Further Investigation of Management Procedures Related to Coastwide Fishing Intensity

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PURPOSE

To present additional results of the closed-loop simulations on investigation of coastwide fishing intensity. Results presented at MSAB012 will be compared to results with an annual constraint on the TCEY.

1 INTRODUCTION

Results from the Management Strategy Evaluation (MSE) investigating coastwide fishing intensity were presented at the 95th Annual Meeting (AM095) in document IPHC-AM095-2019-12 and the associated presentation. The management procedures investigated included a range of SPR values from 30% to 56% and three different control rules (see Section 2 for a description of the elements of the management procedure). Constraints on the annual change in Total Mortality (TM) were also investigated.

Three performance metrics related to three primary objectives were reported for evaluation of the results (Table 1). The objectives were evaluated sequentially, where the conservation objective (1.1) must be met before evaluating the stability objective (2.1), which must be met before evaluating the yield objective (2.2).

Table 1: Primary measurable objectives used for evaluation of MSE results for coastwide fishing intensity presented at AM095. Objective 1.1 is a conservation objective and objectives 2.1 and 2.2 are fishery objectives.

GENERAL OBJECTIVE	MEASURABLE OBJECTIVE	MEASURABLE OUTCOME	TIME-FRAME	TOLERANCE	PERFORMANCE METRIC
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 90% of the time	*SB* < Spawning Biomass Limit (SB_{Lim}) SB_{Lim}=20% spawning biomass	*Long-term*	0.10	$P(SB < SB_{Lim})$
2.1. LIMIT CATCH VARIABILITY	Limit annual changes in the coastwide TCEY	Average Annual Variability (*AAV*) > 15%	Short-term	0.25	$P(AAV > 15\%)$
2.2. MAXIMIZE DIRECTED FISHING YIELD	*Maximize average TCEY coastwide*	*Median coastwide TCEY*	*Short-term*	*STATISTIC OF INTEREST*	*Median* $\overline{TCEY}$

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. 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. Details of the coastwide closed-loop simulations are not included here but can be found in IPHC-2019-MSAB012-07.

2 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 Scale portion of the general management procedure. Data were not generated in these simulations because the error in an estimation model was simulated for simplicity. The coastwide harvest rule portion of the management procedure is discussed below.

2.1 HARVEST RULE

The part of the management procedure being evaluated is a harvest control rule (Figure 1) that is responsive to stock status and consists of a procedural SPR determining fishing intensity, a fishery trigger based on stock status that determines when the fishing intensity begins to be linearly reduced, and 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 only needed to be distributed to the five coastwide sources of mortality (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.

