the coastwide short model: ln(R0) (left panel), initial offset to ln(R0) (center panel), male natural mortality (right panel). Dark horizontal line represents the prior likelihood, symmetric distribution the MLE (vertical line) and asymptotic distribution, and histogram the posterior distribution with dashed line indicating the median.

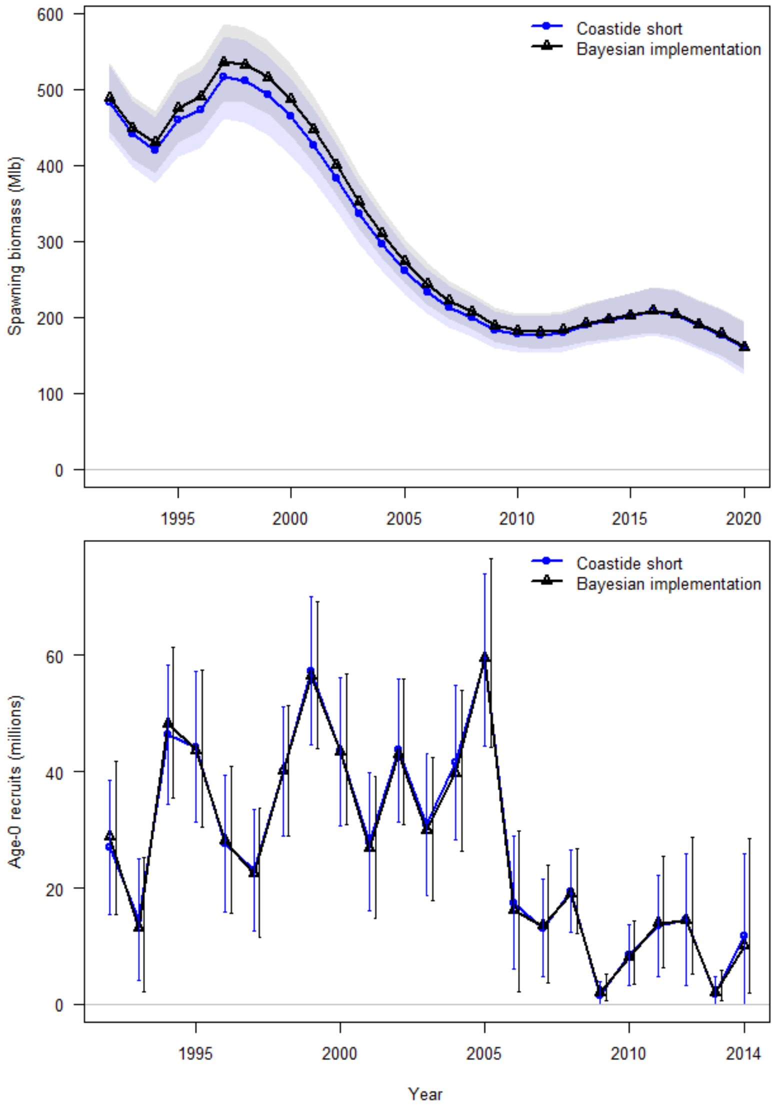


FIGURE 61. Comparison of the coastwide short model maximum likelihood estimates and asymptotic intervals to Bayesian posteriors from a regularized version of the model.

Other uncertainty considerations

There are many important sources of uncertainty not captured in the four models included in this ensemble. These include myriad alternative structural assumptions such as spatially-explicit population dynamics, connection with Russian waters, alternative stock-recruitment functions, age-dependent mortality, different data weighting approaches, and many others. There are also several tractable sources of projection uncertainty that are not in the current approach, including uncertainty in future weight-at-age (although the sensitivity of this was investigated at SRB request in 2016 and found to be low), future selectivity, and projected mortality.

Within the modelled time-series there are also data-related uncertainties that could be addressed via a range of alternative approaches. Uncertainty in the time series of mortality for these models is not currently captured, as they are treated as inputs and assumed to be known without error. In previous assessments, sensitivity analyses have been conducted to the degree of discard mortality in the commercial fishery, potential effects of unobserved whale depredation, as well as to the magnitude of total bycatch mortality. In concept, these types of uncertainties could be included in the models; however, full estimation of catch in statistical catch-at-age models generally requires other stabilizing assumptions, so direct integration of this uncertainty may still prove challenging.

Additional sources of uncertainty and avenues for development are identified in the Research Priorities section below.

The ensemble

Model-integrated quantities are used as the primary output for stock assessment results, as well as the basis for decision table probabilities (Stewart and Hicks 2019). All quantities of management interest are integrated for the recent time period (1992+), for which all four sets of model results are available. These quantities include: spawning biomass, relative spawning biomass, and the Spawning Potential Ratio (SPR; summarized as fishing intensity, $F_{XX\%}$, where the *XX%* represents *SPR*). Decision table quantities are divided into four categories: stock trend (which is the only set of metrics that are independent of any harvest strategy related assumptions), stock status, fishery trend, and fishery status. Integration is performed for all these quantities using the basic approach outlined below.

Methods

The basic approach to model integration remains unchanged from the 2015 and subsequent analyses. A sample of random draws is created from the output from each of the models included in the ensemble. For the spawning biomass time-series, the estimates and associated standard deviations for female spawning biomass from each of the four models were extracted from the report file. A vector of length n is created for each model (m), where the relative weight (w_m) is simply the relative fraction of the total draws across all models comprised by n_m:

$$w_m = \frac{n_m}{\sum_m n_m}$$

This approach allows for easily adjusted weighting of models. For the results presented below n_m for all models was set equal to five million, this generated equal weight for each model and was found to be sufficient to create extremely smooth distributions, with little to no sign of Monte-Carlo error even in the extreme tails of the distributions. Although this choice could potentially be optimized, current integration code (in R) takes only seconds to run, and does not represent a constraining step in the analysis. For each element in the vector a random normal value with mean and standard deviation equal to the estimates from that model was created. Summary statistics for the integrated distribution were saved for reporting and plotting.

Since the 2005 assessment, the IPHC has transitioned to using SPR as the primary metric to measure fishing intensity, and as the basis for the harvest control rule (Hicks and Stewart 2019). Similar to spawning biomass, SPR is a direct output quantity from stock synthesis including a variance estimate for each year. Thus, random draws can be created without additional inputs other than the model report files.

Previous calculation of relative spawning biomass for use as the reference points in the IPHC's harvest control rule was structured to match the assumptions of the IPHC's harvest strategy as closely as possible. The harvest strategy employs a control rule that reduces the coastwide SPR target linearly from the interim 'reference level' at $SB_{30\%}$ to zero at $SB_{20\%}$. Historically, relative biomass was defined relative to poor recruitment conditions and relatively good size-at-age, and the constants defining these conditions were fixed (no variance) and had been estimated through historical analyses that could no longer be recreated (Clark and Hare 2002b, 2006). These reference points could be approximated in the long time series models, but relied on fixed constants in the short time-series models (Stewart and Martell 2016).

For consistency with current MSE analyses informing management decisions about the scale of coastwide mortality (Hicks and Stewart 2019), and better propagation of variance, the calculation of relative spawning biomass is updated in this assessment. The IPHC's ongoing MSE and other research has highlighted the value of dynamic reference points (representing current, rather than average or period-specific historical conditions) when strong direction shifts in productivity occur (Berger 2018). The dynamic estimate of 'unfished' biomass is calculated for each year of the time-series in stock synthesis. This calculation replays the entire time-series, without the fishing mortality, assuming the same parameter values (including recruitment deviations) but accounting for the different level of spawning biomass projected for each year and its effect on subsequent expected (pre-deviation) recruitment in each year.

The only challenge to using the dynamic unfished biomass in the calculation of status and reference points is that it is not currently calculated as an 'sd_report' variable in stock synthesis, and thus has no variance or covariance associated with the point estimate. Therefore, for all relative spawning biomass calculations as simple approximation was used that included the estimates and variance of the estimates of spawning biomass in each year and the point estimate of dynamic unfished biomass in each year. The approach can be summarized in the following steps:

1) Extract the estimate and variance of spawning biomass in each year.
2) Convert the quantities in (1) to a coefficient of variation (CV).
3) Use CV of spawning biomass as a proxy for CV of the dynamic unfished spawning biomass, thereby accounting for the scale difference in the two quantities.
4) Assume a correlation between spawning biomass and dynamic unfished spawning biomass of 0.75.
5) Simultaneously draw random correlated multivariate normal values for spawning biomass and unfished dynamic spawning biomass in each year in order to calculate relative spawning biomass (the ratio of the two).

Two avenues were explored in order to evaluated how appropriate this assumption was, and how sensitive is was to alternative levels of correlation. The first of these was to make a general comparison with the results of the current MSE operating model where both quantities are simulated over many years. The MSE operating models indicated that correlations of around 0.75 were reasonable. Second, results were recalculated under differing assumptions of correlation ranging from 0.35 to 0.95. For current relative spawning biomass in the preliminary 2019 ensemble there was only a 1% difference observed in the median estimate, and less than 5% difference in the tails corresponding to the 95% interval. This calculation includes at least an approximation for more components of the variance in relative spawning biomass than previous methods, and appears to provide a reasonable proxy until revisions can be made to stock synthesis to extract the variance and covariance of the dynamic unfished spawning biomass and estimated spawning biomass for each year.

To calculate the ratio of projected future spawning biomass estimates to current values (e.g., spawning biomass current vs. spawning biomass three years in the future), conditioned on alternative input projected catch streams, both the variance and covariance estimates are directly available. The correlation is included in the calculation of this ratio as well: instead of drawing a vector of independent random normal values for each spawning biomass, the draws are multivariate normal, including the estimated covariance. The decision table also includes a metric reporting the probability that the harvest rate in the upcoming year will exceed to target harvest rate using the estimates and projections of SPR. The ratio of the projected harvest rate to the target rate (modified by the median spawning biomass relative to the $SB_{30\%}$ and $SB_{20\%}$ references points via the 30:20 control rule) is then computed. The proportion of values greater than 1.0 thus represents the probability of exceeding the target. The remaining model-integrated results are the fishery trend metrics. These report the probability that applying the current harvest policy in a future year (one and three years hence) would result in a lower TCEY (Total Constant Exploitation Yield; essentially the mortality limit set by the IPHC each year including all sources except bycatch of small, <26 inch, fish) than the value specified for that row of the decision table. This calculation first creates a distribution of SPRs, then finds the target harvest rate accounting for the spawning biomass relative to the harvest control rule and creates a distribution of future TCEYs.

Preliminary results for 2019

Comparison of the 2020 spawning biomass estimates from the four stock assessment models comprising the ensemble shows that the 95% intervals from any single model are substantially narrower than the aggregate (TABLE 13, FIGURE 62). However, these differences are much smaller than the uncertainty in historical biomass levels in the 1990s (FIGURE 63). Recent recruitment time-series clearly reflect the differences in the various estimates and fixed values of natural mortality, but show very similar relative trends across all four individual models (FIGURE 64).

TABLE 13. Summary of individual model and ensemble distributions for 2020 spawning biomass (millions of pounds).

	Percentile		
Model	2.5%	50%	97.5%
Coastwide Long	141	184	227
Coastwide Short	125	159	193
AAF Long	185	227	269
AAF Short	194	230	265
Ensemble	135	203	261

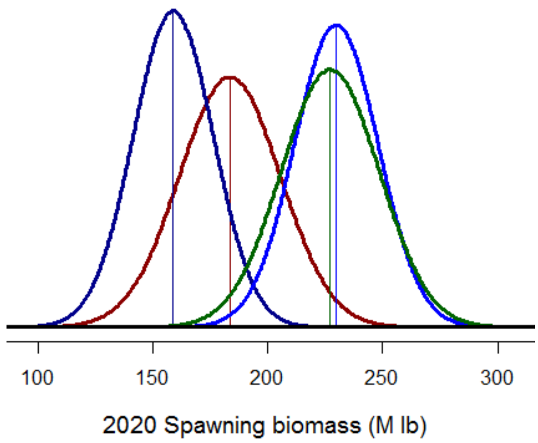


FIGURE 62. Comparison of 2020 spawning biomass distributions (asymptotic approximations) from each of the preliminary models contributing to the 2019 ensemble.

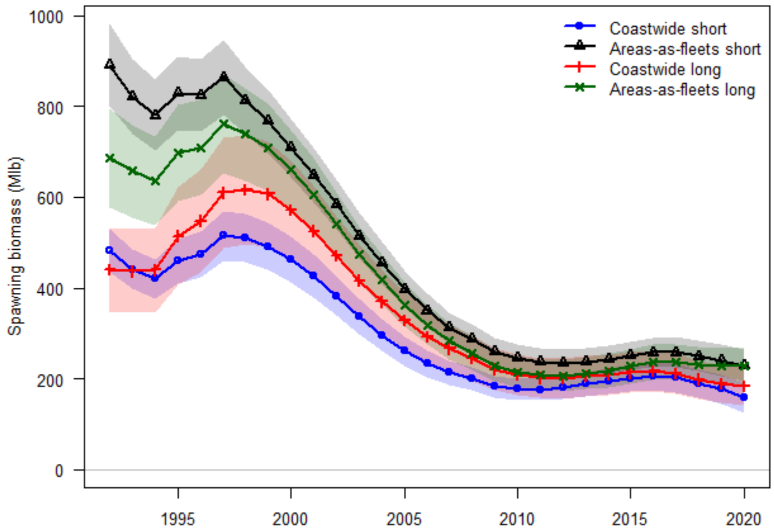


FIGURE 63. Comparison of spawning biomass time series (shaded regions indicate asymptotic approximations to the 95% confidence interval) from each of the preliminary models contributing to the 2019 ensemble.

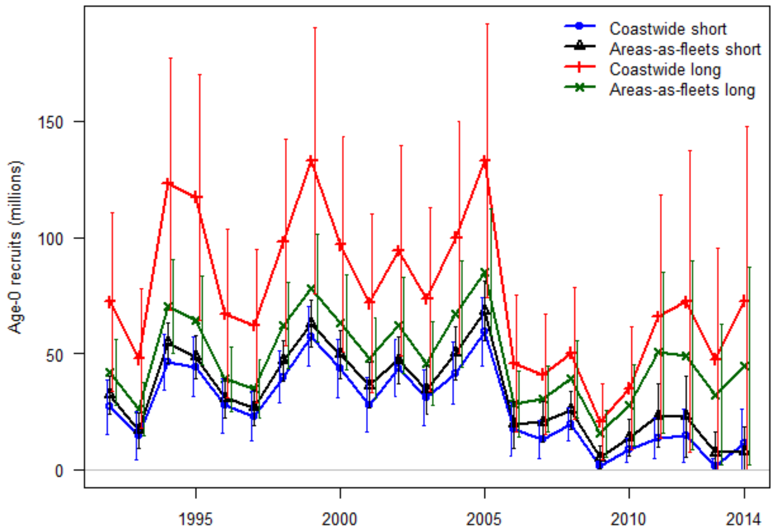


FIGURE 64. Comparison of recruitment time series (vertical lines indicate asymptotic approximations to the 95% confidence interval) from each of the preliminary models contributing to the 2019 ensemble.

As in recent assessments, the four stock assessment models comprising the ensemble are equally weighted. Comparison of ensemble results for the time-series of spawning biomass with recent stock assessment indicates a slightly larger median spawning biomass at the end of the series, but a very similar trend to previous results (TABLE 14, FIGURE 66). Fishing intensity (via SPR) is estimated to be somewhat higher since 2003 (TABLE 14). Because the mortality inputs to the assessment models have not changed and the biomass is larger, this clearly illustrates the effect of an increased fraction of females in the commercial landings, and therefore a greater effect of the lifetime spawning output of the stock.

The median relative spawning biomass (as calculated above) at the beginning of 2020 was estimated to be 31% (95% interval from 20-44%), with a probability of being below $SB_{30\%}$ of 44%, and a probability of being below $SB_{20\%}$ of 2%. Given the change in the calculation of these reference points from the fixed historical inputs to the dynamic calculation, a series of comparisons were made in order to clearly determine how much of the change in status from the 2018 assessment was due to the additional year of projection, the calculation methods, and the new data and updated models. The following reference points were constructed from the 2018 stock assessment and the preliminary 2019 results:

- From the 2018 stock assessment: median relative biomass in 2019 (based on the previous reference points) was estimated to be 43% (95% interval from 27-63%), with a probability of being below $SB_{30\%}$ of 11%, and a probability of being below $SB_{20\%}$ of <1%.
- Extending the 2018 stock assessment assessment time series, but not making any changes to the data or calculations: median relative biomass in 2020 (based on the previous reference points) was estimated to be 38% (95% interval from 22-51%), with a probability of being below $SB_{30\%}$ of 25%, and a probability of being below $SB_{20\%}$ of <1%.

- After updating the assessment to the preliminary 2019 configuration: median relative biomass in 2019 (based on the updated calculations) was estimated to be 32% (95% interval from 23-44%), with a probability of being below $SB_{30\%}$ of 38%, and a probability of being below $SB_{20\%}$ of <1%.

Thus, a portion of the change in status is due to the change in reference points, but the majority of the change (7% of the 12%) is due to the addition of new data and updating of the individual models comprising the ensemble. The considerable uncertainty in these estimates leads to overlapping confidence intervals in all reference point comparisons.

TABLE 14. Summary of ensemble distributions from the 2018 stock assessment and this preliminary analysis.

	2018 assessment				2019 preliminary			
Year	Spawning biomass (Mlb)	95% interval (Mlb)	Fishing intensity ($F_{XX\%}$)	95% interval	Spawning biomass (Mlb)	95% interval (Mlb)	Fishing intensity ($F_{XX\%}$)	95% interval
1992	NA	NA	NA	NA	555	380-950	44%	30-54%
1993	NA	NA	NA	NA	541	376-875	44%	29-54%
1994	NA	NA	NA	NA	535	374-831	45%	30-55%
1995	NA	NA	NA	NA	607	420-882	53%	37-63%
1996	503	398-737	51%	37-66%	632	437-877	52%	37-63%
1997	546	432-762	45%	32-62%	690	477-918	46%	32-58%
1998	543	424-727	43%	30-61%	682	474-864	44%	31-57%
1999	530	406-681	41%	29-60%	663	457-815	42%	30-56%
2000	500	377-633	41%	29-60%	621	430-755	41%	31-56%
2001	461	344-580	38%	28-58%	570	394-691	38%	29-53%
2002	416	307-525	34%	26-55%	510	354-622	34%	26-50%
2003	368	266-467	31%	23-52%	449	310-549	30%	24-46%
2004	327	233-417	28%	22-49%	397	273-487	27%	23-43%
2005	290	204-370	26%	21-48%	348	240-426	25%	22-42%
2006	260	181-332	26%	21-48%	307	214-376	25%	21-41%
2007	238	165-302	26%	21-48%	275	196-336	24%	21-41%
2008	222	154-284	26%	21-48%	252	183-310	24%	20-41%
2009	202	140-260	27%	21-49%	225	167-281	25%	20-42%
2010	194	134-250	27%	21-49%	212	161-265	25%	20-42%
2011	190	132-246	33%	25-53%	205	158-258	29%	25-47%
2012	190	133-247	38%	27-57%	204	160-255	34%	29-51%
2013	196	139-254	41%	29-58%	210	167-258	36%	30-53%
2014	202	142-263	46%	31-61%	216	172-264	42%	33-56%
2015	208	145-275	47%	31-61%	222	176-273	42%	33-56%
2016	215	149-288	48%	31-62%	229	180-281	43%	32-57%
2017	213	144-292	48%	29-61%	227	175-282	42%	30-55%
2018	205	134-288	49%	28-62%	216	163-273	42%	29-55%
2019	199	125-287	47%	NA	209	152-266	39%	24-54%
2020	NA	NA	NA	NA	203	135-261	NA	NA

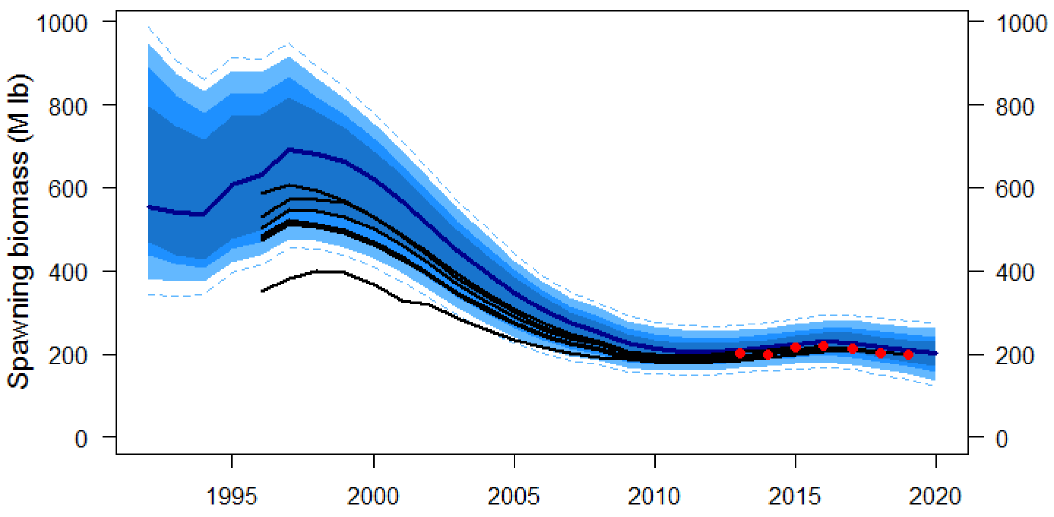


FIGURE 65. Comparison of estimated biomass time series for the preliminary 2019 ensemble (shaded region, colors indicate quantiles) and recent ensembles from 2013-2018 (black lines; red points indicate terminal estimates).

Future development

Several extensions to this preliminary assessment will be possible for the final 2019 analysis. These include:

- Responses to suggestions and comments generated from the external and SRB reviews to be conducted in June, 2019.
- Addition of all 2019 data, extending existing time series (mortality, indices, ages, etc.).
- The sex-ratio of the 2018 commercial fisheries landings may be available to be included in the final 2019 stock assessment.

In addition to the research priorities outlined below, there are potential avenues for development within and among the four models included in the ensemble.

One of these would be further investigation of the specific data sources that were relatively downweighted in one or more of the individual assessment models (see sensitivity analyses above). Alternative parameterizations of the underlying selectivity relationship and the temporally varying components of selectivity may allow for a model configuration that fits the particular data source better (less pattern in the residuals), allowing increased weighting, and perhaps improved fits to other data sources.

Other avenues for development include changes to the ensemble approach itself. Expanding the number of models included in the ensemble to better capture the uncertainty in natural mortality that is missed through using a fixed value in the two short time-series models is one such approach. Using the sensitivity analysis presented above, a comparison of the ensemble results when four additional models were added (two to each short time-series model representing higher and lower values of natural mortality). This comparison suggests that the plausible range of recent spawning biomass would be slightly wider under this expanded ensemble (FIGURE 66), but that the median value would be relatively unaffected due to the two short time-series models falling at the upper and lower ends of the range. If this approach is to be explored further, both weighting and technical efficiency should be considered. The appropriate weighting is likely to be via considering the high and low values of natural mortality for each of the short time-series models to be nested variants of a single model, and therefore each would get one-third of the weight assigned to the nested group consistent with traditional multimodel inference (Burnham and Anderson 2002). Technical costs of adding four additional models to the ensemble (doubling the number of model runs to be conducted overall) include additional time spent running these additional models rather than exploring other sensitivities and identifying clear effects of newly available data during the very short assessment analysis period each fall. Pragmatically, there may be relatively little to be gained from doubling the ensemble in this manner beyond slightly smoother integrated distributions.

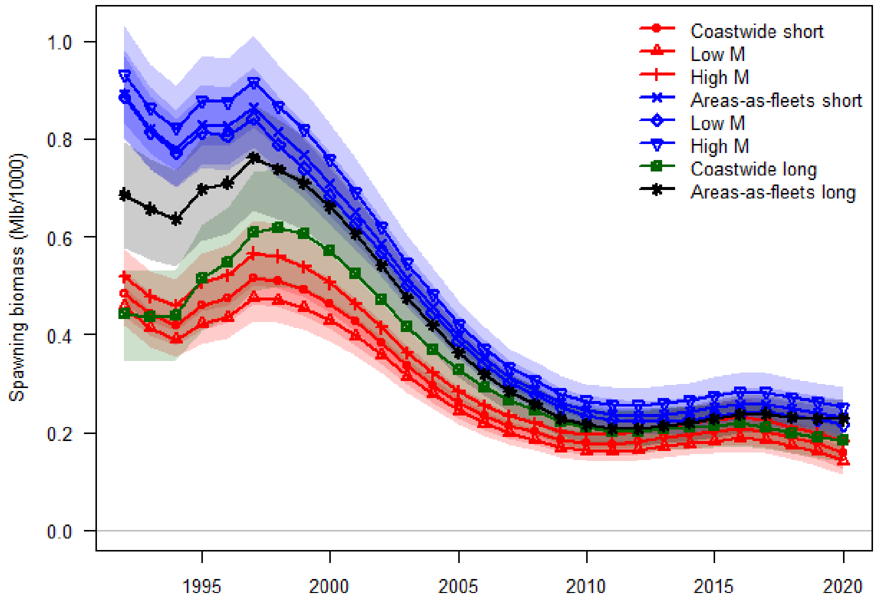


FIGURE 66. Comparison of spawning biomass time series (shaded regions indicate asymptotic approximations to the 95% confidence interval) from each of the preliminary models contributing to the 2019 ensemble with the addition of two alternative values for natural mortality for each of the short models.

The current ensemble is based on maximum likelihood estimates and asymptotic approximations to the posterior distributions for model parameters and derived quantities. Bayesian posteriors represent a conceptually more appealing basis for probability distributions, and could better capture the full range and potential asymmetries in the distributions for model quantities (Magnusson et al. 2012; Stewart et al. 2013b). Bayesian integration may also allow for statistically correct treatment of variance parameters (such as the sigmas governing recruitment variability and selectivity or catchability process error) in the absence of true random effects capability in AD Model builder. Although it would be technically preferable to regularize and run all four assessment models as Bayesian analyses, at present this is technically infeasible given the tight time-line between data availability and the deadline for the annual stock assessment. The analysis time difference between minimization and full posterior integration, even using the most efficient methods available for the coastwide short model (see section above), is still too large. However, if the IPHC were to move to a more formal management procedure and/or to a multi-year mortality limit-setting process, the stock assessment could be conducted at a pace that would allow much greater reliance on Bayesian models.

Finally, since 2015 there have been several investigations into using a revised weighting approach to the individual models contributing to the ensemble. Methods have included fit (and implied aggregate fit for the AAF models) to the coastwide survey time-series, the retrospective behaviour of each model relative to a null (simulated) distribution (Hurtado-Ferro et al. 2015), and the prospective skill of each model to predict the terminal survey index value. During 2015, 2016 and 2017, each of these methods was derived and presented to the SRB, but there was no clear support for deviating appreciably from an equal weighting approach. The benefits of such a weighting 'rule' could be realized if it were applied over time and annual decisions about weighting did not have to be made.

Research priorities

Research priorities for the Pacific halibut stock assessment can be delineated into three broad categories: improvements in basic biological understanding, investigation of existing data series and collection of new information, and technical development of models and modelling approaches.

Biological understanding

During the last several years, the IPHC Secretariat has developed a comprehensive five-year research program (Planas 2019). The development of the research priorities has been closely tied to the needs of the stock assessment and harvest strategy policy analyses, such that the IPHC's research projects will provide data, and hopefully knowledge, about key biological and ecosystem processes that can then be incorporated directly into analyses supporting the management of Pacific halibut. Key areas for improvement in biological understanding include:

- The current functional maturity schedule for Pacific halibut, including fecundity-weight relationships and the presence and/or rate of skip spawning.
- The stock structure of the Pacific halibut population. Specifically, whether any geographical components (e.g., Region 4B) are isolated to a degree that modelling approximations would be improved by treating those components separately in the demographic equations and management decision-making process.
- Movement rates among Biological Regions remain uncertain and likely variable over time. Long-term research to inform these rates could lead to a spatially explicit stock assessment model for future inclusion into the ensemble.
- The relative role of potential factors underlying changes in size-at-age is not currently understood. Delineating between competition, density dependence, environmental effects, size-selective fishing and other factors could allow improved prediction of size-at-age under future conditions.

- Improved understanding of recruitment processes and larval dynamics could lead to covariates explaining more or the residual variability about the stock-recruit relationship than is currently accounted for via the binary indicator used for the Pacific Decadal Oscillation.
- Improved understanding of discard mortality rates and the factors contributing to them may reduce potential biases in mortality estimates used for stock assessment.

Data related research

This section represents a list of potential projects relating specifically to existing and new data sources that could benefit the Pacific halibut stock assessment.

- Continued collection of sex-ratio from the commercial landings will provide valuable information for determining relative selectivity of males and females, and therefore the scale of the estimated spawning biomass, and the level of fishing intensity as measured by SPR. Potential methods for estimating historical sex-ratios from archived scales, otoliths or other samples should be pursued if possible.
- The work of Monnahan and Stewart (2015) modelling commercial fishery catch rates has been extended to include spatial effects. This could be used to provide a standardized fishery index for the recent time-series.
- A revised hook spacing relationship (Monnahan and Stewart 2017) will be investigated for inclusion into IPHC database processing algorithms.
- Reevaluation of the historical length-weight relationship to determine whether recent changes in length-at-age are also accompanied by changes in weight-at-length and how this may change estimates of removals over time is ongoing.
- A historical investigation on the factors influencing observed size-at-age, and ageing of additional samples from key periods and areas to support this analysis is ongoing at the IPHC.
- There is the potential that trawl surveys, particularly the Bering Sea trawl survey, could provide information on recruitment strengths for Pacific halibut several years prior to currently available sources of data. Geostatistical modelling and renewed investigation of the lack of historical correlation between trawl survey abundance and subsequent abundance of Pacific halibut in the FISS and directed fisheries may be helpful for this effort.
- There is a vast quantity of archived historical data that is currently inaccessible until organized, electronically entered, and formatted into the IPHC’s database with appropriate meta-data. Information on historical fishery landings, effort, and age samples would provide a much clearer (and more reproducible) perception of the historical period.
- Additional efforts could be made to reconstruct estimates of subsistence harvest prior to 1991.
- NMFS observer data from the directed Pacific halibut fleet in Alaska could be evaluated for use in updating DMRs and the age-distributions for discard mortality. This may be more feasible if observer coverage is increased and if smaller vessels (< 40 feet LOA, 12.2 m) are observed in the future. Post-stratification and investigation of observed vs. unobserved fishing behavior may be required.
- Historical bycatch length frequencies and mortality estimates need to be reanalyzed accounting for sampling rates in target fisheries and evaluating data quality over the historical period.

- There are currently no comprehensive variance estimates for the sources of mortality used in the assessment models. In some cases, variance due to sampling and perhaps even non-sampling sources could be quantified and used as inputs to the models via scaling parameters or even alternative models in the ensemble.
- A space-time model could be used to calculate weighted FISS age-composition data. This might alleviate some of the lack of fit to existing data sets that is occurring not because of model misspecification but because of incomplete spatial coverage in the annual FISS sampling which is accounted for in the generation of the index, but not in the standardization of the composition information.

Technical development

There are a variety of technical explorations and improvements that could benefit the stock assessment models and ensemble framework. Although larger changes, such as the new data sets and refinements to the models presented in this document, naturally fit into the period full assessment analyses, incremental changes may be possible during updated assessments when and if new data or methods become available. Specifically, development is intended to occur in time for initial SRB review (generally in June), with only refinements made for final review (October), such that untested approaches are not being implemented during the annual stock assessment itself. Technical research priorities include:

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

- Continued refinement of the ensemble of models used in the stock assessment. This may include investigation of alternative approaches to modelling selectivity that would reduce relative downweighting of certain data sources (see section above), evaluation of additional axis of uncertainty (e.g., steepness, as explored above), or others.

- Evaluation of estimating (Thorson 2018) rather than tuning (Francis 2011; Francis 2016) the level of observation and process error in order to achieve internal consistency and better propagate uncertainty within each individual assessment model. This could include the 2d Autoregressive smoother for selectivity, the Dirichlet multinomial, and other features now implemented in stock synthesis (Methot et al. 2019).

- Continued development of weighting approaches for models included in the ensemble, potentially including fit to the survey index of abundance, retrospective, and predictive performance (see section above).

- Exploration of methods for better including uncertainty in discard mortality and bycatch estimates in the assessment (now evaluated only via alternative mortality projection tables or model sensitivity tests) in order to better include these sources uncertainty in the decision table. These could include explicit discard/retention relationships, including uncertainty in discard mortality rates, and allow for some uncertainty directly in the magnitude of mortality for these sources.

- Bayesian methods for fully integrating parameter uncertainty may provide improved uncertainty estimates within the models contributing to the assessment, and a more natural approach for combining the individual models in the ensemble (see section above).

- Exploration of stock synthesis features previously unavailable or unevaluated including: timing of fishery and survey observations, the fishing mortality approximation used (i.e., estimated parameters, ‘hybrid’ or Pope’s approximations)
- An analysis of model sensitivity and statistical performance of treating the environmental relationship between recruitment and the PDO as annual deviates (+/-), a running mean, or annual values (actual PDO), or other methods that differ from the binary indicator variable currently employed.
- Alternative model structures, including a growth-explicit statistical catch-at-age approach and a spatially explicit approach may provide avenues for future exploration. Efforts to develop these approaches thus far have been challenging due to the technical complexity and data requirements of both. Previous reviews have indicated that such efforts may be more tractable in the context of operating models for the MSE, where conditioning to historical data may be much more easily achieved than fully fitting an assessment model to all data sources for use in tactical management decision making.

Acknowledgements

IPHC datasets comprise a wide array of sources based on extensive sampling and reporting efforts by state and national agencies in the U.S. and Canada. The IPHC’s annual stock assessment benefits from the hard work of all of its current and former employees providing high-quality data sets as comprehensive as any used for fisheries analysis. The Scientific Review Board and national science advisors have provided extensive guidance and constructive criticism of the treatment of data sources, the individual models and the stock assessment ensemble. Ray Webster leads, or contributes to, many of the supporting data analyses on which the assessment is based. Cole Monnahan has contributed conceptually to the stock assessment methods employed in this assessment, as well as technically in the implementation of Bayesian algorithms in ADMB.

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Appendices

Appendix A: Supplementary material

In addition to this document, supplementary material is available electronically, including:

1) Input files for each of the assessment models (implemented in stock synthesis) included in the proposed ensemble: data file, weight-at-age file, control file with model configuration, starter and forecast files with additional settings. Each of these files has been extensively annotated to aid in locating the various sections, as well as identifying which options and features were implemented or are irrelevant for the configuration.

2) Output from each of the stock assessment models: a sub-directory of all plotting and diagnostic output from each model created by the r4ss package (the entire set can be loaded at once via opening the HTML files), and the full report (text) file from each model. The report file has not been annotated; content and formats can be determined from the stock synthesis user manual (Methot et al. 2019) and technical documentation (Methot and Wetzel 2013a).

3) Copies of the primary software documentation including the general modelling approach implemented in stock synthesis (Methot and Wetzel 2013b), the technical documentation (Methot and Wetzel 2013a) and the current user manual (Methot et al. 2019). From these documents, detailed model equations, data configurations, and control settings can be evaluated for the specific features implemented in the models for Pacific halibut.

4) The overview of data sources (Stewart and Webster 2019) and the stock assessment results (Stewart and Hicks 2019) from the 2018 analysis.

5) The documentation from the 2015 full stock assessment (Stewart and Martell 2016).

6) Recent relevant IPHC manuscripts describing the history of the halibut stock assessment (Stewart and Martell 2014b), an evaluation of data weighting and process-error considerations (Stewart and Monnahan 2017), the general rationale for the ensemble approach (Stewart and Martell 2015), and the stability properties of ensemble assessments (Stewart and Hicks 2018c).

7) Additional historical stock assessment documentation can be found on the IPHC's web site (https://www.iphc.int/management/science-and-research/stock-assessment). Individual Scientific Review Board reports and presentations (2013-2018) are available (https://www.iphc.int/meetings/calendar?category=4).

An update on the IPHC Management Strategy Evaluation (MSE) process for SRB014

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PURPOSE

To provide an update of International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) activities including defining objectives, results for management procedures related to coastwide fishing intensity, development of a framework for distributing the TCEY, and the MSE program of work.

1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) completed a phase of looking at procedures management relative to the coastwide scale of the Pacific halibut stock and fishery. Results of the MSE simulations were presented at the 95th Session of the IPHC Annual Meeting (AM095) and the 13th Session of the IPHC Management Strategy Advisory Board (MSAB013). 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 (U26) bycatch, and is determined by the Commission at each Annual Meeting for each IPHC Regulatory Area.

This document first presents the objectives that the MSAB and Commission are using to evaluate management procedures. It then summarizes the results of the simulations investigating the coastwide scale portion of the management procedure. The framework describing the progress on developing a framework to investigate distributing the TCEY follows, and the program of work for the next two years is discussed.

2 GOALS AND OBJECTIVES

The MSAB currently has four goals, each one with multiple objectives. The four goals, and primary general objectives for each are

1. Biological Sustainability (also referred to as conservation goal)
   - 1.1. Keep biomass above a limit to avoid critical stock sizes
2. Optimise directed fishing opportunities (also referred to as fishery goal)
   - 2.1. Maintain spawning biomass around a level (i.e., a target biomass reference point) that optimises fishing activities
   - 2.2. Limit catch variability
   - 2.3. Maximize directed fishing yield
3. Minimize discard mortality
4. Minimize bycatch and bycatch mortality

The goal previously called “fishery sustainability, access, and stability” was refined to be “optimise directed fishing opportunities” to better reflect the desires of the directed fishery. In particular, this goal stresses optimising fishery yield with respect to stability and sustainability and optimizing the fishing opportunities ensures access. Discard and bycatch goals have not yet been specifically considered in the MSE but are identified as important goals to consider in the future.

There are two major components of the harvest strategy: coastwide scale and TCEY distribution (Figure 1). The MSE has recently focused on coastwide scale with an input fishing mortality rate (F_{SPR}) determining the total coastwide mortality, thus objectives have been focused at the coastwide level. The MSE program of work is now focusing on both components and the focus will be to refine coastwide objectives and define distributional objectives (i.e., area specific objectives).

In this section, we first present the MSAB-defined objectives related to coastwide scale, and performance metrics linked to those objectives. This is followed by a discussion of potential additional scale objectives. We then present the current proposed distribution objectives defined by the MSAB.

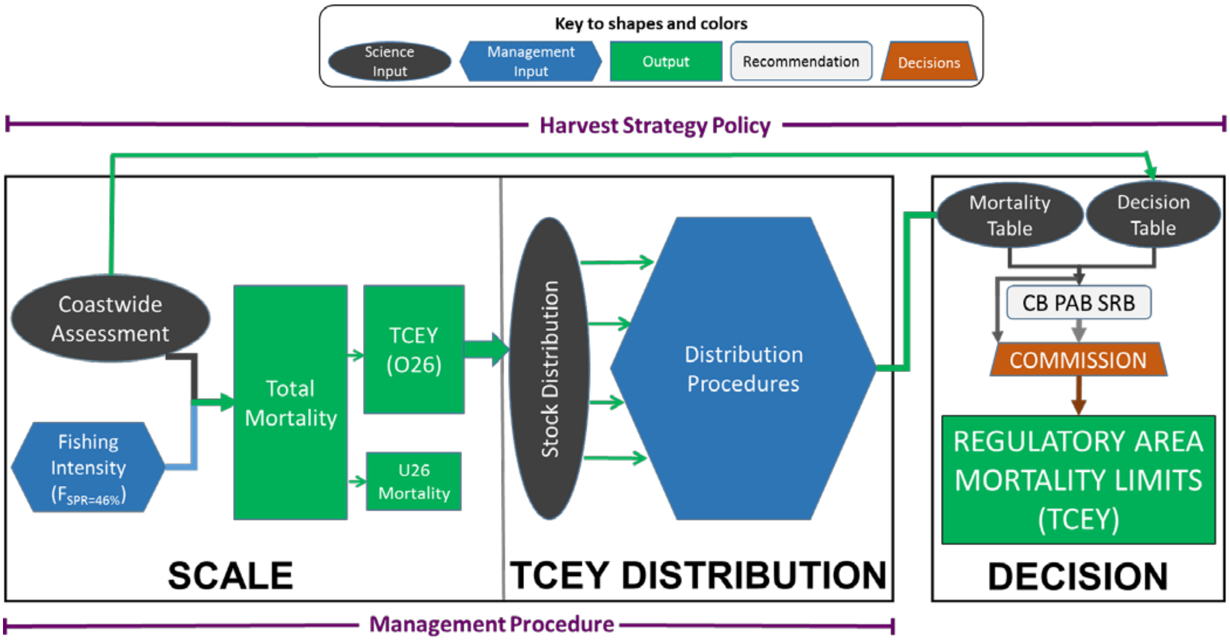

Figure 1: An illustration of the IPHC harvest strategy policy process showing the coastwide scale and TCEY distribution components which make up the management procedure. The decision step is the Commission decision-making procedure, which considers inputs from many sources.

2.1 OBJECTIVES RELATED TO COASTWIDE SCALE

Primary general objectives were identified by the MSAB and the Commission for the evaluation of MSE results related to coastwide fishing intensity that were presented at AM095. At that time, the biological sustainability objective (maintain biomass above a limit) was defined to be met before evaluating the fishery stability objective (limit catch variability), which must be met before evaluating the fishery yield objective (maximize the TCEY). Performance metrics were developed from these objectives by defining a measurable outcome, a tolerance (i.e., level of risk), and a timeframe over which it is desired to achieve that outcome. Many more objectives and performance metrics were identified (Appendix I) which were used to further evaluate the MSE results. Objectives that did not have a measurable outcome, tolerance, and timeframe defined were labeled as "statistics of interest."

A directive from the Commission agreed with the three primary objectives, except that an objective to maintain a minimum catch was identified without a defined level or tolerance.

"While it is recognized that the MSAB has spent considerable time and effort in developing objectives for evaluating management procedures, for the purpose of expediting a recommendation on the level of the coast-wide fishing intensity, and noting SRB11–Rec.02 to develop an objectives hierarchy, the MSAB is requested to evaluate management procedure performance against objectives that prioritize long-term conservation over short-/medium-term (e.g. 3-8 years) catch performance. Where helpful in accelerating progress on scale, the MSAB is requested to constrain objectives to (1) maintain biomass above a limit to avoid critical stock sizes, (2) maintain a minimum average catch, and (3) limit catch variability."

Without definitions of the measurable objective and a tolerance, it was not possible to use this objective in the evaluation of the MSE results. Instead, the third primary objective was to maximize the yield subject to satisfying the other two primary objectives.

Subsequent to the presentation of coastwide objectives and MSE results at the 95th Annual Meeting (AM095), the following paragraphs from the Report of the 95th Annual Meeting (IPHC-2019-AM095-R) have guided further refinement of coastwide objectives.

AM095-R, para 59a. The Commission **ENDORSED** the primary objectives and associated performance metrics used to evaluate management procedures in the MSE process (as detailed in paper IPHC-2019-AM095-12)

AM095-R, para 59c. The Commission **RECOMMENDED** the MSAB develop the following additional objective, as well as prioritize this objective in the evaluation of management procedures, for the Commission's consideration.

i. A conservation objective that meets a spawning biomass target.

The development of a spawning biomass target (i.e. a biomass level to fluctuate around with a 50% probability to be above or below) was discussed extensively at MSAB013. Noting that the current IPHC harvest strategy policy suggests using a proxy for Maximum Economic Yield (MEY), which is related to Maximum Sustainable Yield (MSY), much of the discussion focused around these quantities and what appropriate proxies may be. The need to maximize the economic benefit has been widely recognized, however, the estimation of MEY and related quantities (B_{MEY} and F_{MEY}) is still quite challenging and requires a deep understanding of the economic variables relevant to the fishery. In absence of this information and of a bio-economic model of the fishery, a proxy for MEY may be obtained from MSY. For example, the Australian government's harvest strategy policy uses the relationship: $B_{MEY} = 1.2 \times B_{MSY}$ (Rayns, 2007), and Pascoe *et al*. (2014) suggested that $B_{MEY} = 1.45 \times B_{MSY}$ for data-poor single-species fisheries.

Currently, for halibut, there is no estimate of B_{MSY}. Preliminary analyses based on past stock assessments and equilibrium models has suggested that B_{MSY} may be in the range from 30% and 41% of unfished spawning biomass. However, given the dynamic nature of the stock (i.e. different regimes, changes in individual weight-at-age, and selectivity over time), as well as uncertainty in recruitment steepness, more investigation is needed to identify a robust range of possible estimates.

We plan to use three methods to investigate B_{MSY}. First, we will use a simple equilibrium model to determine B_{MSY}. Second, estimates of B_{MSY} from the current assessment will be determined. Lastly, the coastwide MSE can provide a range of B_{MSY} estimates given the uncertainty and scenarios assumed in the closed-loop simulations. For each of the methods, a grid of scenarios across different selectivity curves, weight-at-age (low, medium, and high), steepness, and environmental regimes (explicitly defined as positive/negative) will characterize the variability used to determine potential ranges of B_{MSY}.

