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

PREPARED BY: IPHC SECRETARIAT (A. HICKS & I. STEWART; 11 MAY 2021)

PURPOSE

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

1 INTRODUCTION

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

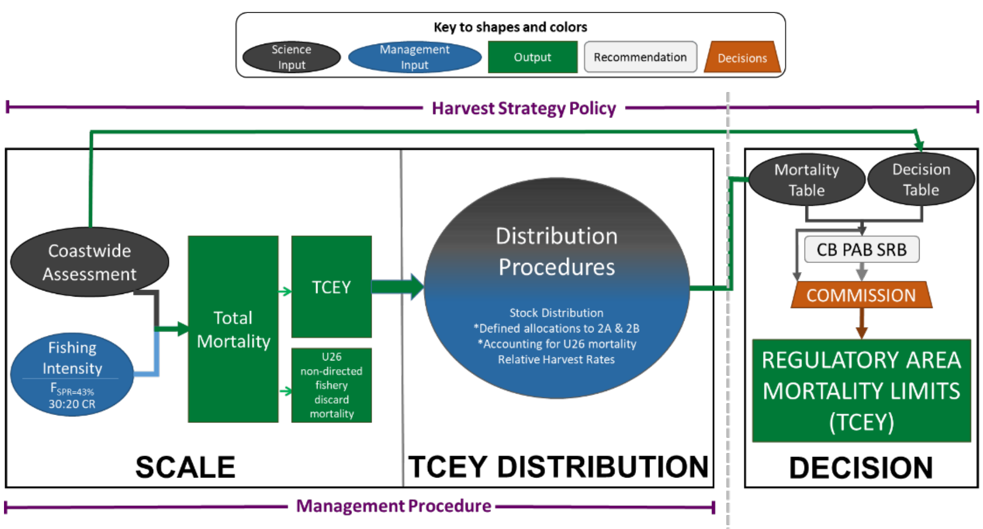

Figure 1. Illustration of the Commission interim IPHC harvest strategy policy (reflecting paragraph ID002 in IPHC CIRCULAR 2020-007) showing the coastwide scale and TCEY distribution components that comprise the management procedure. Items with an asterisk are three-year interim agreements to 2022. The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