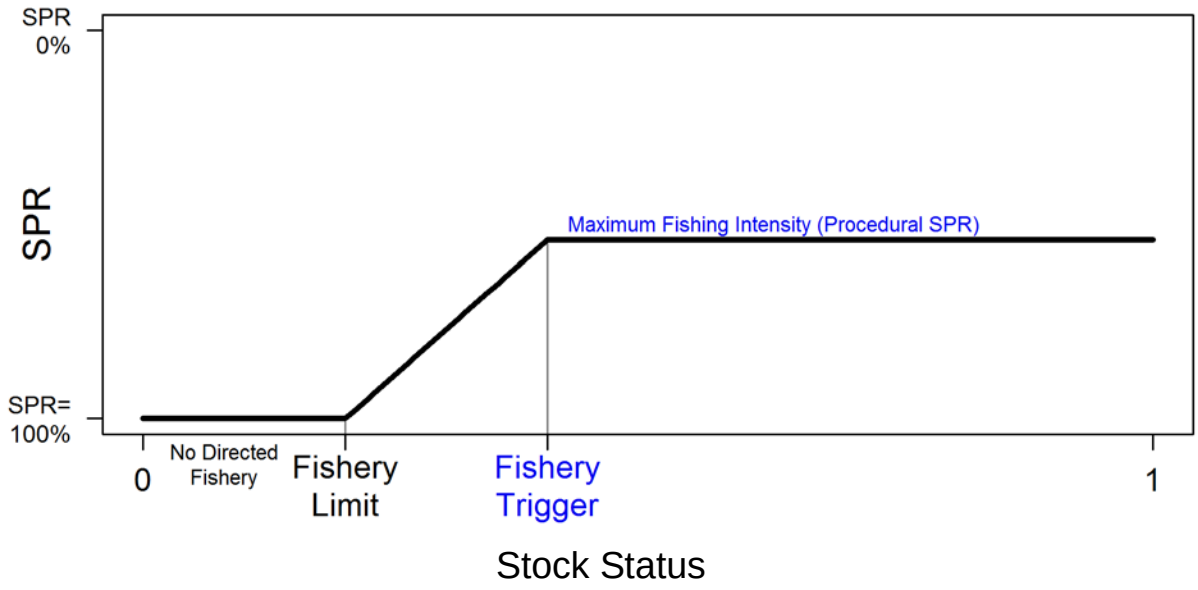

Figure 1: A harvest control rule responsive to stock status that is based on Spawning Potential Ratio (SPR) to determine fishing intensity, a fishery trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a fishery limit based on stock status that 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 Trigger (in blue) are the values that were evaluated.

2.1.1 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 simply constraining the maximum amount of change in the mortality limit from one year to the next, enforcing a maximum mortality limit, or setting a constant limit for three years before updating it. The eight methods are described below.

- **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 20%, 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 the mortality limit every 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.

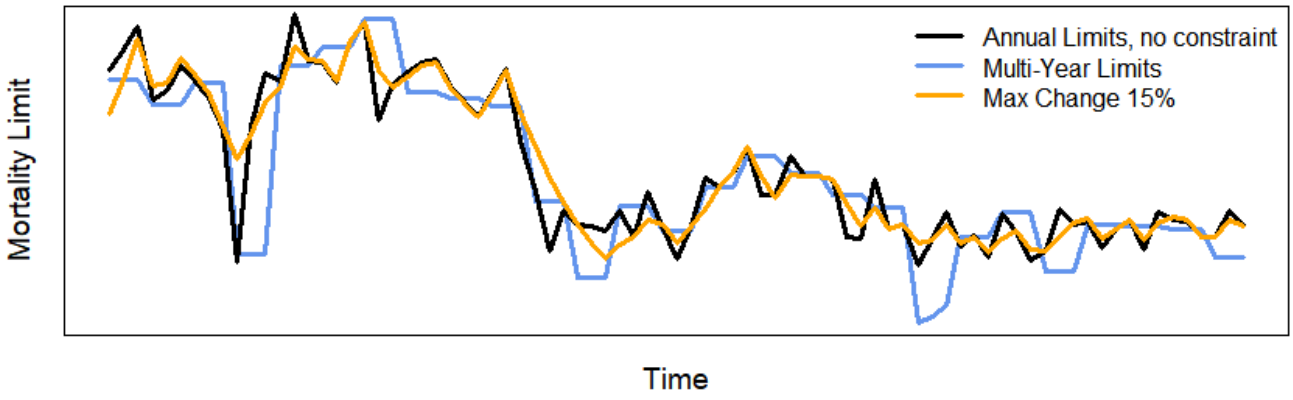

Figure 2: A hypothetical example of the difference between unconstrained and constrained management procedures when determining the total mortality limit. The multi-year limit (blue) is set every third year, but due to allocation to bycatch and other sectors, the limit may be adjusted in years when the 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 PERFORMANCE METRICS

Defining goals and objectives is a necessary part of a management strategy evaluation (MSE) which should be revisited often to make sure that they are inclusive and relevant. The MSAB is currently refining goal and objectives (see IPHC-2019-MSAB013-07), which are translated into performance metrics. Many performance metrics have been developed by defining a measurable outcome, a probability (i.e. level of risk), and time-frame over which it is desired to achieve that outcome. Management procedures can then be evaluated by determining which ones meet various objectives (via the performance metrics). Some performance metrics have been defined by the MSAB that are called statistics of interest, and even though they are associated with various objectives, they do not have all the components of a measurable objective defined (e.g., a tolerance) and cannot be define as a probability of risk. The primary performance metrics and some of the secondary performance metrics being reported are described in Table 2. Additional metrics and elements of the management procedure can be viewed on the online MSE Explorer tool (http://shiny.westus.cloudapp.azure.com/shiny/sample-apps/IPHC-MSAB013/).