The MSAB also discussed the potential to use a threshold spawning biomass level, instead of a target. This is simply a value to remain above with some tolerance to avoid additional management action due to the control rule and to keep the biomass in a range that would likely optimise fishing activities. An objective was proposed to maintain the spawning biomass above the fishery trigger at least 80% of the time (tolerances of 75% and 90% were also considered).

The objective of maintaining the spawning biomass around a target or above a level that optimises fishing activities can be viewed as a fishery objective (e.g., maximize yield and avoid additional management action from the control rule) as well as a biological sustainability objective (e.g., maintain a sustainable biomass). However, sustainability of the Pacific halibut stock would be satisfied by meeting the objective of avoiding low stock sizes that may result in an impairment to recruitment. Therefore, the main biological sustainability objective should be to avoid a minimum stock size threshold (i.e., B_{Lim}) with a high probability. Defining a fishery objective related to MSY or MEY, along with other fishery objectives, would be prioritized after meeting this single conservation objective.

The MSAB also reconsidered the biological sustainability objective to maintain the spawning biomass above a limit to avoid critical stock sizes. A review of the policies and MSE objectives of other agencies around the world showed various proxies for a biomass limit and tolerances for falling below that limit. For example, the Pacific Fishery Management Council defines a default minimum stock size threshold (MSST) as 25% of unfished spawning biomass, the status below which a stock is defined overfished, although the MSST for flatfish stocks is 12.5% (NPFMC 2016). In the North Pacific Fishery Management Council Fishery Management Plan (NPFMC 2018) the MSST is dependent on the tier that the stock assessment is classified as, but one definition is one-half of B_{MSY}. Fisheries and Oceans Canada defines a limit reference point as 40% of B_{MSY} in their fisheries policy document (DFO 2009). Lastly, the Marine Stewardship Council (MSC) fisheries standard V2.01 defines proxies for the point at which recruitment would be impaired (PRI) as one-half B_{MSY} or 20% of unfished spawning biomass for stocks with average productivity (MSC 2018). Furthermore, the certainty that the stock is greater than the PRI must be greater than 95% to reach the highest category of the MSC scoring criteria. On the basis of consistency with other fisheries management approaches, the MSAB retained the spawning biomass limit at 20% of unfished spawning biomass for the biological sustainability objective and updated the tolerance to 5% (Table 1).

The fishery objectives related to stability and maximizing yield were retained in the coastwide objectives (Table 1). The two fishery objectives discussed above that relate to a target and a threshold biomass level were added under a single general objective to maintain the spawning biomass around a level that optimises fishing activities. No specific prioritization of the fishery objectives has been determined.

2.2 OBJECTIVES RELATED TO THE DISTRIBUTION OF THE TCEY

2.2.1 Biological sustainability

Paragraph 30 of IPHC-2018-SRB012-R stated that “[t]he SRB … recognized that biocomplexity is not an appropriate concept because it is poorly defined and not understood for Pacific halibut, especially over large spatial scales. Further, the terms “preserve” and “preservation” should be “conserve” and “conservation” as most fisheries management is about conservation.” In paragraph 31 of IPHC-2018-SRB012-R, “the SRB AGREED that the defined Bioregions (i.e. 2,3,4, and 4b described in paper IPHC-2018-SRB012-08) are presently the best option for implementing a precautionary approach given uncertainty about spatial population structure and dynamics of Pacific halibut.” Therefore, objectives should be defined that relate to conserving some level of spatial population structure, and these can be included under the Biological Sustainability goal. Given the uncertainty about spatial population structure and dynamics of Pacific halibut, these objectives may be more difficult to define. The ad-hoc working group that met in 2018 to discuss objectives did not address spatial biomass objectives beyond identifying a general objective to conserve spatial population structure.

Table 1: Primary measurable objectives revised at MSAB013. Objective 1.1 is a biological sustainability (conservation) objective and objectives 2.1, 2.2, and 2.3 are fishery objectives. **Items in development*

General Objective	Measurable Objective	Measurable Outcome	Time-frame	Tolerance	Performance Metric
1.1. Keep spawning biomass above a limit to avoid critical stock sizes Biomass Limit	Maintain a minimum female spawning stock biomass above a biomass limit reference point at least 95% of the time	*SB* < Spawning Biomass Limit (SB_{Lim}) SB_{Lim}=20% unfished spawning biomass	Long-term	0.05	$P(SB < SB_{Lim})$
*2.1 Maintain spawning biomass around a level that optimises fishing activities	2.1A Spawning Biomass Trigger Maintain the female spawning biomass above a trigger reference point at least 80% of the time	SB<Spawning Biomass Trigger (SB_{Trig}) SB_{Trig}=$SB_{30\%}$ unfished spawning biomass	Long-term	0.20	$P(SB < SB_{Trig})$
	*2.1B Spawning Biomass Target Maintain the female spawning biomass above a biomass target reference point at least 50% of the time	SB<Spawning Biomass Target (SB_{Targ}) SB_{Targ}=$SB_{36\text{-}45\%}$ unfished spawning biomass	Long-term	0.50	$P(SB < SB_{Targ})$
2.2. Limit Catch Variability	Limit annual changes in the coastwide TCEY	Average Annual Variability (*AAV*) > 15%	Short-term	0.25	$P(AAV > 15\%)$
2.3. Maximize Directed Fishing Yield	Maximize average TCEY coastwide	Median coastwide TCEY	Short-term	*STATISTIC OF INTEREST*	$Median\ \overline{TCEY}$

Conserving spatial population structure may mean several different things, such as maintaining the current distribution across regions, maintaining the proportion of spawning biomass in each Region within a specified range, or maintaining a minimum spawning biomass or proportion of spawning biomass in a Region. Multiple measurable objectives may be defined for this general objective to incorporate these different concepts. Based on current knowledge, conserving spatial population structure should relate to the broad Biological Regions currently defined and not necessarily to the finer spatial definition of IPHC Regulatory Areas.

2.2.2 Optimise Directed Fishing Opportunities

Three general objectives are currently defined for this goal: 1) limit catch variability, 2) maximize directed fishery yield, and 3) minimize potential for no catch limit for the directed commercial fishery. Under each general objective, there are coastwide TCEY measurable objectives. An ad hoc working group of the MSAB identified potential measurable objectives specific to IPHC Regulatory Area, which are mostly based on the coastwide measurable objectives. While Biological Regions are the spatial scale for the biological sustainability goal, fishery objectives are related to IPHC Regulatory Areas because quotas are distributed to these areas and are therefore of interest to a quota holder. A finer spatial scale than IPHC Regulatory Areas may be important to individual fishers and may be considered in future evaluations.

It is easy to translate coastwide objectives into area-specific objectives, but additional objectives will be important to each IPHC Regulatory Areas and not all areas will have the same objectives. For example, the coastwide objective to avoid a change in the TCEY greater than 15% with a 25% tolerance can easily be applied to IPHC Regulatory Areas. However, specific areas may want to identify objectives that are important to that stakeholder group. For example, decisions made at AM095 (IPHC-2019-AM095-R) identified two potential measurable objectives for IPHC Regulatory Areas 2A and 2B.

69. The Commission ADOPTED:

a) a coastwide target SPR of 47% for 2019;

b) a share-based allocation for IPHC Regulatory Area 2B. The share will be defined based on a weighted average that assigns 30% weight to the current interim management procedure's target TCEY distribution and 70% on 2B's recent historical average share of 20%. This formula for defining IPHC Regulatory Areas 2B's annual allocation is intended to apply for a period of 2019 to 2022. For 2019, this equates to a share of 17.7%; and IPHC–2019–AM095–R Page 19 of 46

c) a fixed TCEY for IPHC Regulatory Area 2A of 1.65 mlbs is intended to apply for a period from 2019-2022, subject to any substantive conservation concerns.

IPHC Regulatory Area 2A appears to desire a minimum TCEY of 1.65 Mlbs and IPHC Regulatory Area 2B appears to desire a specific percentage of the coastwide TCEY. These objectives could be translated into performance metrics for evaluation or may be formulated directly in a management procedure. Objectives that may apply to IPHC Regulatory Areas are identified in Table 2 and objectives specific to each IPHC Regulatory Area will be defined at MSAB meetings in 2019 and 2020.

3 Investigations of Coastwide Fishing Intensity

Simulation results presented previously at MSAB012 (IPHC-2018-MSAB012-07) showed that none of the management procedures without a constraint on the annual mortality limit met the primary stability objective (average annual variability of the mortality limit is less than 15% at least 75% of the time), as noted in paragraph 59,e,i in IPHC-2019-AM095-R. Therefore, various constraints on the annual mortality limit were introduced into the management procedure for evaluation (as was also recommended by the SRB in document IPHC-2018-SRB013-R, para. 29). This document presents the results documented in IPHC-2019-AM095-12 and presents the new results pertaining to a constraint on the annual mortality limit that were presented at MSAB013 (IPHC-2019-MSAB013-08). Details of the coastwide closed-loop simulations are not included here but can be found in IPHC-2018-MSAB012-07.

3.1 Management Procedure

The elements of the management procedure include data generation, an estimation model, and a harvest rule, where the harvest rule consists of a coastwide Scale portion and a distribution portion to distribute the mortality limits to IPHC Regulatory Areas. The focus of these simulations was on the coastwide Scale portion of the general management procedure (Figure 1). Data were not generated in these simulations, but instead error in an estimation model was simulated for simplicity (IPHC-2018-MSAB012-07). The coastwide harvest rule portion of the management procedure is discussed below.

Table 2: Area-specific objectives that may be considered when evaluating management procedures for distributing the TCEY to IPHC Regulatory Areas.

General Objective	Measurable Objective	Measurable Outcome	Timeframe	Tolerance	Performance Metric
1.1A CONSERVE SPATIAL POPULATION STRUCTURE	Maintain a defined minimum proportion of spawning biomass in each Biological Region	$p_{SB,R} < p_{SB,R,min}$	Med-term Long-term	?? ??	$P(\ldots)$
	Proportion of Pacific halibut spawning biomass in each Biological Region	Proportion of Pacific halibut spawning biomass in each Biological Region	Long-term	*STATISTIC OF INTEREST*	$\frac{SB_A}{SB}$
2.1A MAINTAIN BIOMASS AROUND A TARGET THAT OPTIMISES FISHING ACTIVITIES	Maintain a proportion of O26 Pacific halibut in each area within the range estimated from the space-time model	$p_{B_{O26},A,min} < p_{B_{O26},A} < p_{B_{O26},A,max}$	Long-term Short-term	?? ??	$P(\ldots)$
	Proportion of O26 Pacific halibut biomass in each area	Proportion of O26 Pacific halibut biomass in each area	Long-term Short-term	*STATISTIC OF INTEREST*	$\frac{B_{O26,\ A}}{BO26}$

Table 2 : continued

General Objective	Measurable Objective	Measurable Outcome	Timeframe	Tolerance	Performance Metric
2.2A LIMIT CATCH VARIABILITY	Limit annual changes in the TCEY for each Regulatory Area	Average Annual Variability by Regulatory Area (AAVA) > 15%	Long-term Short-term	0.25	$P(AAV > 15\%)$
		AAV_A	Long-term Short-term	*STATISTIC OF INTEREST*	AAV and variability
		Change in TCEY by Regulatory Area > 15% in any year	Long-term Short-term	*STATISTIC OF INTEREST*	$\frac{TCEY_{i+1} - TCEY_i}{TCEY_i}$
2.3A MAXIMIZE DIRECTED FISHING YIELD	Maximize average TCEY by Regulatory Area	Median Reg Area TCEY	Long-term Short-term	*STATISTIC OF INTEREST*	Median $\overline{TCEY}$
	Maintain TCEY above a minimum level by Regulatory Area	$TCEY_A < TCEY_{A,min}$	Long-term Short-term	?? ??	$P(TCEY < TCEY_{A,min})$
	Maximize high yield (TCEY) opportunities by Regulatory Area	$TCEY_A >$?? Mlbs	Long-term Short-term	*STATISTIC OF INTEREST*	$P(TCEY <?? \ Mlbs)$
	Present the range of TCEY by Regulatory Area that would be expected	Range of TCEY by Regulatory Area	Long-term Short-term	*STATISTIC OF INTEREST*	5th and 75th percentiles of TCEY
2.4A MINIMIZE POTENTIAL OF NO CATCH LIMIT FOR DIRECTED FISHERY	Maintain catch limit for directed fishery in each Regulatory Area above zero	$DirectedYield_A = 0$	Long-term Short-term	?? ??	$P(DirY_A = 0)$

3.1.1 Harvest Rule

The coastwide part of the management procedure being evaluated is a harvest control rule (Figure 2) that is responsive to stock status and consists of i) a procedural SPR determining fishing intensity, ii) a fishery trigger based on stock status that determines when the fishing intensity begins to be linearly reduced, and iii) a fishery limit that determines when there is theoretically no fishing intensity (this may differ from the biological limit defined in Table 1). For these simulations, the two coastwide models were used, thus mortality was distributed to the five coastwide sources of mortality in those models (directed commercial, discard mortality, bycatch mortality, recreational, and subsistence). Simulations used a range of SPR values from 30% to 56% and fishery trigger:limit points of 40:20, 30:20, and 25:10.

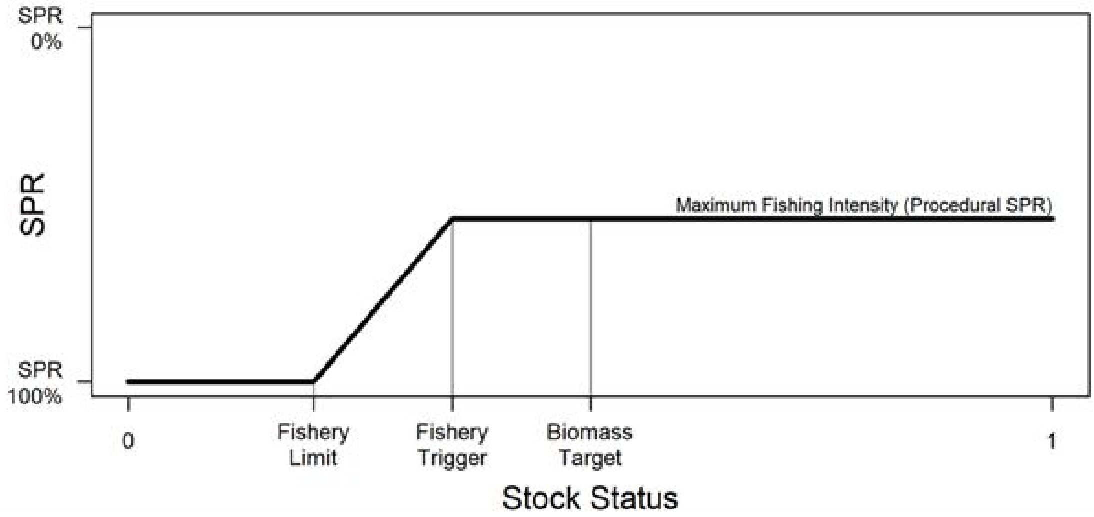

Figure 2: A harvest control rule responsive to stock status that is based on Spawning Potential Ratio (SPR) to determine fishing intensity, a fishery trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a fishery limit based on stock status that determines when there is theoretically no fishing intensity (SPR=100%). In reality, it is likely that only the directed fishery would cease. The Procedural SPR, the Fishery Trigger, and the Fishery Limit are the elements that were evaluated by assigning a range of values for each.

3.1.2 Constraints on the change in the annual mortality limit

Some management procedures in the simulated set included an annual constraint on the change in the annual mortality limit. Eight different combinations of methods and parameterizations were tested. These included to simply constrain the maximum amount of change in the mortality limit from one year to the next, to enforce a maximum mortality limit, or to set a constant limit for three years before updating it. The eight methods are described below and a hypothetical comparison is shown in Figure 3.

- **MaxChangeBoth15%:** Not allow the mortality limit to change by more than 15% up or down, even if the harvest rule suggests a larger change. When the change in the mortality limit would be more than 15%, the mortality limit is set at the limit corresponding to a 15% change.
- **MaxChangeBoth20%**: Not allow the mortality limit to change by more than 20% up or down, even if the harvest rule suggests a larger change. When the change in the mortality limit would be more than 20%, the mortality limit is set at the limit corresponding to a 20% change.

- **MaxChangeUp15%**: Not allow the mortality limit to increase by more than 15%, even if the assessment suggests a larger change, but allow the mortality limit to decrease by any amount (as determined by the harvest rule). When the increase in the mortality limit would be more than 15%, the mortality limit is set at the limit corresponding to a 15% change.
- **SlowUpFastDown**: Increase the mortality limit by one-third of the change suggested by the harvest rule and decrease the mortality limit by one-half of the change suggested by the harvest rule. Therefore, the mortality limit from the harvest rule is never implemented in a given year, but potential inter-annual variability is dampened.
- **SlowUpFullDown**: Increase the mortality limit by one-third of the change suggested by the harvest rule and decrease the mortality limit fully to the value suggested by the harvest rule. Therefore, an increase in the mortality limit from the harvest rule is never implemented in a given year, but a decrease is fully implemented.
- **Cap60**: Not allow the total mortality limit to exceed 60 million pounds. When below 60 million pounds, the harvest rule is unconstrained.
- **Cap80**: Not allow the total mortality limit to exceed 80 million pounds. When below 80 million pounds, the harvest rule is unconstrained.
- **MultiYear**: Set a single mortality limit every third year to apply to a period of three years. Therefore, the mortality limit is constant for a three-year period, but the harvest rule results in an unconstrained change every third year.

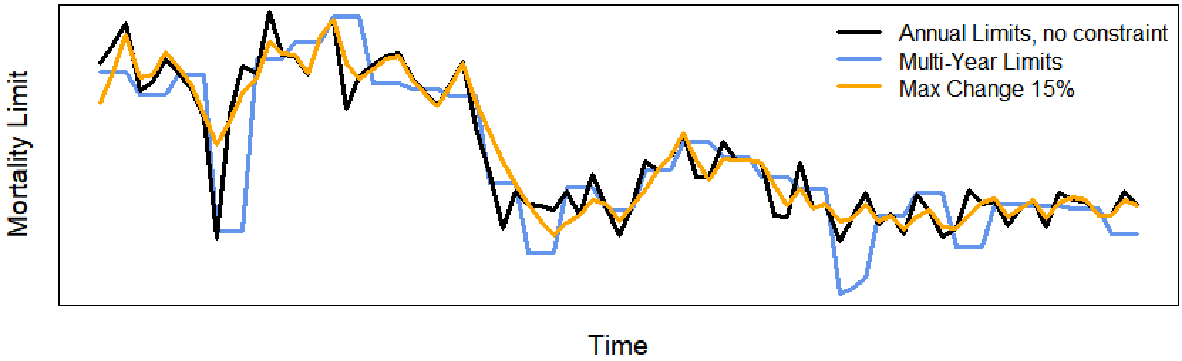

Figure 3: A hypothetical example of the difference between unconstrained and constrained management procedures when determining the total mortality limit. The multi-year limit (blue) is set every third year, but due to allocation to bycatch and other sectors, the limit may be adjusted in years when the total mortality limit is small. A maximum change of 15% is applied to “Max Change 15%”, shown in orange, and compared to the unconstrained mortality limit shown in black.

3.2 Simulation Results

Table 3 and Table 4 show the long-term primary biological performance metric and the medium-term (14-23 years) fishery sustainability performance metrics for the main management procedures requested at MSAB011 (IPHC-2018-MSAB011-R). Table 5 shows the same long-term performance metrics for a control rule of 25:10. Short-term performance metrics were similar for these management procedures because the current spawning biomass is likely to be above the fishery trigger (e.g., 30%), thus are not shown. For long-term results with a control rule, the probability that the stock is below 20% of the dynamic unfished equilibrium biomass is less than 0.01 (<1/100) for all cases using control rules 30:20 or 40:20. This is a result of the control rule limiting the fishing intensity as the stock approaches the 20% threshold even with estimation error present, and since dynamic relative spawning biomass is a measure of the effect of fishing, reducing the fishing intensity reduces the risk of dropping below this threshold. It is rare that positive estimation error persists for a long enough period that fishing intensity remains high and the stock falls below the 20% threshold. The outcome of this reduction in fishing intensity can be seen in the average annual variability (AAV), which is a measure of the change in the mortality limit from year to year. At fishing intensities greater than that associated with an SPR of 40% (i.e., SPR values less than 40%) the probability that the AAV is greater than 15% is more than two-thirds (>67/100) for all control rules tested. This probability declines to around 0.60 (60/100) at an SPR of 56% for the 30:20 and 25:10 control rules. The 40:20 control rule resulted in higher variability in the mortality limit, even though the slope is not as steep, because the reduction in fishing intensity occurs more often given the 40% fishery trigger value and the range of SPR values evaluated. The absolute value of the Total Mortality limit was highly variable for a given SPR (Figure 4).

The use of SPR values without a control rule (results not shown) also did not meet the stability objective for any SPR considered, which means that estimation error is a large part of the variability in the total mortality limits. Therefore, to meet the stability objective, additional elements of a management procedure need to be included to stabilize the limits (alternatively, the objective could be updated such that a management procedure will meet the objective). Eight different general options for constraining the limit were simulated to evaluate their potential to meet the primary objectives (see Section 3.1.2). With the 30:20 control rule and SPR values of 38%, 40%, 42%, and 46%, the biological sustainability goal was met for all constraint options (Table 6 and Table 7, Figure 5 and Figure 6). However, only the maxChangeBoth15%, slowUpFastDown, slowUpFullDown, and multiYear constraints had SPR options that were able to meet the stability objective. The top five ranked management procedures used the constraints slowUpFastDown, maxChangeBoth15%, and multiYear constraints with SPR values ranging from 42% to 38%. The median yield across these five ranged from 48.9 Mlbs to 51.1 Mlbs and the probability that the AAV was greater than 15% ranged from 0.05 to 0.19. The top ranked management procedure was slowUpFastDown with an SPR of 38%; maxChangeBoth15% with an SPR of 38% was very similar with a median TM 0.2 Mlbs less and a smaller probability of exceeding the AAV tolerance (Figure 6). However, the median AAV for slowUpFastDown was less than the median AAV for maxChangeBoth15%.

Setting the limit every third year (multiYear) was able to meet the stability objective (calculated on an annual basis) with little loss to median yield and no increase to biological sustainability risk. However, the change that occurs every third year (median of 27% with SPR=46%) was greater than the similar unconstrained management procedure (median change every third year of 25%).

Many more performance metrics calculated for a subset of management procedures are presented in Appendix I. The full set of simulated management procedures and performance metrics are available for interactively viewing in a table or on plots at http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/IPHC-MSAB013/.

Table 3: Primary performance metrics for a 30:20 control rule, and a range of input SPRs from 0.3 to 0.56. P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Biological Sustainability (Long-term)											
P(all dRSB<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_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 (medium-term)											
P(all AAV > 15%)	0.60	0.66	0.69	0.72	0.76	0.80	0.84	0.88	0.93	0.96	0.98
Median average TM[3]	39.4	45.5	46.8	48.0	49.5	50.6	51.8	52.1	52.4	53.2	52.8
Rankings (lower is better) over all management procedures without a constraint (Table 3, Table 4, and Table 5)											
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	No	No	No	No	No	No	No	No	No	No	No
Maximum catch (TM)[3]	30	27	24	21	14	11	9	8	7	4	5
Overall Ranking	—	—	—	—	—	—	—	—	—	—	—

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that no procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error, for all management procedures without a constraint (Table 3, Table 4, and Table 5). Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

[4] The overall ranking applies to all management procedures without a constraint (Table 3, Table 4, and Table 5)

Table 4: Primary performance metrics for a 40:20 control rule, and a range of input SPRs from 0.3 to 0.56. P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**	**40:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Biological Sustainability (Long-term)											
P(all dRSB<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_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 (medium-term)											
P(all AAV > 15%)	0.718	0.843	0.880	0.915	0.954	0.966	0.977	0.987	0.991	0.994	0.995
Median average TM[3]	39.2	44.4	45.5	46.4	47.6	48.3	48.8	48.9	49.4	49.5	49.8
Rankings (lower is better) over all management procedures without a constraint (Table 3, Table 4, and Table 5)											
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	No	No	No	No	No	No	No	No	No	No	No
Maximum catch (TM)[3]	32	29	27	25	22	20	18	17	16	14	13
Overall Ranking	—	—	—	—	—	—	—	—	—	—	—

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that no procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error, for all management procedures without a constraint (Table 3, Table 4, and Table 5). Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

[4] The overall ranking applies to all management procedures without a constraint (Table 3, Table 4, and Table 5)

Table 5: Primary performance metrics for a 25:10 control rule, and a range of input SPRs from 0.3 to 0.56. P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**	**25:10**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Biological Sustainability (Long-term)											
P(all dRSB<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.02	0.03	0.05
P(any dRSB_y<20%)	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.02	0.03	0.06	0.10	0.14
Fishery Sustainability (medium-term)											
P(all AAV > 15%)	0.58	0.60	0.63	0.65	0.66	0.67	0.69	0.74	0.77	0.83	0.88
Median average TM[3]	39.4	45.9	47.1	48.5	49.9	51.2	52.6	54.0	55.0	55.3	55.3
Rankings (lower is better) over all management procedures without a constraint (Table 3, Table 4, and Table 5)											
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Meet stability objective?[2]	No	No	No	No	No	No	No	No	No	No	—
Maximum catch (TM)[3]	30	26	23	19	12	10	6	3	2	1	—
Overall Ranking[4]	—	—	—	—	—	—	—	—	—	—	—

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective, except for an SPR of 30%.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that no procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error, for all management procedures without a constraint (Table 3, Table 4, and Table 5). Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

[4] The overall ranking applies to all management procedures without a constraint (Table 3, Table 4, and Table 5)

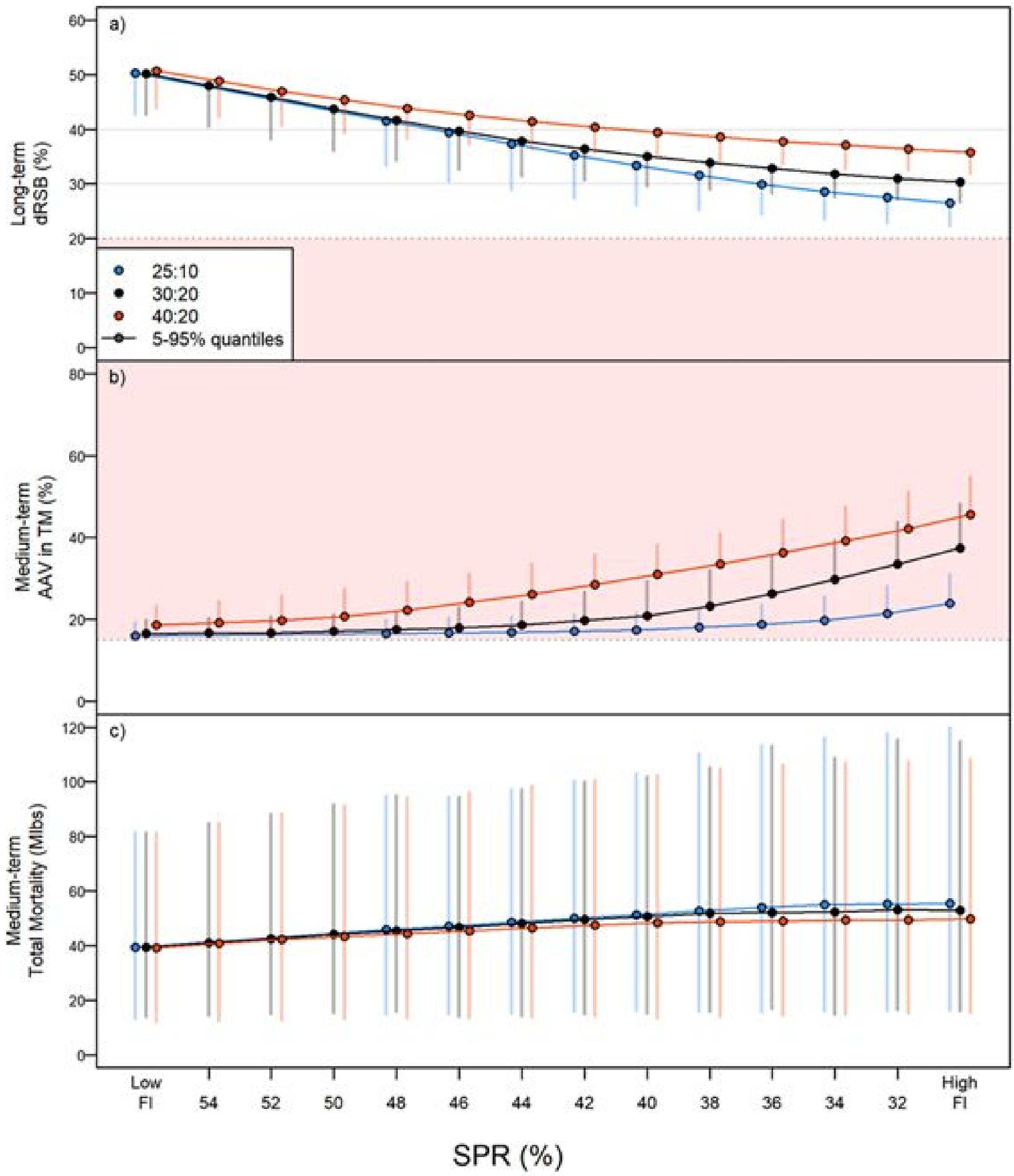

Figure 4. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.3 to 0.56 and control rules 40:20, 30:20, and 25:10. The points are the median values from the simulations and the vertical bars indicate the tolerance defined for that biological sustainability objective (plot a) and the catch stability objective (plot b); if the bar is in the red area, the objective is not met. The vertical bars for total mortality are the 90% intervals (i.e. 5th and 95th percentiles from the simulations).

Table 6: Primary performance metrics and ranking of management procedures for a 30:20 control rule, input SPRs, and various constraints on the annual change in the total mortality (see Section 3.1.2). P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**30:20**											
Constraint	**maxChangeBoth15%**				**slowUp FastDown**				**multiYear**			
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**
Biological Sustainability (Long-term)												
P(all dRSB<20%)	0.02	0.02	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_y<20%)	0.02	0.02	0.02	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Fishery Sustainability (medium-term)												
P(all AAV > 15%)	0.04	0.05	0.05	0.06	0.07	0.11	0.14	0.15	0.14	0.19	0.26	0.3
Median average TM[3]	46.1	48.6	49.5	50.9	45	48.2	49.5	51.1	46.5	48.9	50.5	51.2
Rankings (lower is better) over all management procedures with a constraint (Table 6 and Table 7)												
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Maximum catch (TM)[3]	20	14	9	4	23	15	9	2	17	13	6	1
Overall Ranking	**10**	**6**	**3**	**2**	**11**	**7**	**3**	**1**	**9**	**5**	---	---

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that some procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error. Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

Table 7: Primary performance metrics and ranking of management procedures for a 30:20 control rule, input SPRs, and various constraints on the annual change in the total mortality (see Section 3.1.2). P(all …) is the probability of that the event occurs in a given year, and P(any …) is the probability that the event occurs in at least 1 year out of a 10 year period. Long-term is a ten-year period after simulating 90 annual cycles. Medium-term is a ten-year period after simulating 13 annual cycles (i.e., simulated years 14-23).

Input Control Rule	**30:20**												
Constraint	**maxChangeBoth20%**				**maxChangeUp**		**slowUp FullDown**			**Cap80**		**Cap60**	
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**40%**	**46%**	**42%**	**40%**	**46%**	**40%**	**46%**	**40%**
Biological Sustainability (Long-term)													
P(all dRSB<20%)	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P(any dRSB_y<20%)	0.01	0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fishery Sustainability (medium-term)													
P(all AAV > 15%)	0.26	0.3	0.34	0.39	0.27	0.35	0.13	0.21	0.26	0.58	0.61	0.45	0.48
Median average TM[3]	46.5	49.1	49.9	51.1	44	45.3	44.7	47.5	49.3	46.4	50.7	46.1	50
Rankings (lower is better) over all management procedures with a constraint (Table 6 and Table 7)													
Meet biological objective?[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?[2]	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No
Maximum catch (TM)[3]	17	12	8	2	25	22	24	16	11	19	5	20	7
Overall Ranking	---	---	---	---	---	---	**12**	**8**	---	---	---	---	---

[1] This is determined using P(any dRSB < 20%) and the objective to maintain RSB above 20% at least 90% of the time. Note that all procedures meet this objective.

[2] This is determined using P(all AAV >15%) and the objective to maintain AAV below 15%.at least 75% of the time. Note that some procedures meet this objective.

[3] This ranking is determined using median average TM, which may be subject to Monte Carlo error. Note that the highest fishing intensity meets this objective, although the yield curve begins to flatten at those low SPR values.

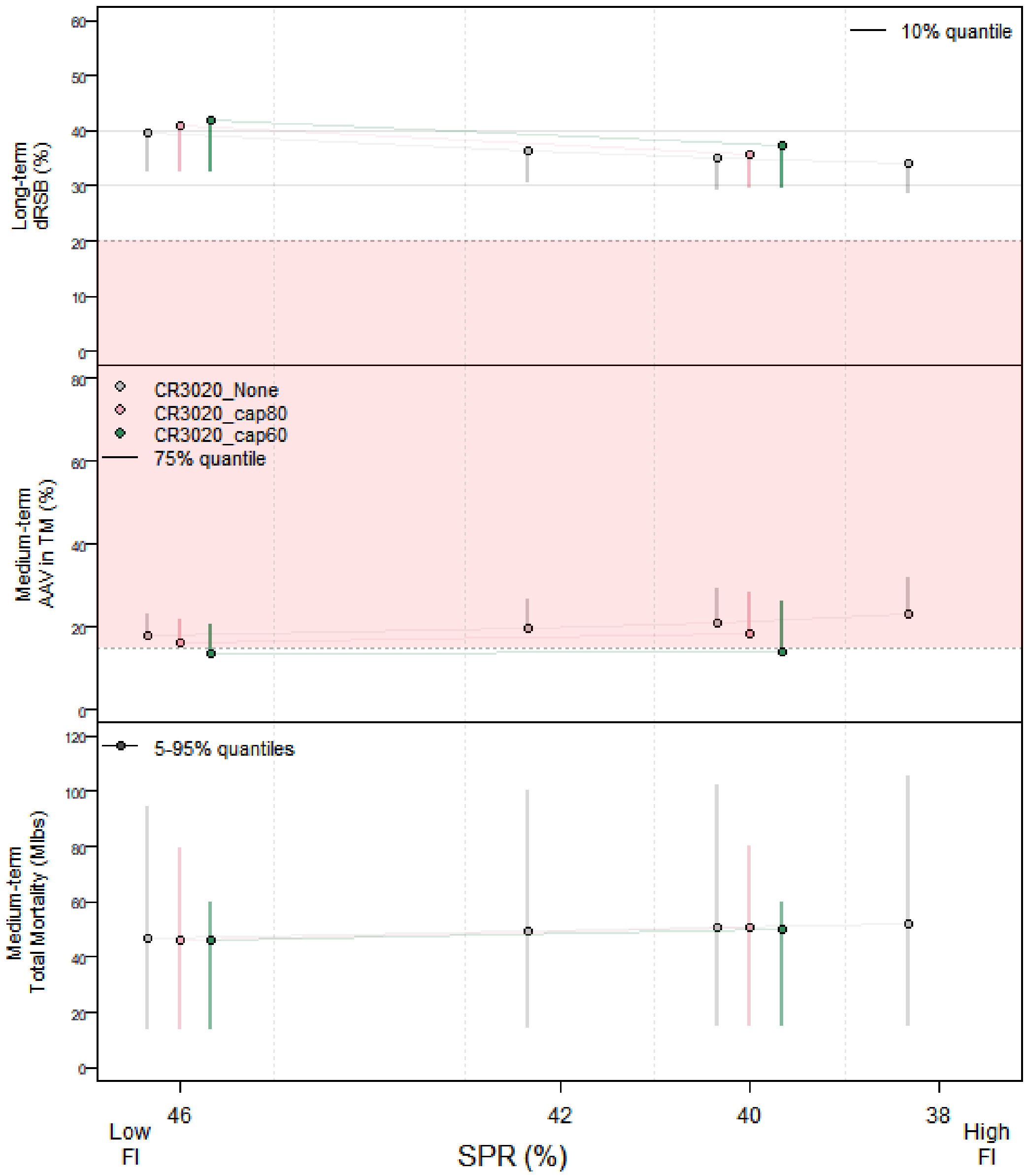

Figure 5. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using caps on the total mortality limit of 60 and 80 Mlbs. The points are the median values from the simulations and the vertical bars indicate the tolerance defined for that biological sustainability objective (plot a) and the catch stability objective (plot b); if the bar is in the red area, the objective is not met. The vertical bars for total mortality are the 90% intervals (i.e. 5^{th} and 95^{th} percentiles from the simulations).

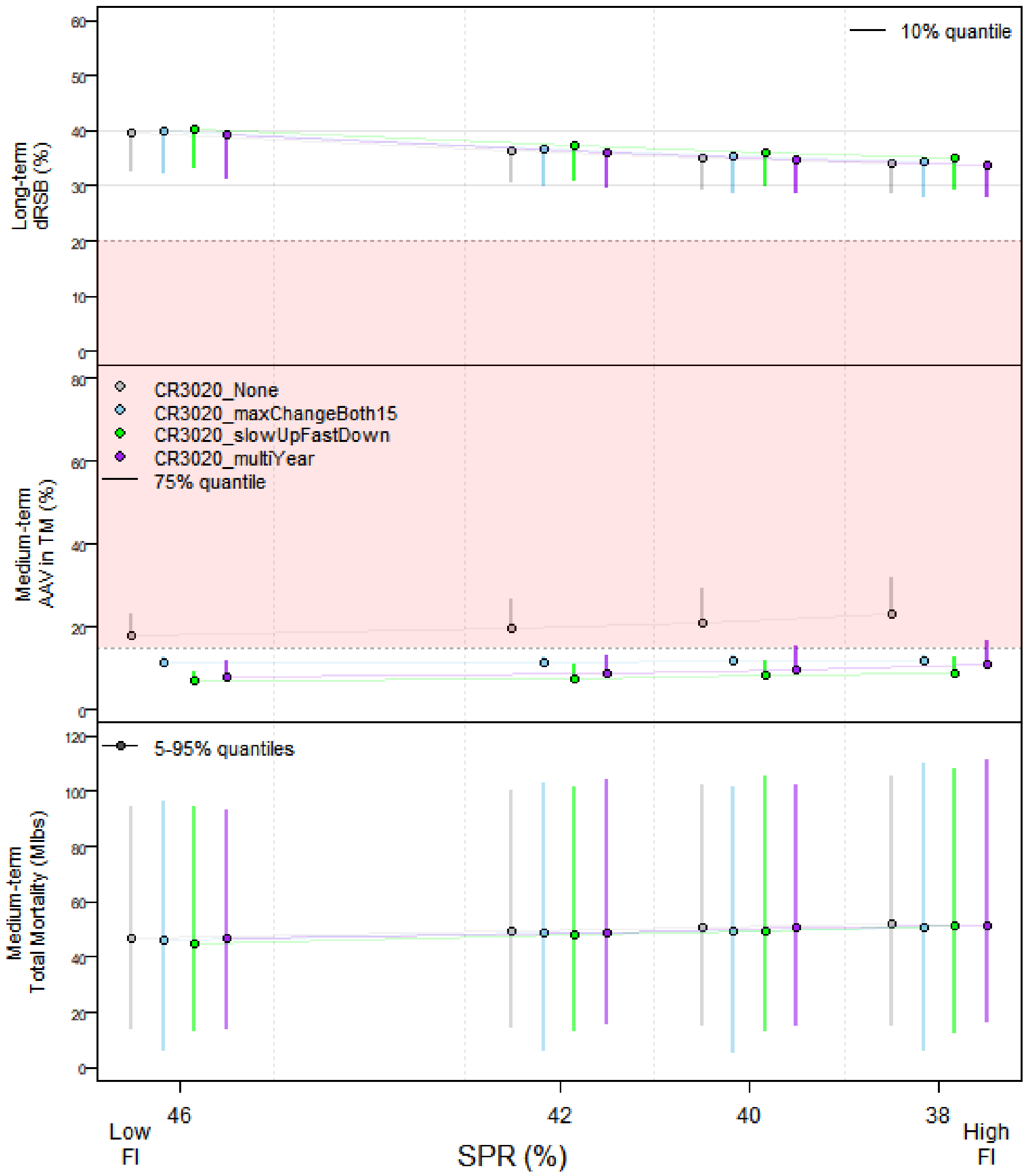

Figure 6. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term fishery sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using three different constraints on the total mortality limit: maxChange15, slowUpFastDown, and multiYear (see Section 3.1.2). The points are the median values from the simulations and the vertical bars indicate the tolerance defined for that biological sustainability objective (plot a) and the catch stability objective (plot b); if the bar is in the red area, the objective is not met. The vertical bars for total mortality are the 90% intervals (i.e. 5th and 95th percentiles from the simulations).

The additional measurable objectives related to maintaining the spawning biomass around a level that optimises fishing activities (Table 1) define a target biomass related to B_{MSY} or B_{MEY} as well as a tolerance to remain above the fishery trigger threshold. Past assessments and equilibrium models suggest that B_{MSY} is likely within the range of 30% to 41% of unfished spawning biomass. Using B_{MSY} as a target, the SPR that would meet the objective would be in the range of less than 30% to greater than 44% with a 30:20 or 40:20 control rule (Figure 7). In fact, very high fishing intensities (low SPR) could be chosen because the control rule reduces the input fishing intensity to a stable level as the stock is fished lower (see the upper left plot in Figure 7). With a 25:10 control rule, the fishing intensity is allowed to increase to higher levels and the SPR values that would meet a B_{MSY} target objective are within the range of 36% to 48%. Using the objective to maintain the biomass above the fishery trigger at least 80% of the time would choose an SPR between 42 and 43% with a 30:20 control rule (Figure 7).

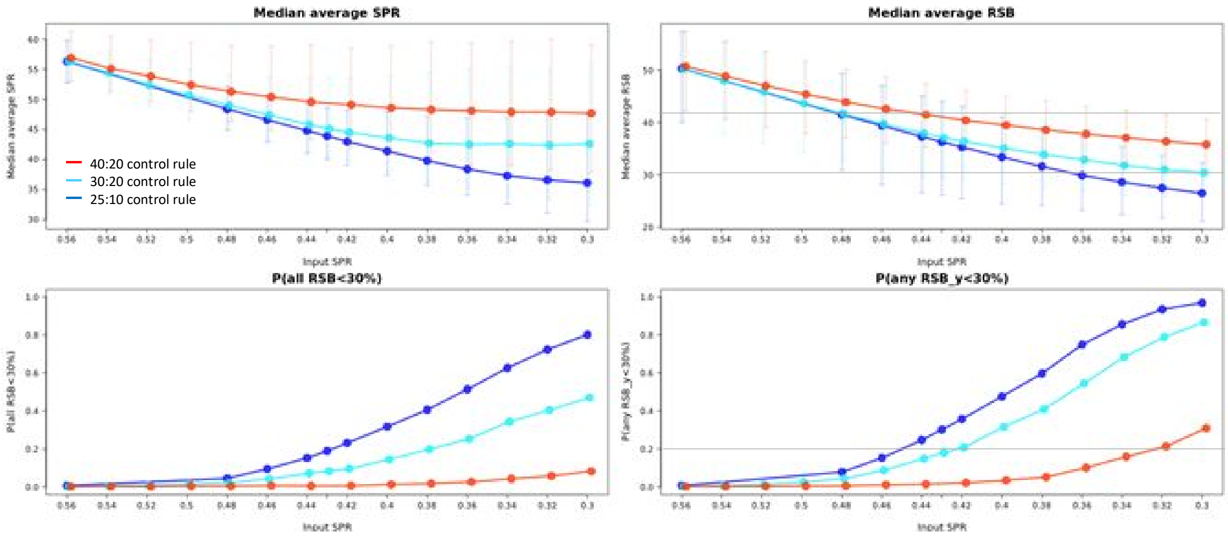

Figure 7: Performance metrics for the MSE simulation results when using 40:20, 30:20, and 25:10 control rules. The vertical lines represent the 5th and 95th percentiles of the simulation results. The P(all RSB<30%) represents the probability that the event may occur in a single year. The P(any RSB<30%) represents the probability that the event may occur in at least 1 out of 10 years.

Even though there is a specific procedural (input) SPR (Figure 2), this is not the fishing intensity that would typically be realized in a specific year. There is the applied SPR that is a result of applying the control rule. Often, the applied SPR will be equal to the procedural SPR, except when the stock status is estimated to be below the fishery trigger. Then, there is the realized SPR which is a result of applying the control rule and accounting for estimation error and implementation variability (e.g., not catching the entire mortality limit), and is realized in a specific year. This variability is seen in recent IPHC stock assessments which estimate a confidence interval for SPR and have produced estimates of past SPR values that are not equal to the SPR chosen by the Commission for that year (which also includes implementation variability).

Figure 7 (upper left panel) shows the three SPR quantities. The procedural SPR is shown along the x-axis. The applied SPR is represented by the dots, which are affected by the control rule and stabilizes as the input SPR increases. The realized SPR is represented by the vertical bars showing the percentiles of SPR values that were realized in the simulations as a result of estimation and variability in the operating model. With an input SPR of 46% and a 30:20 control rule, the median average SPR is 47% and the realized SPR ranges from approximately 43% to 54%.