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

2 SIMULATION RESULTS

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

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

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

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

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

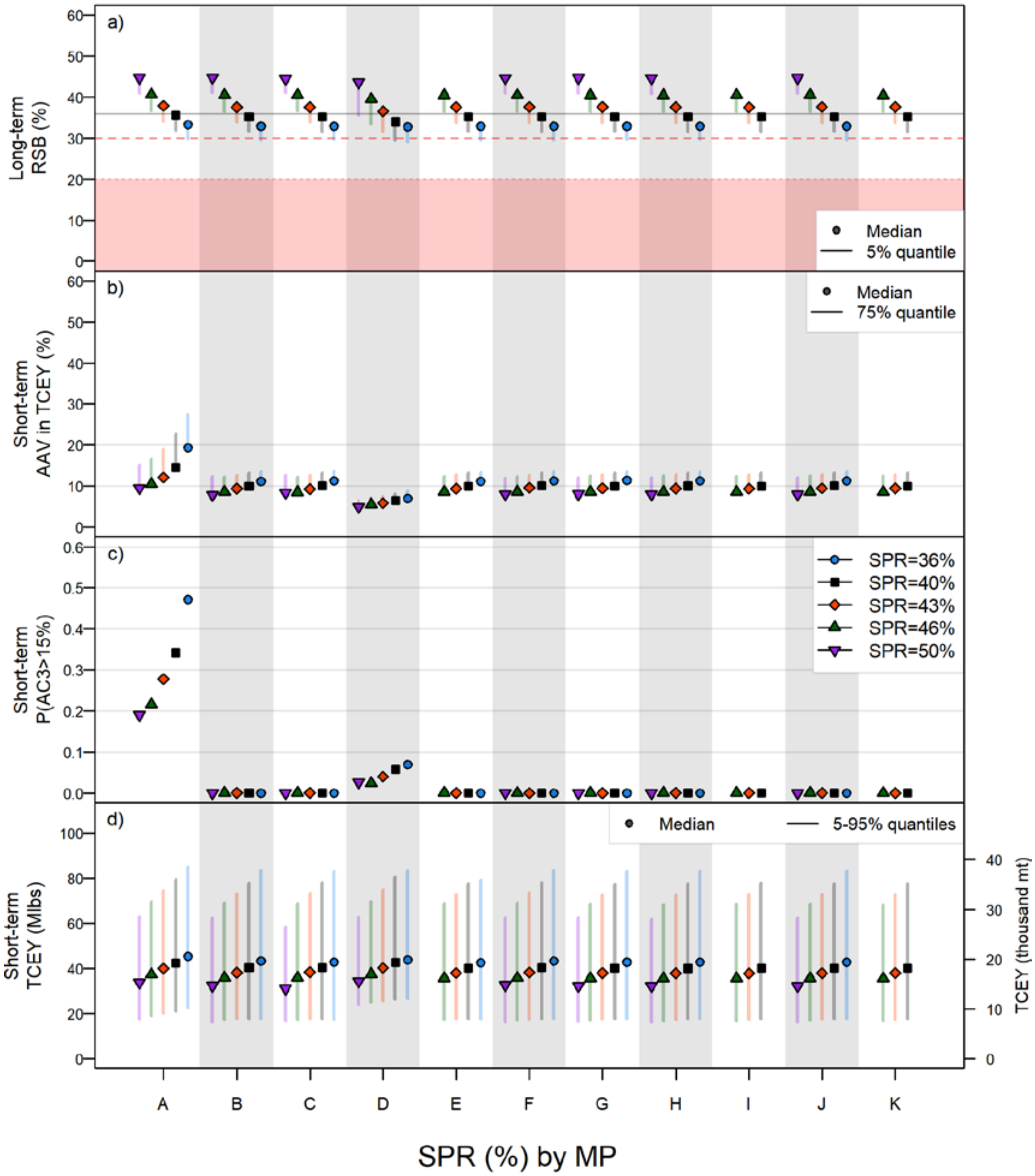

Figure 2. Coastwide performance metrics for MPs A through K using simulated estimation error with SPR values of 40%, 43%, and 46% for all and 36% and 50% for some. The relative spawning biomass and the limit (20%), trigger (30%) and target (36%) are shown in a). The AAV for TCEY is shown in b). The probability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

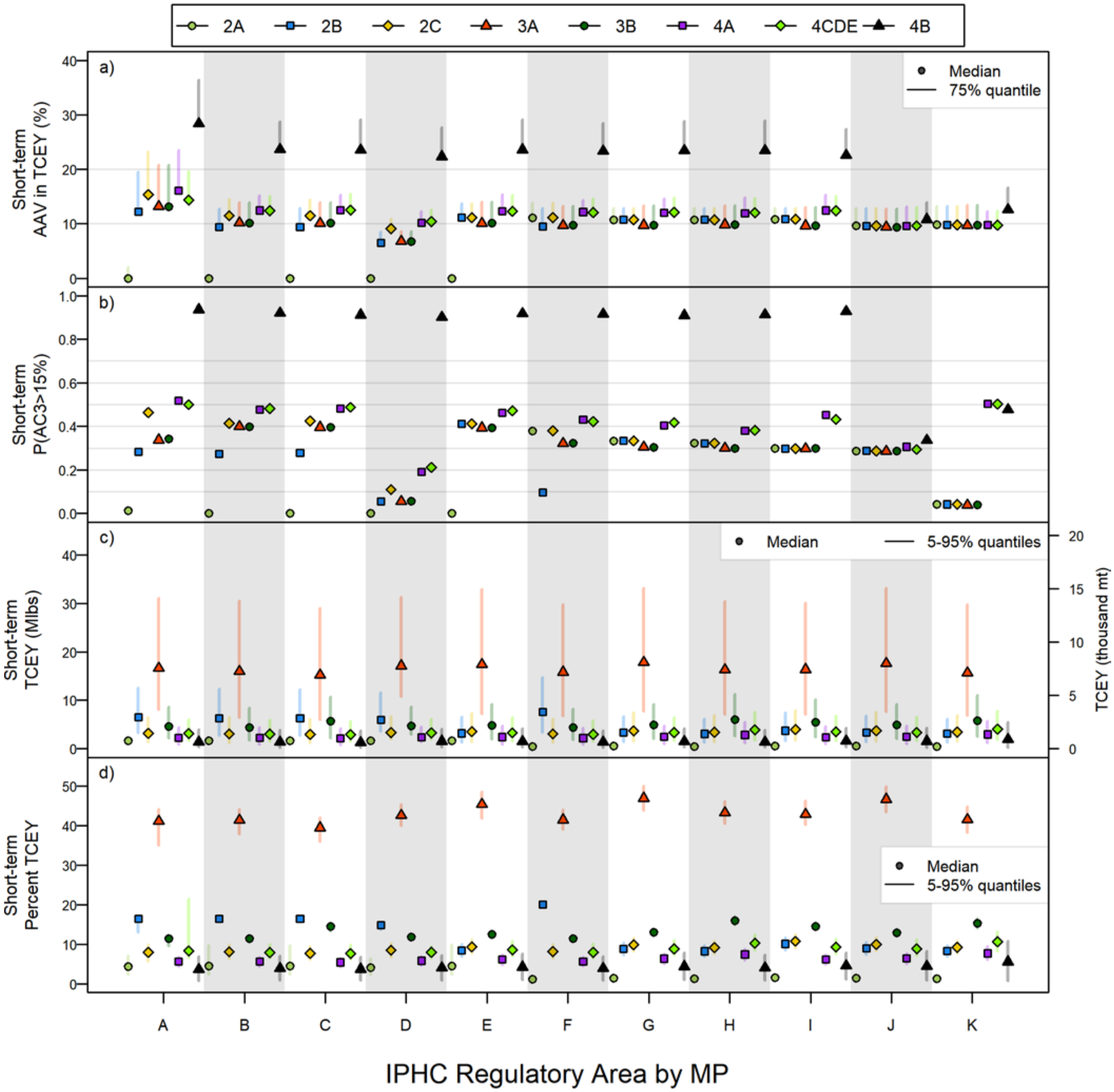

Figure 3. Performance metrics by IPHC Regulatory Areas for MPs A through K using simulated estimation error with an SPR value of 43%. The AAV for TCEY is shown in a). The probability that the annual change exceeds 15% in 3 or more years is shown in b). The median TCEY with 5th and 95th quantiles is shown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