Table 2. Primary and secondary performance metrics used to evaluate the management procedures. Primary metrics are the main performance metrics for the evaluation and secondary metrics are intended to supplement and inform that evaluation.

Primary Metrics	
Performance metric	**Description**
P(dRSB < SB_{Lim})	Times out of 100 that the stock biomass (status) is below the limit. The limit is defined as 20% of the biomass if no fishing had occurred and no more than 10 out of 100 is acceptable. This metric is reported as the proportion over the individual simuations, called P(all), and the proportion out of a 10 year period, called P(any). Note that a 10-year period is considered after simulating 90 annual cycles in a long-term perspective, and after simulating 13 annual cycles in a medium-term perspective.
P(AAV > 15%)	Times out of 100 that the average annual variability (AAV) is greater than 15%. AAV can be thought of as the average change in the mortality limit (total mortality, TM, is used here) from year to year.
Median TM	The median total mortality is calculated on the average over the time period defined for each simulation (e.g. medium term average is at 14-23 projected years). Hence, the median total mortality is the simulated mortality limit where half of the simulated mortality limits were greater than this value and half of the simulated mortality limits were less than this value.
Secondary Metrics	
Performance metric	**Description**
Median realized SPR	The realized SPR given that the control rule reduced fishing intensity occasionally
Median dRSB	The median relative spawning biomass expected in the long-term
Median AAV	The median Average Annual Variability over the simulations, which can be thought of as the average change in the mortality limit from year to year.
P(↓TM > 15%)	Times out of 100 that the mortality limit decreases by more than 15% compared to the previous year.
P(dRSB<30%)	Times out of 100 that the relative spawning biomass is less than 30%. This metric is reported as the proportion over the individual simulations, called P(all), and the proportion out of a 10 year period, called P(any).
P(TM < 34 Mlbs)	Times out of 100 that the total mortality limit is less than 34 Mlbs, where 34 Mlbs is an *ad hoc* value, which is the minimum Total Mortality observed since 1906.
5^{th} & 75^{th} TM	The 5^{th} and 75^{th} percentiles of the Total Mortality limit from the simulations. This means that 5 out of 100 are less than or equal to the 5^{th} percentile and 25 out of 100 are greater than or equal to the 75^{th} percentile.

4 SIMULATION RESULTS

Table 4 and Table 5 show the long-term primary biological performance metric and the medium-term (14-23 years) fishery sustainability performance metrics for the main runs requested at MSAB011 (IPHC-2018-MSAB011-R). Table 6 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 showed 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 3).

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 2.1.1). 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). 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 (Table 6). However, the median AAV for slowUpFastDown was less than the median AAV for maxChange15 (Figure 5 and Appendix I).

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/.

In summary, long-term performance metrics showed little risk of falling below the 20% dynamic biomass threshold 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. 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 3).

5 RECOMMENDATIONS

That the MSAB:

1) **NOTE** paper IPHC-2019-MSAB013-08 which provides the MSAB with an update on the coastwide MSE results including constraints on the total mortality limit.
2) **NOTE** that no management procedure without constraints met the stability objective.
3) **NOTE** 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).
4) **RECOMMEND** additional ways to present the results and examine trade-offs between objectives.
5) **RECOMMEND** a management procedure approaches to consider when examining scale and distribution components of the harvest strategy policy.

6 APPENDICES

Appendix I: Additional long- and short-term performance metrics

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)

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 2.1.1). 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). Ranking are over all management procedures with a constraint (Table 6 and Table 7).

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 over all constrained management procedures (lower is better)												
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 2.1.1). 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). Ranking are over all management procedures with a constraint (Table 6 and Table 7).

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 over all constrained management procedures (lower is better)													
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.