In summary, long-term performance metrics showed little risk of falling below the 20% dynamic biomass limit for nearly all management procedures evaluated. In the medium-term, high variability in catches increased with higher fishing intensities (i.e. lower SPR), and median Total Mortality limits increased slightly with greater fishing intensity. Therefore, all SPR's greater than 30% met the biological sustainability objective, but no unconstrained management procedure met the stability objective, mainly due to estimation error. However, the procedural SPR values that would likely meet target objectives is between 36% and 48%. Constrained management procedures were able to meet biological and stability objectives and maxChangeBoth15%, slowUpFastDown, and multiYear performed the best. Additionally, at fishing intensities greater than those associated with an SPR of 40% (i.e., SPR values less than 40%) the variability in total mortality increased rapidly and median total mortality made minimal gains (Figure 4). If a constraint was to be implemented, it may be useful to introduce a precaution, such as the constraint is not applied if the estimated stock status is nearing the biomass limit, and vice versa, a measure that allows for increased harvest if the stock status is highly likely to be much greater than the target biomass.

4 A Framework to Distribute the TCEY

The report from the 95th Session of the IPHC Annual Meeting (AM095) contained one paragraph that noted the TCEY distribution component of the IPHC harvest strategy policy (IPHC-2019-AM095-R).

> *62. The Commission **RECOMMENDED** that the MSAB and IPHC Secretariat continue its program of work on the Management Procedure for the Scale portion of the harvest strategy, NOTING that Scale and Distribution components will be evaluated and presented no later than at AM097 in 2021, for potential adoption and subsequent implementation as a harvest strategy.*

There are many notes, requests, and recommendations from past Annual Meetings and MSAB meetings that pertain to distributing the TCEY (see Appendix I of IPHC-2019-MSAB013-09). Some important themes from these paragraphs are

- Distributing the TCEY to IPHC Regulatory Areas may result in a change to the coastwide total mortality or to the coastwide SPR.
- There are science-based and management derived elements to distributing the TCEY. A framework has been proposed that incorporates these elements.
- The IPHC Secretariat has described four biological Regions (consistent with IPHC Regulatory Area boundaries) based on the best available science.
- The MSAB has identified many potentials tools for use in distribution procedures.

This document summarizes IPHC-2019-MSAB013-09 and reports progress on the topic of distributing the TCEY.

In 2017, the Commission agreed to move to an SPR-based management procedure to account for the mortality of all sizes and from all fisheries (Figure 1). The procedure uses a coastwide fishing intensity based on spawning potential ratio (SPR), which defines the "scale" of the coastwide catch. The current interim management procedure for distributing the TCEY among IPHC Regulatory Areas contains two inputs: 1) the current estimated stock distribution and 2) relative target harvest rates.

4.1 Current interim management procedure to distribute the TCEY

4.1.1 Stock distribution

The IPHC uses a space-time model to estimate annual Weight-Per-Unit-Effort (WPUE) for use in estimating the annual stock distribution of Pacific halibut (IPHC-2019-AM095-07). Briefly, observed WPUE is fitted with a model that accounts for correlation between setline survey stations over time (years) and space (within Regulatory Areas). Competition for hooks by Pacific halibut and other species, the timing of the setline survey relative to annual fishery mortality, and observations from other fishery-independent surveys are also accounted for in the approach. This fitted model is then used to predict WPUE (a measure of relative density) of Pacific halibut for every setline survey station in the design, including all setline survey expansion stations, regardless of whether it was fished in a particular year. These predictions are then averaged within each IPHC Regulatory Area, and combined among IPHC Regulatory Areas, weighting by the “geographic extent” (calculated area within the survey design depth range) of each IPHC Regulatory Area. It is important to note that this produces relative indices of abundance and biomass, but does not produce an absolute measure of abundance or biomass because it is weight-per-unit-effort scaled by the geographic extent of each IPHC Regulatory Area. These indices are useful for determining trends in stock numbers and biomass and are also useful to estimate the geographic distribution of the stock. The proportion of estimated biomass in each IPHC Regulatory Area is used in the current interim management procedure to determine stock distribution.

4.1.2 Relative Harvest Rates

The distribution of the TCEY for 2019 was shifted from the estimated stock distribution based on relative harvest rates of 1.00 for IPHC Regulatory Areas 2A–3A and 0.75 for IPHC Regulatory Areas 3B–4CDE. This application shifted the target TCEY distribution away from the stock distribution by moving TCEY into IPHC Regulatory Areas 2A, 2B, 2C, and 3A and removing TCEY from IPHC Regulatory Areas 3B, 4A, 4B, and 4CDE (Table 8), thus harvesting at a higher rate in eastern IPHC Regulatory Areas.

Table 8. IPHC Regulatory Area stock distribution estimated from the 2018 space-time model O32 WPUE, IPHC Regulatory Area-specific relative target harvest rates, and resulting 2019 target TCEY distribution based on the IPHC’s 2019 interim management procedure (reproduced from the mortality projection tool https://iphc.int/data/projection-tool).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
O32 stock distribution	1.8%	11.2%	14.3%	37.2%	9.0%	6.7%	5.9%	13.9%	100%
Relative harvest rates	1.00	1.00	1.00	1.00	0.75	0.75	0.75	0.75	--
Target TCEY Distribution	1.9%	12.3%	15.6%	40.9%	7.4%	5.5%	4.9%	11.5%	100%

4.2 Redefining the Distribution of the TCEY

Distributing the TCEY is composed of a purely scientific component to distribute the TCEY in proportion to its estimated biomass and steps to further modify the distribution of the TCEY based on additional considerations (distribution procedures). These two components are described below.

4.2.1 Stock Distribution

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 pertinent portions of the stock. One method for addressing this objective, without knowing the relative importance of each portion of the stock, is to distribute the fishing mortality relative to the distribution of observed stock biomass. This requires defining appropriate areas for which the distribution is to be conserved, hence balancing the removals to protect against localized depletion of spatial and demographic components of the stock that may produce differential recruitment success under changing environmental and ecological conditions. Splitting the coast into many small areas for conservation objectives can result in complications, including i) making it cumbersome to determine if conservation objectives are met, ii) making it difficult to accurately determine the proportion of the stock in that area resulting in inter-annual variability in estimates of the proportion, iii) forcing arbitrary delineation among areas despite evidence of strong stock mixing, and iv) not representing biological importance. Emerging understanding of Pacific halibut diversity across the geographic range of the Pacific halibut stock indicates that IPHC Regulatory Areas should only be considered as management units and do not represent relevant sub-populations (Seitz et al. 2017). Biological Regions, defined earlier and shown in Figure 8, are considered by the IPHC Secretariat, and supported by the SRB (paragraph 31 IPHC-2018-SRB012-R), to be the best current option for biologically-based areas to meet management needs and conserve spatial population structure. Biological Regions are also the most logical scale over which to consider conservation objectives related to distribution of the fishing mortality.

In addition to using Biological Regions for stock distribution, the "all sizes" WPUE from the space-time model (Figure 9), which is largely composed of over 26 inch (O26) Pacific halibut, due to selectivity of the setline gear, is more congruent with the TCEY (O26 catch levels) than over 32 inch (O32) WPUE. Therefore, when distributing the TCEY to Biological Regions, the estimated proportion of "all sizes" WPUE from the space-time model should be used for consistency.

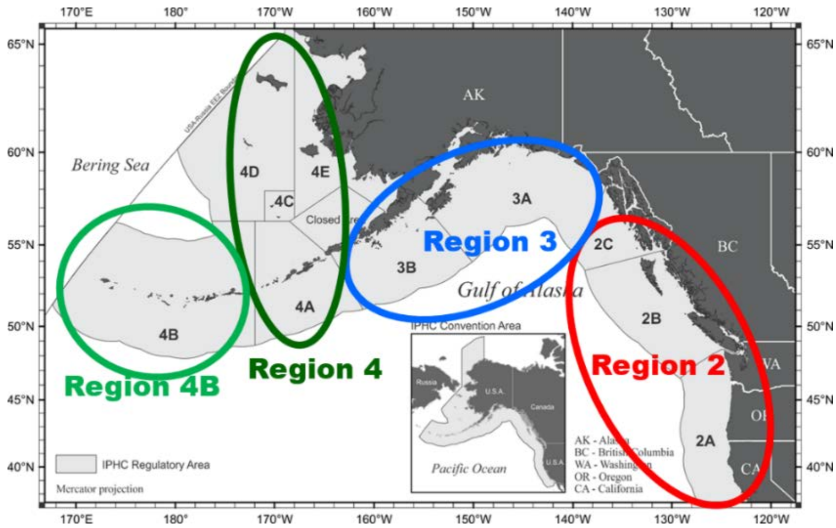

Figure 8. Biological Regions overlaid on IPHC Regulatory Areas with Region 2 comprised of 2A, 2B, and 2C, Region 3 comprised of 3A and 3B, Region 4 comprised of 4A and 4CDE, and Region 4B comprised solely of 4B.

4.2.2 Distribution Procedures

The Distribution Procedures component contains additional steps of further modifying the distribution of the TCEY among Biological Regions and then distributing the TCEY among IPHC Regulatory Areas within Biological Regions (Figure 10). Modifications at the level of Biological Regions or IPHC Regulatory Areas may be based on differences in productivity between areas, observations in each area relative to other areas (e.g. fishery-dependent WPUE), uncertainty of data or mortality in each area, defined allocations, national shares, or other methods. Data may be used as indicators of stock trends in each Region or IPHC Regulatory Area and are included in the Distribution Procedures component because they may be subject to certain biases or include factors unrelated to the biomass in that Biological Region or IPHC Regulatory Area. For example, fishery-dependent WPUE may not always be proportional to biomass, but is a popular source of data used to infer trends in a population and is at least useful to understand fishery trends.

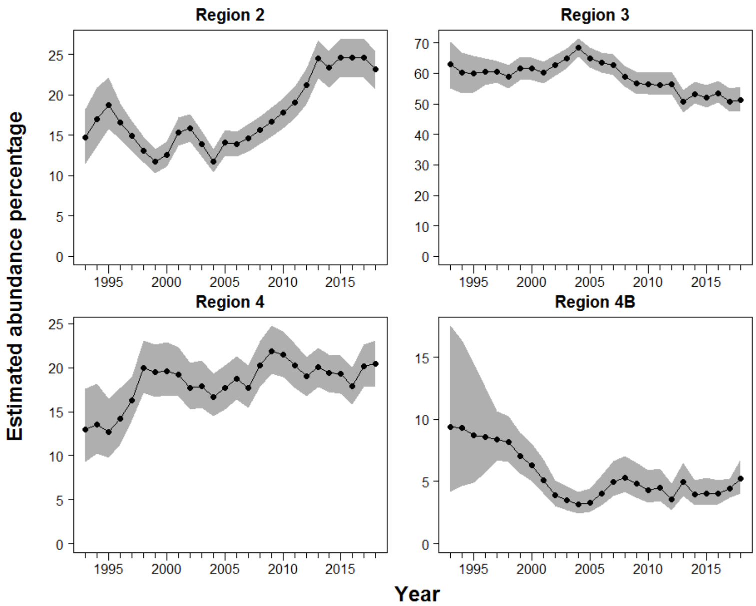

Figure 9. Estimated stock distribution (1993-2018) based on estimate "all sizes" WPUE for Pacific halibut from the space-time model. Shaded zones indicate 95% credible intervals. Reproduced from IPHC-2019-AM095-08.

The MSAB013 report (IPHC-2019-MSAB013-R) listed eleven potential tools for use in developing distribution procedures

60. *The MSAB **NOTED** the following potential elements of management procedures for the distribution of the TCEY:*
   a) *IPHC fishery-independent setline survey estimates by IPHC Regulatory Area, biological regions, or multi-area management zones;*
   b) *relative harvest rates;*
   c) *O32:O26 ratios or other proxies to represent discard mortality in directed fisheries;*
   d) *trends in the IPHC fishery-independent setline survey WPUE/NPUE by IPHC Regulatory Area, biological regions, or multi-area management zones;*
   e) *Trends in fishery CPUE by IPHC Regulatory Area, biological regions, or multi-area management zones;*
   f) *Smoothing algorithms on area-specific catch limits;*
   g) *Percentage allocation to an IPHC Regulatory Area (e.g., a method to calculate a proportion of the TCEY for IPHC Regulatory Area 2B);*
   h) *a floor on the TCEY (e.g. a minimum of 1.65 Mlbs in IPHC Regulatory Area 2A);*
   i) *A maximum SPR with catch distribution by IPHC Regulatory Area determined from the IPHC fishery-independent setline survey WPUE;*
   j) *Coastwide TCEY target and maximum calculated; distribution by target, but with ability to adjust TCEY up to the maximum;*

There are many other tools that could be used, and AM095 implemented two tools for IPHC Regulatory Areas 2A and 2B (IPHC-2019-AM095-R).

69. The Commission ADOPTED:

a) a coastwide target SPR of 47% for 2019;

b) a share-based allocation for IPHC Regulatory Area 2B. The share will be defined based on a weighted average that assigns 30% weight to the current interim management procedure's target TCEY distribution and 70% on 2B's recent historical average share of 20%. This formula for defining IPHC Regulatory Areas 2B's annual allocation is intended to apply for a period of 2019 to 2022. For 2019, this equates to a share of 17.7%; and IPHC–2019–AM095–R Page 19 of 46

c) a fixed TCEY for IPHC Regulatory Area 2A of 1.65 mlbs is intended to apply for a period from 2019-2022, subject to any substantive conservation concerns.

These elements can easily be incorporated into a management procedure.

The steps in the Distribution Procedures may consider conservation objectives, but they will mainly be developed with respect to fishery objectives, which will likely be diverse and in conflict across IPHC Regulatory Areas. Pacific halibut mortality levels are defined for each IPHC Regulatory Area and quota is accounted for by those IPHC Regulatory Areas. Therefore, IPHC Regulatory Areas are the appropriate scale to consider fishery objectives.

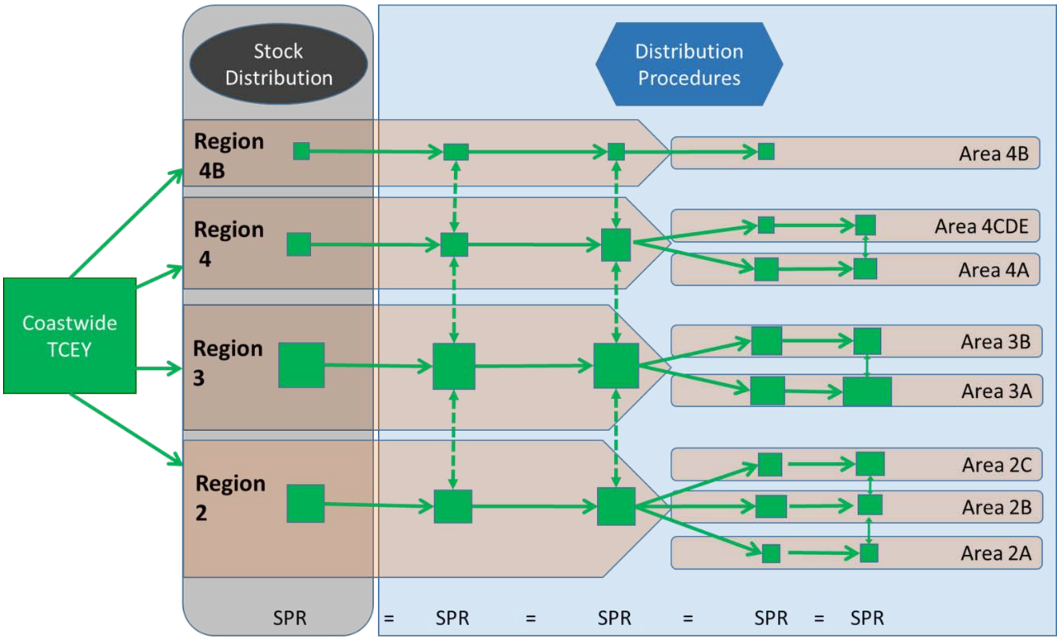

Figure 10. The process of distributing the TCEY to IPHC Regulatory Areas from the coastwide TCEY. The first step is to distribute the TCEY to Biological Regions based on the estimate of stock distribution. Following this, a series of adjustments may be made based on observations or social, economic, and other considerations. Finally, the adjusted regional TCEY's are allocated to IPHC Regulatory Areas. The allocation to IPHC Regulatory Areas may occur at any point after regional stock distribution. The dashed arrows represent the balancing required to maintain a constant coastwide SPR.

4.3 A Framework for Distributing the TCEY among IPHC Regulatory Areas

The harvest strategy policy begins with the coastwide TCEY determined from the stock assessment and fishing intensity determined from a target SPR (Figure 1). To distribute the TCEY among regions, stock distribution (Section 4.2.1) occurs first to satisfy conservation objectives. This is followed by adjustments across Biological Regions and Regulatory Areas based on distribution procedures to further encompass conservation objectives and consider fishery objectives. A constraint could be enforced such that given relative adjustments, the overall fishing intensity (i.e., target SPR) is maintained (i.e., a zero-sum game relative to fishing intensity). This is consistent with many management procedures for fisheries around the world. If a target SPR is not maintained, the minimum SPR value in the range produced by the distribution procedure would be considered the *de facto* target.

A framework for a management procedure that ends with the TCEY distributed among IPHC Regulatory Areas and would encompass conservation and fishery objectives is described below.

1. **Coastwide Assessment (science-based) and Target Fishing Intensity (management-derived):** Determine the coastwide total mortality using a target SPR that is most consistent with IPHC objectives defined by the Commission. Separate the total mortality into ≥26 inches (O26) and under 26 inches (U26) components. The O26 component is the coastwide TCEY.
2. **Regional Stock Distribution (science-based):** Distribute the coastwide TCEY to four (4) biologically-based Regions (Figure 8) using the proportion of the stock estimated in each Biological Region for all sizes of Pacific halibut using information from the IPHC setline survey and the IPHC space-time model. “All sizes” WPUE is the most appropriate metric to distribute the TCEY.
3. **Regional Relative Fishing Intensity (science-based):** Adjust the distribution of the TCEY among Biological Regions to account for migration, productivity, data availability/uncertainty, and other biological characteristics of the Pacific halibut observed in each Biological Region.
    3.1. The IPHC Secretariat may be able to provide Yield-Per-Recruit (YPR) and/or surplus production calculations as further supplementary information to inform this step.
4. **Regional Allocation Adjustment (management derived):** Adjust the distribution of the TCEY among Biological Regions to account for other factors.
    4.1. Further adjustments are part of a management/policy decision that may be informed by data and observations. 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. The regional relative harvest rates may also be determined through negotiation, leading to an allocation agreement for further Regional adjustment of the TCEY.
5. **Regulatory Area Allocation (management derived):** Apply IPHC Regulatory Area allocation percentages within each Biological Region to distribute the Region-specific TCEY’s to Regulatory Areas.
    5.1. This management or policy decision may be informed by data, based on past or current observations, or defined by an allocation agreement. For example, recent trends in estimated all sizes WPUE from the setline survey or fishery, 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 data, observations, or agreements

The four 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 1).

6. **Annual Regulatory Area Adjustment (policy)**: Adjust individual Regulatory Area TCEY limits to account for other factors as needed. This is the policy part of the harvest strategy policy and occurs as a final step where other objectives are considered (e.g., economic, social, etc.).
    6.1. A departure from the target 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.

5 DEVELOPMENT OF THE CLOSED-LOOP SIMULATION FRAMEWORK

An MSE is a scientifically defensible, forecast-driven study of the tradeoffs between fisheries management scenarios, and requires that the software underpinning these simulations be robust, well-documented, performant, and extensible. It should return reproducible results, maximize ease-of-use, and be written with standard software development and testing processes and tools. With these guidelines in mind, the IPHC MSE development project will produce a simulation, analysis, and visualization tool set that can support Pacific halibut fisheries management in the future.

The structure of the software to be developed resembles the MSE process, highlighting the interplay between forecast models conditioned on historical data that characterize the stock, and a management procedure to be evaluated against conservation and fishery objectives. Aspects include

- the creation of an operating model
- an ability to condition model parameters using historical catches, survey data, and other observations
- integration with stock assessment tools or data
- application of a management procedure with closed-loop feedback into the operating model
- production of performance metrics to evaluate management procedures
- support for hypothesis testing, stock performance investigation, and detailed tradeoff analysis
- a platform and data source for customizable visualizations and analytics
- standardization of the computer-based format, structure, and content of management procedures
- leveraging existing high-performance scientific computing methodologies, software, and infrastructure

In practical terms, the operating model and related high-performance scientific and statistical codes will be written in C++ and heavily leverage available libraries, such as the AD Model Builder package. Configuration files and templates will utilize YAML, a human-readable but machine-parseable text specification. Additional statistical tooling used for analysis and visualization will utilize R. A workflow management system will be used to manage and monitor the execution of computational jobs, and will support their execution both locally and on third-party (e.g., cloud or HPC center) resources.

A summary of the framework components is below.

1. Operating Model
    1.1. An open-source C++ codebase developed at the IPHC, simulating the dynamics of
        - fish biology and population dynamics
        - ocean regime
        - environmental and ecological effects
        - partitions for year, age, sex, and more
        - variability in various processes
    1.2. Customizable spatial mapping, but at minimum per Region and IPHC Regulatory Area
    1.3. Fleet mapping for consistency with stock assessment models (commercial, discards, bycatch, sport, personal use by IPHC Regulatory Area as necessary).
    1.4. Uncertainty of parameters and model structure, and simulated variability in factors such as future weight-at-age and recruitment.
2. Management Procedure
    2.1. Estimation Models, including
        - Perfect information, as if we knew population values exactly when applying the harvest rule.
        - Simulate error in the total mortality limit and relative spawning biomass (i.e., stock status), and their autocorrelation, from the simulated time-series to mimic an unbiased stock assessment.
        - Use a single existing stock assessment
        - Use an ensemble of stock assessment techniques
        - Survey-based harvest rules that eliminate a complex stock assessment
    2.2. Data Generation
        - Use the operating model to generate simulated realizations of data products (e.g., survey index) at the Region or IPHC Regulatory Area level with variability and bias
    2.3. Harvest Rule
        - Coastwide fishing intensity (FSPR) using a procedural input SPR.
        - A control rule to reduce the fishing intensity (increase SPR) between a fishery trigger and fishery limit.
        - Constraints on the annual change in the mortality limit
        - Other coastwide and area-specific elements as defined by the MSAB
3. Analysis, Visualization, and Reporting tools
    3.1. Statistical tools for data analysis and quick-look visualization, written in R and C++
    3.2. Web-based visualization tools, written in R and Javascript, for easy stakeholder viewing and data manipulation
    3.3. Reporting tools, allowing customizable summaries of MSE output for later analysis, inclusion in documents, and stakeholder review
4. Computing infrastructure
    4.1. Human- and machine-readable configuration files for operating model and management procedures (YAML)
    4.2. Workflow management system for the management and monitoring of computational tasks (e.g., Drake, Airflow, Dask)
    4.3. Ability to run locally, on cloud providers (Amazon Web Services, Microsoft Azure, Google Cloud) or on third-party supercomputing resources (Open Science Grid, XSEDE)

5.1 MULTI-AREA OPERATING MODEL

The operating model will be generalized and able to model a single-area or multiple areas such as IPHC Regulatory Areas. However, based on current knowledge, biology and inter-annual movement of Pacific halibut is best modeled with Biological Regions (Figure 8). Distribution of the TCEY will still occur to IPHC Regulatory Areas by modelling multiple sectors within a Biological Region, and sector-specific performance metrics will be calculated at the IPHC Regulatory Area level.

6 MSE PROGRAM OF WORK

The presentation of results for the MSE investigating the full harvest strategy policy is scheduled to occur at the 97th Annual Meeting in early 2021. The tasks to be delivered at each MSAB meeting before then are listed in Table 9. The SRB will review the technical details of the framework and operating model in September 2019, see preliminary results in June 2020, and review the full MSE in September 2020.

Table 9: Program of work and tasks for 2019 and 2020 to deliver the full MSE results at the 97th Annual Meeting in early 2021.

May 2019 MSAB Meeting
Evaluate additional Scale MPs
Review Goals
Spatial Model Complexity
Identify MPs (Distribution & Scale)
Review Framework
October 2019 MSAB Meeting
Review Goals and Objectives
Spatial Model Complexity
Identify MPs (Distribution & Scale)
Review Framework
Review multi-area model development
Annual Meeting 2020
Update on progress
May 2020 MSAB Meeting
Review Goals and Objectives
Review multi-area model
Review final results to be presented at AM097
October 2020 MSAB Meeting
Review Goals and Objectives
Review final results
Annual Meeting 2021
Presentation of first complete MSE product to the Commission Recommendations on Scale and Distribution MP

7 RECOMMENDATIONS

That the SRB **NOTE**:

a) paper IPHC-2019-SRB014-08 which provides the SRB with an update on the IPHC MSE process including defining objectives, results for management procedures related to coastwide fishing intensity, a framework for distributing the TCEY, and a program of work.

b) the primary objectives used to evaluate management procedures related to coastwide scale and the additional primary objectives related to a target biomass.

c) that no coastwide management procedure without constraints met the stability objective.

d) that the three different constraints were ranked in the top 5 management procedures (a slow-up fast-down approach, a maximum change of 15%, and a multi-year limit).

e) the distribution framework consisting of a coastwide TCEY distributed to Biological Regions based on stock distribution, relative fishing intensities, and other allocation adjustments, then distributed to IPHC Regulatory Areas based other data, observations, or agreement.

f) the development of a closed-loop simulation framework to evaluate management procedures related to coastwide scale and distribution of the TCEY.

g) that the SRB will review the technical details of the MSE framework and operating model in September 2019, and review the full MSE in September 2020.

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9 APPENDICES

Appendix I: Additional long- and medium-term performance metrics for the coastwide simulations

APPENDIX I: ADDITIONAL LONG- AND SHORT-TERM PERFORMANCE METRICS FOR THE COASTWIDE SIMULATIONS

Table A1. Long-term performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, and a range of input SPRs.

Input Est Error	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**
Input Autocorrelation	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Input Control Rule	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Median SPR	56.3%	49.0%	47.4%	45.8%	44.5%	43.6%	42.7%	42.5%	42.6%	42.4%	42.6%
Biological Sustainability											
Median average dRSB	50.2%	41.6%	39.7%	37.9%	36.4%	35.1%	33.9%	32.9%	31.8%	31.0%	30.4%
P(all dRSB<20%)	0.002	0.002	0.003	0.004	0.002	0.003	0.004	0.005	0.005	0.004	0.004
P(any dRSB_y<20%)	0.002	0.003	0.004	0.004	0.003	0.004	0.005	0.006	0.008	0.008	0.011
P(all dRSB<30%)	0.002	0.023	0.043	0.073	0.096	0.146	0.199	0.253	0.343	0.405	0.470
P(any dRSB_y<30%)	0.003	0.044	0.088	0.151	0.209	0.317	0.409	0.545	0.684	0.789	0.867
P(all dRSB<40%)	0.052	0.408	0.531	0.658	0.769	0.856	0.911	0.948	0.969	0.980	0.989
P(any dRSB_y<40%)	0.087	0.574	0.721	0.854	0.939	0.979	0.992	0.999	1.000	1.000	1.000
Fishery Sustainability											
P(all AAV > 15%)	0.606	0.689	0.717	0.767	0.812	0.849	0.905	0.927	0.957	0.988	0.993
P(all TM < 34 Mlbs)	0.507	0.455	0.460	0.453	0.446	0.450	0.440	0.439	0.465	0.458	0.465
P(any TM < 34 Mlbs)	0.662	0.627	0.637	0.644	0.666	0.686	0.721	0.758	0.808	0.862	0.891
5^{th} percentile of TM	9.47	9.08	8.8	8.94	9.56	9.33	9.28	9.74	8.41	9.16	9.28
Median average TM	33.95	37.39	37.56	38.08	38.98	38.79	40.33	40.6	39.35	41.84	42.06
75^{th} percentile of TM	55.14	62.11	62.49	64.15	65.37	66.49	68.28	70.61	69.21	70.94	72.26
P(all decrease TM > 15%)	0.221	0.236	0.247	0.263	0.274	0.286	0.301	0.319	0.337	0.352	0.365
P(any decrease TM > 15%)	0.921	0.932	0.942	0.946	0.955	0.963	0.973	0.982	0.990	0.992	0.997
median AAV TM	16.3%	17.5%	18.4%	19.6%	21.3%	23.6%	26.4%	30.2%	34.0%	37.3%	41.8%

Table A2. Medium-term (14-23 annual time-steps) performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, and a range of input SPRs.

Input Est Error	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**
Input Autocorrelation	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Input Control Rule	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**	**30:20**
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Median SPR	56.7%	49.2%	47.4%	45.7%	44.1%	42.6%	41.4%	40.7%	40.4%	40.2%	40.5%
Biological Sustainability											
Median average dRSB	49.5%	42.9%	41.4%	39.8%	38.3%	36.8%	35.4%	34.1%	33.0%	32.0%	31.1%
P(all dRSB<20%)	0.013	0.013	0.011	0.011	0.011	0.011	0.011	0.013	0.011	0.014	0.014
P(any dRSB_y<20%)	0.019	0.019	0.017	0.017	0.017	0.016	0.015	0.020	0.019	0.023	0.027
P(all dRSB<30%)	0.042	0.055	0.072	0.082	0.100	0.124	0.151	0.193	0.263	0.331	0.410
P(any dRSB_y<30%)	0.054	0.083	0.115	0.140	0.180	0.236	0.313	0.432	0.574	0.698	0.816
P(all dRSB<40%)	0.174	0.346	0.433	0.531	0.642	0.747	0.841	0.903	0.943	0.967	0.980
P(any dRSB_y<40%)	0.249	0.486	0.606	0.742	0.856	0.944	0.982	0.997	0.999	1.000	1.000
Fishery Sustainability											
P(all AAV > 15%)	0.604	0.656	0.694	0.719	0.756	0.799	0.841	0.884	0.929	0.964	0.980
P(all TM < 34 Mlbs)	0.415	0.330	0.323	0.306	0.296	0.286	0.277	0.279	0.296	0.299	0.318
P(any TM < 34 Mlbs)	0.626	0.531	0.520	0.517	0.524	0.554	0.603	0.666	0.727	0.773	0.832
5th percentile of TM	13.78	15.71	13.9	14.17	15.01	15.23	15.71	16.71	14.71	16.37	15.88
Median average TM	39.37	45.5	46.76	48.04	49.51	50.64	51.78	52.11	52.38	53.15	52.82
75th percentile of TM	52.87	61.7	62.67	64.76	66.67	68.46	69.93	71.99	71.64	72.74	74.21
P(all decrease TM > 15%)	0.196	0.218	0.226	0.234	0.247	0.258	0.276	0.295	0.313	0.337	0.357
P(any decrease TM > 15%)	0.909	0.921	0.929	0.937	0.948	0.956	0.965	0.977	0.983	0.992	0.995
median AAV TM	16.5%	17.5%	17.9%	18.7%	19.7%	20.9%	23.1%	26.2%	29.7%	33.5%	37.3%

Table A3. Long-term performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, three different constraints on the annual change in the mortality limit, and a range of input SPRs.

Input Est Error	**0.15**											
Input Autocorrelation	**0.4**											
Input Control Rule	**30:20**											
Constraint	**maxChangeBoth15%**				**slowUp FastDown**				**multiYear**			
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**
Median SPR	48.4%	44.9%	43.2%	41.7%	48.8%	45.3%	43.7%	42.1%	47.8%	44.3%	42.7%	41.3%
Biological Sustainability												
Median average dRSB	42.5%	39.6%	38.1%	36.9%	42.9%	40.0%	38.5%	37.1%	41.5%	38.4%	36.9%	35.4%
P(all dRSB<20%)	0.053	0.053	0.058	0.053	0.018	0.018	0.018	0.019	0.011	0.013	0.011	0.014
P(any dRSB_y<20%)	0.066	0.066	0.072	0.066	0.023	0.023	0.023	0.025	0.017	0.021	0.018	0.023
P(all dRSB<30%)	0.094	0.107	0.133	0.138	0.054	0.074	0.088	0.109	0.072	0.102	0.137	0.172
P(any dRSB_y<30%)	0.140	0.185	0.239	0.274	0.079	0.140	0.186	0.234	0.131	0.209	0.296	0.395
P(all dRSB<40%)	0.370	0.537	0.639	0.720	0.366	0.524	0.616	0.716	0.431	0.617	0.709	0.795
P(any dRSB_y<40%)	0.549	0.776	0.874	0.931	0.528	0.758	0.851	0.921	0.637	0.839	0.934	0.967
Fishery Sustainability												
P(all AAV > 15%)	0.042	0.047	0.054	0.055	0.068	0.109	0.143	0.151	0.144	0.187	0.256	0.296
P(all TM < 34 Mlbs)	0.340	0.319	0.323	0.314	0.336	0.304	0.292	0.267	0.324	0.283	0.283	0.280
P(any TM < 34 Mlbs)	0.474	0.453	0.452	0.456	0.449	0.434	0.440	0.444	0.468	0.458	0.483	0.510
5^{th} percentile of TM	6.16	6.13	5.86	6.18	13.33	13.52	13.88	12.97	14.19	15.98	15.81	16.62
Median average TM	46.13	48.55	49.52	50.88	44.99	48.17	49.47	51.11	46.53	48.88	50.49	51.18
75^{th} percentile of TM	62.46	66.75	67.82	70.06	63.49	67.98	70.43	70.77	62.58	67.73	68.19	70.68
P(all decrease TM > 15%)	0.091	0.098	0.104	0.112	0.045	0.064	0.078	0.088	0.093	0.101	0.111	0.117
P(any decrease TM > 15%)	0.549	0.582	0.600	0.614	0.298	0.385	0.435	0.491	0.664	0.699	0.746	0.760
median AAV TM	11.2%	11.3%	11.6%	11.7%	7.0%	7.7%	8.1%	8.8%	8.0%	8.8%	9.8%	10.8%

Table A4. Medium-term (14-23 annual time-steps) performance metrics for an estimation error CV of 0.15, autocorrelation of 0.4, a 30:20 control rule, three different constraints on the annual change in the mortality limit, and a range of input SPRs.

Input Est Error	**0.15**											
Input Autocorrelation	**0.4**											
Input Control Rule	**30:20**											
Constraint	**maxChangeBoth15%**				**slowUp FastDown**				**multiYear**			
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**
Median SPR	48.4%	44.9%	43.2%	41.7%	48.8%	45.3%	43.7%	42.1%	47.8%	44.3%	42.7%	41.3%
Biological Sustainability												
Median average dRSB	42.5%	39.6%	38.1%	36.9%	42.9%	40.0%	38.5%	37.1%	41.5%	38.4%	36.9%	35.4%
P(all dRSB<20%)	0.053	0.053	0.058	0.053	0.018	0.018	0.018	0.019	0.011	0.013	0.011	0.014
P(any dRSB_y<20%)	0.066	0.066	0.072	0.066	0.023	0.023	0.023	0.025	0.017	0.021	0.018	0.023
P(all dRSB<30%)	0.094	0.107	0.133	0.138	0.054	0.074	0.088	0.109	0.072	0.102	0.137	0.172
P(any dRSB_y<30%)	0.140	0.185	0.239	0.274	0.079	0.140	0.186	0.234	0.131	0.209	0.296	0.395
P(all dRSB<40%)	0.370	0.537	0.639	0.720	0.366	0.524	0.616	0.716	0.431	0.617	0.709	0.795
P(any dRSB_y<40%)	0.549	0.776	0.874	0.931	0.528	0.758	0.851	0.921	0.637	0.839	0.934	0.967
Fishery Sustainability												
P(all AAV > 15%)	0.042	0.047	0.054	0.055	0.068	0.109	0.143	0.151	0.144	0.187	0.256	0.296
P(all TM < 34 Mlbs)	0.340	0.319	0.323	0.314	0.336	0.304	0.292	0.267	0.324	0.283	0.283	0.280
P(any TM < 34 Mlbs)	0.474	0.453	0.452	0.456	0.449	0.434	0.440	0.444	0.468	0.458	0.483	0.510
5^{th} percentile of TM	6.16	6.13	5.86	6.18	13.33	13.52	13.88	12.97	14.19	15.98	15.81	16.62
Median average TM	46.13	48.55	49.52	50.88	44.99	48.17	49.47	51.11	46.53	48.88	50.49	51.18
75^{th} percentile of TM	62.46	66.75	67.82	70.06	63.49	67.98	70.43	70.77	62.58	67.73	68.19	70.68
P(all decrease TM > 15%)	0.091	0.098	0.104	0.112	0.045	0.064	0.078	0.088	0.093	0.101	0.111	0.117
P(any decrease TM > 15%)	0.549	0.582	0.600	0.614	0.298	0.385	0.435	0.491	0.664	0.699	0.746	0.760
median AAV TM	11.2%	11.3%	11.6%	11.7%	7.0%	7.7%	8.1%	8.8%	8.0%	8.8%	9.8%	10.8%

INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC-2019-SRB014-09

Report on Current and Future Biological Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, T. LOHER, L. SADORUS, C. DYKSTRA, J. FORSBERG, 24 MAY 2019)

PURPOSE

To provide the Scientific Review Board with an update of current progress on research projects conducted and planned by the Biological and Ecosystem Science Research Program.

BACKGROUND

The primary biological research activities at IPHC that follow Commission objectives are identified and described in the proposed Five-Year Research Plan for the period 2017-21. These activities are summarized in five broad categories, as follows:

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

UPDATE ON PROGRESS ON THE MAIN RESEARCH ACTIVITIES

1. Migration.

Knowledge of Pacific halibut migration throughout all life stages is necessary in order to gain a complete understanding of stock distribution and the factors that influence it.

1.1. Larval distribution and connectivity between the Gulf of Alaska and Bering Sea. Work is nearing completion on this cooperative project between NOAA EcoFoci and the IPHC. Larval advection modeling is producing information about possible connectivity pathways during cold and warm years as well as quantifying the degree of connectivity between known spawning grounds and settlement both between and within the Gulf of Alaska and Bering Sea. Application of the IPHC-developed space-time model is being used to assess distribution of young fish from 2-year-old to adult ages as they move away from the settlement grounds. Results will provide a new understanding of linkages between spawning grounds, eventual settlement, and subsequent migration of young fish, as well as variability in these pathways under different environmental scenarios. This work will fill a gap in knowledge of early life history dispersal utilized by Pacific halibut. Final results and manuscript draft are expected later this year.

1.2. Wire tagging of U32 Pacific halibut. Wire tagging of Pacific halibut caught in the NOAA/NMFS trawl surveys which began in 2015, is continuing in 2019. Through 2018, 4,749 tags had been released and 39 recovered to date. The wire tagging effort that has taken place during the FISS in recent years is not taking place in 2019 due to work load commitments on the surveys. Through 2018, a total of 3,112 U32 Pacific halibut had been wire tagged and 39 of those have been recovered to date.

1.3. Electronic archival tagging. Electronic archival tags that allow for daily light-based geo-positioning as well as depth and temperature recording will be deployed on U32 Pacific halibut caught in the eastern Bering Sea during 2019. The project began in 2018 aboard the IPHC's Fishery Independent Setline Survey (FISS), during which 255 fishery-recovery long-term (7 year recording capacity) archival tags were deployed coastwide and 13 Pop-up Archival Transmitting (PAT) tags were deployed in the Aleutian Islands. This year's effort will deploy fishery-recovery archival tags (n = 62) from the NOAA/NMFS Eastern Bering Sea (EBS) trawl survey; a combination of fishery-recovery (n = 35) and PAT (n = 9) tags around the Pribilof Islands in collaboration with the Central Bering Sea Fishermen's Association (CBSFA); and a combination of fishery-recovery (n = 50) and PAT (n = 16) tags in the Norton Sound and St. Lawrence Island region in collaboration with the Norton Sound Economic Development Corporation (NSEDC). Of the tags that are planned for deployment in the EBS trawl survey, roughly half will be deployed along the Alaska Peninsula and half at stations on or northward of 58º50' N latitude and west of 162º W longitude. In addition, a small number of PAT tags (n = 6) will be deployed north of St. Lawrence Island via the NMFS Northern Bering Sea trawl survey. These efforts will be accompanied by tagging of large (>100 cm) Pacific halibut by NSEDC in the Norton Sound region, so as to produce data that are comparable to the IPHC's prior PAT-tagging research conducted to examine adult connectivity and spawning stock structure throughout the managed range,

2. Reproduction.

Efforts at IPHC are currently underway to address two critical issues in stock assessment for estimating the female spawning biomass: the sex ratio of the commercial landings and maturity estimations.

2.1. Sex ratio of the commercial landings. For the first time, the IPHC has generated sex information of the entire set of age commercial landings in 2017. Genetic assays developed in collaboration with the University of Washington (Drinan *et al*. Identification of genomic regions associated with sex in Pacific halibut. *J. Heredity*, 2018, 326-332) consisting in a multiplex Taqman assay for two single nucleotide polymorphisms (SNPs) that are exclusive for females have been conducted at the IPHC biological laboratory on a QuantStudio6 instrument. Fin clips from over 10,000 aged Pacific halibut collected coastwide by IPHC port samplers in 2017 were used for genomic DNA extraction in 96 well plates and Taqman assays were conducted in 384 well plates.

2.2. Maturity estimations. In order to characterize the gonadal maturation schedule, the IPHC is conducting a full characterization of the annual reproductive cycle in female and male Pacific halibut. Biological samples (gonads, blood, pituitary, otolith, fat content) were collected at monthly intervals from female (N=30) and male (N=30) Pacific halibut captured from the Portlock region in the central Gulf of Alaska throughout an entire calendar year, from September 2017 until August 2018. Formalin-fixed gonadal samples were processed for histology in early 2019 and duplicate histological slides for each sampled Pacific halibut gonad (N = 360 per sex) were stained with Hematoxylin and Eosin and are now available for staging. An MSc student from Alaska Pacific University, with funding from IPHC, was trained for this purpose in March 2019 and will begin staging the entire collection of ovarian histological samples in June 2019. The revision of maturity schedules and the comparison of macroscopic and microscopic ovarian staging will constitute the basis of her MSc dissertation. Preliminary results include the temporal progression of the four maturity classification stages used for staging females in the IPHC FISS (Fig. 1) and of the gonadosomatic index (gonad weight/round weight x 100; GSI) for both females and males and a classification of the different oocyte developmental stages that is critical for accurate staging.

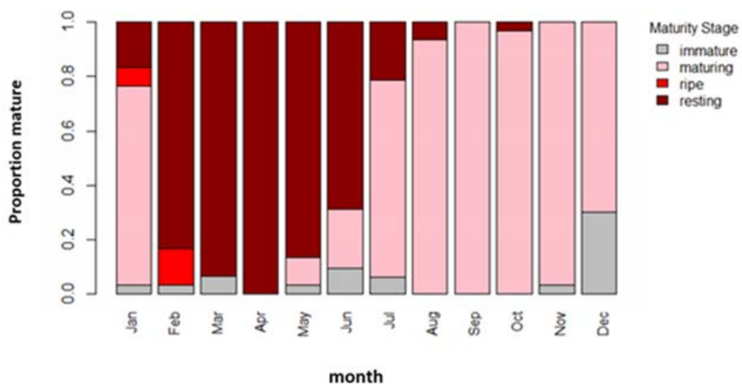


Figure 1. Temporal changes in the proportion of female Pacific halibut staged macroscopically according to the maturity classification criteria used in the FISS throughout an entire calendar year in the Portlock region (Central Gulf of Alaska).

Future plans include: 1) analysis of the entire collection of testicular histological samples and 2) the temporal characterization of reproductive hormones in the blood (17β-estradiol, testosterone and 17α, 20 β-dihydroxy-4-pregnen-3-one for females and 11-ketotestosterone, testosterone and 17 α, 20 β-dihydroxy-4-pregnen-3-one for males) and the gene expression profiles of gonadotropic hormones (follicle-stimulating hormone and luteinizing hormone) in the pituitary of female and male Pacific halibut. In addition to characterizing the progression of reproductive development throughout an entire annual reproductive cycle (intraseasonal) reproductive samples, the IPHC will collect samples in June 2019 to compare with those collected in June 2018 and June 2017 in the Portlock region in order to evaluate possible differences in interseasonal variation in maturity schedules.

3. Growth.

In order to improve our understanding of the possible role of growth alterations in the observed historical changes in size-at-age in Pacific halibut, the IPHC Secretariat is conducting studies aimed at: 1) the identification and validation of physiological markers for growth; and 2) the use of growth markers for evaluating growth patterns in the Pacific halibut population and the effects of environmental influences. The IPHC Secretariat is conducting investigations on the effects of temperature variation on growth performance, as well as on the effects of density, hierarchical dominance and handling stress on growth in juvenile Pacific halibut in captivity. These studies are partially funded by a grant from the North Pacific Research Board to the IPHC (Appendix I).