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

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

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

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

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

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

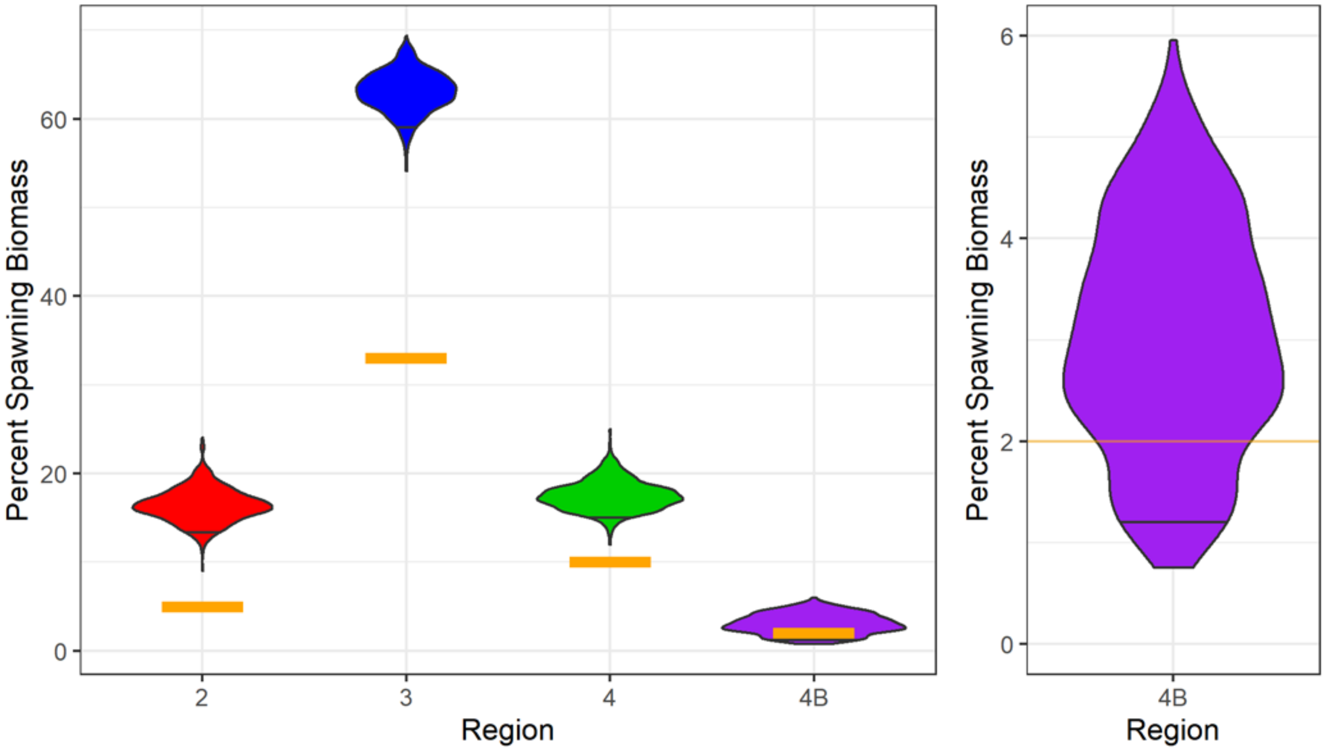

Figure 4. Distribution of the percentage of spawning biomass in each Biological Region after 60 years of projections with no fishing mortality. The right panel is zoomed in on Biological Region 4B. A horizontal line shows the 5% quantile in each plot. Primary objectives are to maintain the female spawning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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.1 A closer look at the best performing management procedures