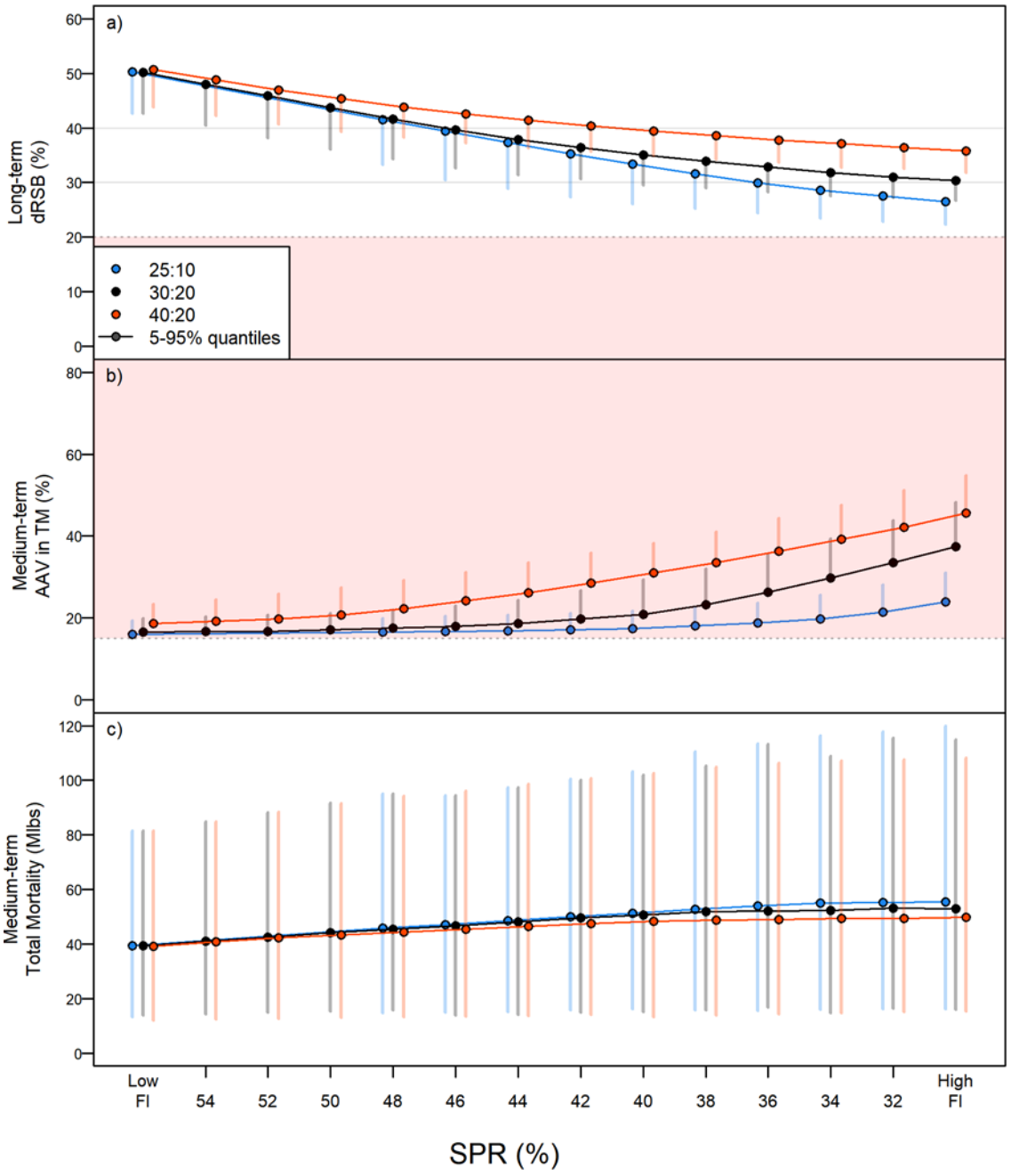

Figure 3. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term biological sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.3 to 0.56 and control rules 40:20, 30:20, and 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).