3.1. Effects of temperature. Temperature acclimation laboratory studies were conducted in collaboration with the Alaska Fisheries Science Center in Newport, OR and resulted in the successful manipulation of growth patterns: growth suppression by acclimation to low water temperature and growth stimulation by temperature-induced growth compensation in juvenile Pacific halibut. White skeletal muscle samples from the control and treatment groups resulting from the two types of growth manipulations were collected and processed for transcriptomic (i. e. RNAseq) and proteomic analyses. Temperature induced growth suppression resulted in a significantly decrease in the mRNA expression levels of 676 annotated genes and in a significantly decrease in the abundance of 150 annotated proteins. In contrast, temperature-induced growth stimulation resulted in a significant increase in the mRNA expression levels of 202 annotated genes and a significant increase in the abundance of 149 annotated proteins. Efforts are currently underway to analyze these data and prepare a manuscript for submission to a peer-reviewed journal. Based on the transcriptomic results, a set of potential growth marker genes has been selected for validation by qPCR as well as a set of potential housekeeping genes for normalization of expression levels.

3.2. Effects of density. In order to investigate the effects of density on somatic growth, laboratory experiments have been conducted. Fish were held in groups of 8 fish per tank (with 4 replicate tanks), 4 fish per tank (with 4 replicate tanks) and also individually (with 10 replicate tanks) under restricted feeding (at 50% of maximal feeding rate) for a period of 6 weeks. White skeletal muscle samples and liver samples were collected from fish at different densities for target gene expression analyses by qPCR.

3.3. Effects of hierarchical dominance and handling stress. Laboratory experiments designed to investigate the effects of hierarchical dominance and handling stress are currently being conducted. Muscle and liver samples will be collected for target gene expression analyses by qPCR.

4. Discard Mortality Rates (DMRs) and Survival Assessment. In order to better estimate post-release survival of Pacific halibut caught incidentally in the directed longline fishery, the IPHC Secretariat is conducting investigations to understand the relationship between fish handling practices and fish physical and physiological condition and survival post-capture as assessed

by tagging. These studies are partially funded by a grant from the Saltonstall-Kennedy Grant Program NOAA to IPHC (Appendix I).

4.1. Evaluation of the effects of **hook release techniques** on injury levels and association with the physiological condition of captured Pacific halibut. The IPHC has evaluated the effects of different release techniques on injury levels (Fig. 2) and the results indicate that a majority (more than 70%) of Pacific halibut released by careful shake and by gangion cutting are classified in the excellent injury category. In contrast, Pacific halibut that encounter the hook stripper are primarily classified in the medium and poor injury categories.

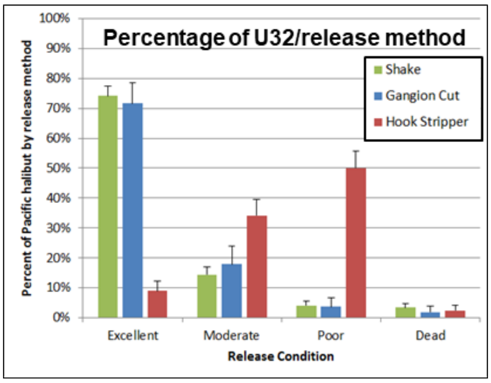


Figure 2. Prevalence of types of injuries (as indicated by injury classification or release condition) in U32 fish released by different hook release techniques (careful shake, gangion cut and hook stripper).

The physiological condition of Pacific halibut subjected to the different hook release techniques is currently being assessed by relating the injury category assigned to each fish with the condition factor, fat levels and levels of blood stress indicators. Blood glucose levels from all fish released have been determined using a colorimetric method. A colorimetric method for measuring blood lactate levels and an enzyme-linked immunoabsorbance (ELISA) method for measuring blood cortisol levels have been validated for Pacific halibut plasma samples and will be used next to measure blood lactate and cortisol levels.

4.2. Post-release survival estimations. In order to evaluate the survival of discarded fish, two types of tagging approaches were used. 1) Classical mark-and-recapture of released fish with wire tags: 1,027 fish (under 33 inches in length) were tagged. 2) Biotelemetric monitoring of released fish with the use of satellite-transmitting electronic archival tags equipped with accelerometers: results from a total of 79 Pacific halibut ranging from 53-81 cm FL allowed us to estimate that the DMR of U32 Pacific halibut that were categorized as being in excellent-condition at the time of their release was approximately 4%.

4.3. Application of electronic monitoring (EM) for capturing the hook release methods. Evaluation of EM data whereby reviewers recorded the release method and condition of released fish evidenced a high degree (95%-100%) of agreement between the actual release method used and that captured by EM. Therefore, once the survival estimates of fish released by the different hook release techniques are determined, these results strongly suggest that mortality rates could be deduced from EM-captured hook release techniques.

4.4. Discard mortality rates of Pacific halibut in the charter recreational fishery. The IPHC will begin shortly a research project aimed at experimentally deriving DMRs from the charter recreational fishery for the first time. This project has received funding from the National Fish and Wildlife foundation (Appendix I). As an initial step in this project, information from the charter fleet on types of gear and fish handling practices used will be collected through stakeholder meetings and on dock interviews with charter captains and operators. This information will inform the design of the experimental test fishing that will take place in 2020 and in which fish mortality will be estimated as described in 4.2.

5. Genetics and genomics. The IPHC Secretariat is exploring avenues for incorporating genetic approaches for a better understanding of population structure and distribution and is also building genomic resources to assist in genetics and molecular studies on Pacific halibut.

5.1. Genetics. In an effort to revisit past studies on the genetic structure of the Pacific halibut population conducted with the use of a panel of microsatellites (Drinan *et al*. Subtle genetic population structure in Pacific halibut *Hippoglossus stenolepis*. *J. Fish Biol*., 2016, 89: 2571-2594) on a set of samples covering the entire distribution range of the species, the Secretariat is planning on collecting additional winter samples in those geographic areas that only provided summer samples for that particular study (i.e. Western Aleutian Islands). The additional winter samples from spawning groups in the Western Aleutian islands are critical since the subtle population structure differences observed in the past study were precisely from fish sampled in those areas. Revised genetic analyses will be conducted using state-of-the-art genetics techniques that incorporate a much larger number of markers (e.g. SNPs) and that will provide improved genetic resolution, such as RADseq or whole genome sequencing.

5.2. Genomics. The IPHC Secretariat is currently conducting a project aimed at generating a first draft sequence of the Pacific halibut genome. This study is being conducted in collaboration with the National Institute of Agrogenomic Research (INRA, Rennes, France) and the University of Washington. An initial sequencing effort using genomic DNA from one Pacific halibut female in half an Illumina lane in 2 x 250 pair end mode resulted in a total size of assembled scaffolds of 700 Mb, likely corresponding to the size of the Pacific halibut genome. This non-contiguous genomic sequence is currently being complemented by long read sequencing using the Nanopore technology (i.e. PromethION) combined with Hi-C sequencing for chromosome-scale scaffolding of the genome assembly. The sequencing effort is expected to be completed by the end of summer 2019. Plans to establish a collaboration with Canadian scientists to establish a genomic comparison between Pacific and Atlantic halibut genomes are being discussed, including the possibility of a joint publication highlighting the comparative genomics approach. In addition to genome sequencing, the IPHC Secretariat has completed transcriptome sequencing of a wide variety of tissues (12) in Pacific halibut including white and red skeletal muscle, liver, heart, ovary, testis, head kidney, brain, gill, pituitary, spleen and retina. Current plans regarding this extensive transcriptomic dataset include generating a reference transcriptome for the species and to create a user-friendly, searchable database to be made public in the IPHC website.

APPENDIX I

Summary of current awarded research grants

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**Saltonstall-Kennedy NOAA**	Improving discard mortality rate estimates in the Pacific halibut by integrating handling practices, physiological condition and post-release survival (Award No. NA17NMF4270240)	IPHC	Alaska Pacific University	$286,121	Bycatch estimates	September 2017 – August 2019 (no cost extension requested)
2	**North Pacific Research Board**	Somatic growth processes in the Pacific halibut (*Hippoglossus stenolepis*) and their response to temperature, density and stress manipulation effects (NPRB Award No. 1704)	IPHC	AFSC-NOAA-Newport, OR	$131,891	Changes in biomass/size-at-age	September 2017 – February 2020
3	**Bycatch Reduction Engineering Program - NOAA**	Adapting Towed Array Hydrophones to Support Information Sharing Networks to Reduce Interactions Between Sperm Whales and Longline Gear in Alaska	Alaska Longline Fishing Association	IPHC, University of Alaska Southeast, AFSC-NOAA	TBD	Whale Depredation	September 2018 – August 2019
4	**Bycatch Reduction Engineering Program - NOAA**	Use of LEDs to reduce Pacific halibut catches before trawl entrainment	Pacific States Marine Fisheries Commission	IPHC, NMFS	TBD	Bycatch reduction	September 2018 – August 2019
5	**National Fish & Wildlife Foundation**	Improving the characterization of discard mortality of Pacific halibut in the recreational fisheries	IPHC	Alaska Pacific University, U of A Fairbanks, charter industry	$98,902	Bycatch estimates	January 2019 – December 2019
				Total awarded ($)	**$516,914**		

INTERNATIONAL PACIFIC HALIBUT COMMISSION

Migration and population genetics research at IPHC

(T. Loher, L. Sadorus, J. Planas)

Agenda item 8.3
IPHC-2019-SRB014-09

Outline

1) Structure and Frameworks for recent connectivity research
2) Summary of major Findings from that work
3) A Model for project selection
   - Identification of products and deliverables
   - Quantification of research plans
4) Some Topics of current interest
5) Incorporation of genetics into migration-related research

Research Program Structure

***Circa* 2002, we developed an integrated research program that was structured around Scale-dependent Processes and their relationship to Management Structure**

… that can be nested into three Temporal Scales relative to life history:

A) Large-scale = multigenerational / population-level

- Long-term; cumulative ontogenic

B) Meso-scale = intragenerational / cohort-level

- Ontogenic

C) Fine-scale = intrannual / individual-based

- Diurnal, sub-diurnal, seasonal

Research Program Structure

***Circa* 2002, we developed an integrated research program that was structured around Scale-dependent Processes and their relationship to Management Structure**

… and developed under two Overarching Frameworks:

1) Applied Fisheries Science

- That is, seeking to produce results that will lead to *specific* **management actions**

2) Theoretical Ecology

- Producing parameters leading to the **better understanding** of population function in general terms

Framework #1: Applied Science

Scale-dependent Processes and Management Actions

A) Large-scale: intergenerational / population-level

- How is the stock structurally organized, from a population-level perspective?
- Vaguely: Does this match our underlying management design?
- Specifically: Would we need additional Regulatory Areas to accurately encompass all functional population components?

For example, if Area 4B is composed of two genetically-distinct subpopulations, should we create a new Reg Area west of Amchitka?

Framework #1: Applied Science

Scale-dependent Processes and Management Actions

B) Meso-scale: intragenerational / cohort-level

- Spatial recruitment patterns: where do “our” fish come from?
- Vaguely: To what degree does fishing mortality in one Area affect other(s)?
- Specifically: Exactly *how* “wrong” is it to apply a region’s U32 trawl-bycatch mortality to its directed longline yield, when we “know” that those fish would not have stayed in that region? That is, where is that lost yield truly being felt?*

* Historically posed (repeatedly; from ~2002-2006) by Commissioner Dick Beamish as: “How many Canadian fish are you Alaskans killing, and how much would you owe us for them?”

Framework #1: Applied Science

Scale-dependent Processes and Management Actions

C) Fine-scale: intrannual / individual-based

- How does individual fish behavior interact with harvest strategy?
- Vaguely: Does seasonal migration redistribute fish in ways in which we do not understand?
- Specifically: To what extent does the distribution of fish as surveyed during summer (i.e., that which we simply call "stock distribution") reflect regional mean abundance integrated over nine- (or twelve-) month fishing seasons?

That is, if we're looking to achieve a relatively constant SPR among all regulatory areas within a Biological Region, how far from our target(s) might we be (by Area) "knowing" that the fish are unlikely to be where we surveyed them if they're harvested prior to May or after September?

Framework #1: Applied Science

Scale-dependent Processes and Management Actions

C) Fine-scale: intrannual / individual-based

- How does individual fish behavior interact with assessment?
- Vaguely: How do foraging dynamics affect indices of abundance?
- Specifically: To what extent does fish behavior introduce biases into the relationship between CPUE and true abundance?

For example, seeing as survey CPUE is a more direct an index of feeding motivation than of abundance *per se* … and feeding motivation in fishes tends to be highly influenced by water temperature … does a given CPUE imply the same thing (read: catch limit) in the Bering Sea as in Canada? Or, are we missing some critical "adjustment factors"?

Framework #2: Theoretical Ecology

Generate data for the construction, parameterization, and validation of age- and sex-specific spatial-distribution models

- The ecological equivalent of spatially-explicit assessment models
  - but numerical abundance estimation is not necessarily required; relative abundance or simple spatial coverage are valid goals

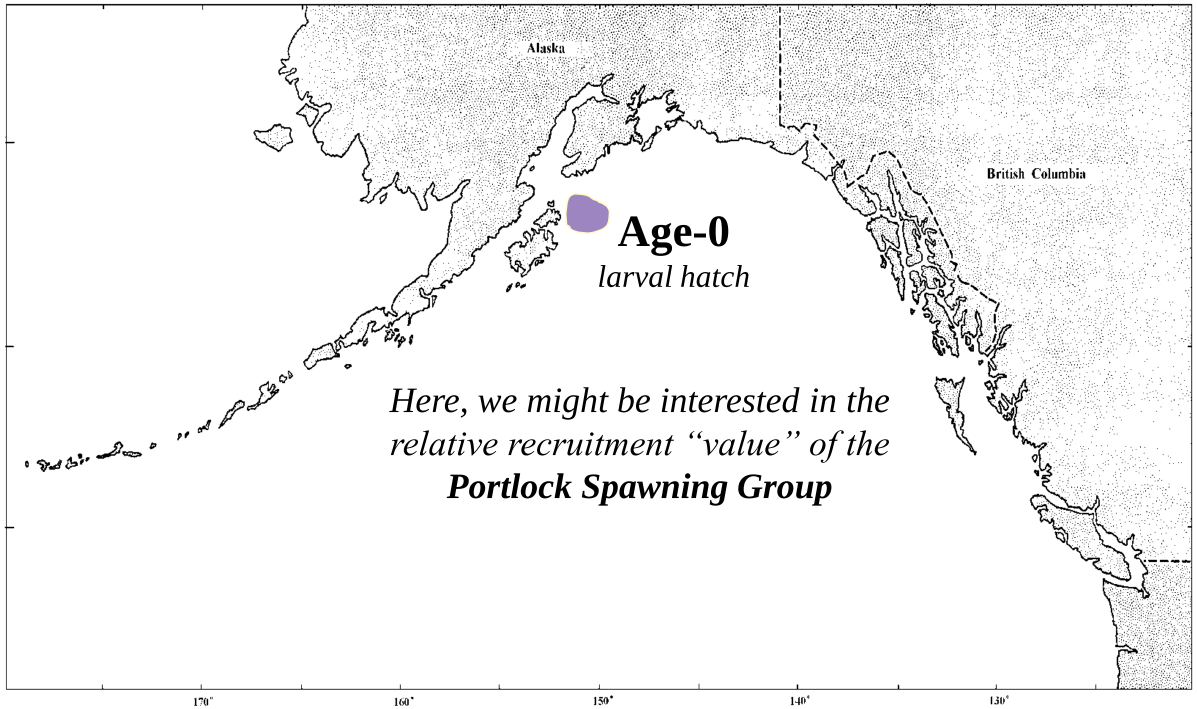
- Often referred to as “metapopulation modeling”
  - except, not really … because extinction-recolonization dynamics are not the focus

- More appropriately: a form of “landscape ecology modelling”

Framework #2: Theoretical Ecology

Generate data for the construction, parameterization, and validation of age- and sex-specific spatial-distribution models

- Example: spatial progression of a distinct source population



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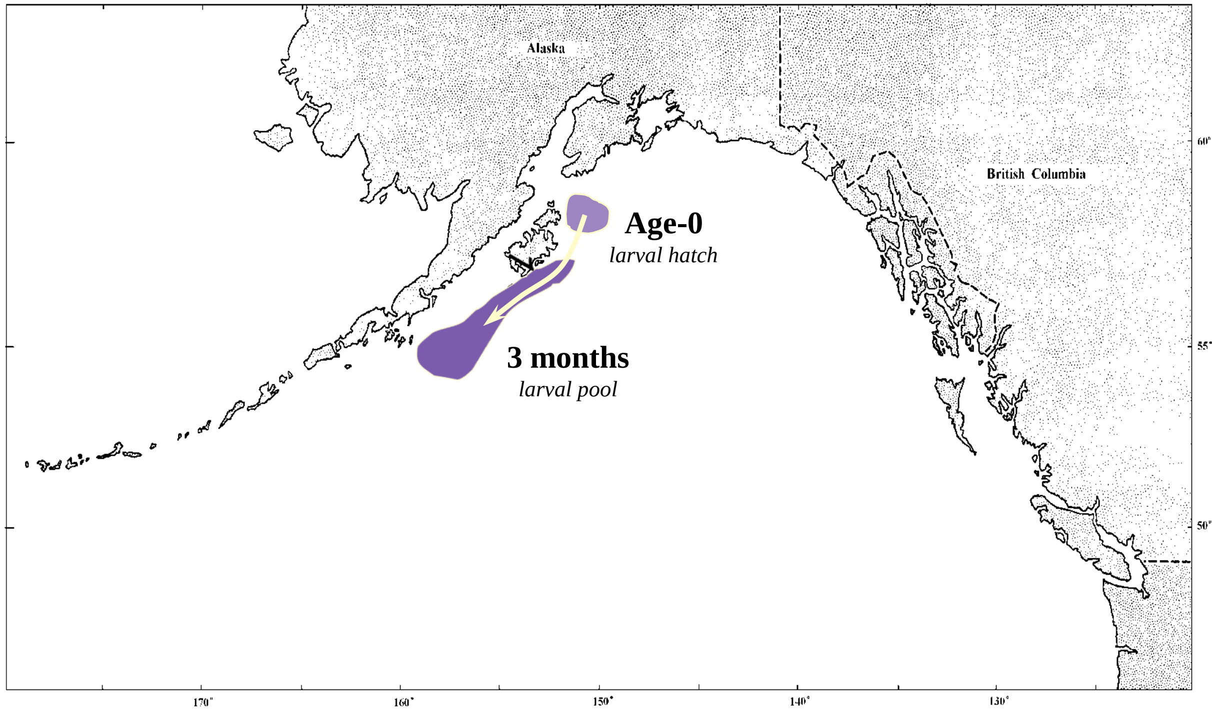

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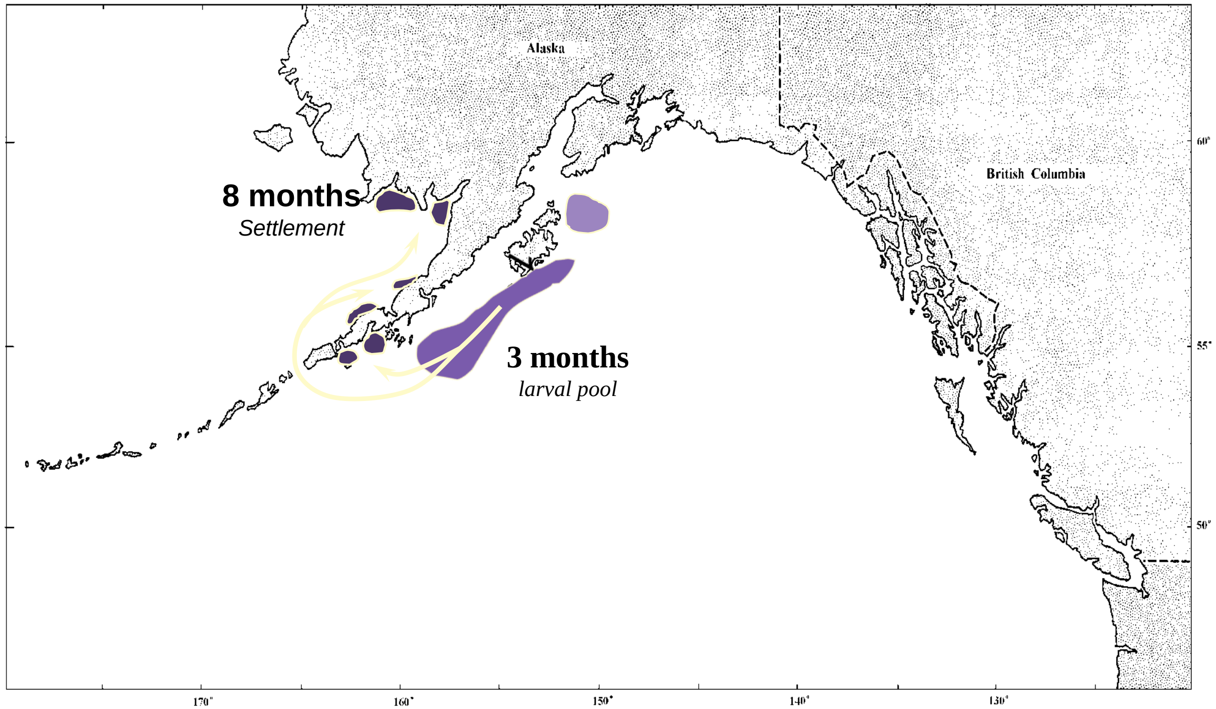

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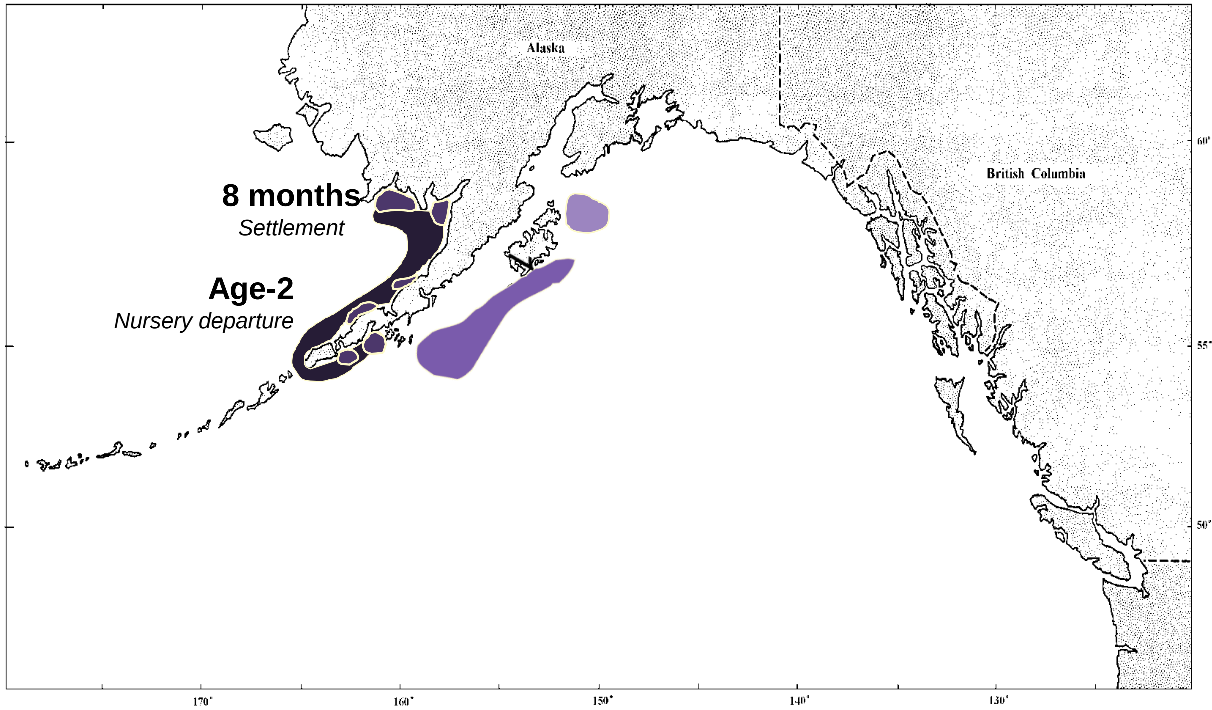

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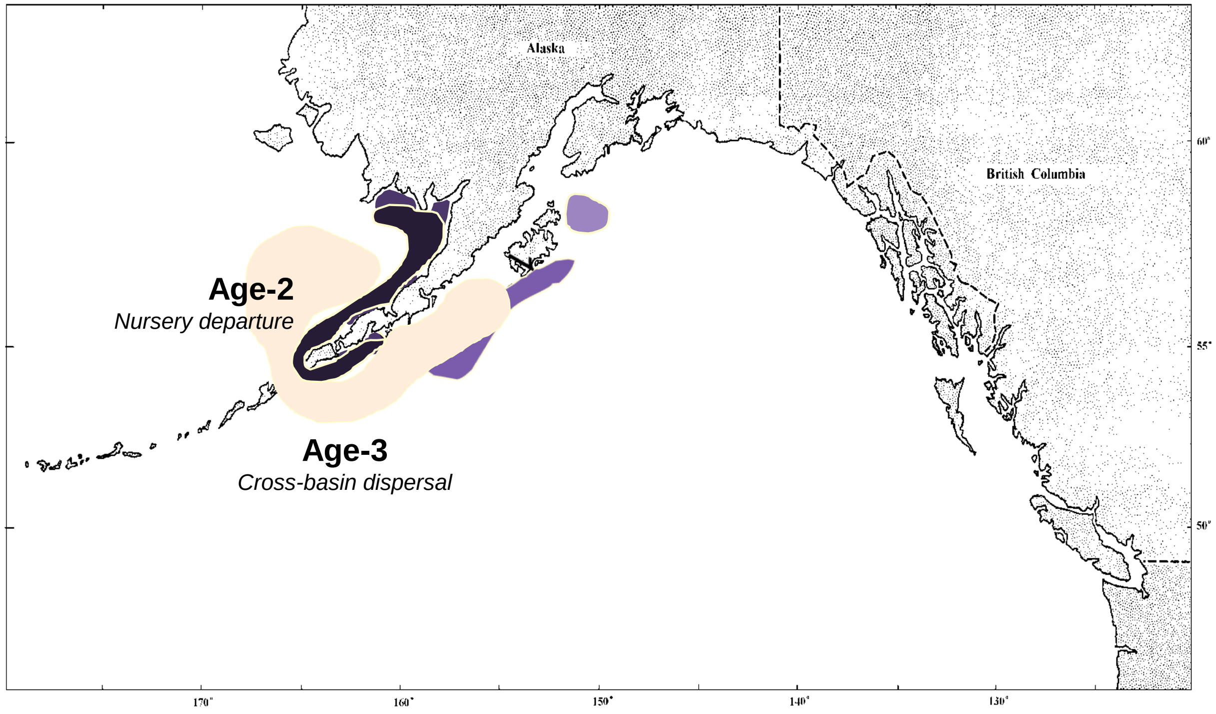

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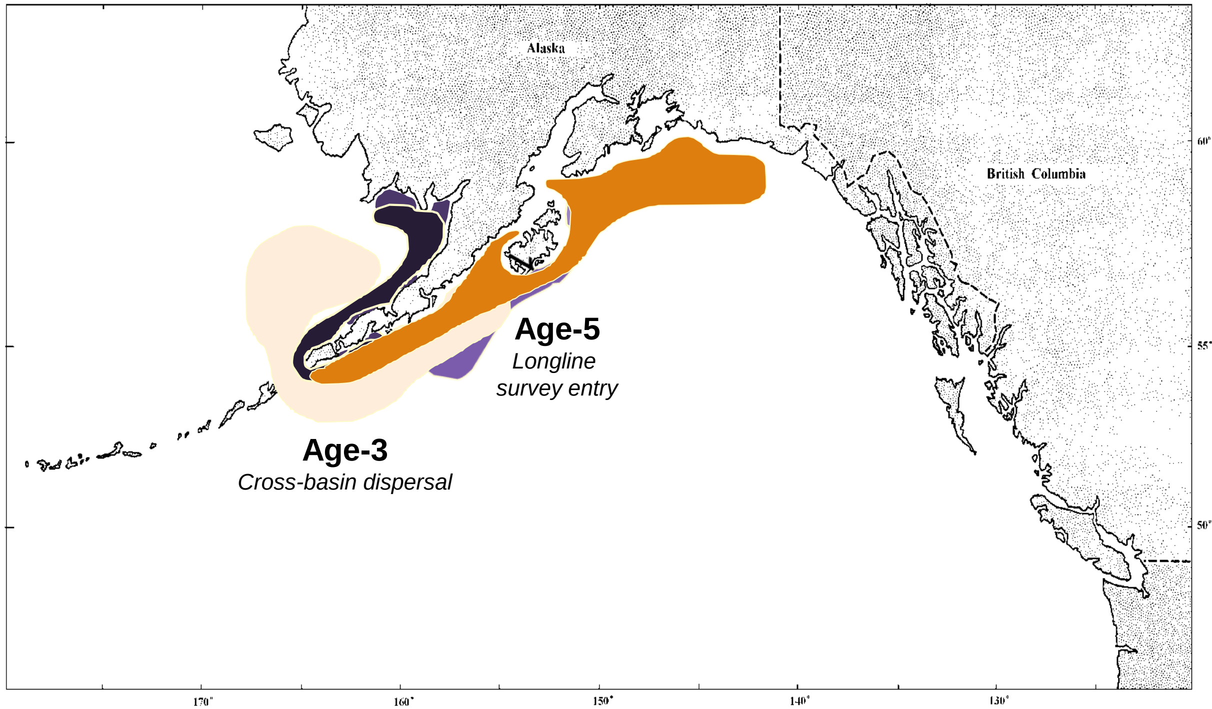

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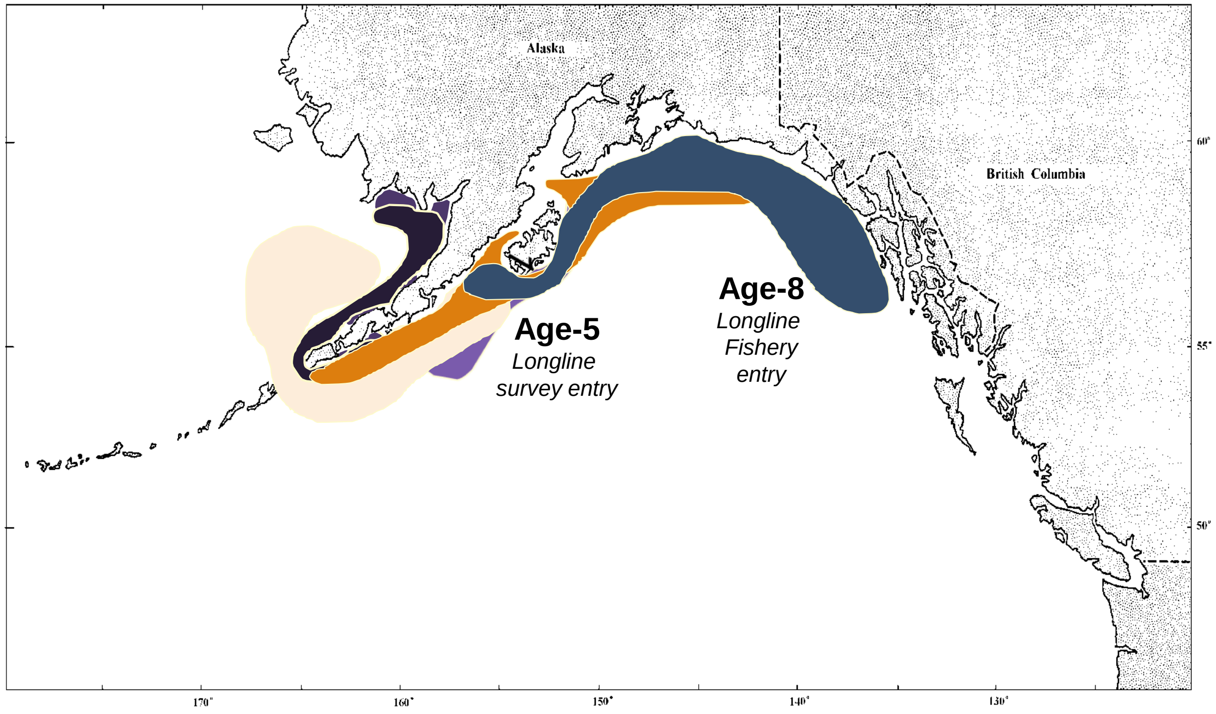

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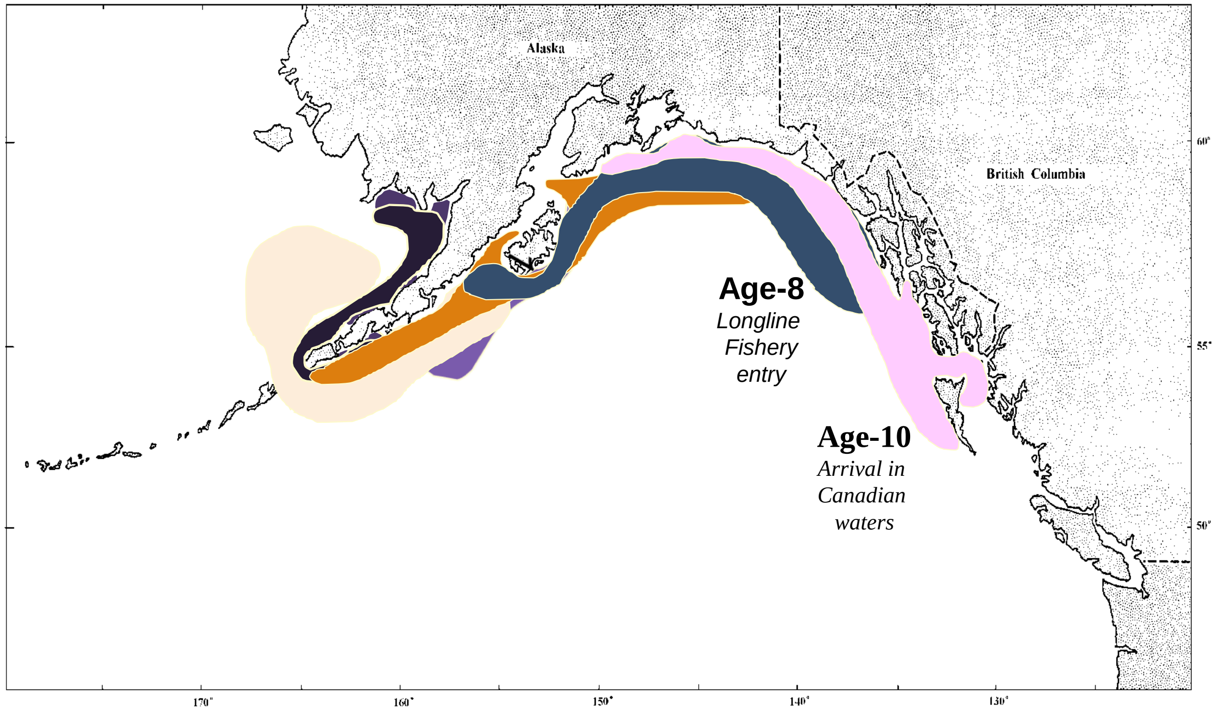

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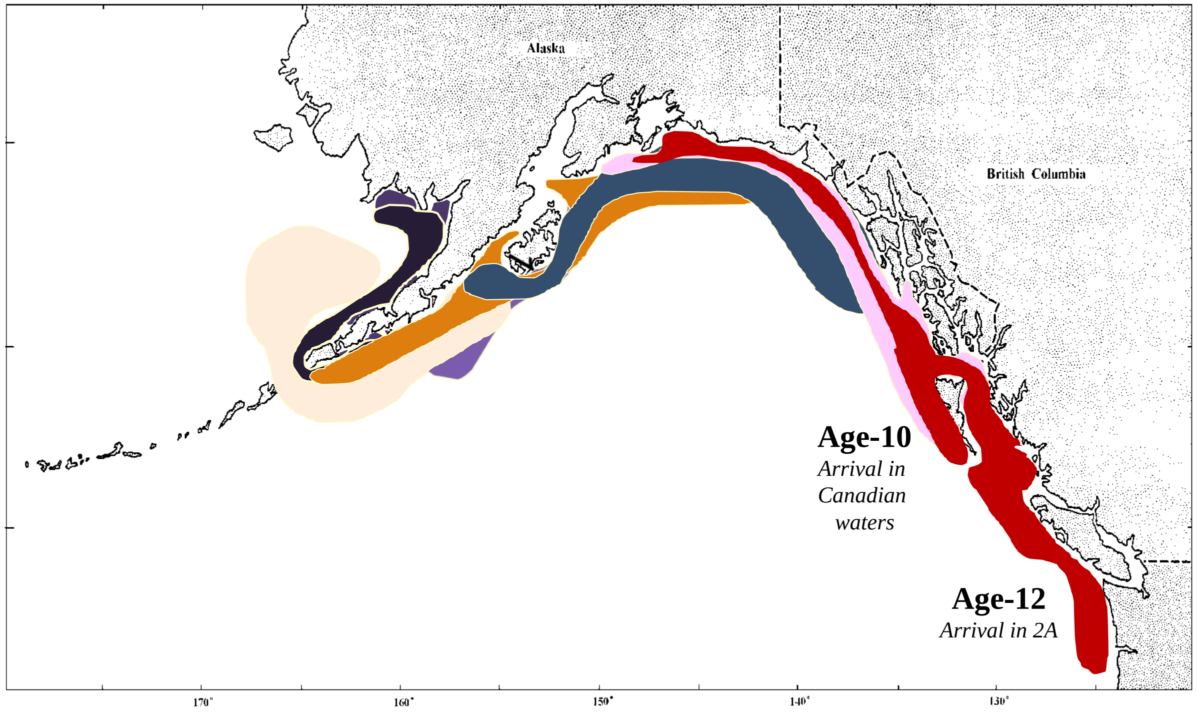

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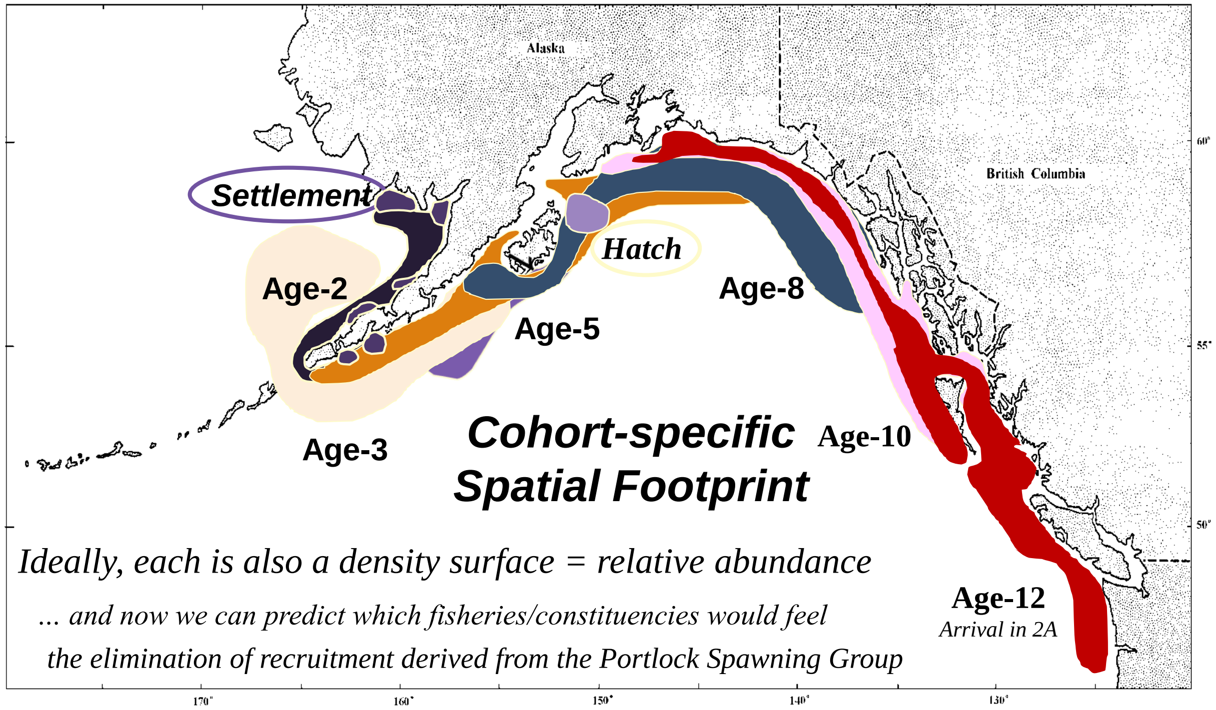

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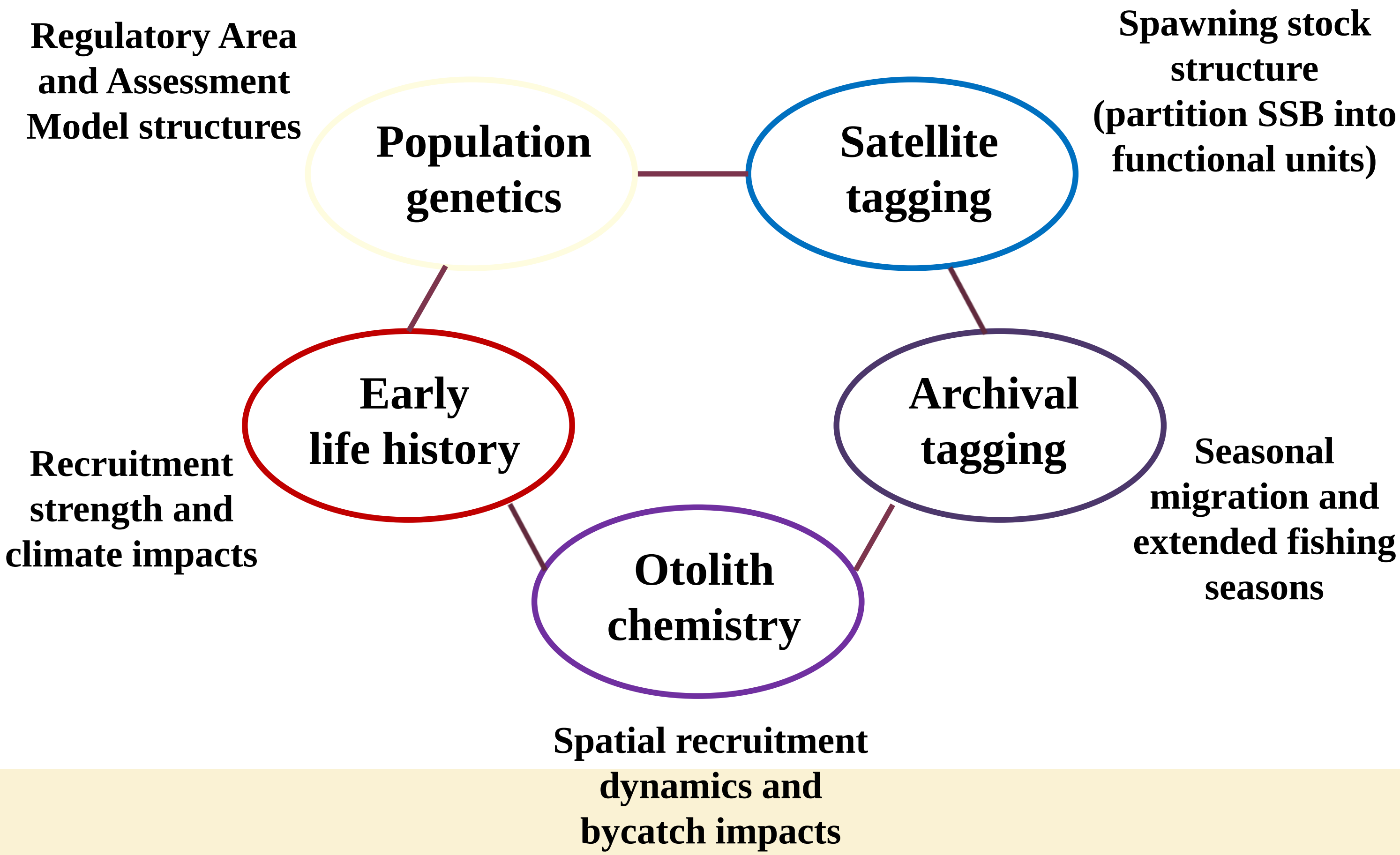
The Integrated Research Design



Some major findings

From coastwide deployment of 67,436 PIT tags (2001-2009)

Pre-dated the Integrate Design and was not intended for this context

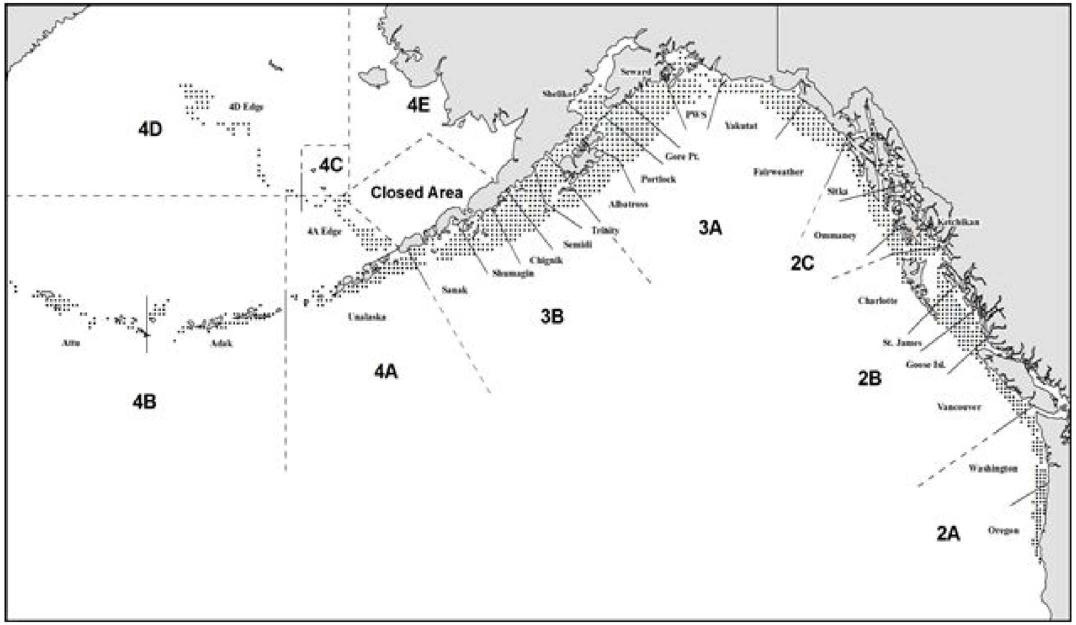
- Preparations began in 2000 and had nothing to do with connectivity: rather, designed for mortality (F, M) and abundance estimation

  - Unexpectedly low tag-recovery rates in some areas led to questionable estimates of fishing mortality

- However, the resultant data were highly amenable to migration analysis

Some major findings

From coastwide deployment of 67,436 PIT tags (2001-2009)

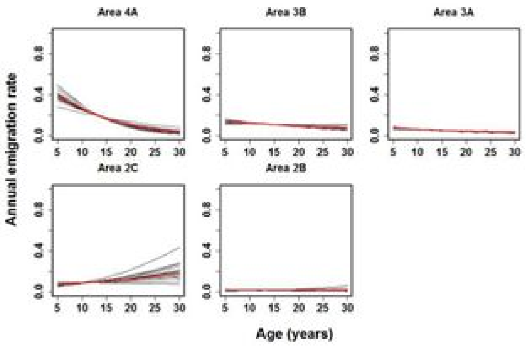


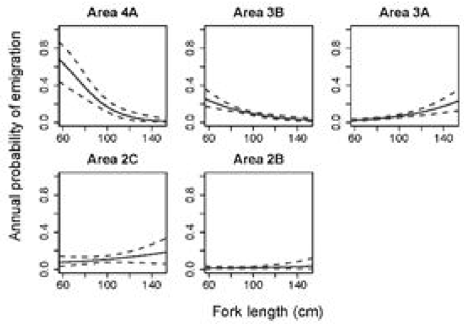
Recovered via an extensive portside commercial-harvest recovery program

Some major findings

From coastwide deployment of 67,436 PIT tags (2001-2009)

Movement rates of 032 fish modelled as functions of length and age …





… and tabulated Area-to-Area

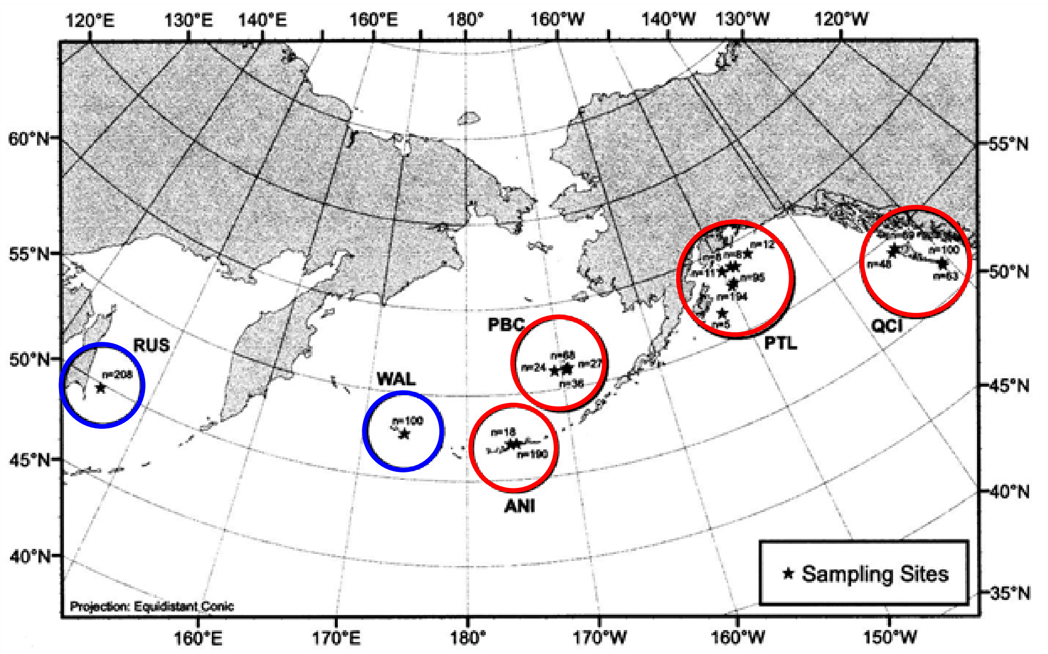
Estimated annual migration rates for 100 cm fish from PIT tags 2003-2009 (Webster *et al*. 2013).