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

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

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

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

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

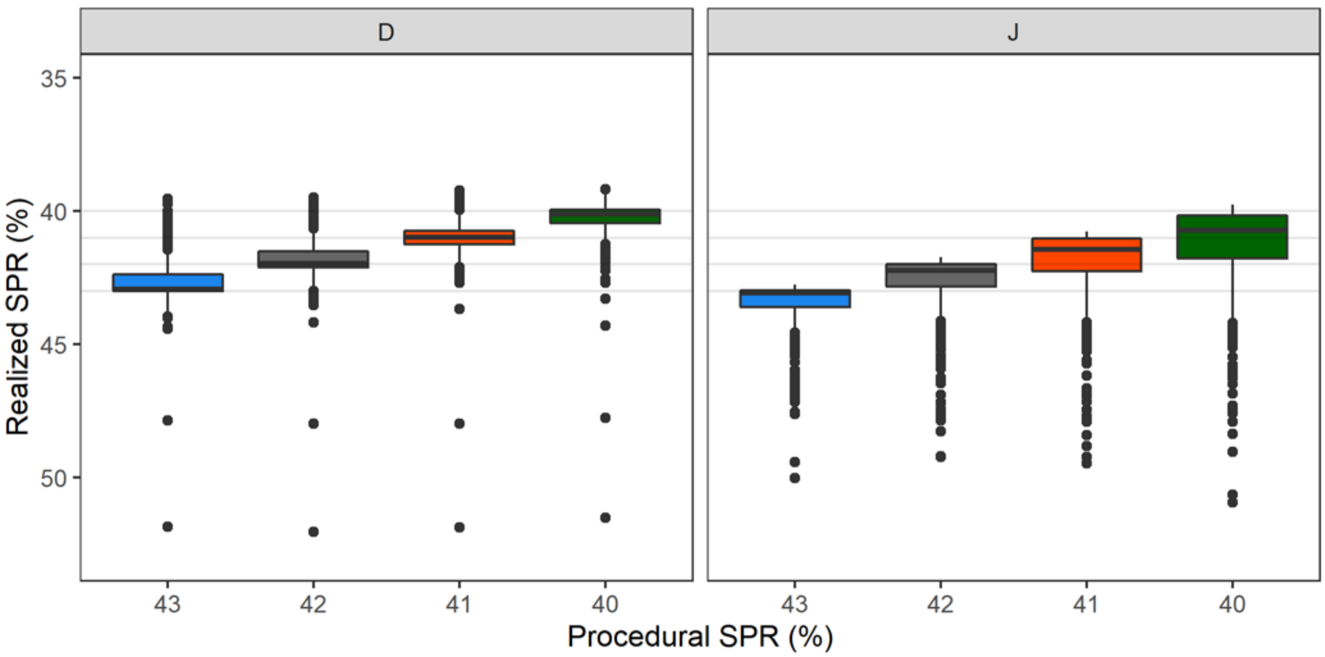

Figure 5. The average realized SPR over the long-term period for combinations of SPR values from 40-43% with MP-D and MP-J. The box outlines the 25th and 75th percentiles and the median is plotted as a horizontal line). Horizontal grid lines are shown for 40%, 41%, 42%, and 43% for reference. Sixteen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

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

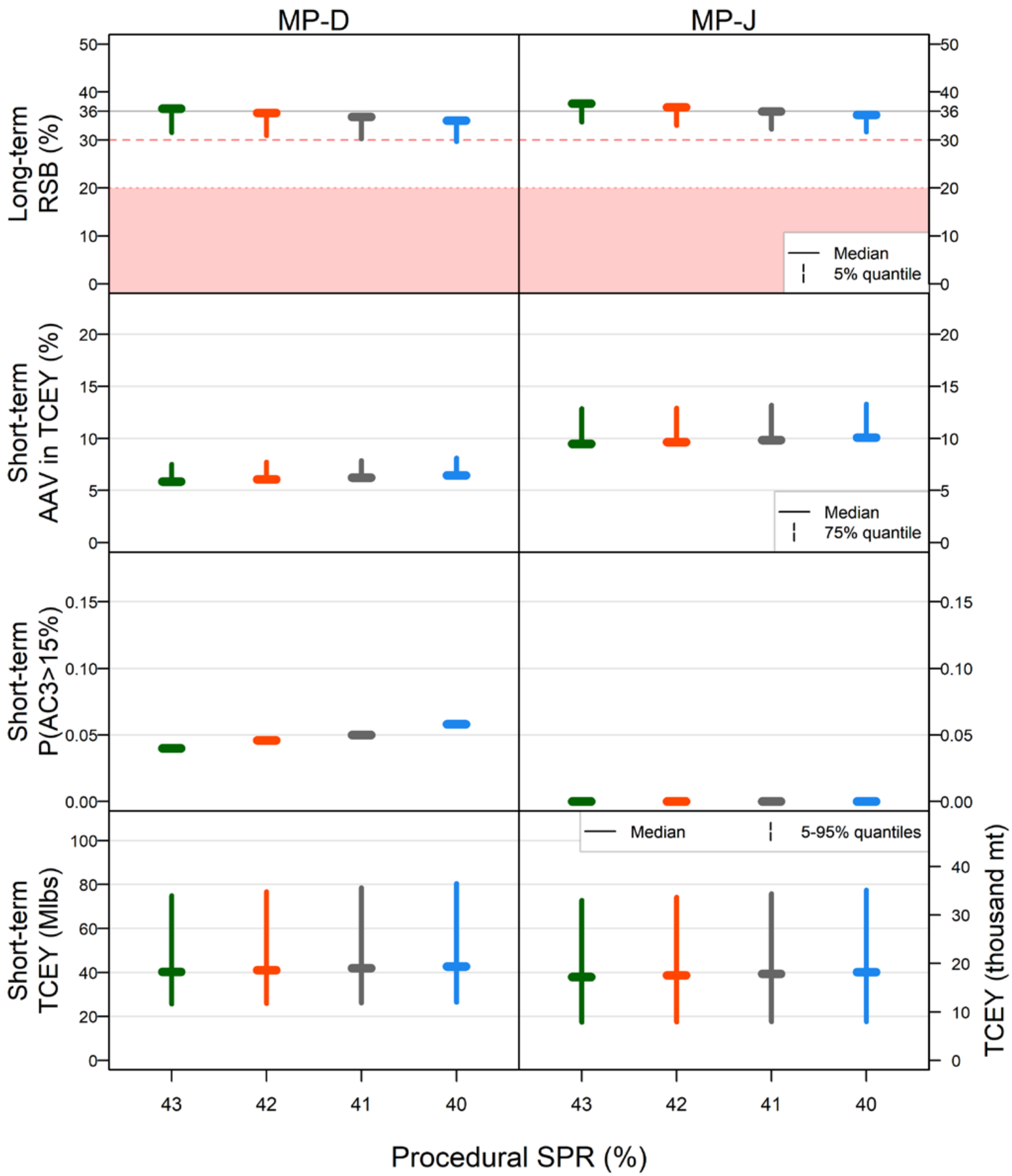

Figure 6. Coastwide performance metrics for SPR values ranging from 40 to 43% using MP-D and MP-J. The median value is shown as a horizontal line and quantiles are shown with vertical lines. Light gray horizontal lines are drawn for reference.