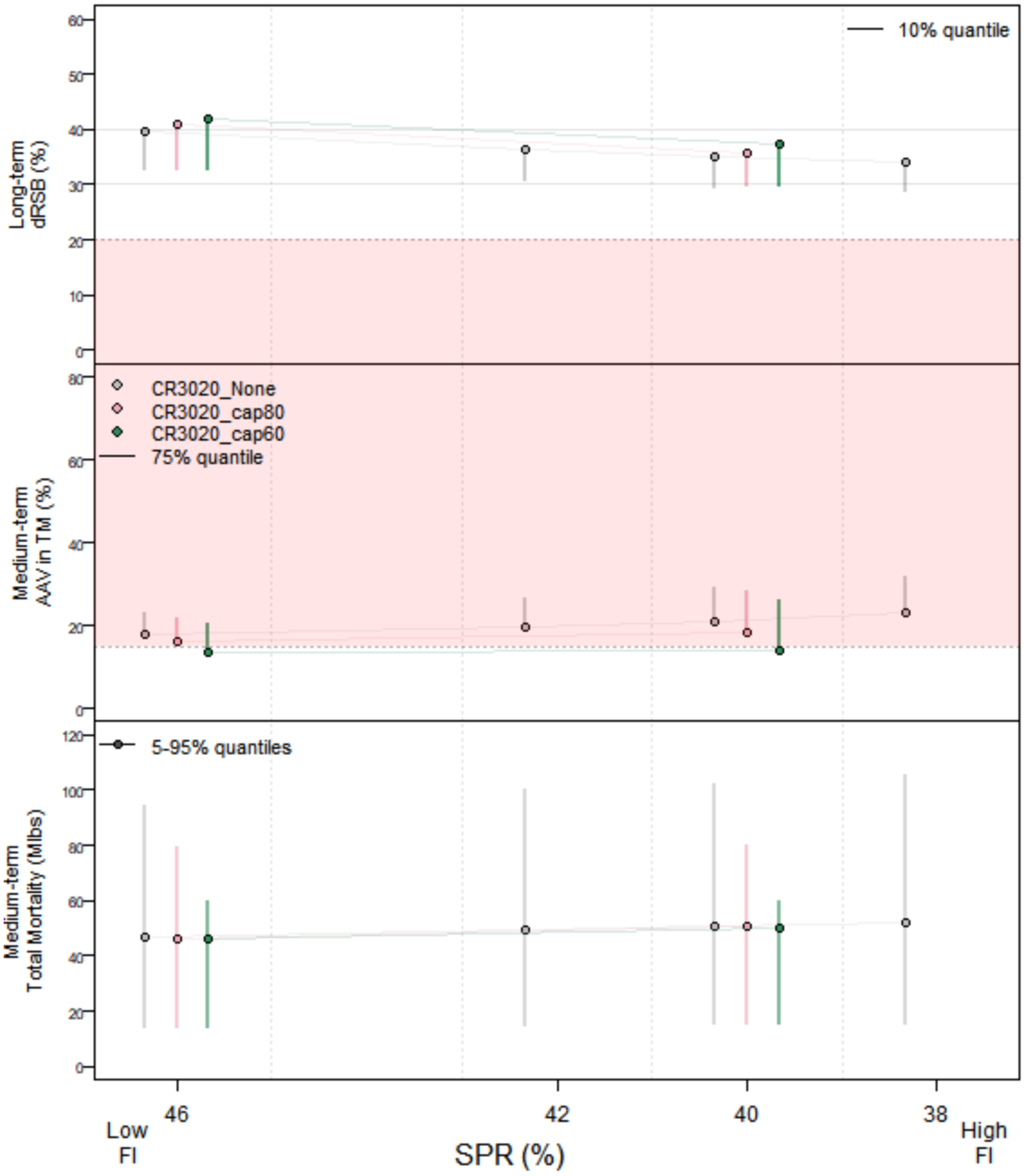

Figure 4. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term biological sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using 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. 5th and 95th percentiles from the simulations).