Area in yr i	Area in yr i+1: 4A	3B	3A	2C	2B
4A	**0.833**	0.041	0.093	0.013	0.019
3B	0.002	**0.907**	0.084	0.004	0.003
3A	0.000	0.059	**0.934**	0.003	0.004
2C	0.000	0.000	0.025	**0.895**	0.080
2B	0.006	0.000	0.002	0.008	**0.984**

Some major findings

From Population genetic analyses (1998-2017)

- (968) mature fish sampled at winter spawning grounds from British Columbia to the eastern Aleutian Islands; plus (308) summer-collected samples from the western Aleutians and Russia



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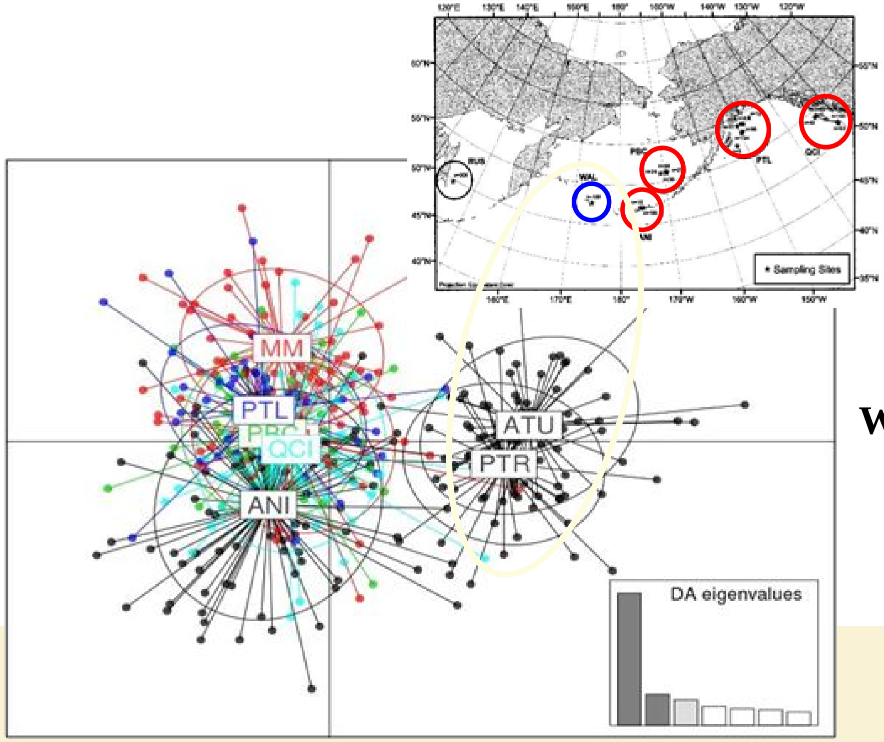
Some major findings

From Population genetic analyses (1998-2017)

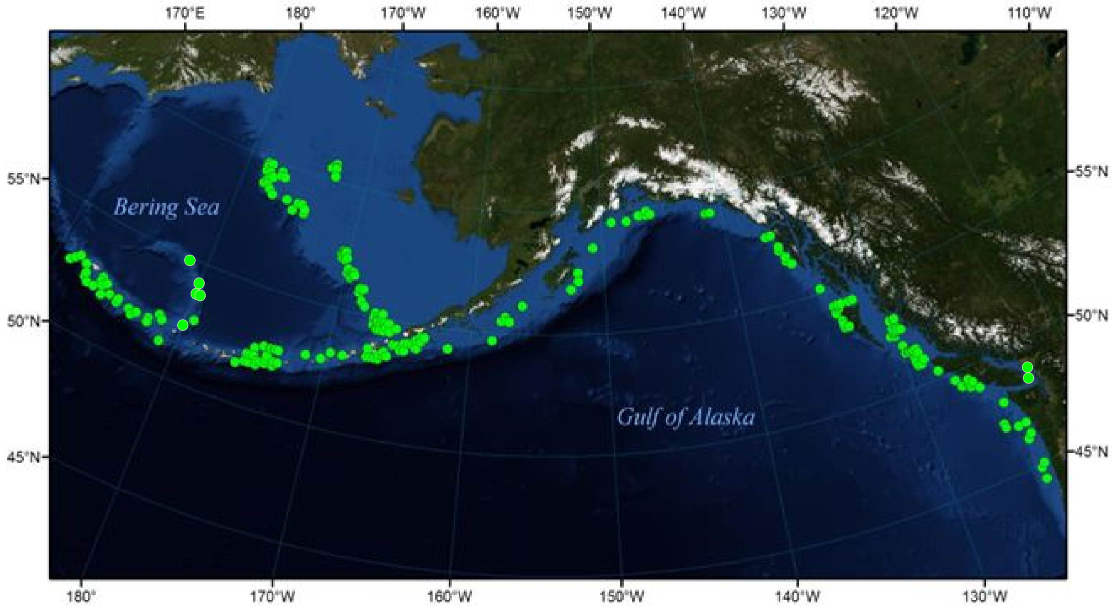
- Analyses based on 61 microsatellite loci
    - 23 anonymous loci and 38 Expressed Sequence Tags (ESTs)



Evidence of Western Aleutian isolation

Some major findings

From 401 summer-deployed PAT tags (2002-2017)



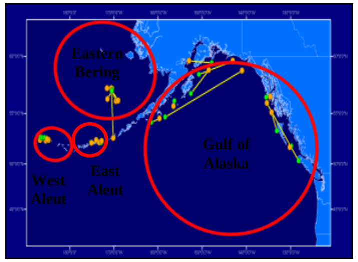
Programmed as a mixture of winter reporting for spawning locations …
… and summer reporting of site fidelity and regional mixing

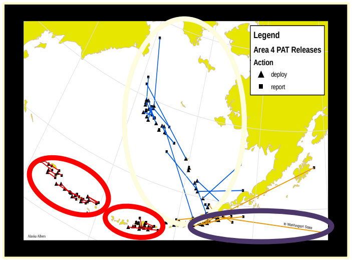
Some major findings

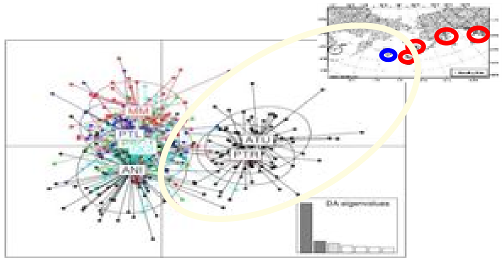
From 401 summer-deployed PAT tags (2002-2017)

Indication of basin-scale spawning stock structure with West Aleutian isolation…

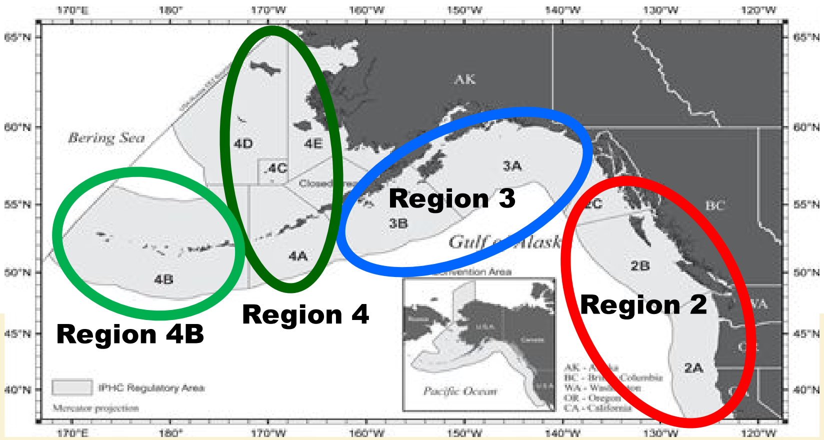
… consistent with population-genetic analyses







Supporting our move towards metrics within Biological Regions



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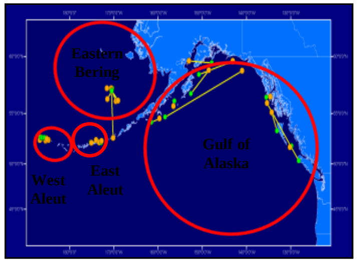
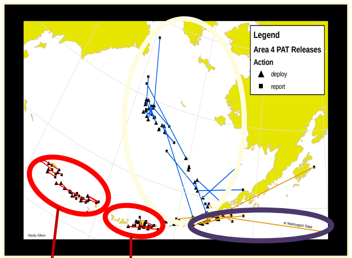
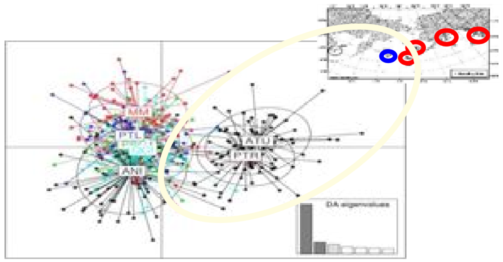
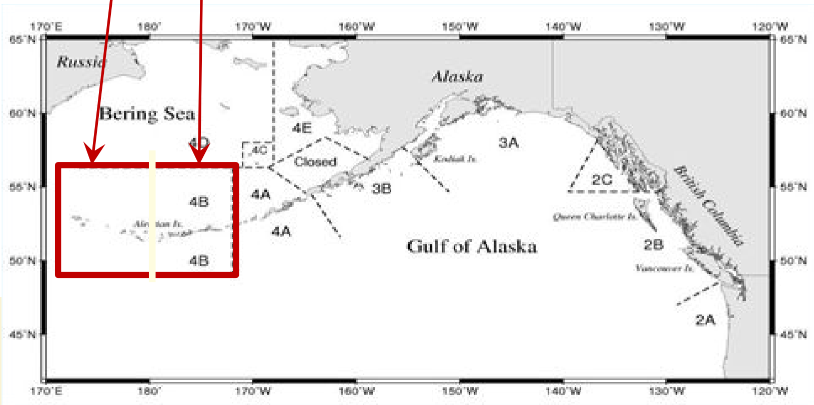






But, suggesting that Area 4B represents two discrete population components



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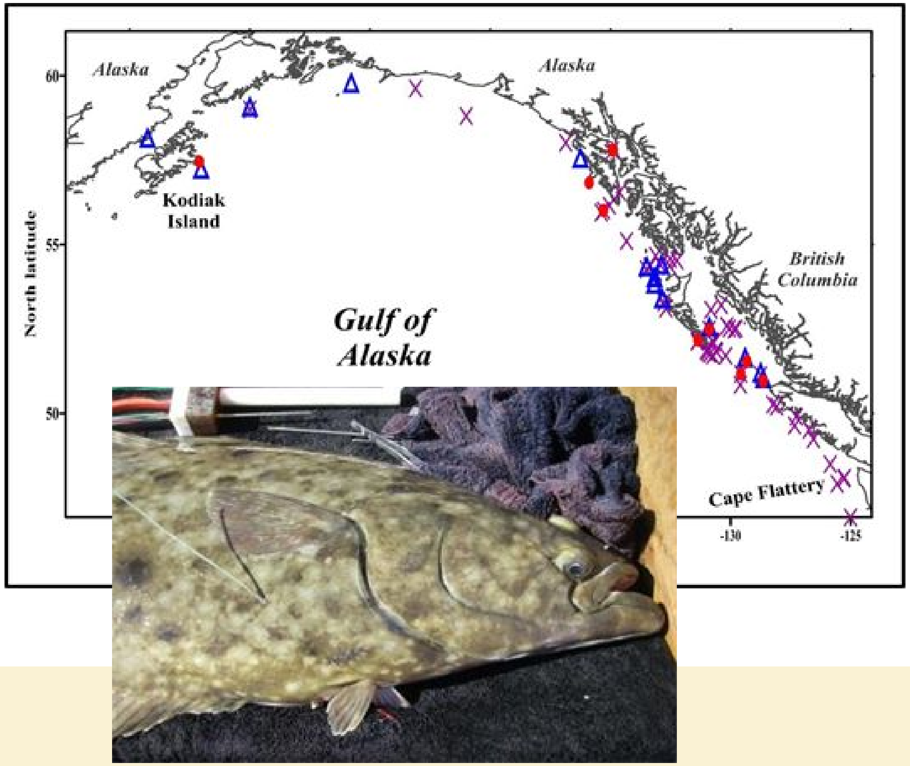
Some major findings

From seasonal analysis of archival depth data (2002-2009)

- Using archival tag data to quantify group-level seasonal migration



Some major findings

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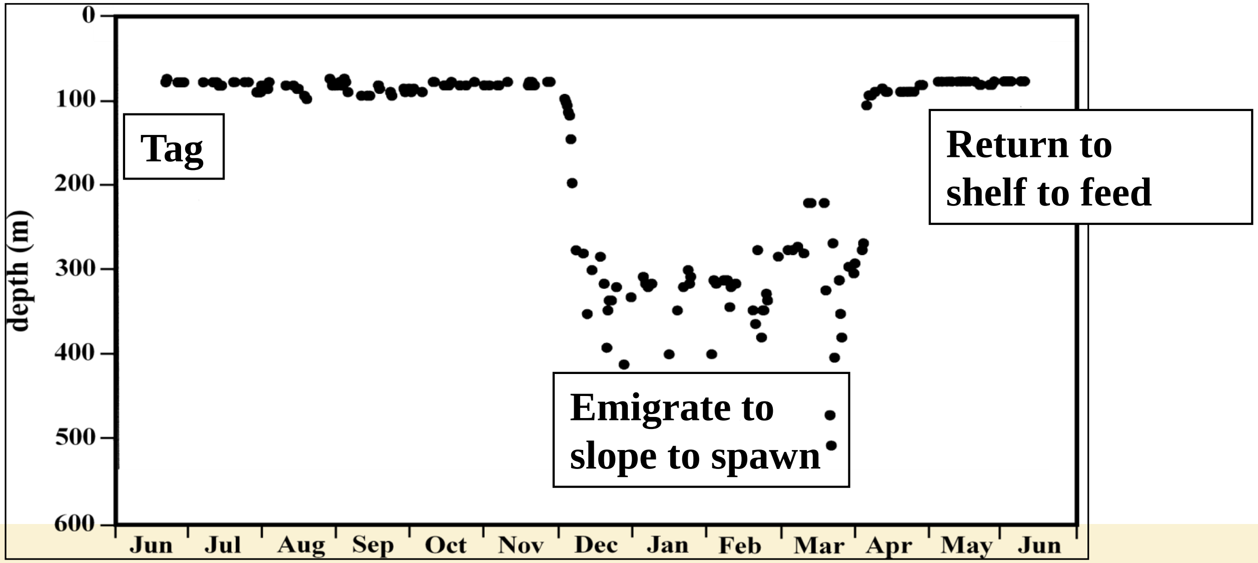
Ability to define seasons from the perspective of the fish



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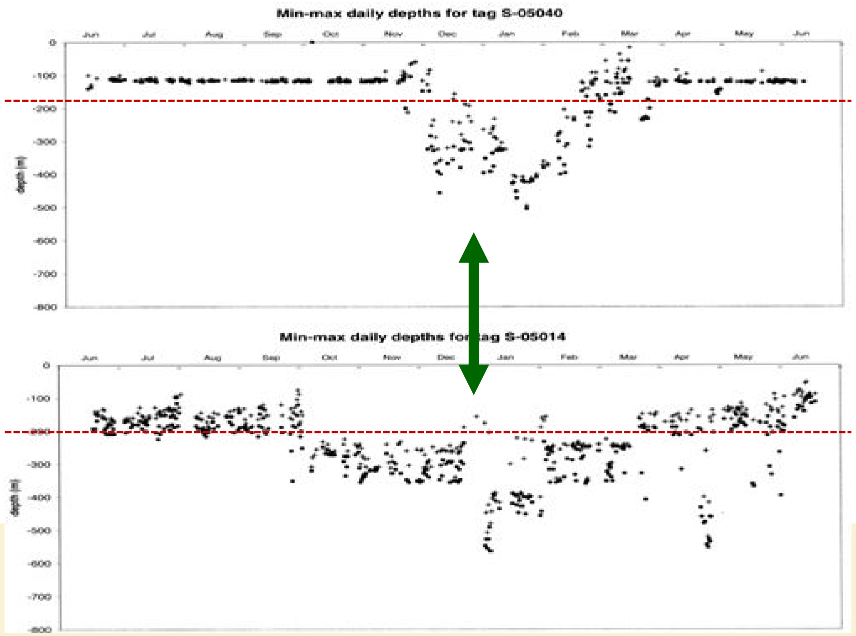

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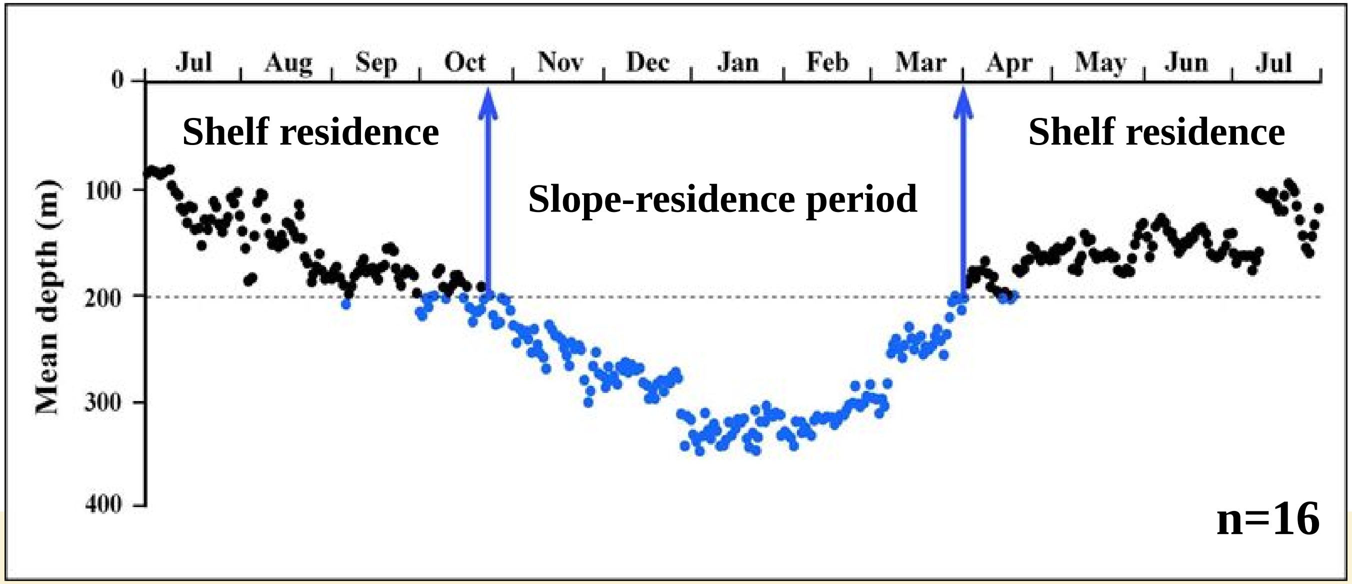

INTERNATIONAL PACIFIC HALIBUT COMMISSION

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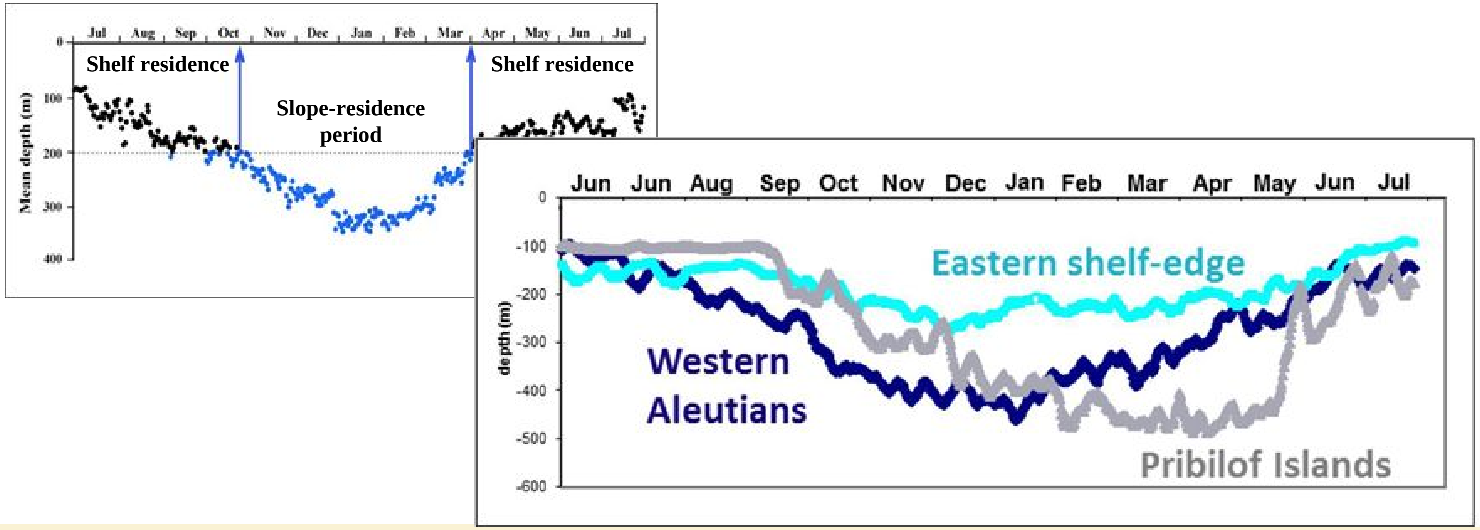
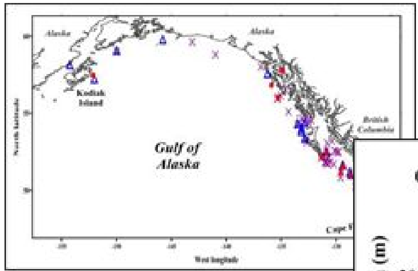


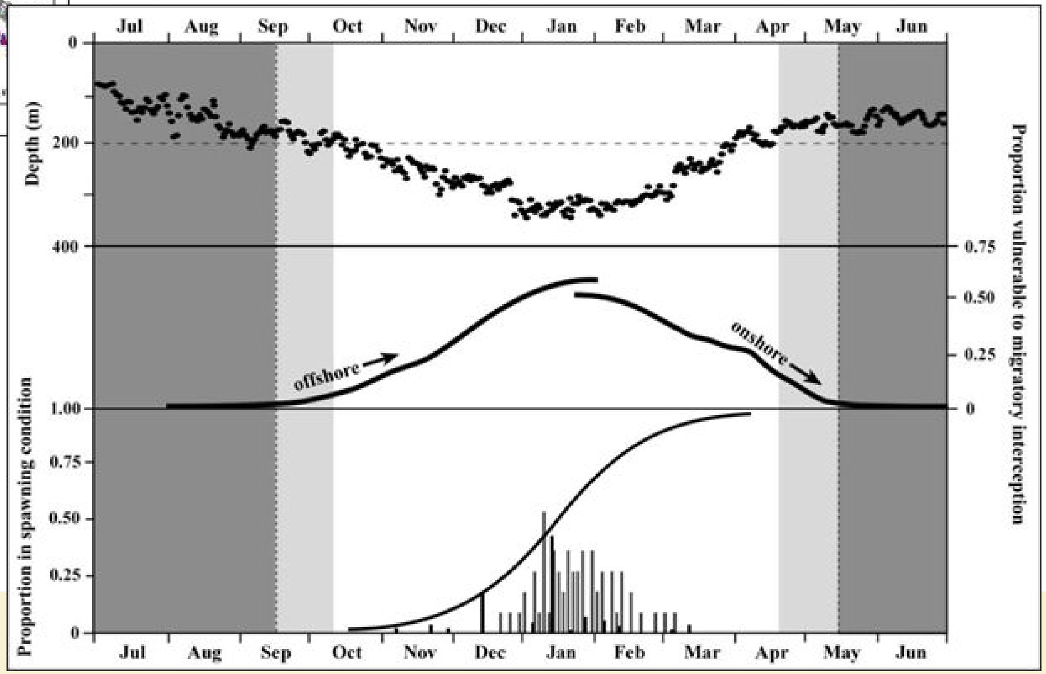
Noting evidence of regional variance …

Some major findings

From seasonal analysis of archival depth data (2002-2009)



Integrated metrics to describe habitat use and spatial redistribution

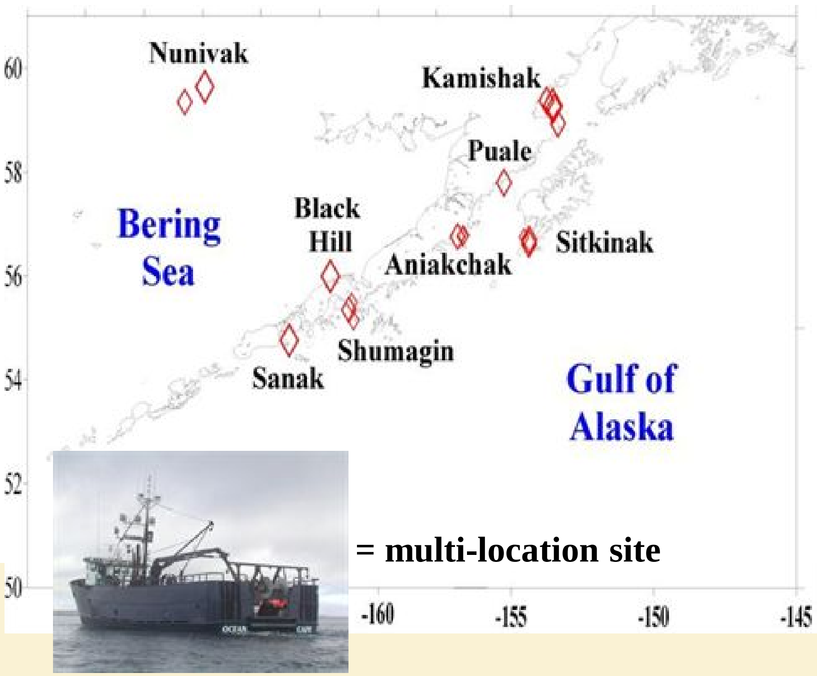


Some major findings

From analyses of otolith microchemistry (2002-2007)

- Looking for *spatially-trended* patterns allowing for source identifications not prone to assigning fish from unsampled locations to those sampled

Relied on fish from NMFS trawl surveys

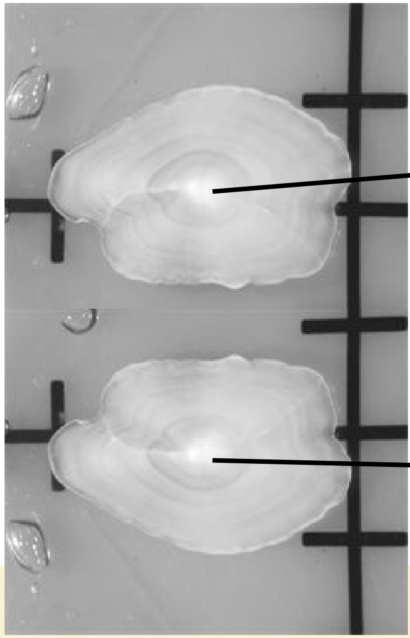


- **From 16 locations representing 8 sites, from west-central GOA to the southeast Bering Sea**
- **Spatial coverage of ~2300 km of coastline**

Some major findings

From analyses of otolith microchemistry (2002-2007)

- Looking for *spatially-trended* patterns allowing for source identifications not prone to assigning fish from unsampled locations to those sampled



Right otolith: stable isotope ratios

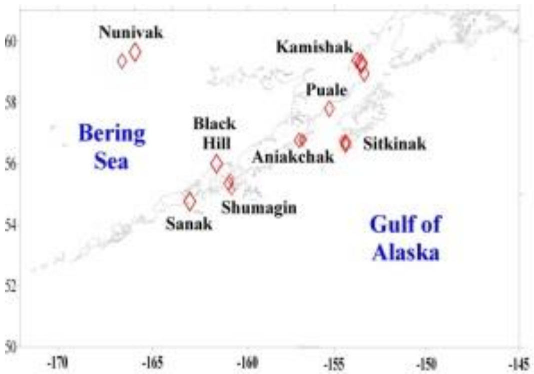
Ratio Mass Spectrometry

Inductively-Coupled Plasma Mass Spectrometry (IC-PMS)

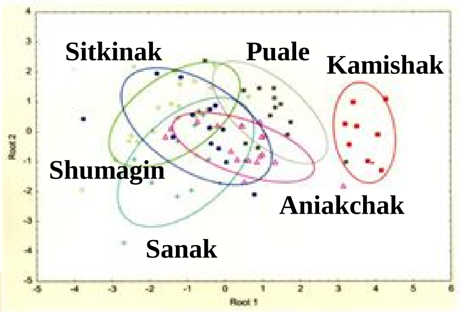
Left otolith: trace metals

Some major findings

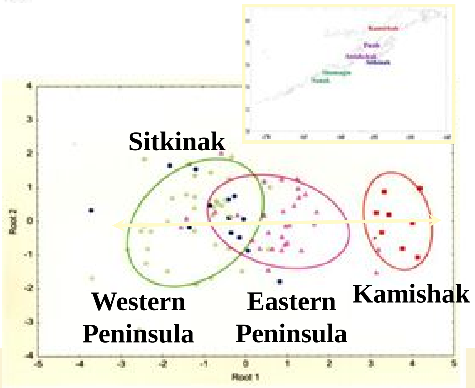
From analyses of otolith microchemistry (2002-2007)



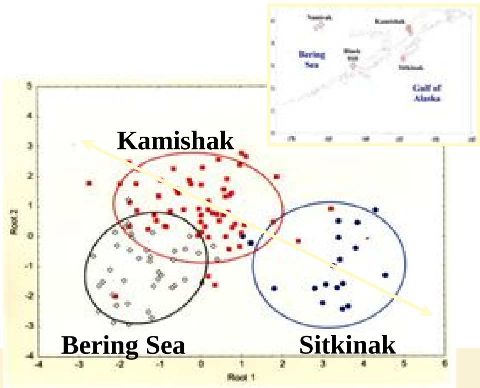
Suggesting that regional origin for individual fish *might* be distinguishable and robust



Local = muddled



GOA Regional = E-W trend



Basin-scale = Bering offset

Some major findings

From larval dispersal modelling (2015-2019)

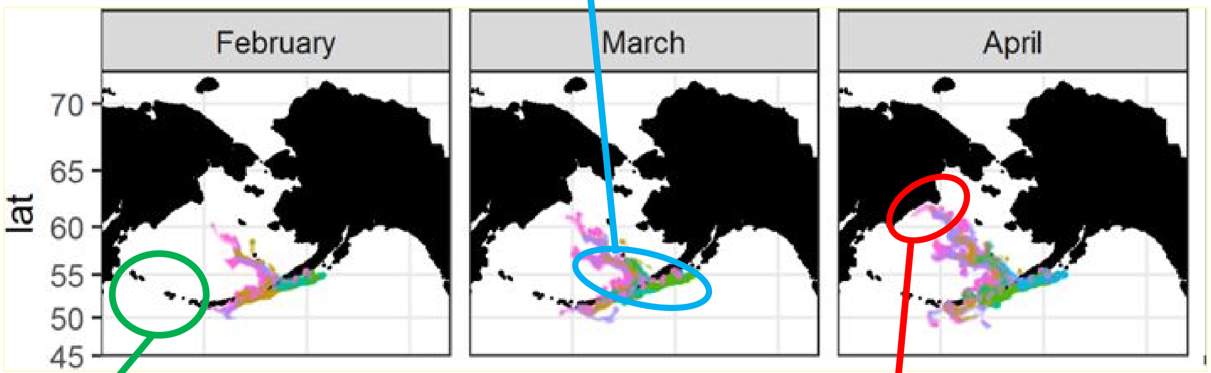
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

From larval dispersal modelling (2015-2019)

- IPHC and NOAA EcoFOCI cooperative project

- Nearing completion: final results and draft manuscript expected 2019

Cross-basin larval delivery that connects the Gulf of Alaska and eastern Bering Sea …



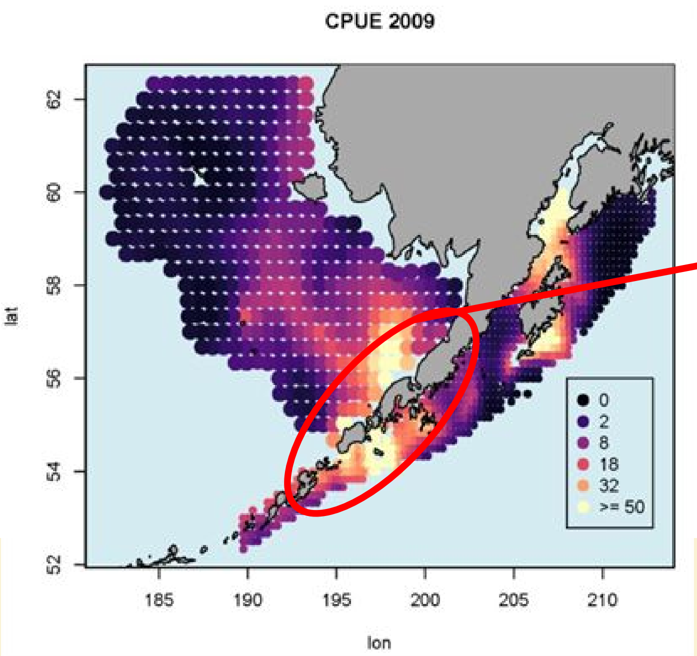
…western Aleutian isolation

… a mechanism for connectivity between eastern Pacific spawning stock and Russian coastal nurseries

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

From larval dispersal modelling **(2015-2019)**

- IPHC and NOAA EcoFOCI cooperative project
- Nearing completion: final results and draft manuscript expected 2019

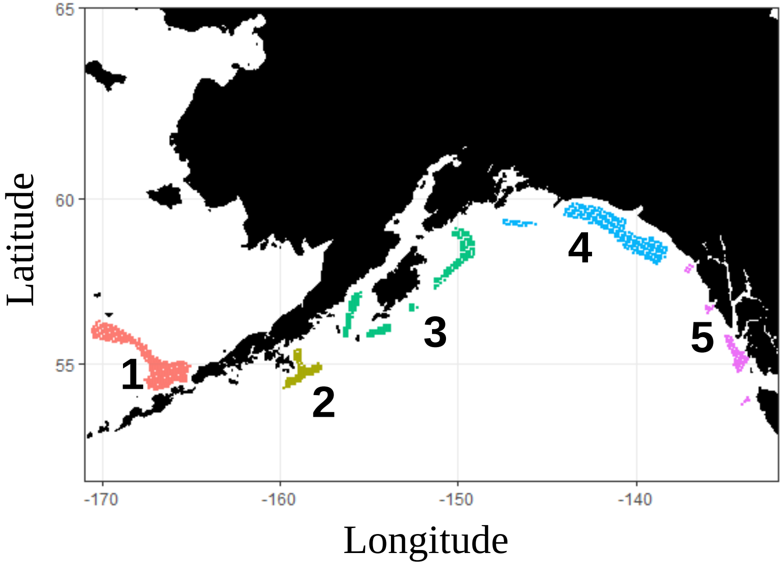


… and connectivity between basins of young fish actively migrating away from the settlement grounds

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

From larval dispersal modelling (2015-2019)

Individual-based Biophysical Model +
Oceanographic model (ROMS NEP6) + Pacific halibut larval traits



Warm years – stronger year classes

2003
2004
2005

Cold years – weaker year classes

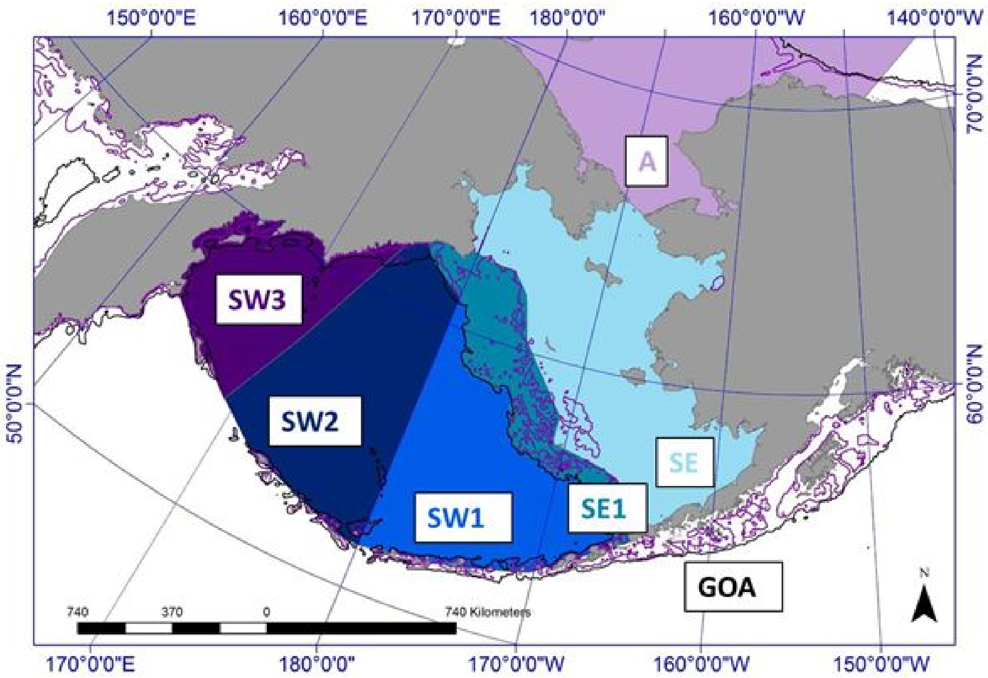
2009
2010
2011

Do dispersal patterns correlate with environmental regimes?

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

Key questions

- Are there environmentally driven differences in dispersal?
- To what degree does the GOA spawning stock contribute to the Bering Sea settled population?