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

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

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

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

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

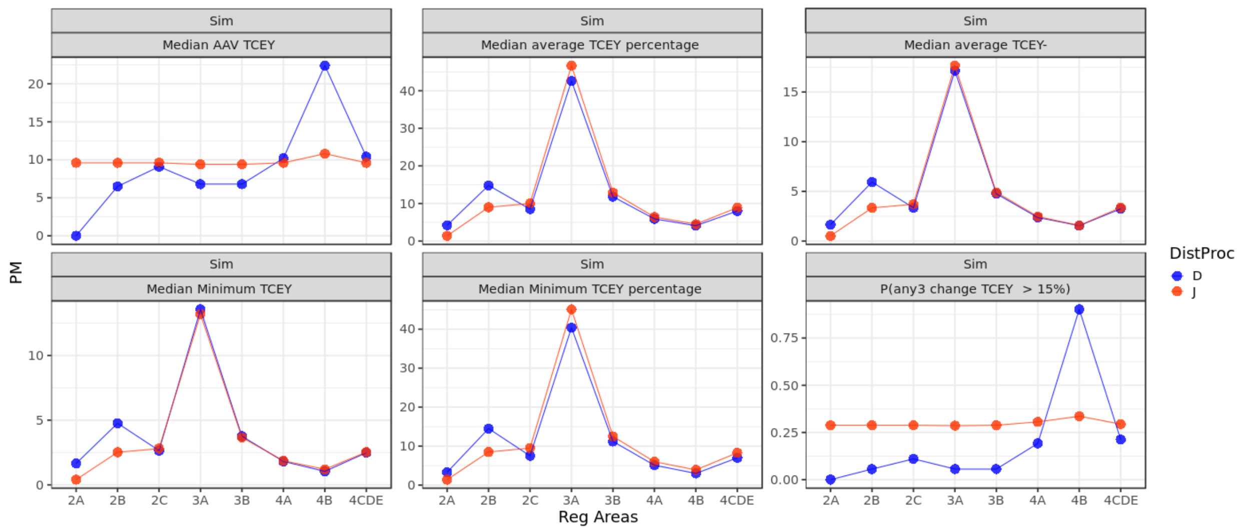

Figure 7. Short-term fishery sustainability performance metrics for IPHC Regulatory Areas using an SPR of 43% with MP-D (blue) and MP-J (red).

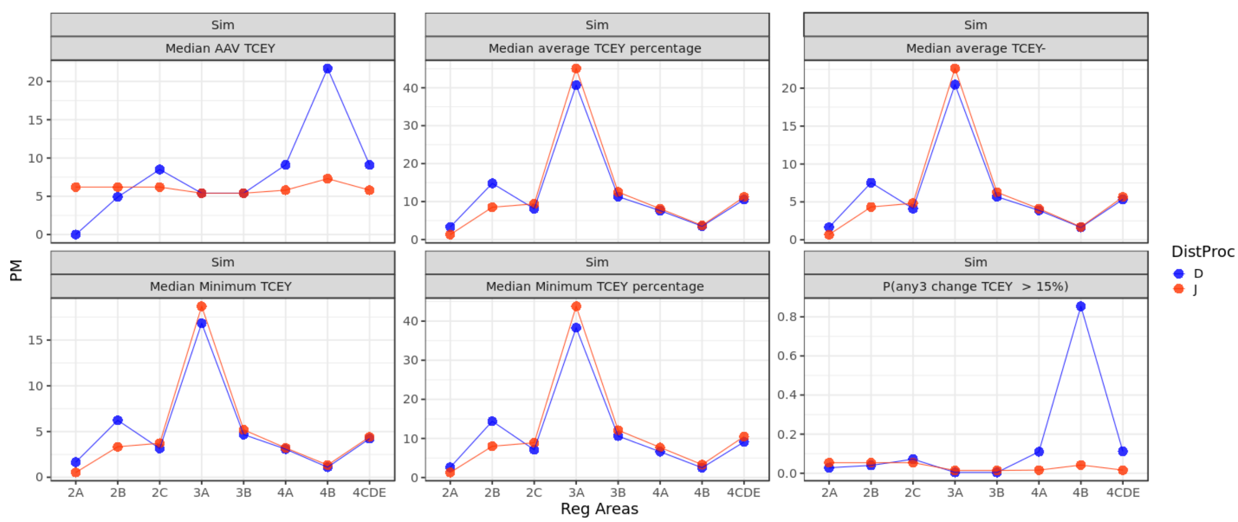

Figure 8. Long-term fishery sustainability performance metrics for IPHC Regulatory Areas using an SPR of 43% with MP-D (blue) and MP-J (red).