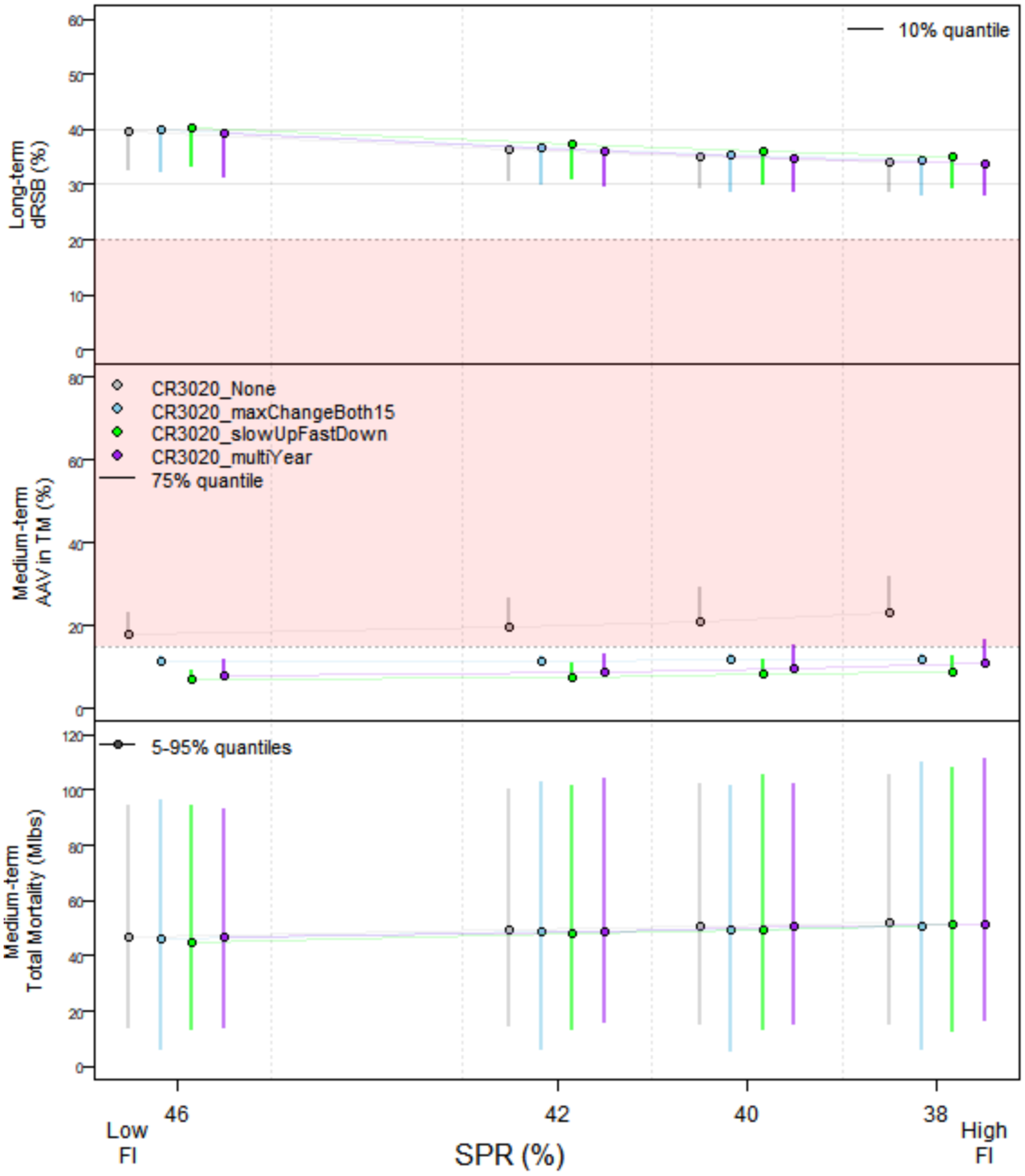

Figure 5. Primary long-term biological sustainability performance metric (dynamic relative spawning biomass), and primary medium-term biological sustainability performance metrics (AAV of TM, and Total Mortality in millions of pounds) for SPR values from 0.38 to 0.46 and the 30:20 control rule using three different constraints on the total mortality limit: maxChange15, slowUpFastDown, and multiYear (see Section 2.1.1). 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).

APPENDIX I: ADDITIONAL LONG- AND SHORT-TERM PERFORMANCE METRICS

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
5^{th} 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
75^{th} 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%