Divided the model domain into 7 regions:

GOA
SE
SE1
SW1
SW2
SW3
A

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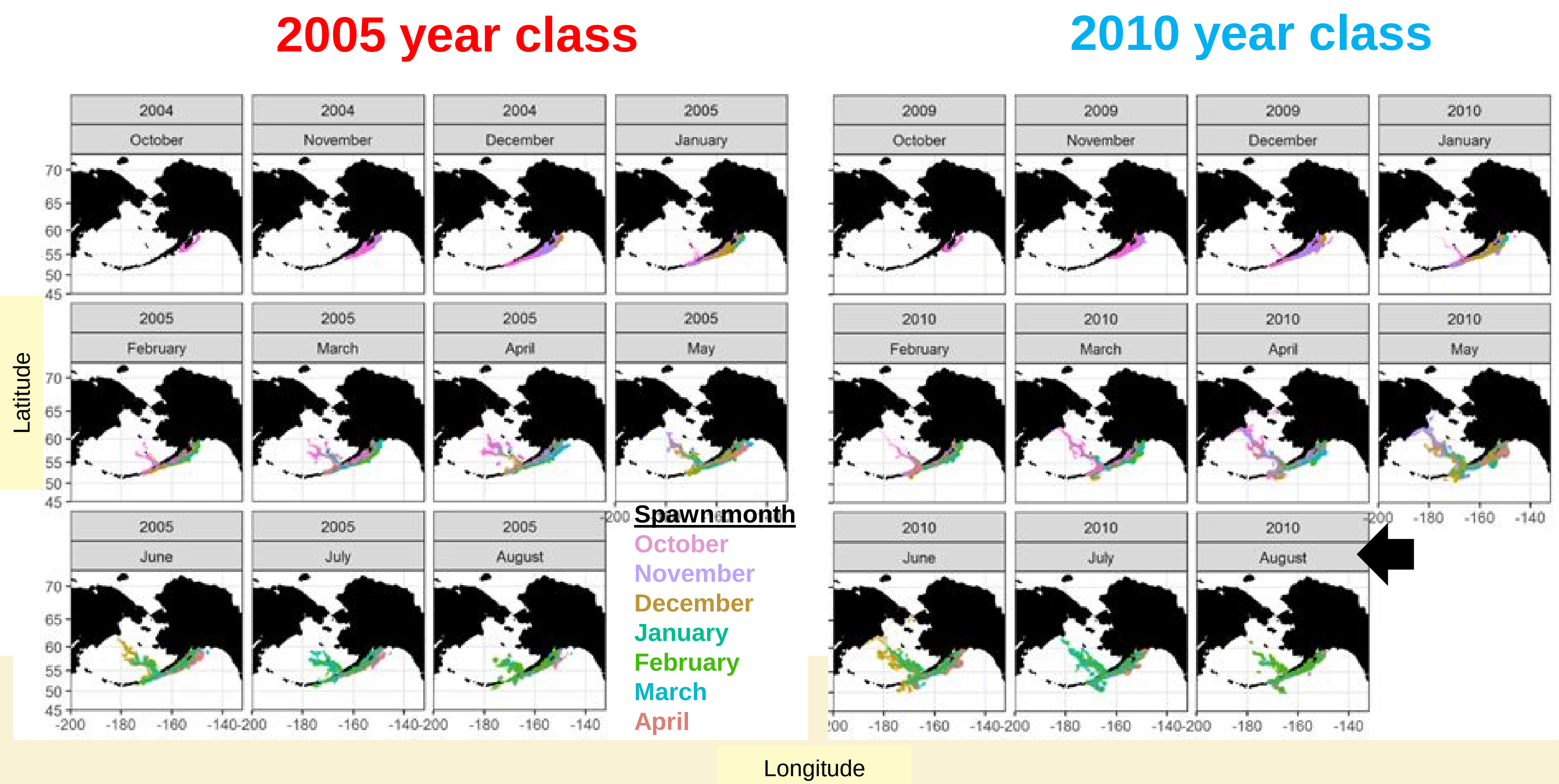
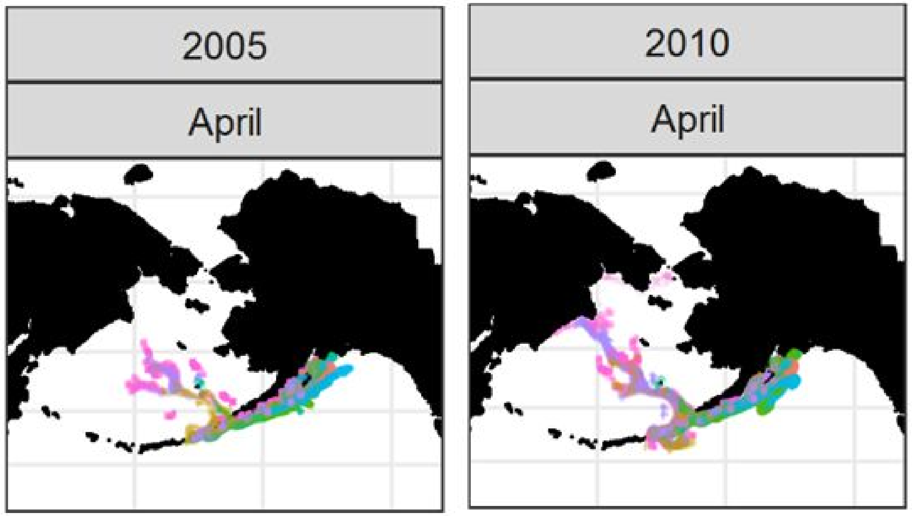
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

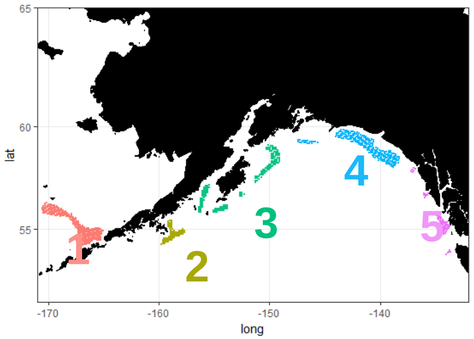
Example output from larval migration model: Spawning region 3



Pacific halibut connectivity: Gulf of Alaska & Bering Sea

- Modeling shows inter-annual differences in northward transport





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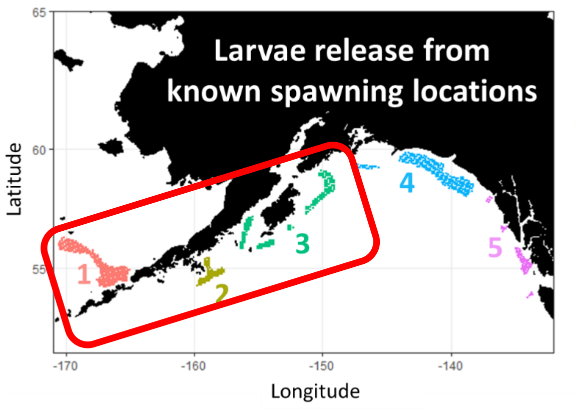
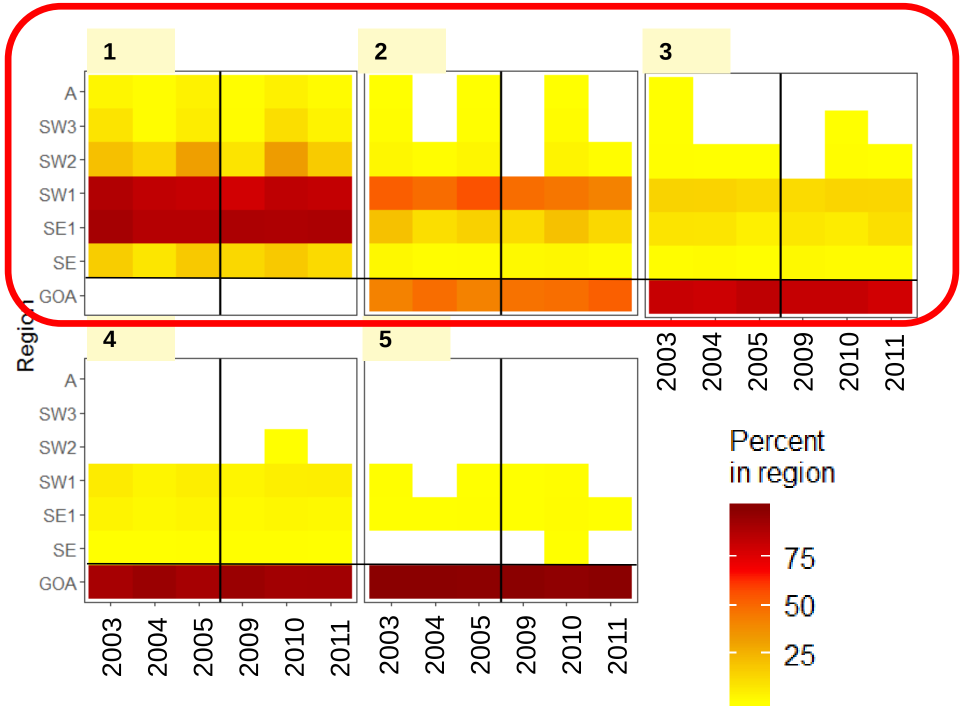
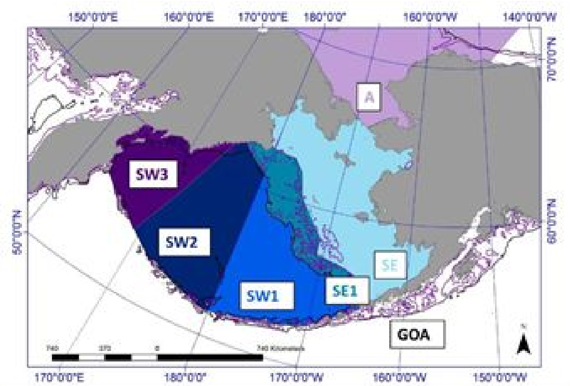
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

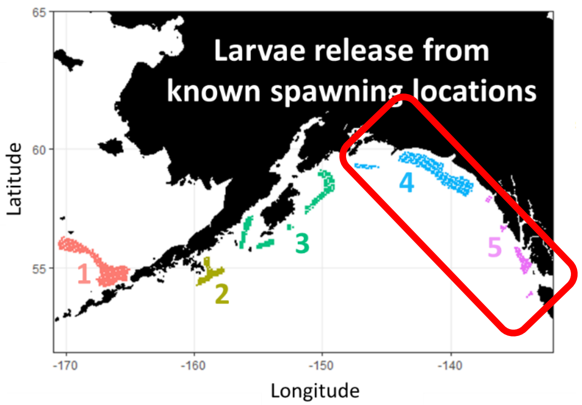


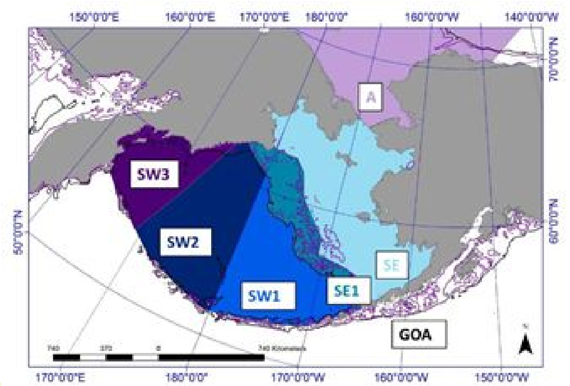


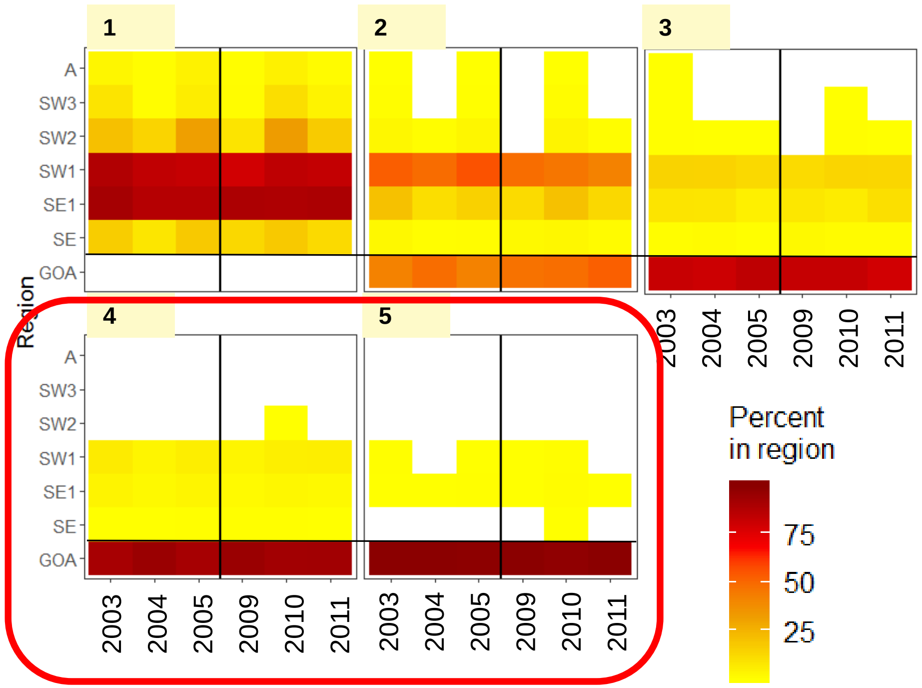


Spawn regions 1, 2, and 3 contribute to Bering Sea settlement population

Pacific halibut connectivity: Gulf of Alaska & Bering Sea







Spawn regions 4 and 5 contribute primarily to the Gulf of Alaska settlement population

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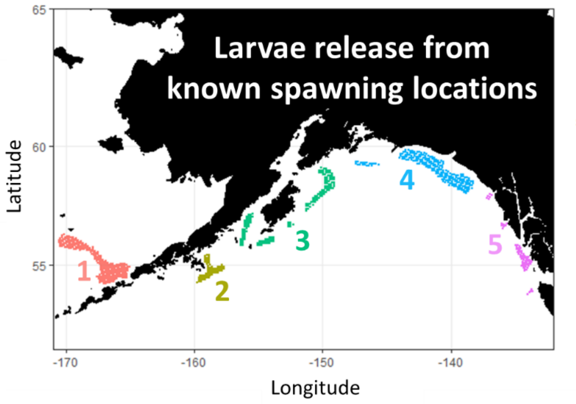
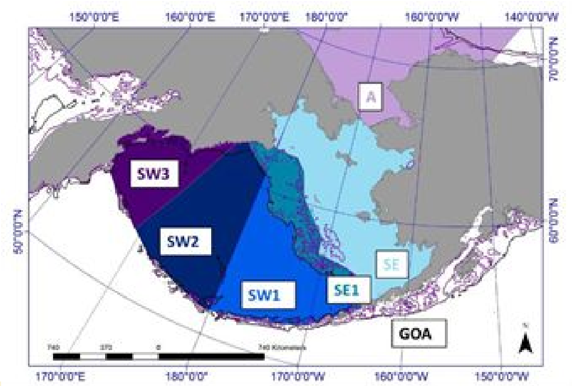
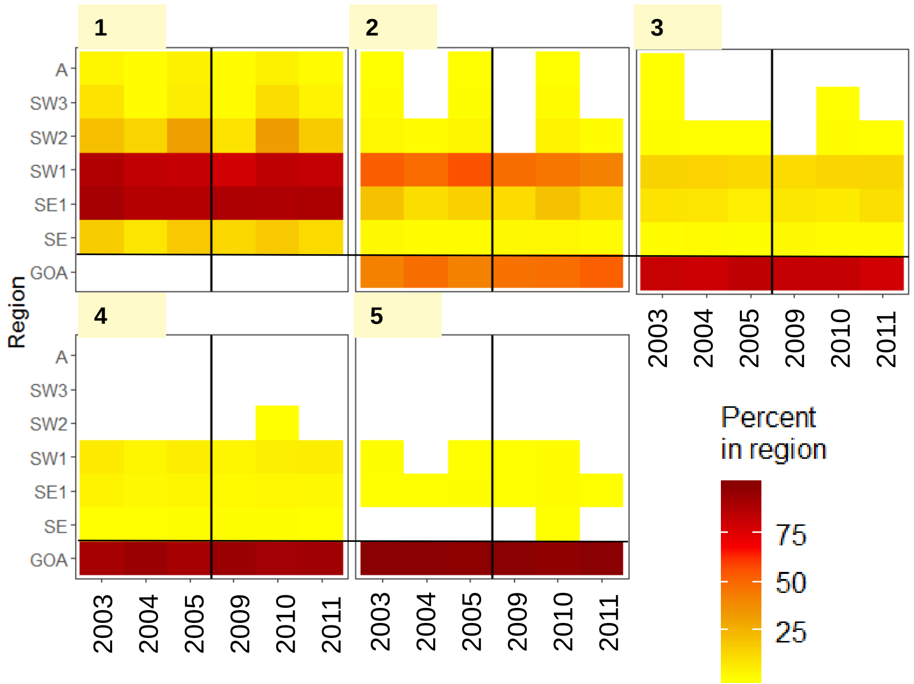
Pacific halibut connectivity: Gulf of Alaska & Bering Sea







Although there are inter-annual dispersal differences, there are no obvious differences between warm and cold regimes

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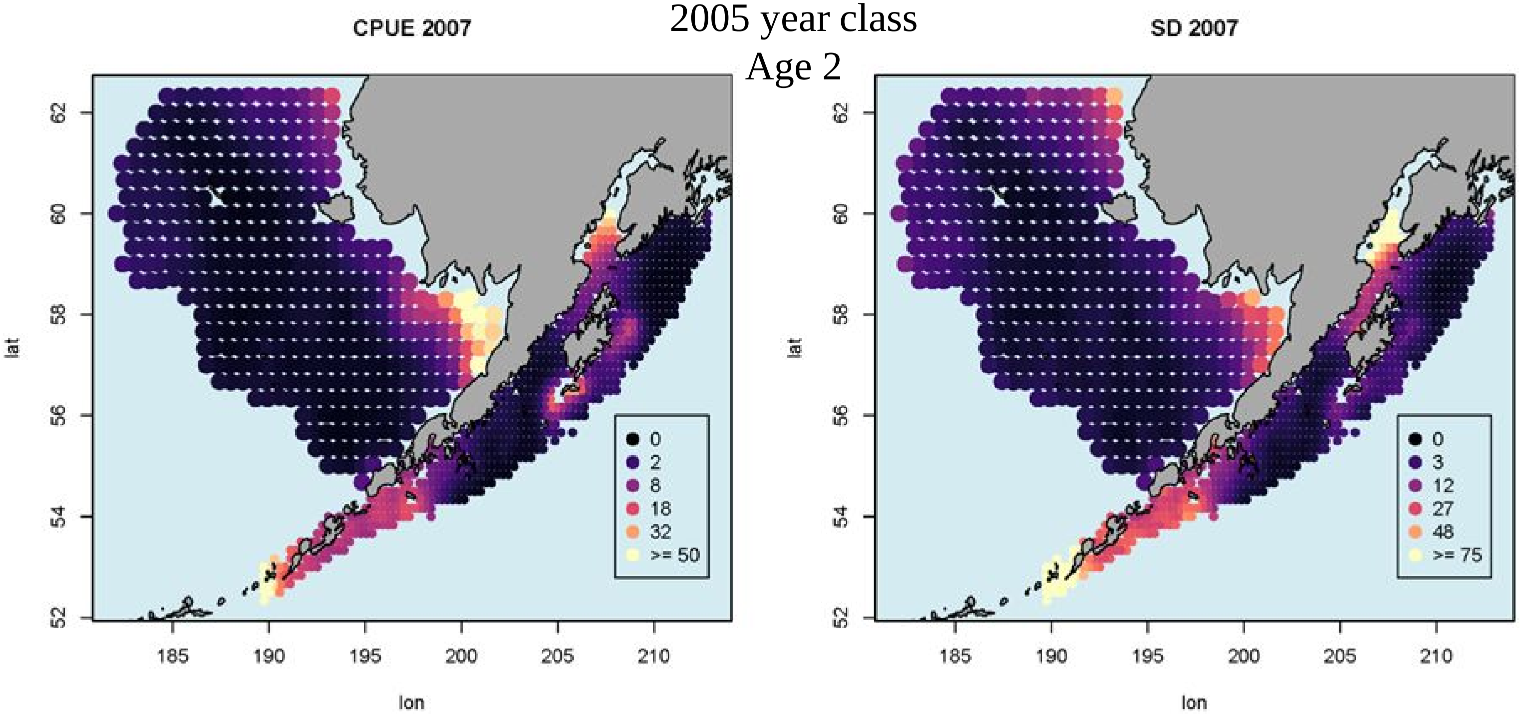
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

And the story continues…

2005 year class
Age 2



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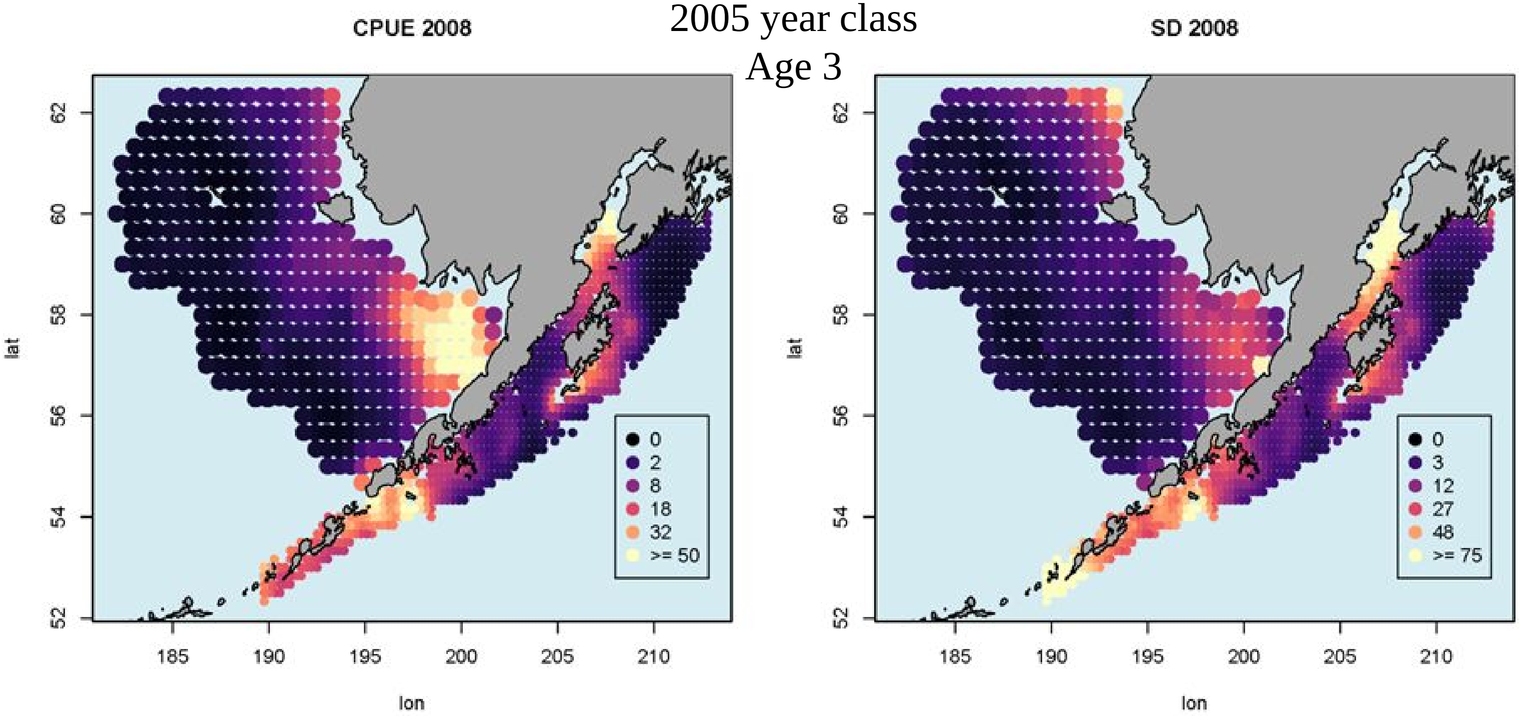
Using the IPHC Spatial Model to map the distribution of a cohort
Example output of the 2005 year class

Pacific halibut connectivity: Gulf of Alaska & Bering Sea

2005 year class

Age 3



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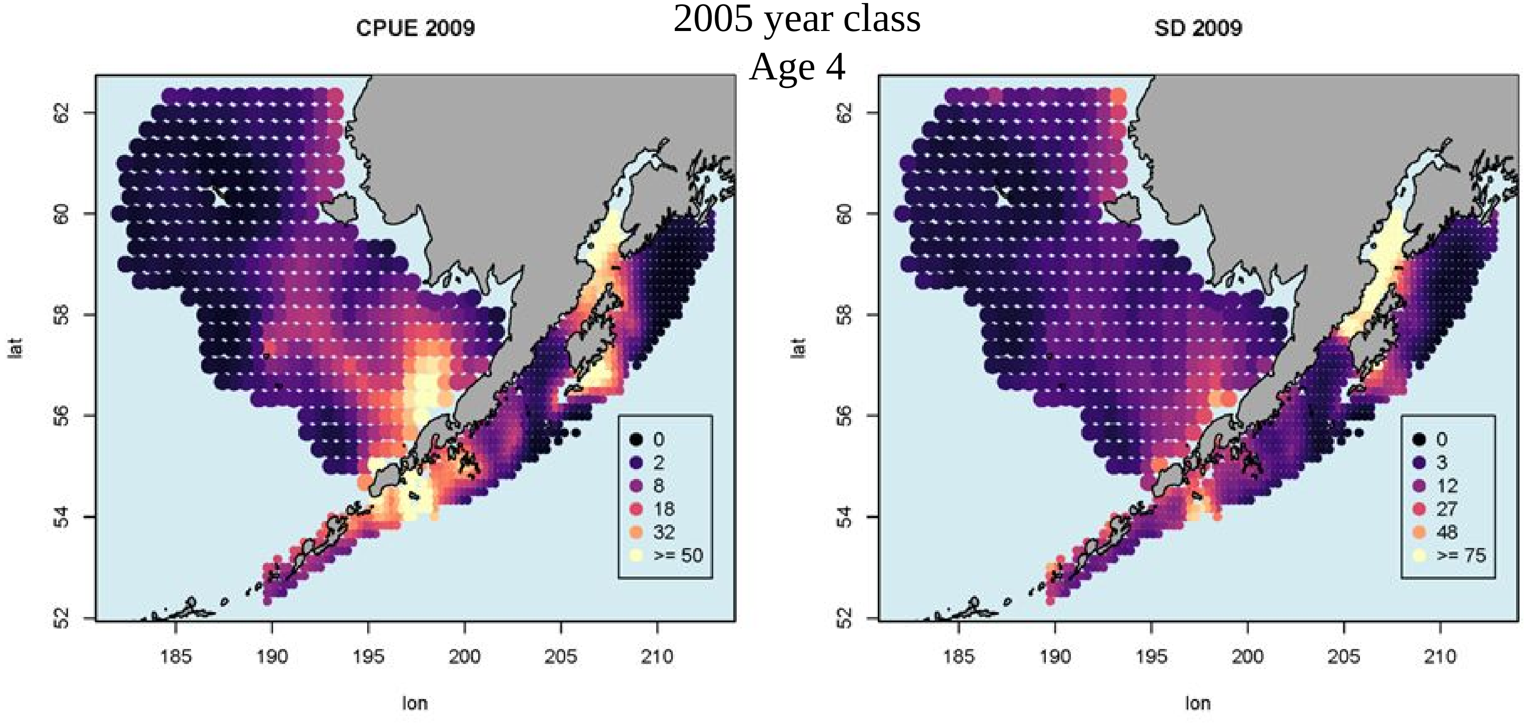
Pacific halibut connectivity: Gulf of Alaska & Bering Sea

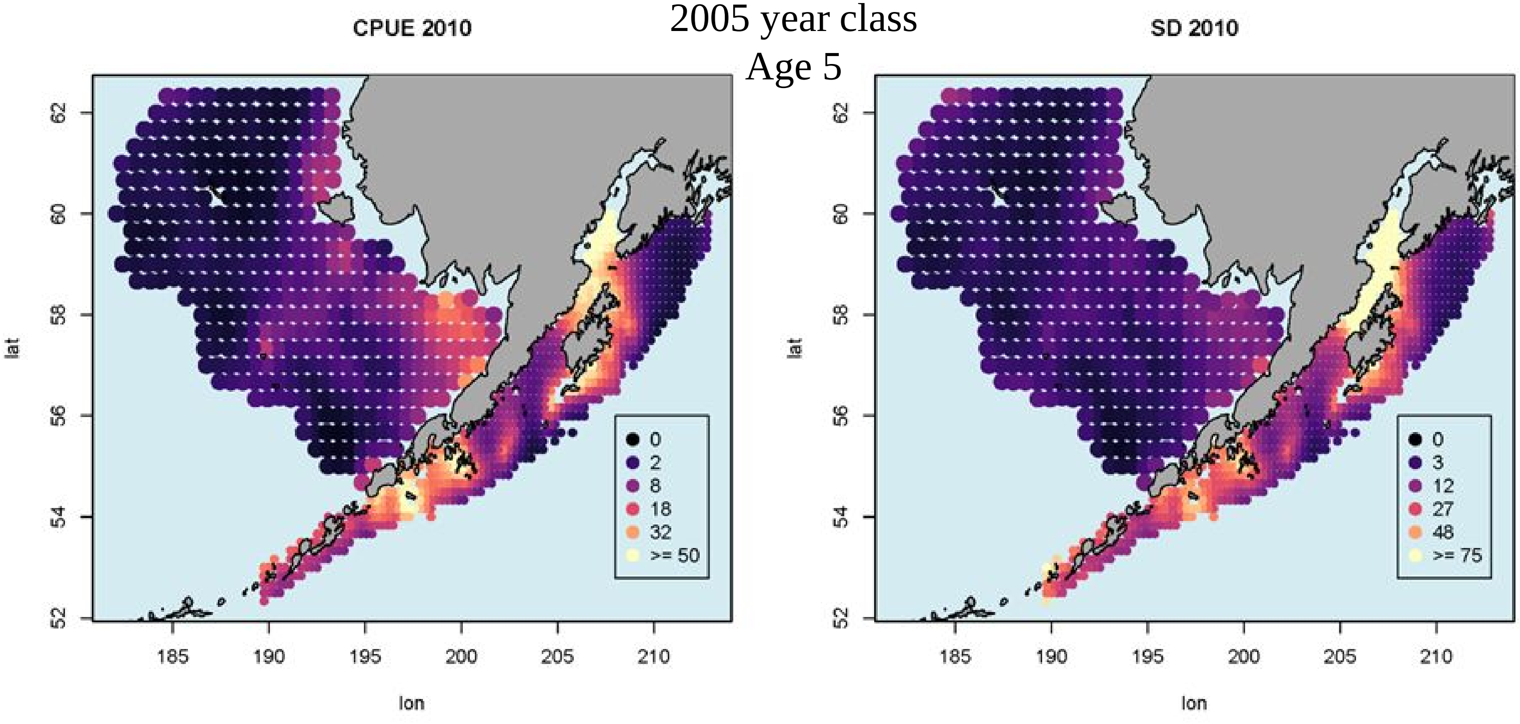
2005 year class
Age 4



Pacific halibut connectivity: Gulf of Alaska & Bering Sea

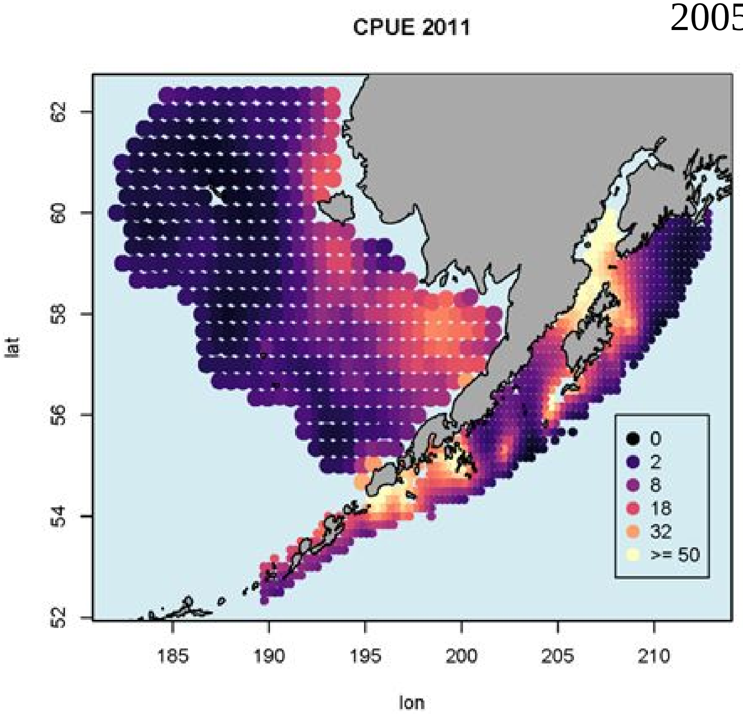
2005 year class

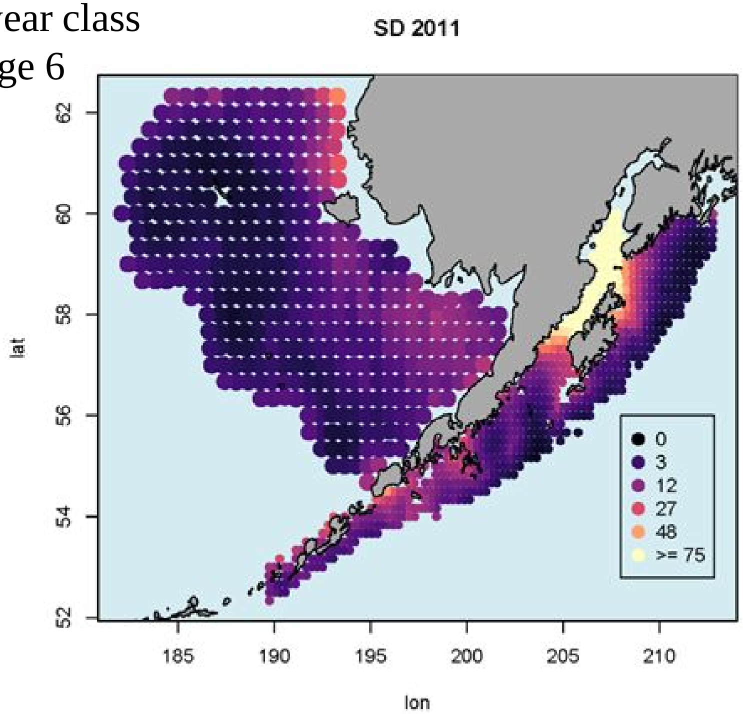
Age 5



Pacific halibut connectivity: Gulf of Alaska & Bering Sea

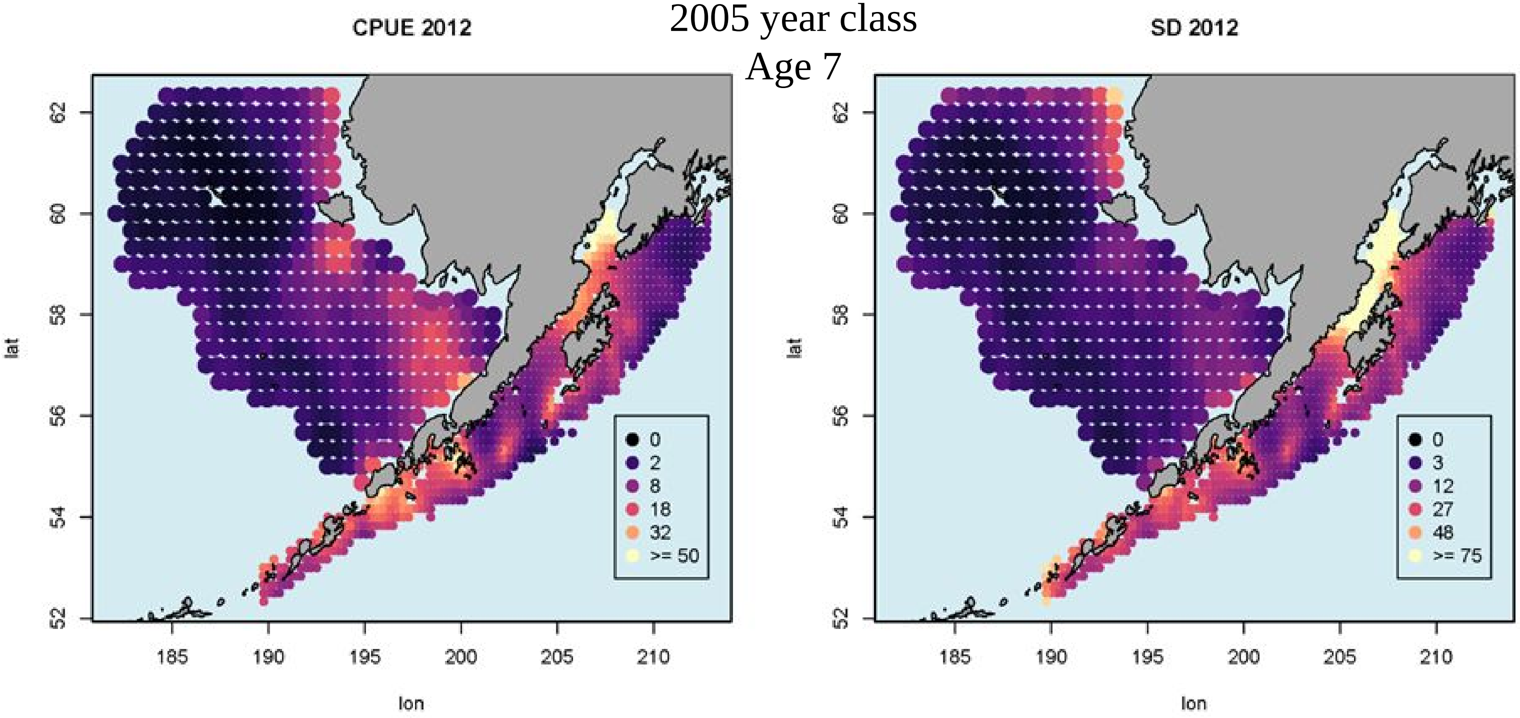
2005 year class
Age 6





Pacific halibut connectivity: Gulf of Alaska & Bering Sea

2005 year class
Age 7



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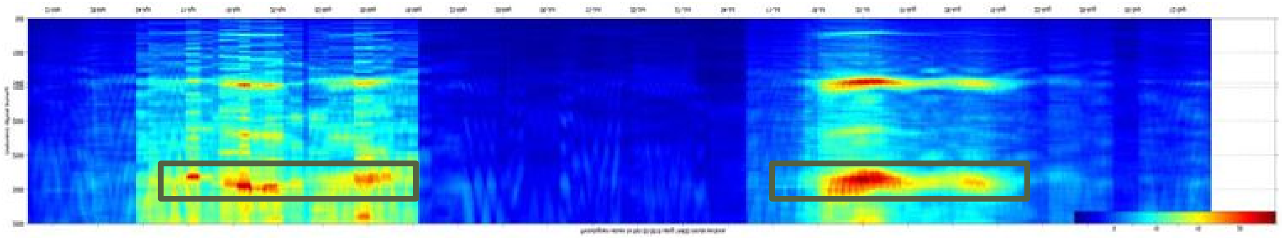
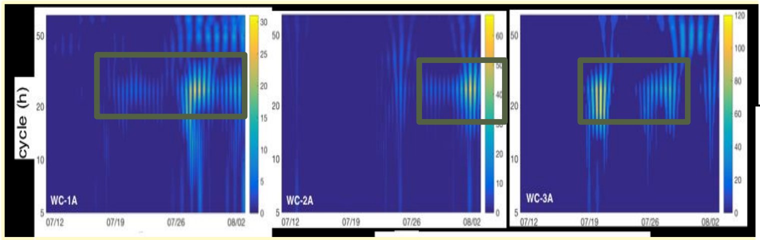
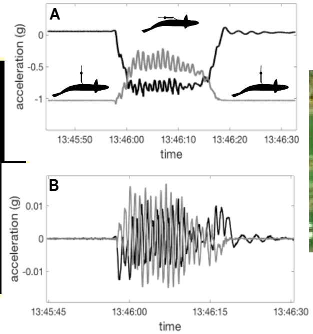
Results suggest active migration of young fish from the Bering Sea to the Gulf of Alaska counter to larval dispersal

Some major findings

From fine-scale analysis of depth and accelerometry (2012-2015)







Quantification of diurnal and tidal activity, swimming speed, and *in situ* growth rates

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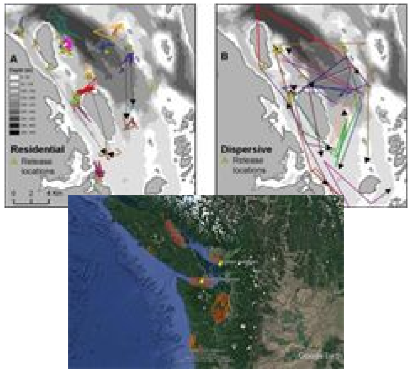
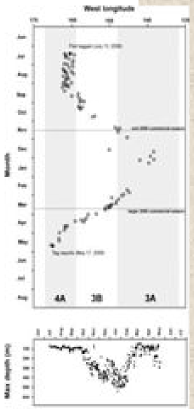
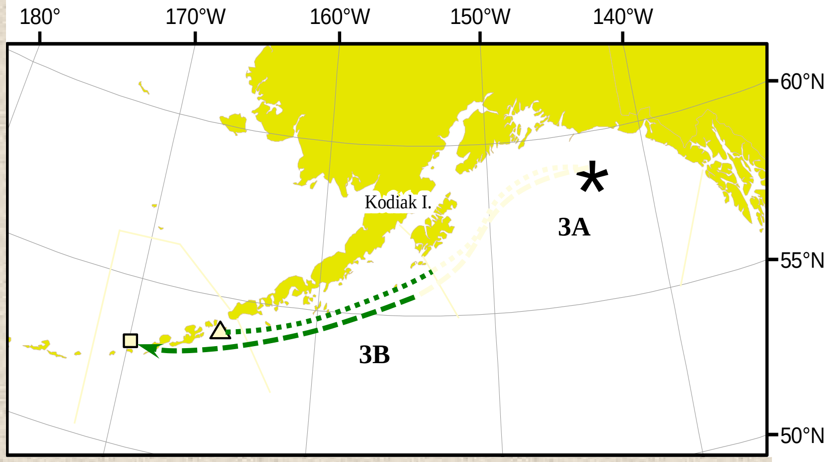
Some major findings

From refinements of Hidden Markov Modelling (2014-2019)







A statistically-based method for tracking movements and modelling distributions

So, where do we go from here?

Philosophies of research planning

Ultimately, research planning and project selection can be viewed to exist along a continuum of planning horizons

- Using historical IPHC connectivity projects as an example:

Multi-decadal scale
Far-reaching institutional objectives

Identify recruitment sources for all harvest sectors, quantify downstream mortality impacts, and resolve between long-term changes in migration versus spatial recruitment dynamics

Juvenile otolith microchemistry (Proj. 620)

Most of what we do falls somewhere in the middle

Annual scale
Immediate Constituency concerns

2A Tribes question whether the Southern Salish should be a separate Regulatory Area

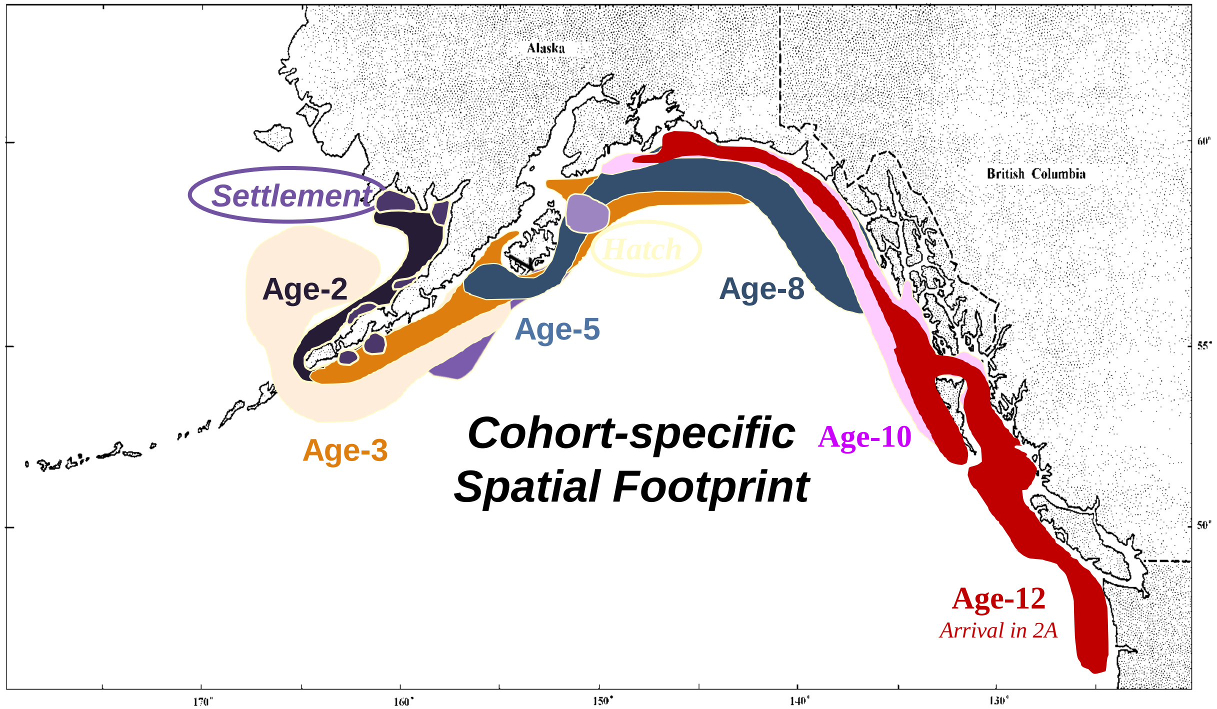
Salish Sea PAT-tagging (Proj. 646.13)

In this Planning Model I'll tend toward the left side: i.e., essentially decadal-scale

An operational question

What information/data would we need to model each step in the process?

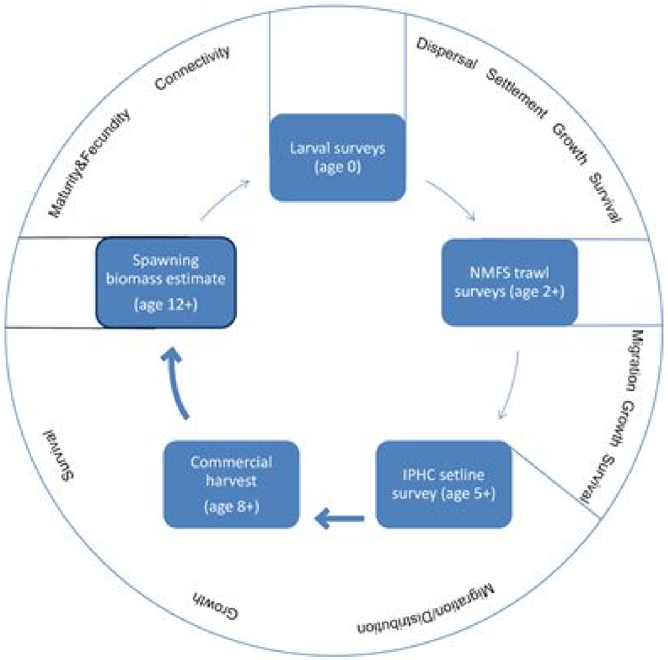
- Example: spatial progression of a distinct source population



A conceptual approach

What information/data would we need to model each step in the process?