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

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

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

3.1 Recent Commission and SRB recommendations and requests

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

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

> **AM097, para.** ***71.*** *The Commission AGREED to meet intersessionally to review the draft MSE program of work for the IPHC Secretariat and provide direction on the prioritisation of tasks over the next 1-2 years, as well as the role of the MSAB in contributing to those tasks.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

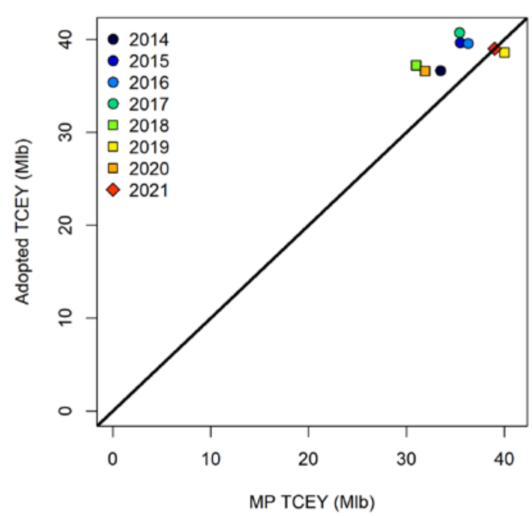

Figure 9. Comparison of adopted coastwide TCEY mortality limits for 2014-2021. Circles represent the years using the "blue line" MP, squares are years using an $F_{SPR=46\%}$ reference fishing intensity, and the diamond for 2021 is when $F_{SPR=43\%}$ was the reference fishing intensity. The diagonal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

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

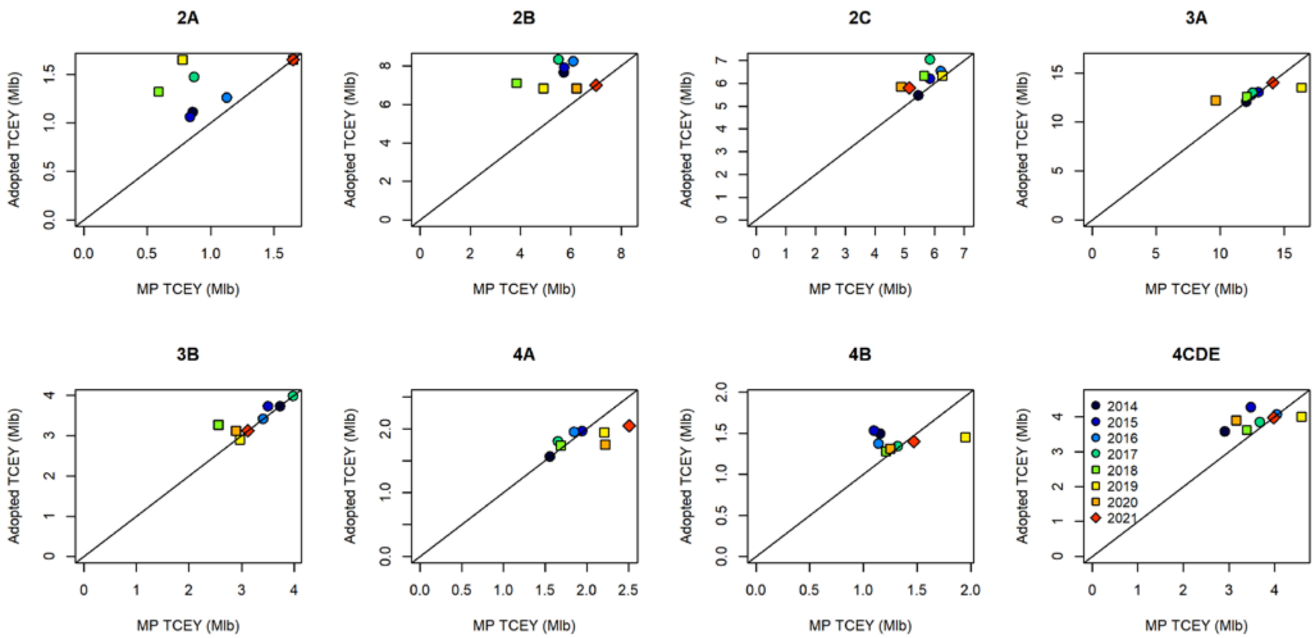

Figure 10. Adopted TCEYs plotted against the MP TCEYs for each IPHC Regulatory Area and years 2014–2021. Circles represent the years using the "blue line" MP, squares are years using an $F_{SPR=46\%}$ reference fishing intensity, and the diamond for 2021 is when $F_{SPR=43\%}$ was the reference fishing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