- *A conceptual life-history model* allows us to identify elements



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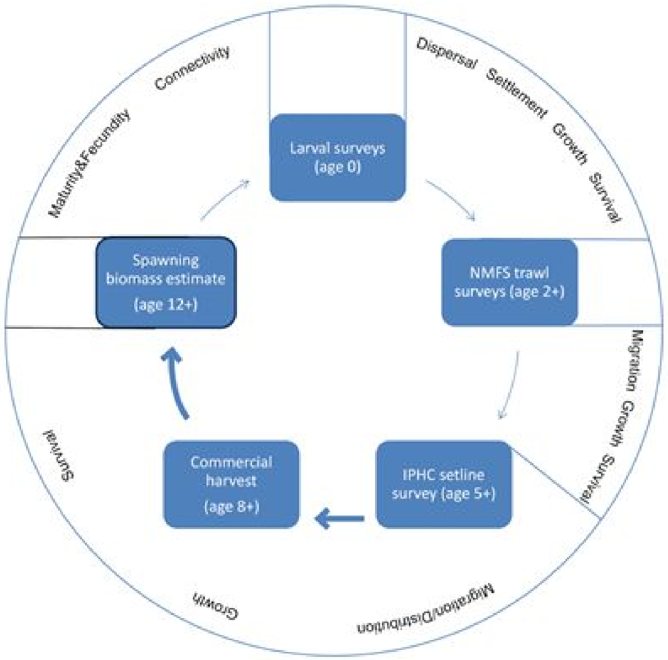
"Elements" will translate directly into individual research projects (= budgetary plans)

A conceptual approach

WARNING: this is about to metamorphose!



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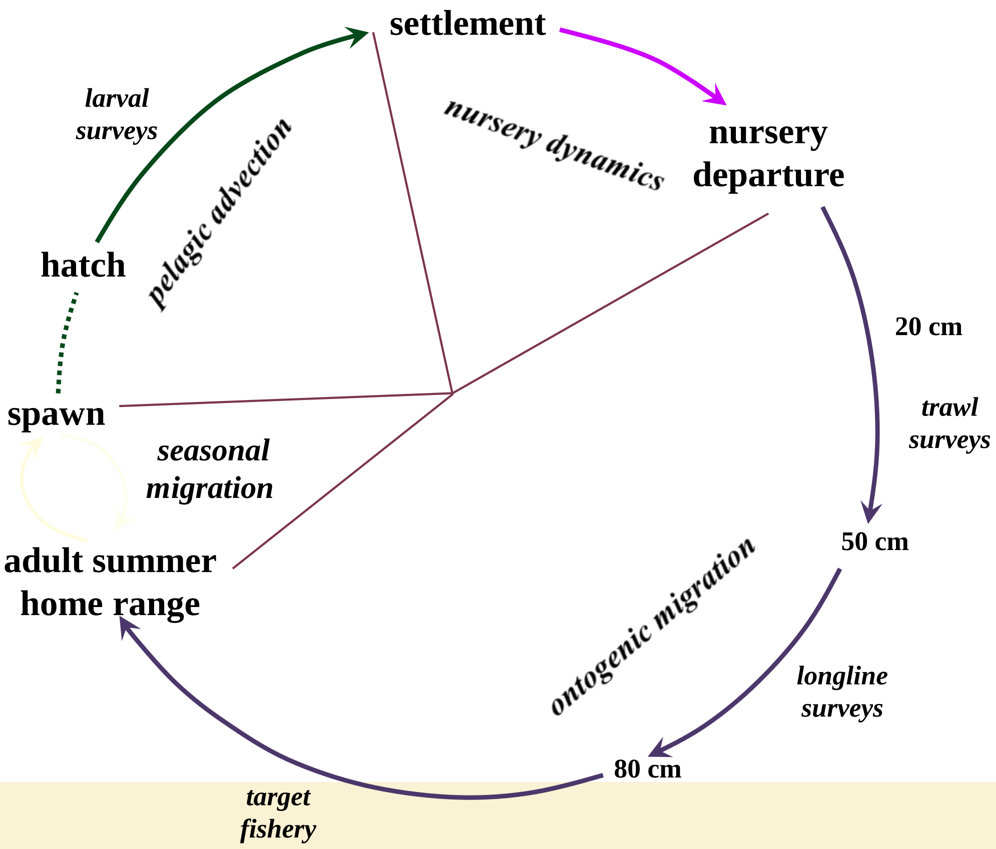
A connectivity-based life-history circle

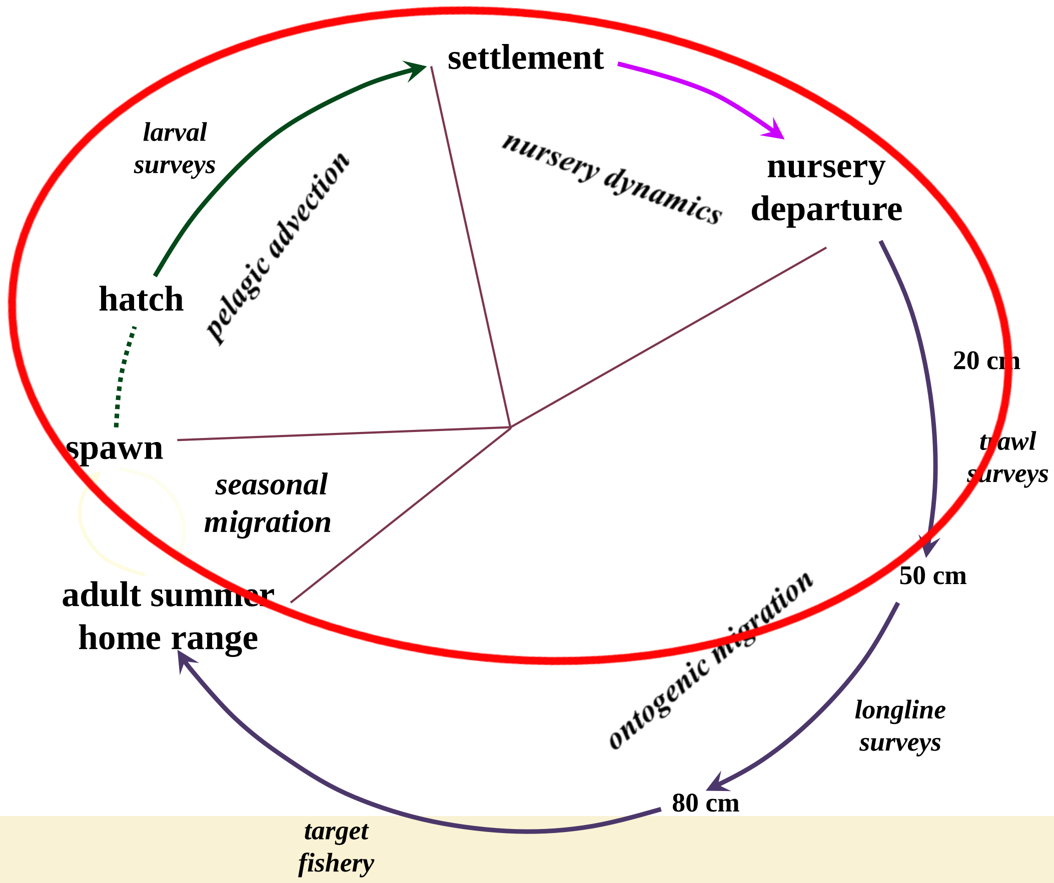
… to follow an individual through time



A connectivity-based life-history circle

A connectivity-based life-history circle

What data are needed*: from egg release to appearance in surveys?



* to parameterize a spatially-explicit landscape ecology model

From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

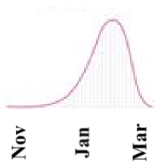
<u>Step 1: Release (spawn) eggs</u>

Locations

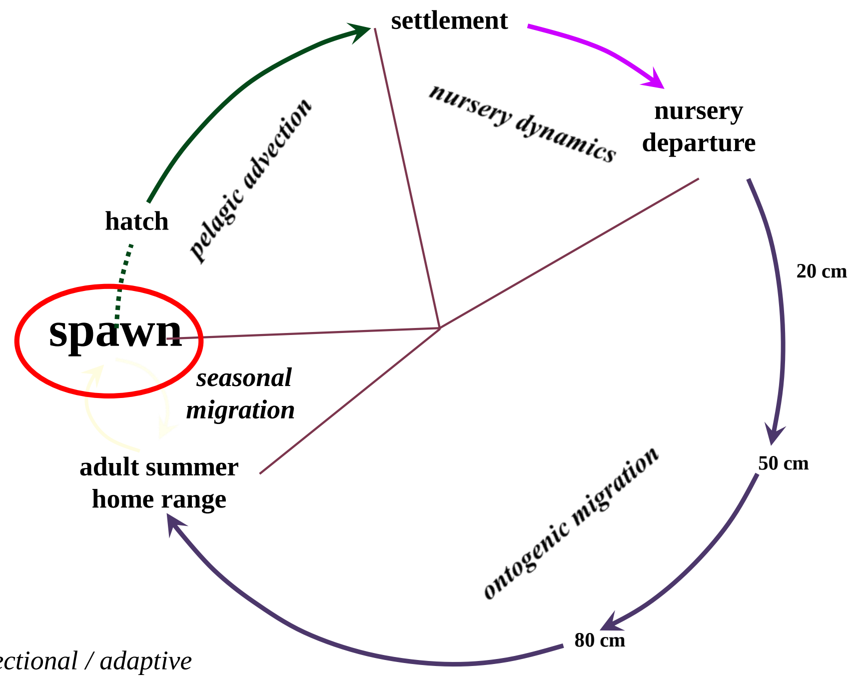
- latitude / longitude
- spatial extent (= initial larval-pool coverage)
- depth strata

Timing

- single-location, group-level distributions



- spatial variance (e.g., latitudinal trend?)
- temporal variance (e.g., climate change?)
  - *site fidelity vs. straying; random straying vs. directional / adaptive*



* to parameterize a spatially-explicit landscape ecology model

From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

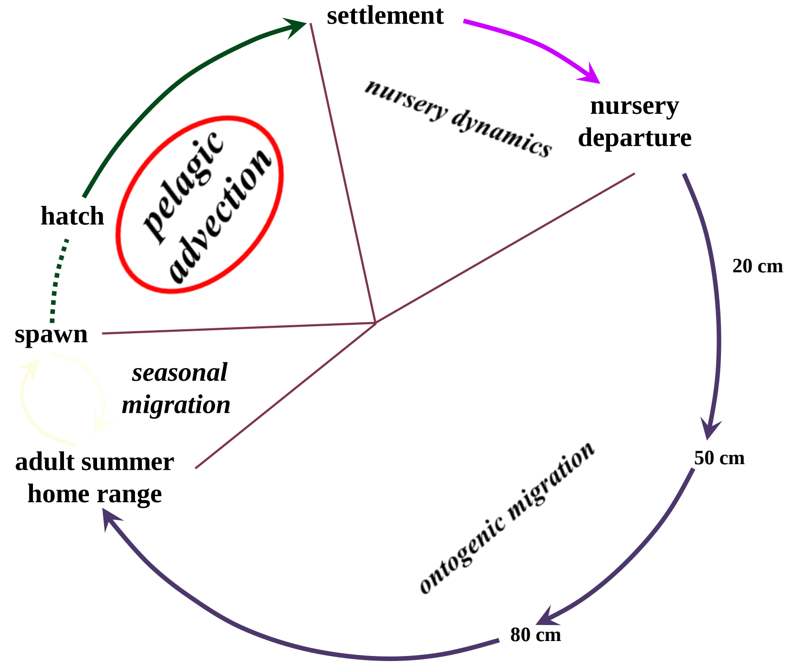
<u>Step 2: Advect larvae</u>

Physical-oceanographic forcing model

- collaborator with appropriate skills

Larval IBM

- developmental model: rates (e.g., degree-day formula); critical feeding periods; temperature / salinity tolerance; mean vertical position by stage
- vertical migration (DVM vs RDVM) & taxis
- swimming speeds / cues (e.g., auditory coastal orientation *sensu* reef fish)



From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

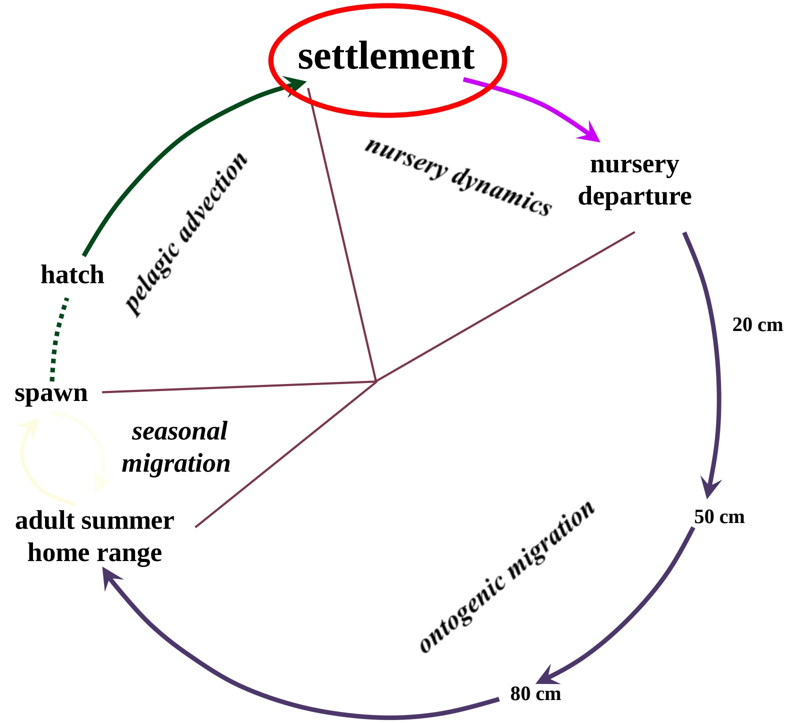
<u>Step 3: Settle larvae</u>

Larval IBM

- settlement preferences (habitat type)
- plastic larval duration (delayed settlement?)

Spatial benthic model

- habitat distribution



* to parameterize a spatially-explicit landscape ecology model

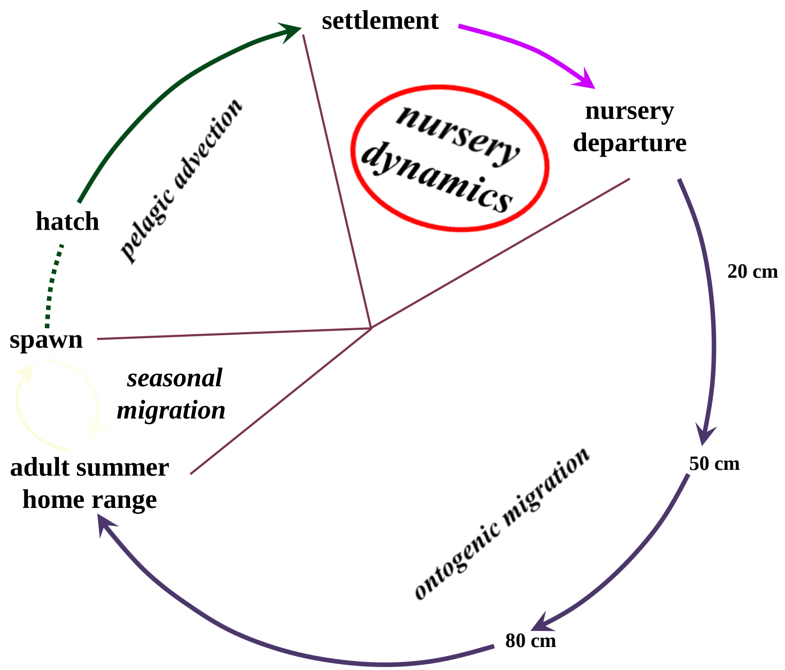
From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

Step 4: Distribute settlers

Spatial nursery-dynamic model

- early benthic dispersal kernels (magnitudes and forms; random vs. directed; density dependence)
- spatial attrition (mortality)
- emigration cues (developmental, environmental)



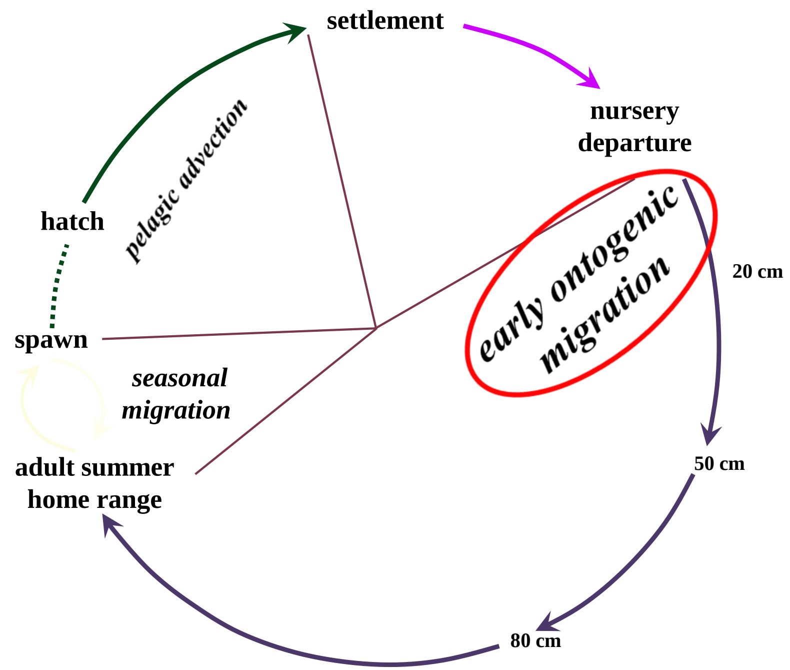
From life-history model to research planning

What data are needed*: from egg release to appearance in surveys?

Step 5: Grow and migrate emigrants

Early ontogenic movement

- dispersal kernels ~ages 2-4 (magnitudes and forms; random vs. directed; sex-specific?)



* to parameterize a spatially-explicit landscape ecology model

Translate data needs into discrete projects

For example:

ELEMENT I - Spawning dynamics

A) Summer-to-winter PAT tagging *(continues Project #s 622, 622.11.84, 622.12, 621.15, 650.21)*

Work Summary*:

Deploy tags in Northern California; GOA Inside Waters; northeastern Bering Sea coastal waters and Navarin Canyon System

Primary Data Product(s):**

Spatial connectivity between feeding (fishing) grounds and functional spawning groups (SSB designations); especially, identification of spawning locations, depths, and coarse-scale spawn-timing

Management Application(s)*:**

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds

****Amenable to conversion into formal research proposals***

***** Can be expressed as Metadata summaries describing the variables to be quantified***

****** Noting that this category would ideally be populated by the Quantitative Sciences Branch***

Translate data needs into discrete projects

For example:

ELEMENT I - Spawning dynamics

B) Coastwide long-term archival tagging of spawning stock *(NEW)*

Work Summary:

Deploy fishery-recovery archival tags at strategic locations coastwide on mature stock

Primary Data Product(s):

Refined data on spawn timing; especially individual, latitudinal, and temporal variance in mean spawn timing and duration of the spawning season

Management Application(s):

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT II – Larval ecology

A) Larval development *(NEW)*

Work Summary:

Conduct larval rearing experiments investigating effects on development of temperature, salinity, and ration

Primary Data Product(s):

Degree-day, salinity, and ration-based developmental schedules/formulae

Management Application(s):

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT II – Larval ecology

B) Larval behavior: pelagic processes *(NEW)*

Work Summary:

Conduct larval swimming and taxis experiments

Primary Data Product(s):

Quantification of stage-specific swimming speeds and predictions of forcing-dependent vertical distribution

Management Application(s):

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT II – Larval ecology

C) Larval behavior: settlement processes *(NEW)*

Work Summary:
Continue larval rearing through settlement competence

Primary Data Product(s):
Quantification of physiological settlement window

Management Application(s):
- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT II – Larval ecology

D) Numerical advection modelling *(continues Duffy-Anderson/Goldstein analyses)*

Work Summary:

Conduct numerical advection analysis for unstudied regions and conditions (e.g., Aleutian Ridge; connectivity between US Bering shelf edge and Russian coast)

Primary Data Product(s):

Estimates of environmentally-governed connectivity distances and relative magnitudes

Management Application(s):

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT III – Early-benthic (settlement to ~age 2) dynamics

A) Theoretical habitat mapping *(NEW)*

Work Summary:
Examine nautical charts and habitat databases to produce maps of likely settlement distribution

Primary Data Product(s):
Estimates of regionally-explicit settlement (= recruitment source) potential

Management Application(s):
- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT III – Early-benthic (settlement to ~age 2) dynamics

B) Field mapping and sample collection ***(NEW)***

Work Summary:

Larval-collector and small-beam trawl surveys at selected settlement areas coastwide

Primary Data Product(s):

Quantification of pelagic larval duration and settlement period (via otolith increment analysis), and relationship between larval supply and relative settlement densities

Management Application(s):

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT III – Early-benthic (settlement to ~age 2) dynamics

C) Intrinsic dispersal and density-dependent processes ***(NEW)***

Work Summary:
Within-year repeat sampling of representative settlement site(s) and translocation studies

Primary Data Product(s):
Estimates of post-settlement attrition (mortality), dispersion, and emigration timing

Management Application(s):
- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT III – Early-benthic (settlement to ~age 2) dynamics

D) Otolith microchemistry as natural tags *(continues Project # 620)*

<u>Work Summary</u>:

Chemical and statistical analysis of otoliths collected under EIII-B

<u>Primary Data Product(s):</u>

Estimation of elemental spatial trending and robustness of elementally-based assignment to spurious errors due to spatial undersampling

<u>Management Application(s):</u>

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

For example:

ELEMENT IV – Early dispersive-phase (~ ages 2-5) processes

A) Early dispersal ***(NEW)***

Work Summary:

Focused high-density archival and wire tagging at a single representative nursery source

Primary Data Product(s):

Age- and sex-specific dispersal/dispersion kernels

Management Application(s):

- Definition of Biological Regions
- Establishment of regionally-explicit spawning biomass thresholds
- Estimation of seasonally-integrated biomass distribution

Translate data needs into discrete projects

Summary: this would define a early life-history Connectivity Research Program composed (11) discrete Projects nested into (4) life-history Elements:

ELEMENT I - Spawning dynamics

- Summer-to-winter PAT tagging
- Coastwide archival tagging of spawning stock

ELEMENT II – Larval ecology

- Larval development
- Pelagic-phase behavior
- Larval settlement
- Numerical advection modelling

ELEMENT III – Early-benthic dynamics

- Theoretical habitat mapping
- Field mapping and sample collection
- Intrinsic dispersal and density-dependent processes
- Otolith microchemistry

ELEMENT IV – Early dispersive-phase

- Early dispersal

Migration-related topics of potential current interest

1) **Short-term migratory responses to hypoxic conditions**
   - Has bearing on the relationship between survey CPUE and underlying abundance
   - Might be investigated with acoustic tracking, displacement studies, and targeted collection of environmental data

2) **Experimental validation of regional isolation** (e.g., movement across Amchitka Pass)
   - Addressing stock structure, Bioregion, and Local Area Management concerns
   - Well-suited to acoustic gating studies

3) **Sex- and maturity-dependent seasonal redistribution and spawning dynamics** (e.g., migration pathways and spawning-ground-arrival timing)
   - Addresses concerns that winter fisheries could cause long-term demographic shifts
   - Amenable to fishery-recovery and pop-up archival tagging in conjunction with HMM

4) **Effects of climate change on stock on stock redistribution**
   - Addresses concerns regarding changes in total recruitment (long-term yield), regional productivity (quota shifts), and spatial bycatch impacts
   - Invokes studies on larval delivery, settlement patterns, and long-term migration

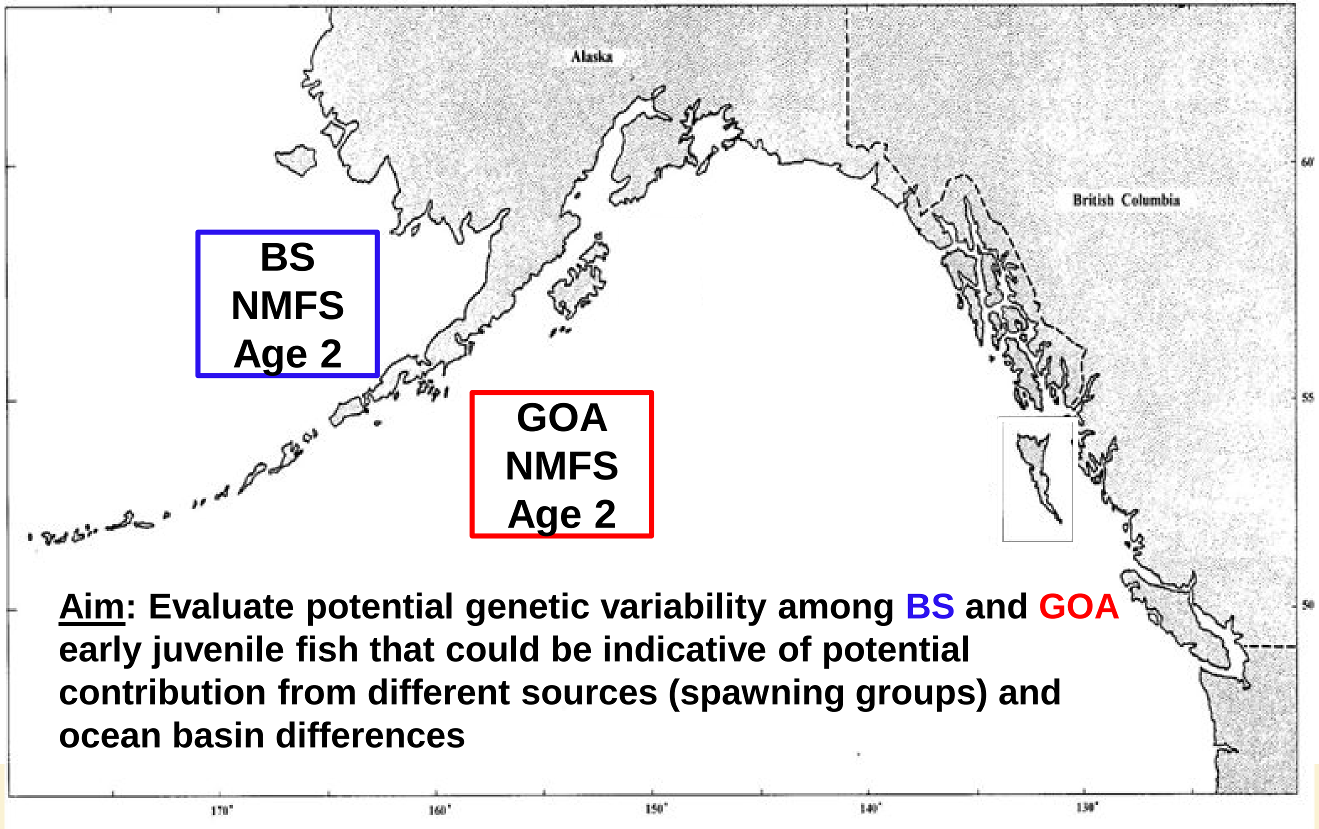
Incorporation of genetics into migration-related research

Initial projects:

- **Genetic variability among juvenile Pacific halibut in the Bering Sea and Gulf of Alaska**
- **Identification of potential genetic signatures of origin (spawning groups)**

Incorporation of genetics into migration-related research

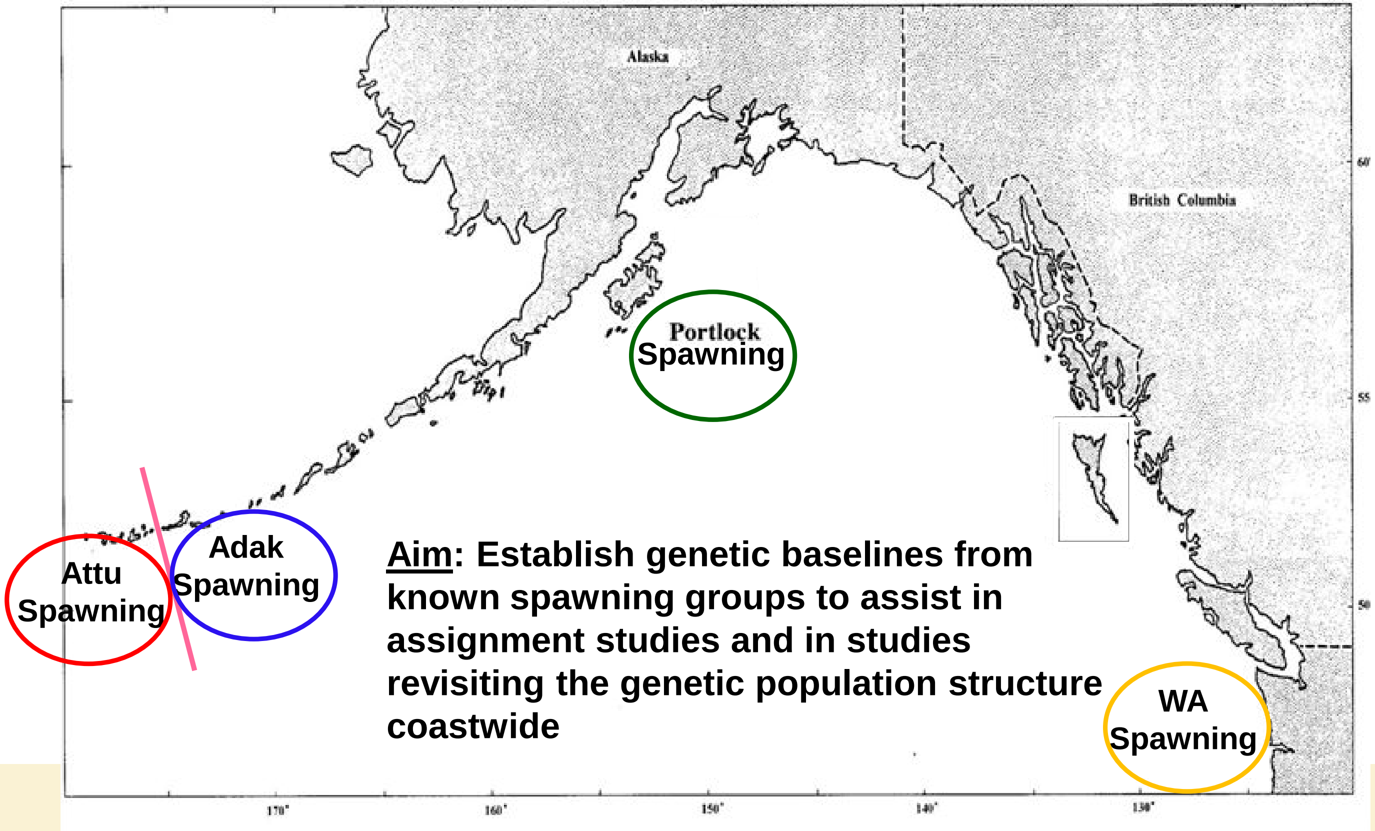
- **Genetic variability among juvenile Pacific halibut in the Bering Sea and Gulf of Alaska**



Aim: Evaluate potential genetic variability among BS and GOA early juvenile fish that could be indicative of potential contribution from different sources (spawning groups) and ocean basin differences

Incorporation of genetics into migration-related research

- Identification of potential genetic signatures of origin (spawning groups)



Aim: Establish genetic baselines from known spawning groups to assist in assignment studies and in studies revisiting the genetic population structure coastwide

INTERNATIONAL PACIFIC HALIBUT COMMISSION

IPHC MSE Update

Agenda Item 7

IPHC-2019-SRB014-08

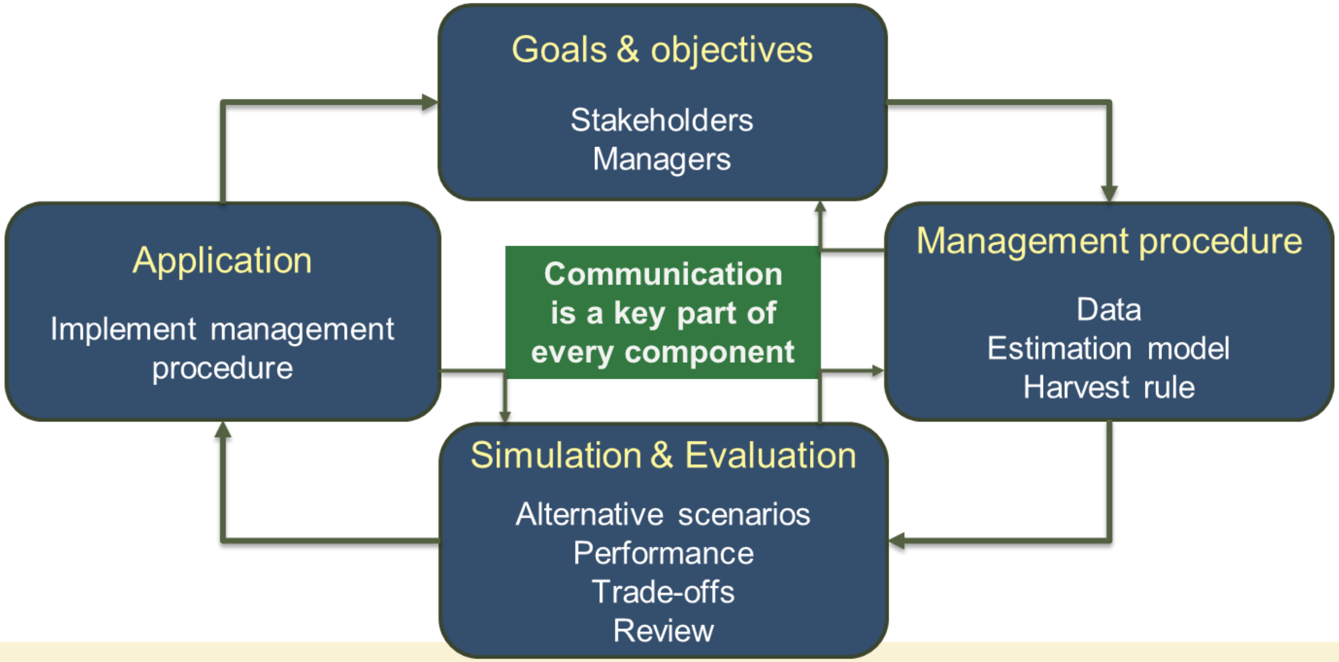
14th Meeting of the IPHC Scientific Review Board (SRB014)

Outline

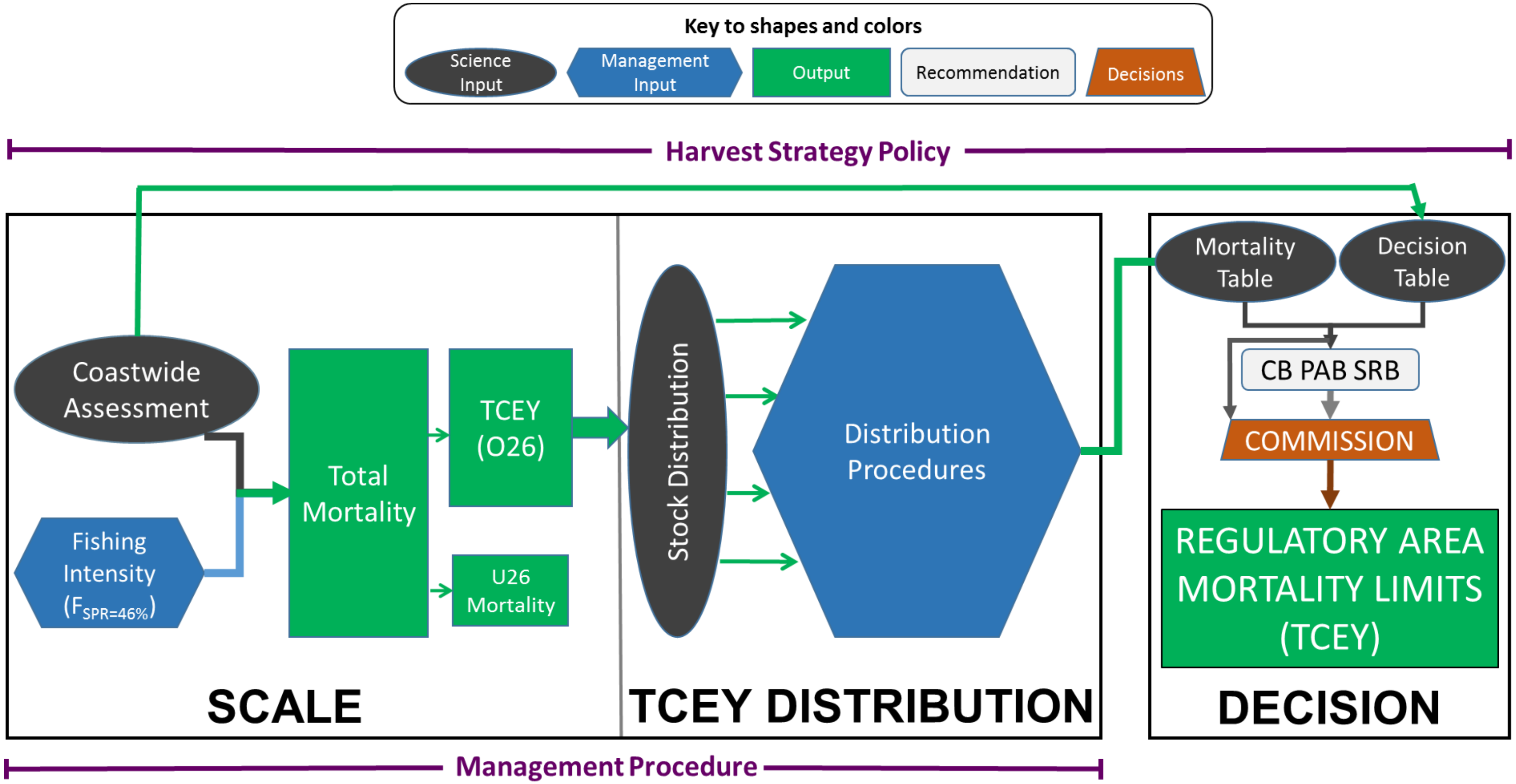
- Brief review
- Update from MSAB013
  - Goals & objectives
  - Coastwide simulation results
  - Distribution framework
- Timeline and SRB deliverables

Management Strategy Evaluation (MSE)

a process to evaluate harvest strategies and
develop a management procedure that is
robust to uncertainty and
meets defined objectives



Management Procedure



Goals and primary objectives (coastwide)

1. Biological Sustainability (conservation goal)
   1.1. Keep biomass above a limit to avoid critical stock sizes
2. Optimise directed fishing opportunities (fishery goal)
   2.1. Maintain spawning biomass around a level (i.e., a target biomass reference point) that optimises fishing activities
   2.2. Limit catch variability
   2.3. Maximize directed fishing yield
3. Minimize discard mortality
4. Minimize bycatch and bycatch mortality

AM095-R (para. 59): develop a conservation objective that meets a spawning biomass target

Biological Sustainability objectives: update

General Objective	Measurable Objective	Measurable Outcome	Time-frame	Tolerance
1.1. Keep biomass above a limit to avoid critical stock sizes Biomass Limit	Maintain a minimum female spawning stock biomass above a biomass limit reference point at least 95% of the time	*SB* < Spawning Biomass Limit (SB_{Lim}) SB_{Lim}=20% unfished SB	Long-term, 10-yr period	0. 05

Consistent with MSC

Updated tolerance

Primary fishery objectives: target biomass

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	MEASURABLE OUTCOME	TIME-FRAME	TOLERANCE
*2.1 MAINTAIN SPAWNING BIOMASS AROUND A LEVEL THAT OPTIMISES FISHING ACTIVITIES	2.1A SPAWNING BIOMASS TRIGGER Maintain the female spawning biomass above a trigger reference point at least 80% of the time	SB<Spawning Biomass Trigger (SB_{Trig}) $SB_{Trig}=SB_{30\%}$ unfished spawning biomass	Long-term	0.20
	*2.1B SPAWNING BIOMASS TARGET Maintain the female spawning biomass above a biomass target reference point at least 50% of the time	SB<Spawning Biomass Target (SB_{Targ}) $SB_{Targ}=SB_{36\text{-}45\%}$ unfished spawning biomass	Long-term	0.50

New fishery objective for 2019

Primary fishery objectives: target biomass

- B_{MSY}
  - Maximizing the yield in the long-term with minimal risk of being less than SB_{Lim} would naturally result in the stock to fluctuate around a target biomass that would sustainably produce MSY (SB_{MSY})
  - Is likely dynamic, depending on regime
  - We plan to use three methods to investigate B_{MSY}
    1. Simple equilibrium model with life-history parameters
    2. Use the 2019 assessment model
    3. MSE coastwide operating model
- B_{MEY}
  - Proxy of $1.2 \times B_{MSY}$
  - Economist will help understand MEY

Primary fishery objectives: stability

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	MEASURABLE OUTCOME	TIME-FRAME	TOLERANCE
2.2. LIMIT CATCH VARIABILITY	Limit annual changes in the coastwide TCEY	Average Annual Variability (*AAV*) > 15%	Short-term	0.25

Primary fishery objectives: maximize yield

- Maximizing the yield was used instead of maintaining the catch above a specified level.
  - Need to define the minimum catch level (and a tolerance)

General Objective	Measurable Objective	Measurable Outcome	Time-frame	Tolerance
2.3. Maximize Directed Fishing Yield	Maintain TCEY above a minimum level coastwide	Coastwide TCEY < $TCEY_{min}$ $TCEY_{min}$=???	Short-term	??
2.3. Maximize Directed Fishing Yield	Maximize average TCEY coastwide	Median coastwide TCEY	Short-term	STATISTIC OF INTEREST

Define

Additional objectives and performance metrics

- See Appendix I of IPHC-2019-MSAB013-07
- Many of these are *statistics of interest*, which means that they are reported as a metric without a tolerance assigned

Prioritizing coastwide objectives

- No specific prioritization determined with new target objective
- Conservation objective must be met first
- Stability objective is also very important
- Maximizing catch is generally after all objectives have been met

Conservation objectives related to distribution

Conserve spatial population structure

- Relative to biological regions

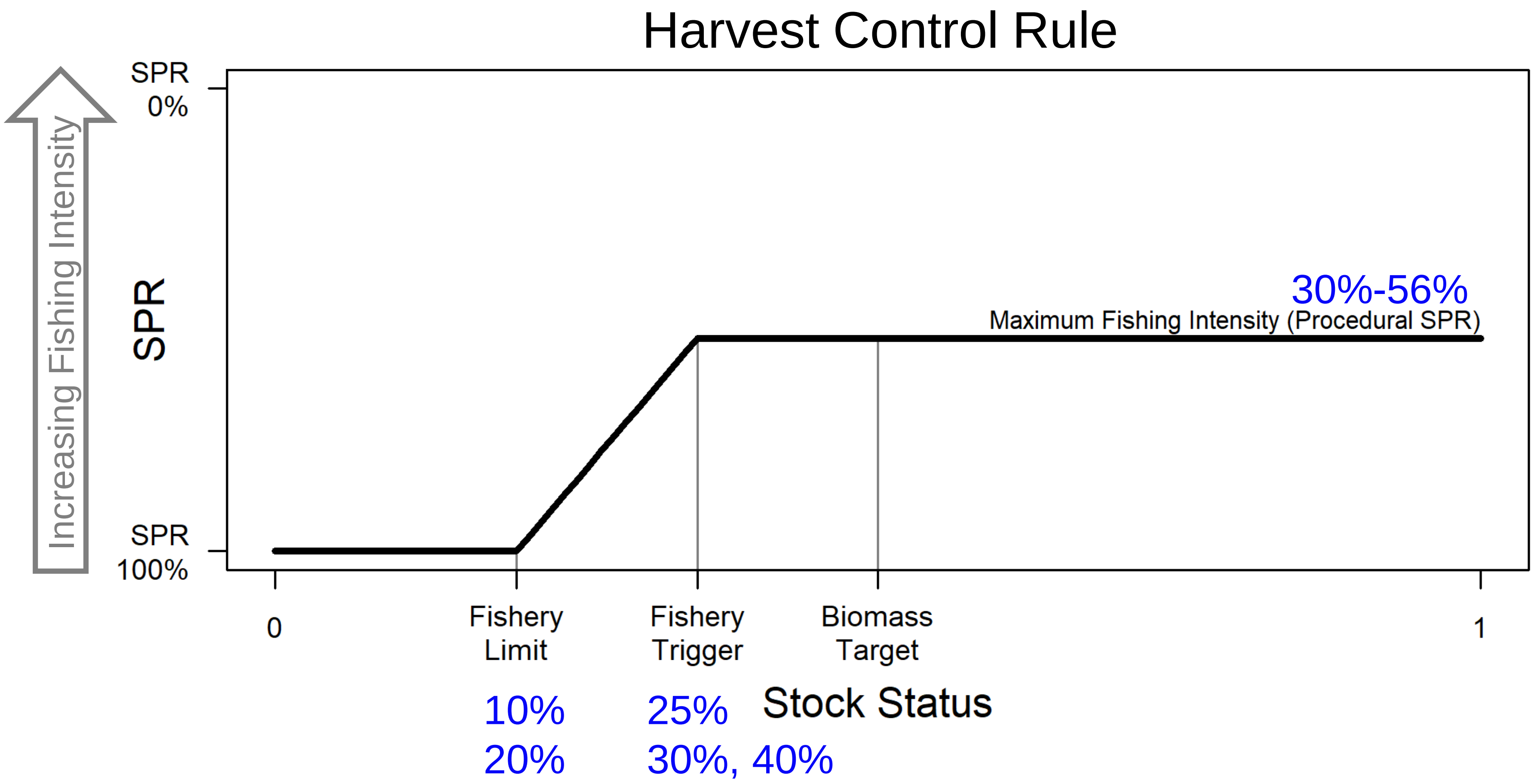
IPHC-2018-SRB012-R: "the SRB AGREED that the defined Bioregions (i.e. 2,3,4, and 4b described in paper IPHC-2018-SRB012-08) are presently the best option for implementing a precautionary approach given uncertainty about spatial population structure and dynamics of Pacific halibut."