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

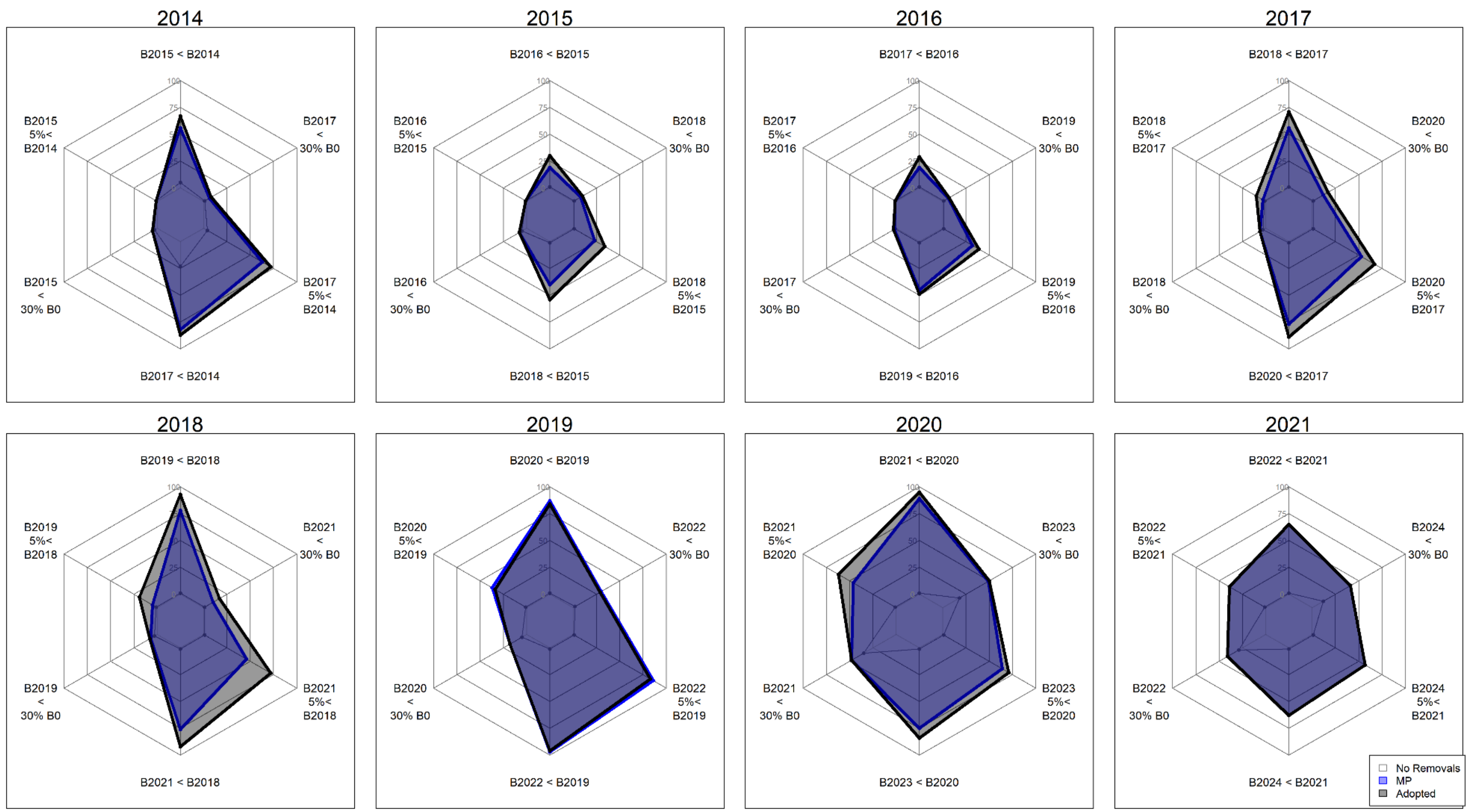

Figure 11. Radar plots comparing the risk levels from the decision table for the options “no removals” (thin line and points in center), the MP at that time (blue), and the adopted mortality limits (think line and gray) in each year from 2014–2021.

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

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

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

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

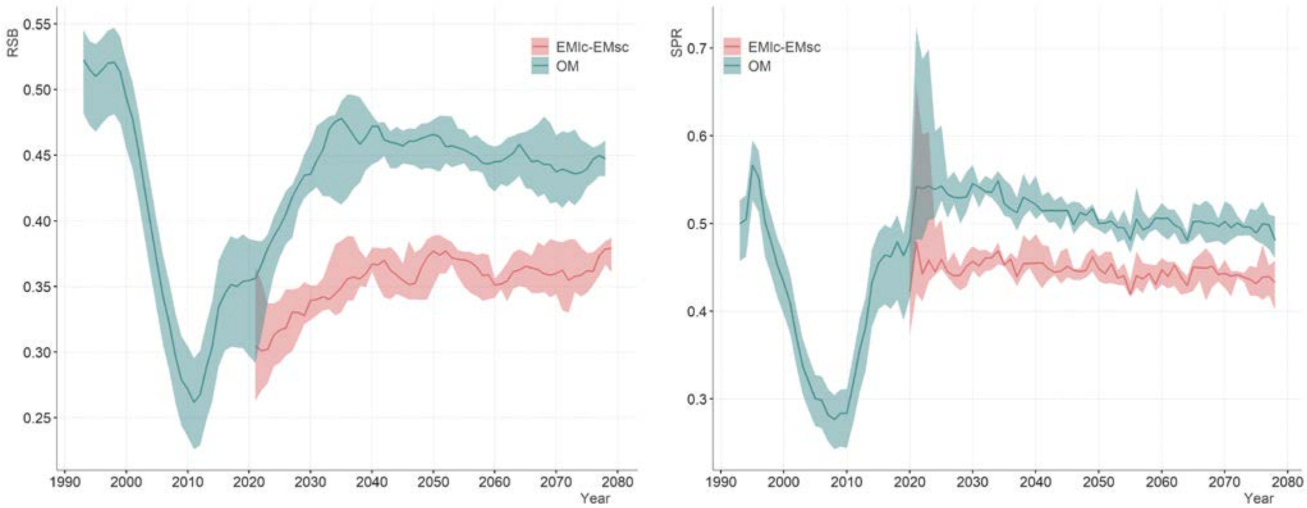

Figure 12. Results from ten simulated trajectories to examine the performance of a simplified ensemble estimation model (red) with the OM (green). Relative spawning biomass (RSB) is shown on the left and spawning potential ratio (SPR) is shown on the right for a simulated period of 60 years.

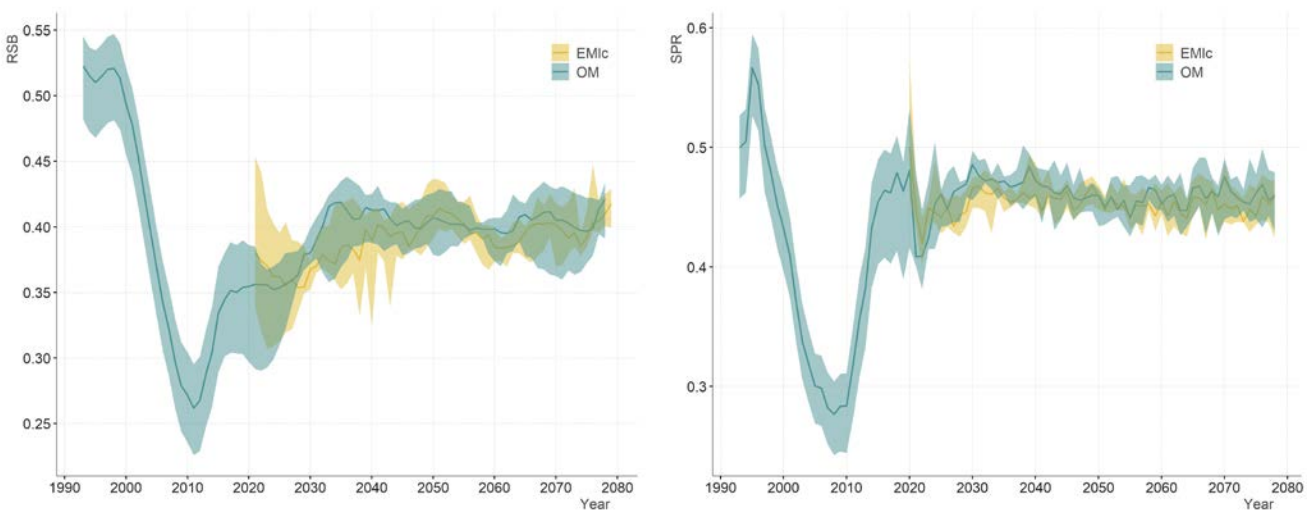

Figure 13. Results from ten simulated trajectories to examine the performance of the simplified long coastwide estimation model (yellow) with the OM (green). Relative spawning biomass (RSB) is shown on the left and spawning potential ratio (SPR) is shown on the right for a simulated period of 60 years.

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

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

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

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

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

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

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

3.2 Integration with Research Planning

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

3.2.1 Biological and population parameterisation

1. *Distribution of life stages and stock connectivity*

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

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

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

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

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

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

3. *Understanding growth variation*

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

3.2.2 Fishery parameterization

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

3.3 Potential general categories for a program of work

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

1. **Objectives**: The goals and objectives that are used in the evaluation.

1. **Management Procedures (MPs)**: Specific, well-defined management procedures that can be coded to produce simulated TCEYs for each IPHC Regulatory Area.

2. **Framework**: The specifications and computer code for the closed-loop simulations including the operating model and how it interacts with the MP.

3. **Evaluation**: The performance metrics and presentation of results. This includes how the performance metrics are evaluated (e.g. tables, figures, and rankings), presented to the Commission and its subsidiary bodies, and disseminated for outreach.

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

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

RECOMMENDATION/S

That the SRB:

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

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

4 REFERENCES

Hicks, A, P Carpi, I Stewart, and S Berukoff. 2021. *IPHC Management Strategy Evaluation for Pacific halibut (Hippoglossus stenolepis).* IPHC-2021-AM097-11, 49. https://iphc.int/uploads/pdf/am/am097/iphc-2021-am097-11.pdf.

Hicks, A, P Carpi, S Berukoff, and I Stewart. 2020. *An update of the IPHC Management Strategy Evaluation process for SRB017.* IPHC-2020-SRB017-09, 36. https://iphc.int/uploads/pdf/srb/srb017/iphc-2020-srb017-09.pdf.

Sadorus, Lauri L, Esther D Goldstein, Raymond A Webster, William T Stockhausen, Josep V Planas, and Janet T Duffy-Anderson. 2021. "Multiple life-stage connectivity of Pacific halibut (Hippoglossus stenolepis) across the Bering Sea and Gulf of Alaska." *Fisheries Oceanography* 30: 174–193. doi:https://doi.org/10.1111/fog.12512.

Stawitz, C Christine, and Tim Essington. 2019. Somatic growth contributes to population variation in marine fishes. Journal of Animal Ecology 88. pp. 315–329.

Stewart, Ian J, and Allan C Hicks. 2018. "Interannual stability from ensemble modelling." *Canadian Journal of Fisheries and Aquatic Sciences* 75 (12): 2109–2113. doi:https://doi.org/10.1139/cjfas-2018-0238.

Stewart, Ian J, Bruce M. Leaman, Steven Martell, and Raymond A. Webster. Assessment of the Pacific halibut stock at the end of 2012. *In* IPHC Report of Assessment and Research Activities 2012. pp. 93–186.

Stewart, Ian J, and Steven Martell. 2013. Assessment of the Pacific halibut stock at the end of 2013. *In* IPHC Report of Assessment and Research Activities 2013. pp. 169–196.