Fishery objectives related to distribution

Relative to IPHC Regulatory Areas

- Limit catch variability
- Maximize directed fishery yield
- Minimize potential for no catch limit for directed fishery

Scale Management Procedure

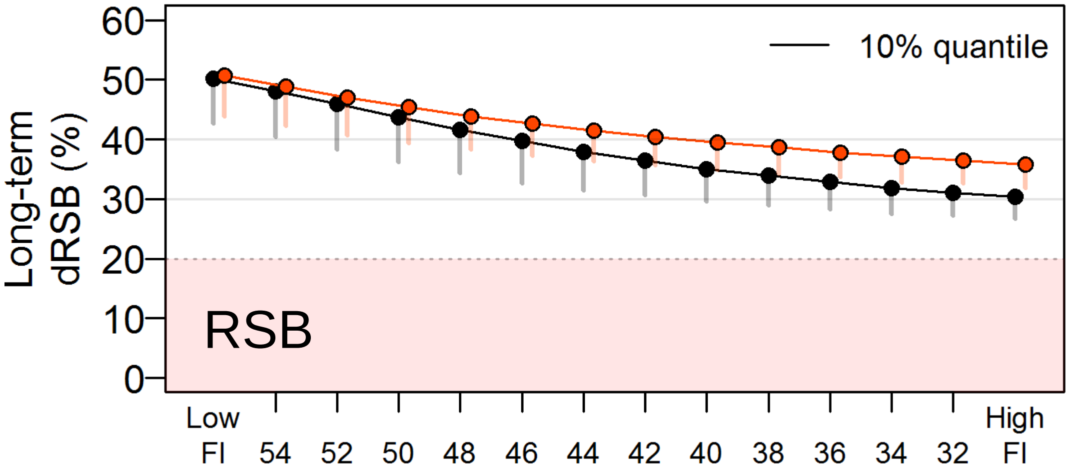


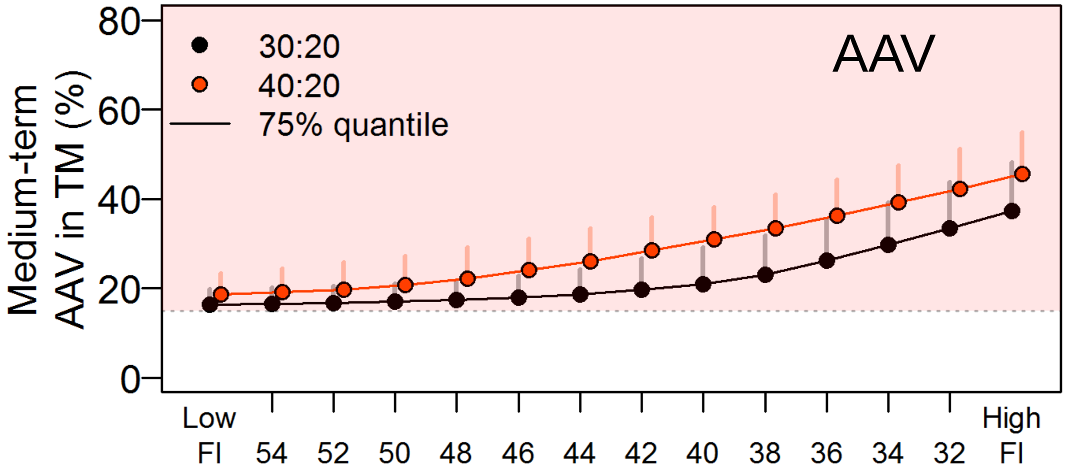
Simulation Results: Performance metrics

- Three performance metrics
  1. RSB: dynamic relative spawning biomass, long-term
     - A measure of stock status
     - Avoid going below 20% more than 10% of the time
  2. AAV: average annual variability, medium-term
     - Average percent change in TM limit from year to year
     - Avoid going above 15% more than 25% of the time
  3. TM: total mortality limit, medium-term
     - Maximize the median value

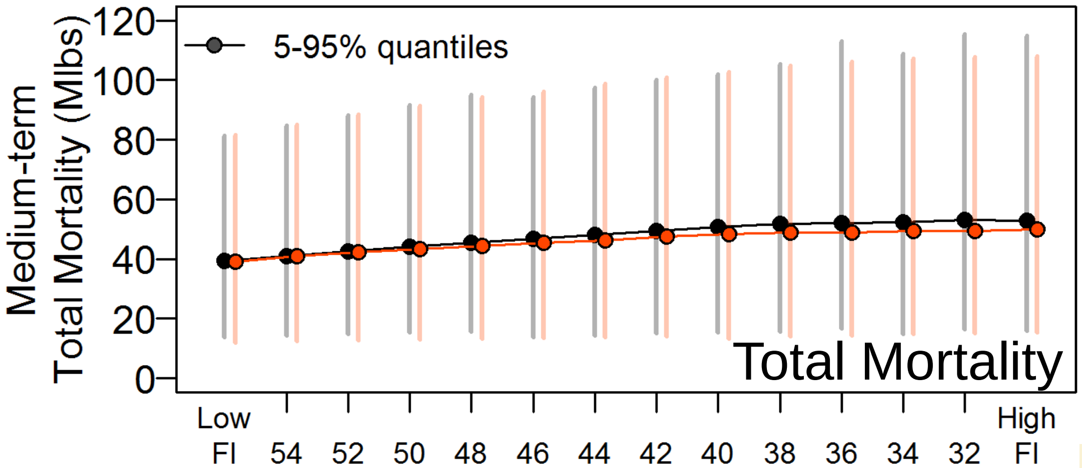
Performance metrics (40:20 & 30:20 CRs)

IPHC-2019-AM095-12
Figure 6





- Bio objective satisfied for all procedures
- AAV objective not satisfied for all procedures
- Median TM increases slightly and range increases with FI



SPR (%)

Results table

Input Control Rule	30:20	30:20	30:20	30:20	30:20	30:20	30:20	30:20	30:20	30:20	30:20
Input SPR	**56%**	**48%**	**46%**	**44%**	**42%**	**40%**	**38%**	**36%**	**34%**	**32%**	**30%**
Biological Sustainability (Long-term)											
P(all RSB<20%)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
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 (medium-term)											
P(all AAV > 15%)	0.60	0.66	0.69	0.72	0.76	0.80	0.84	0.88	0.93	0.96	0.98
Median average TM	39.4	45.5	46.8	48.0	49.5	50.6	51.8	52.1	52.4	53.2	52.8
Rankings (lower is better) over all management procedures without a constraint (Table 3, Table 4, and Table 5)											
Meet biological objective?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?	No	No	No	No	No	No	No	No	No	No	No
Maximum catch (TM)	30	27	24	21	14	11	9	8	7	4	5
Overall Ranking	—	—	—	—	—	—	—	—	—	—	—

Ranking results (lower is better)

CR	Input SPR	56%	48%	46%	44%	42%	40%	38%	36%	34%	32%	30%
30:20	Meet biological objective?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Meet stability objective?	No	No	No	No	No	No	No	No	No	No	No
	Maximum catch (TM) rank	30	27	24	21	14	11	9	8	7	4	5
	Overall Ranking	—	—	—	—	—	—	—	—	—	—	—
40:20	Meet biological objective?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Meet stability objective?	No	No	No	No	No	No	No	No	No	No	No
	Maximum catch (TM) rank	32	29	27	25	22	20	18	17	16	14	13
	Overall Ranking	—	—	—	—	—	—	—	—	—	—	—
25:10	Meet biological objective?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Meet stability objective?	No	No	No	No	No	No	No	No	No	No	No
	Maximum catch (TM) rank	30	26	23	19	12	10	6	3	2	1	—
	Overall Ranking	—	—	—	—	—	—	—	—	—	—	—

INTERN... HALIBUT COMMISSION

Recommendation from MSAB012

MSAB012–Rec.03 (para. 37) The MSAB **RECOMMENDED** that a coastwide fishing intensity SPR should not be lower than 40% nor higher than 46%, with a target SPR of 42%-43% with a 30:20 HCR.

Additional MPs from MSAB012

MSAB012–Req.03 (para. 40) The MSAB **REQUESTED** that additional MPs components be considered to meet the objective of catch stability. The IPHC Secretariat may consider the following MPs, but is **ENCOURAGED** to explore other options to report at SRB014.

a) 25:10 control rule, and other control rules, as possible, potentially including 30:10 and 30:15 and 30:20;
b) Multi-year quotas, defined as setting the TCEY in one year and sticking with the same TCEY in one or more following years, noting that AAV may not be an appropriate metric to measure variability
c) Limiting change in catch limits from the previous year to +/-15% per year, in addition to other relevant percentages, with the goal of finding MPs that meet the main objectives
d) Limiting change in catch limits from the previous year to a maximum increase of 15% per year with no limit on decreasing the catch limit
e) Slow up (33% of the change in TCEY), fast down (-50% of the change in TCEY).

Additional MPs: SRB013 foresight

SRB013–Req.02 (para. 29) The SRB **REQUESTED** that in future iterations of the MSE, the IPHC Secretariat and MSAB consider:

- b) a management procedure include a constraint on the TMq change to be consistent with the maximum change that has happened historically;
- c) the current conditioned operating model be used to simulate a 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).

Constrained Management Procedures

1) MaxChangeBoth15% & 2) MaxChangeBoth20%
   - TM limit constrained to change no more than 15% or 20%

3) MaxChangeUp15%
   - TM limit constrained to increase no more than 15%

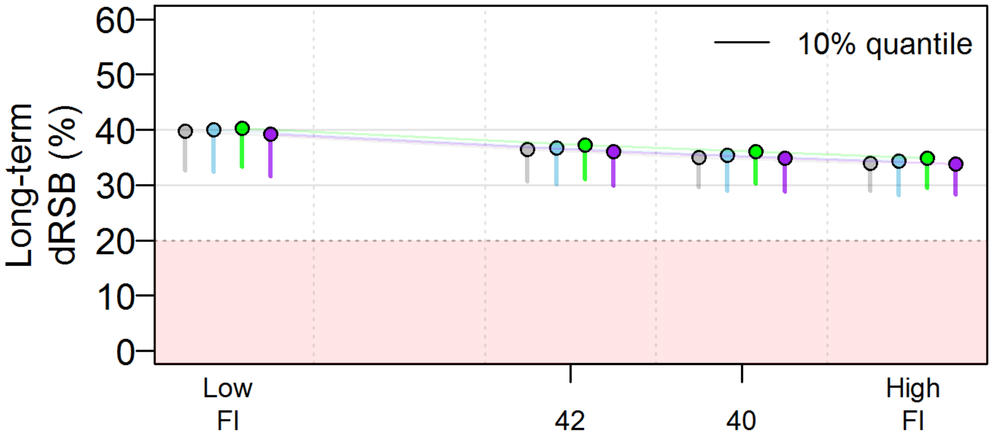
4) SlowUpFastDown & 5) SlowUpFullDown
   - TM limit increases by 1/3rd of increase suggested by harvest control rule
   - TM limit decreases by ½ or full of decrease suggested by harvest control rule

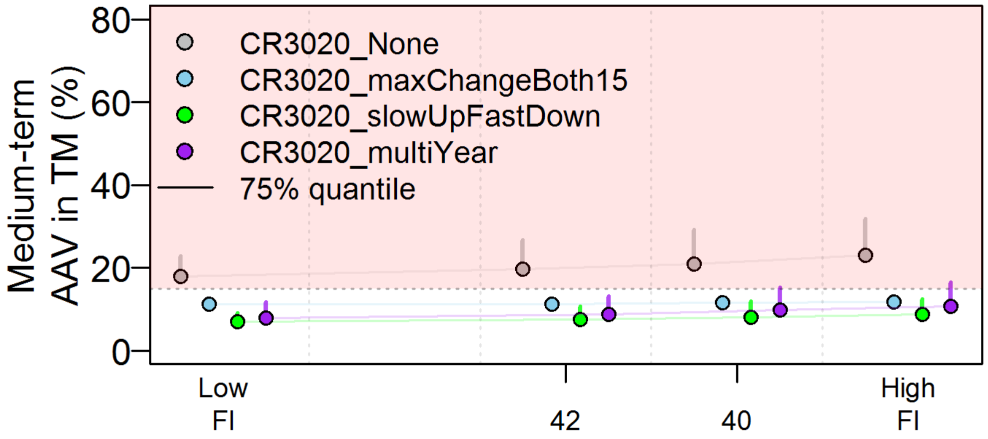
6) Cap60 & 7) Cap80
   - TM limit cannot exceed 60 or 80 Mlb

8) Multi-year
   - Set the TM limit every third year

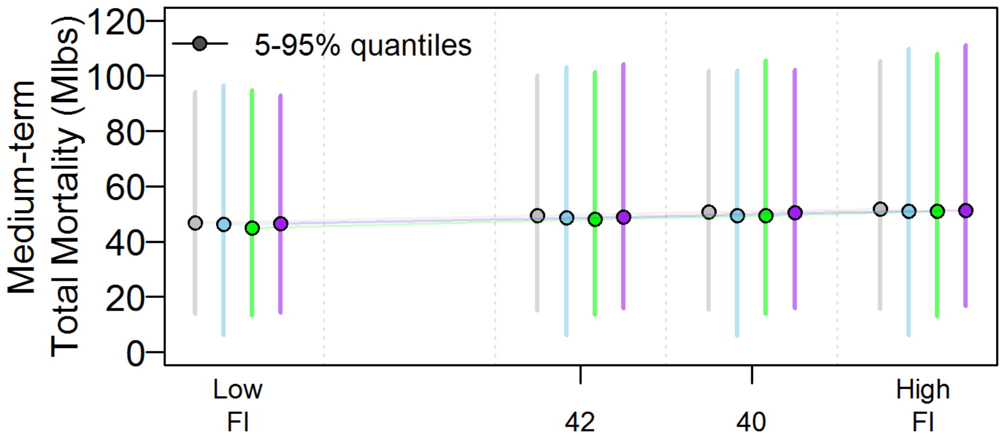
All use a 30:20 control rule

Constrained results





- Bio objective satisfied for all procedures
- AAV objective satisfied for some constraints
- Median TM slightly higher with increasing FI



SPR (%)

Ranking constrained results (lower is better)

Constraint	maxChangeBoth15%				slowUp FastDown				multiYear			
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**	**46%**	**42%**	**40%**	**38%**
Meet biological objective?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Maximum catch (TM)	20	14	9	4	23	15	9	2	17	13	6	1
Overall Ranking	**10**	**6**	**3**	**2**	**11**	**7**	**3**	**1**	**9**	**5**	---	---

Constraint	maxChangeBoth20%				maxChangeUp		slowUp FullDown			Cap80		Cap60	
Input SPR	**46%**	**42%**	**40%**	**38%**	**46%**	**40%**	**46%**	**42%**	**40%**	**46%**	**40%**	**46%**	**40%**
Meet biological objective?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meet stability objective?	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No
Maximum catch (TM)	17	12	8	2	25	22	24	16	11	19	5	20	7
Overall Ranking	---	---	---	---	---	---	**12**	**8**	---	---	---	---	---

MSE Explorer

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

Additional Management Procedures

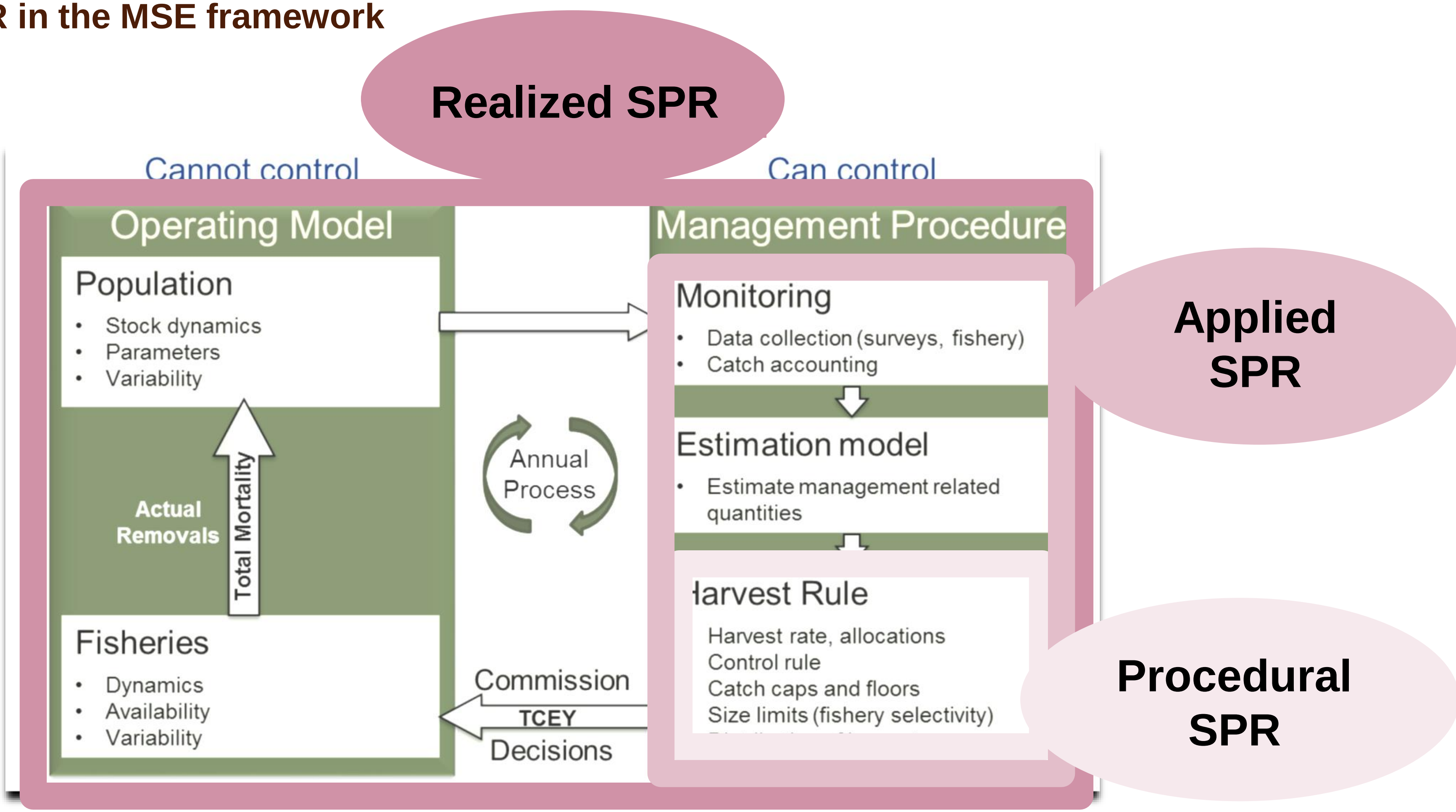
- Other control rules
- MP based on coastwide survey index

AM095-R (para. 52.) The Commission **NOTED** the potential benefits in terms of transparency and simplicity, of a management procedure setting mortality limits directly from modelled survey results, particularly for long-lived species where year-to-year demographic change will be relatively minor.

Meaning of SPR in the MSE framework

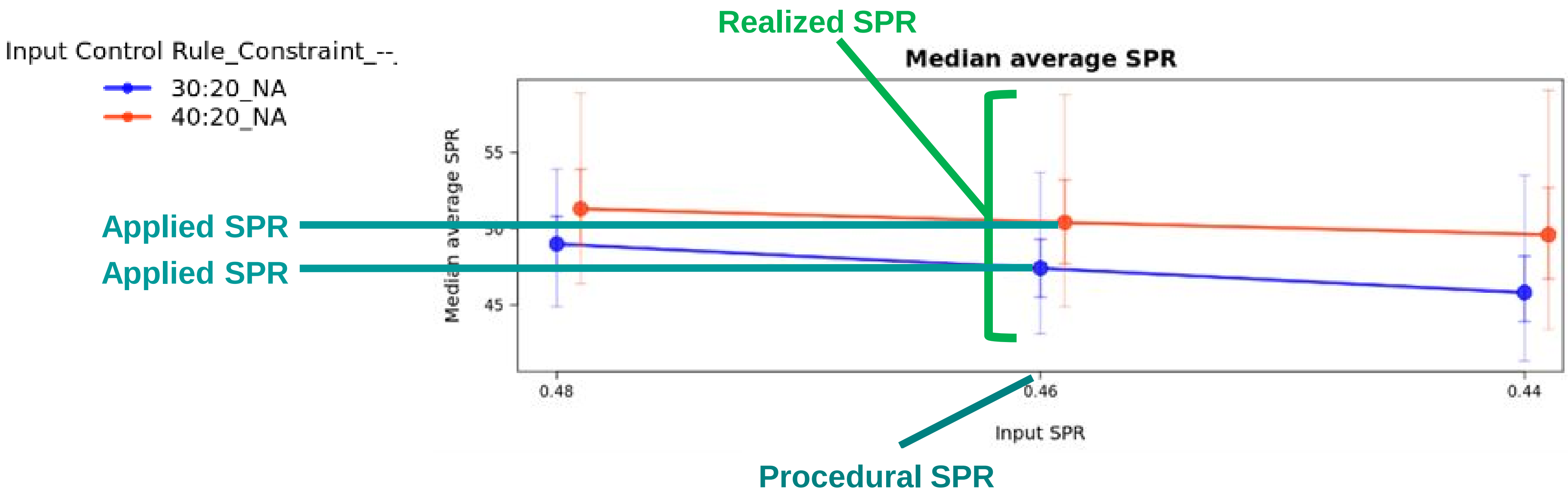
- **Procedural SPR (pSPR):** the biological target of the management strategy.
- **Applied SPR (aSPR)**: the SPR generated from the management procedure after the application of the harvest control rule, which includes uncertainty on stock status.
- **Realized SPR (rSPR):** the resulting SPR that includes all the uncertainties (OM + Assessment + application of control rule).

Meaning of SPR in the MSE framework



Example 1

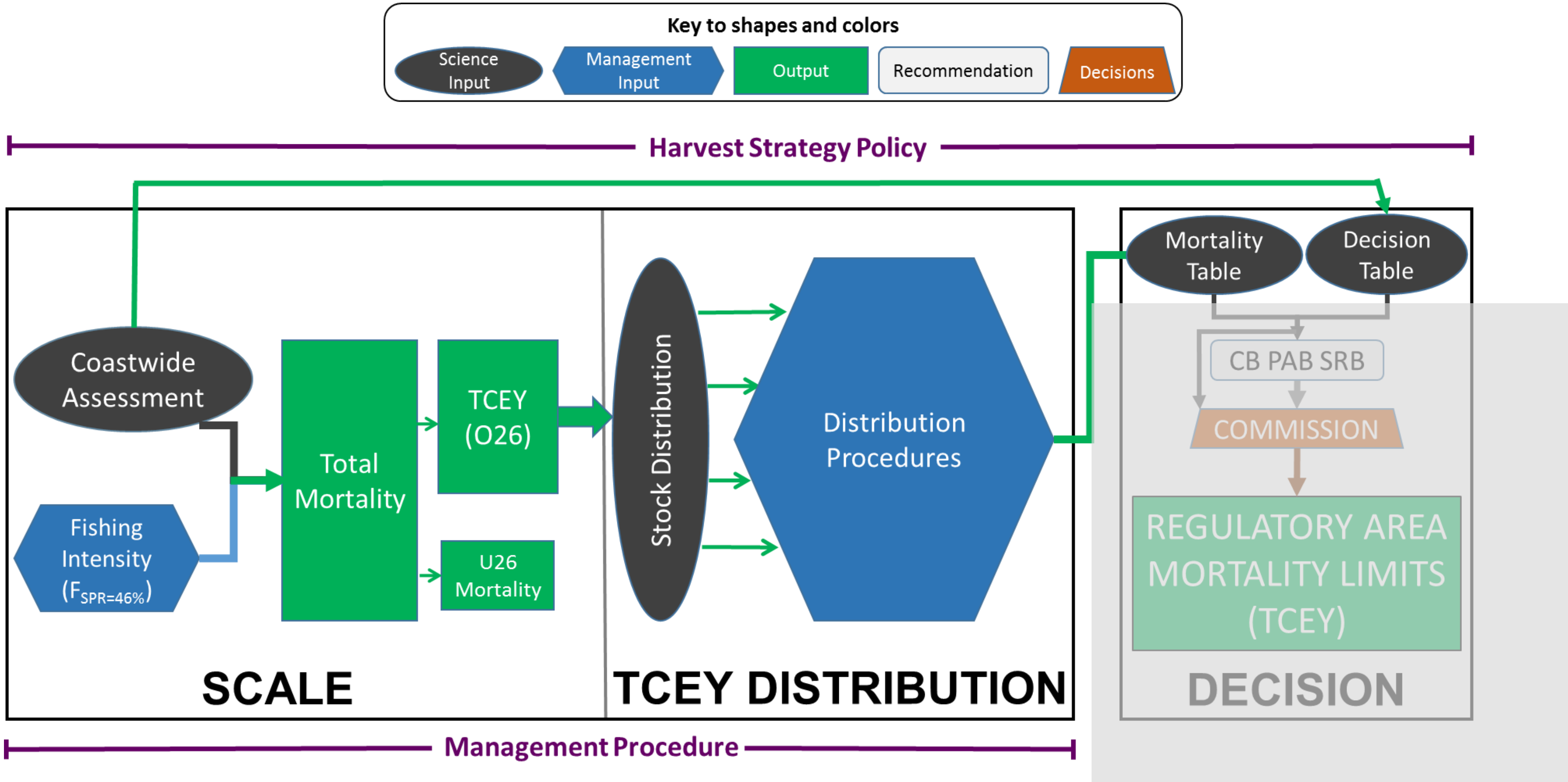
Effect of two different CRs on the aSPR and on the rSPR.



Distribution Framework

*AM095-R (para. 62). The Commission **RECOMMENDED** that the MSAB and IPHC Secretariat continue its program of work on the Management Procedure for the Scale portion of the harvest strategy, NOTING that Scale and Distribution components will be evaluated and presented no later than at AM097 in 2021, for potential adoption and subsequent implementation as a harvest strategy*

Management Procedure



Foundations for distributing the TCEY

There are two foundations for the elements in the TCEY distribution procedure

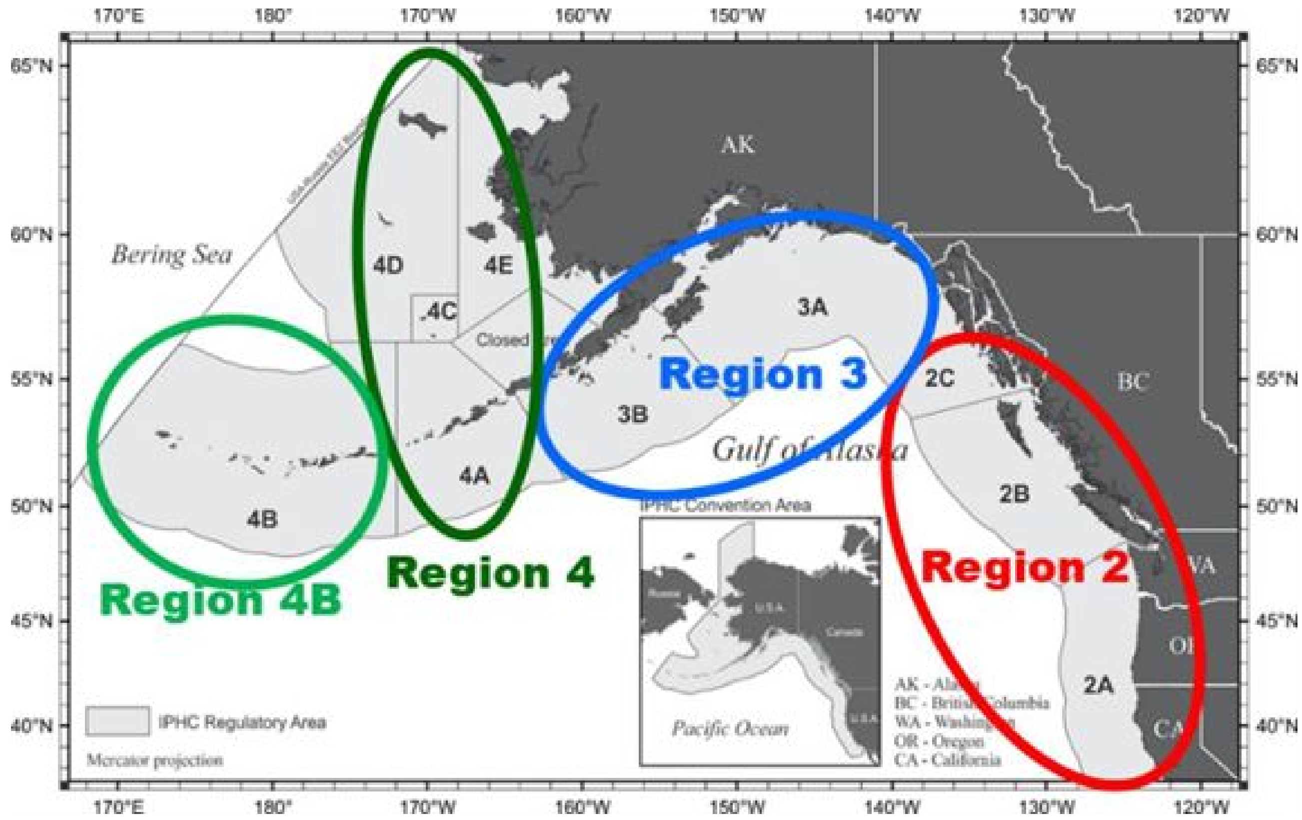
1. **Science-based**: understanding of biology, based on analysis of observations and data from the stock to meet biological objectives
2. **Management-derived**: procedure to distribute TCEY, based on any method, to meet biological and fishery objectives

Recent Interim MP

- **Stock Distribution** (science-based foundation)
  - The proportion of the stock in IPHC Regulatory Areas
  - Estimated from the space-time model mean WPUE indices for each IPHC Regulatory Area
  - Uses O32 WPUE index
  - Linked to Biological Sustainability objectives
- **Relative Harvest Rates** (both foundations)
  - Shift stock distribution to account for additional factors
    - Lower productivity in western areas (3B, 4A, 4B, and 4CDE)
    - Quantity and quality of data (e.g., uncertainty)
    - ¾ relative harvest rate in western areas

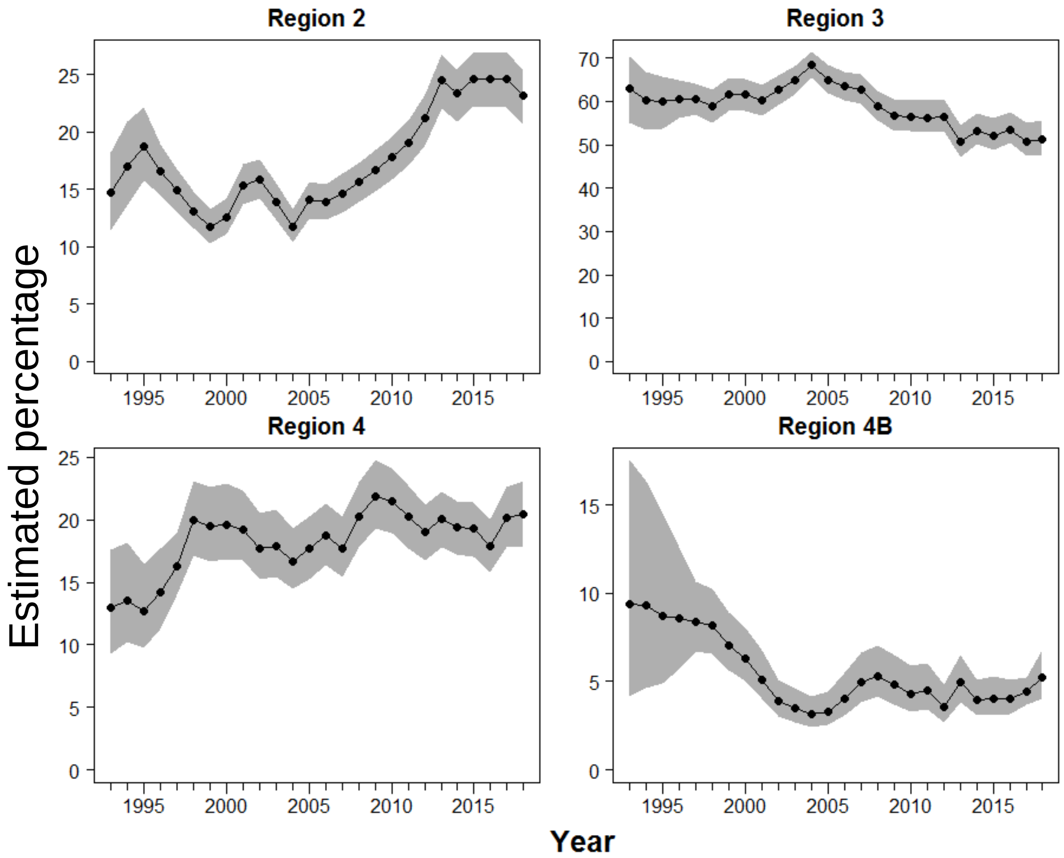
Changes to Stock Distribution

- Use Biological Regions
  - Best option for biologically-based areas to meet management needs



Changes to Stock Distribution

- All-sizes WPUE is more similar to TCEY
  – TCEY is over 26 inches (O26)
  – "All-sizes" is predominately O26



Changes to Relative Harvest Rates

- Apply by Biological Region
- Conduct research on productivity in each Region
- Enumerate uncertainty of data in each Region
- Consider other factors

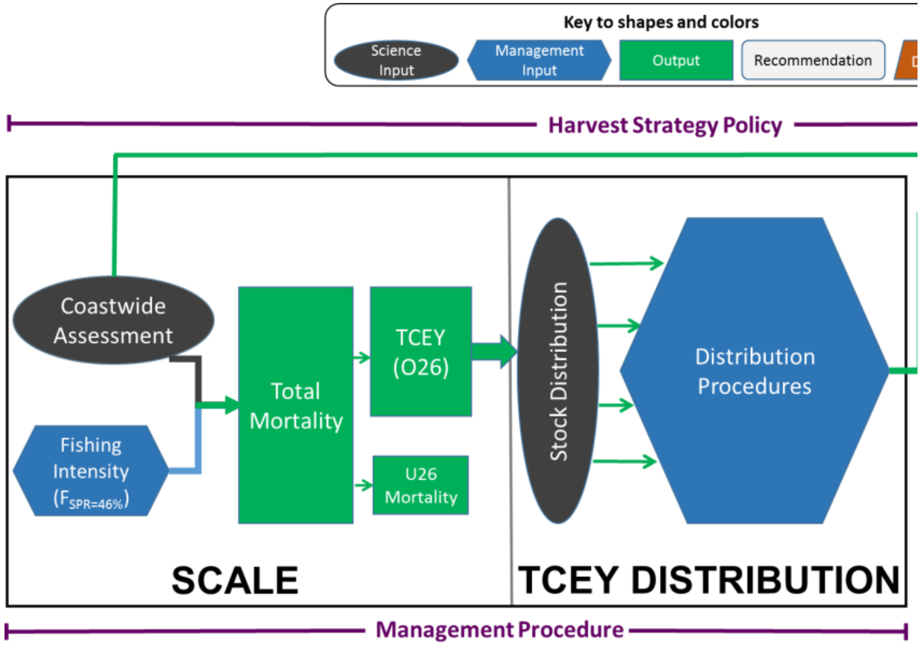
Future elements for distributing the TCEY to IPHC Regulatory Areas

Management foundation

- Procedures based on policy
  - Incorporate other objectives
  - May be based on data
- Examples
  - Use trends from fishery-dependent catch-rates (CPUE)
  - Age or size compositions
  - Economic and social concerns
  - Agreements

Elements of distributing the TCEY

- Coastwide target fishing intensity
- Regional Stock Distribution
- Regional Allocation Adjustment
- Regulatory Area Allocation
  - Various tools have been identified

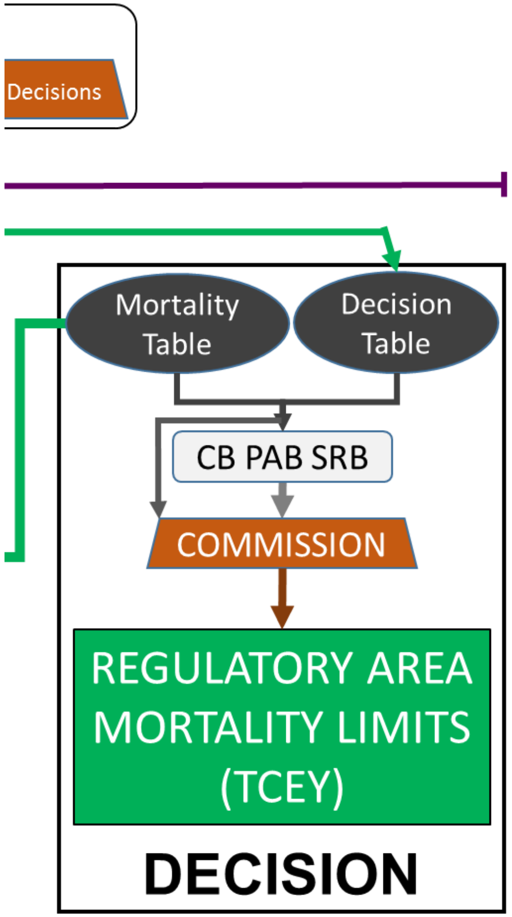


Other orders of elements or procedures may also be evaluated

Decision-Making

Annual Regulatory Area Adjustment

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



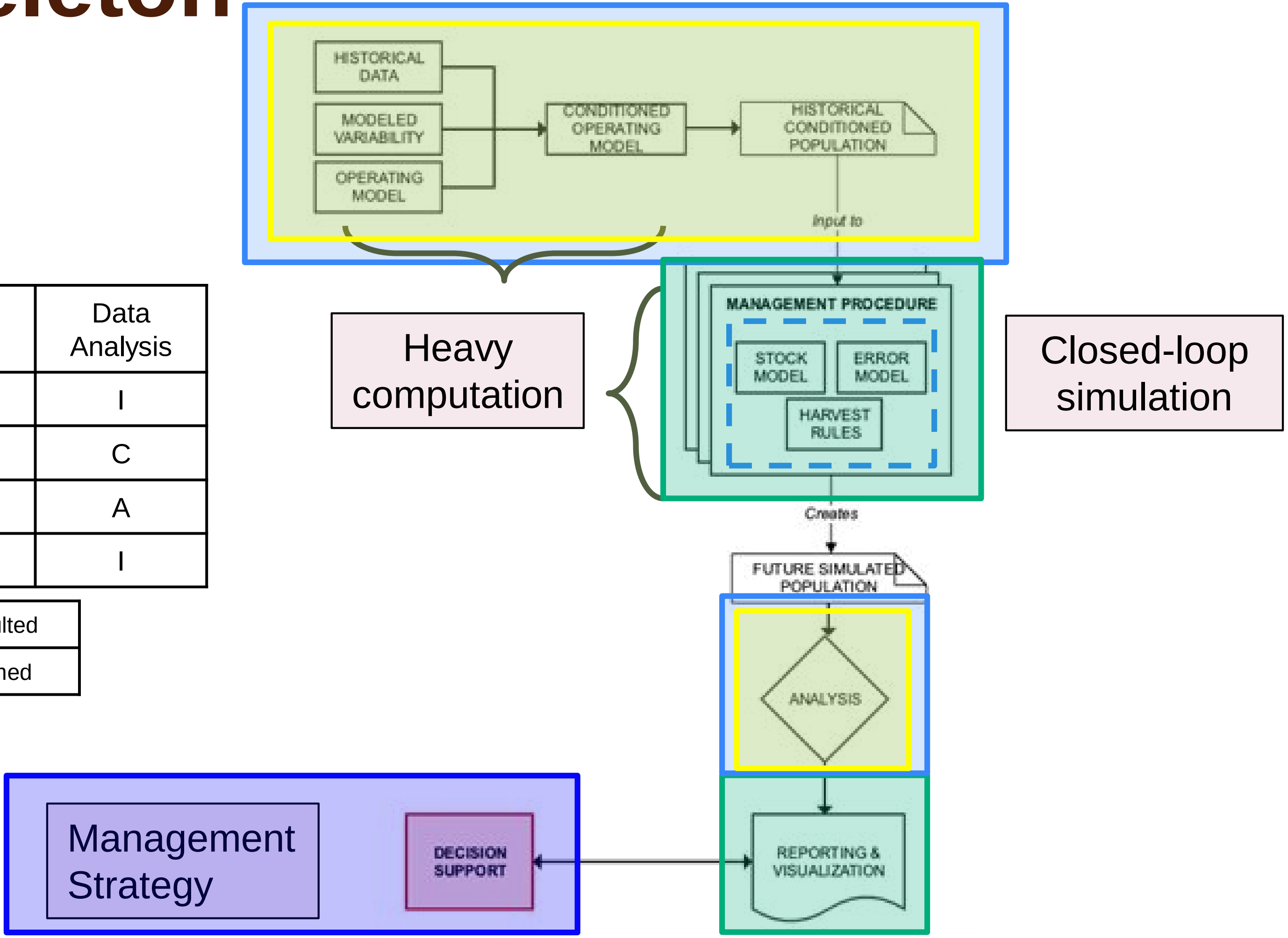
MSE Framework

- Goals
  - Performance
  - Fidelity and reproducible
  - Easy to use
  - Modular, extensible
  - Maintainable

Framework Skeleton

	Operating Model	Management Procedures	Data Analysis
MSAB	I	C	I
SRB	C	I	C
IPHC	R/A	R	A
Comm.	I	A	I

R	Responsible	C	Consulted
A	Accountable	I	Informed



Operating Model Specifications

- Regional biological dynamics
- IPHC Regulatory Area fishery dynamics
- Multiple sectors within each area

- Generalized to accommodate different structures

Operating Model Specifications

- Parameterized using
  - current and past knowledge
  - Input from MSAB and SRB
- Conditioned using data and informed assumptions
- Incorporate variability and uncertainty
- Technical details will be reviewed at SRB015

Program of Work

May 2019 MSAB Meeting
Evaluate additional Scale MPs
Review goals and objectives
Identify MPs (Distribution & Scale)
Review Framework
June 2019 SRB Meeting
Review goals and objectives
Review final scale results
Information on development of distribution framework
September 2019 SRB Meeting
Review goals and objectives
Review technical details of multi-area OM
Review development of distribution framework
October 2019 MSAB Meeting
Review Goals and Objectives
Identify MPs (Distribution & Scale)
Review Framework
Review multi-area model development
Annual Meeting 2020
Update on progress

Program of Work

May 2020 MSAB Meeting
Review goals and objectives
Review multi-area operating model
Review preliminary results to be presented at AM097
June 2020 SRB Meeting
Review goals and objectives
Review multi-area operating model
Review preliminary results
September 2020 SRB Meeting
Review goals and objectives
Review multi-area operating model
Review final results
October 2020 MSAB Meeting
Review Goals and Objectives
Review final results
Annual Meeting 2021
Presentation of first complete MSE product to the Commission Recommendations on Scale and Distribution MP

SRB014

NOTE:

- paper IPHC-2019-SRB014-08
- the primary objectives used to evaluate management procedures related to coastwide scale
- additional primary objectives related to a target biomass.
- that no coastwide management procedure without constraints met the stability objective.
- that the three different constraints were ranked in the top 5 management procedures (a slow-up fast-down approach, a maximum change of 15%, and a multi-year limit).
- the distribution framework consisting of
  – a coastwide TCEY distributed to Biological Regions based on stock distribution,
  – relative fishing intensities, and
  – other allocation adjustments, distributed to IPHC Regulatory Areas
- the development of a closed-loop simulation framework to evaluate management procedures related to coastwide scale and distribution of the TCEY.
- that the SRB will review the technical details of the MSE framework and operating model in September 2019, and review the full MSE in September 2020
- methods to investigate B_{MSY}

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