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EVALUATION OF POTENTIAL REBUILDING STRATEGIES FOR OUTSIDE YELLOWEYE ROCKFISH IN BRITISH COLUMBIA

Yelloweye Rockfish, Sebastes ruberrimus (DFO ROV team, 2011).

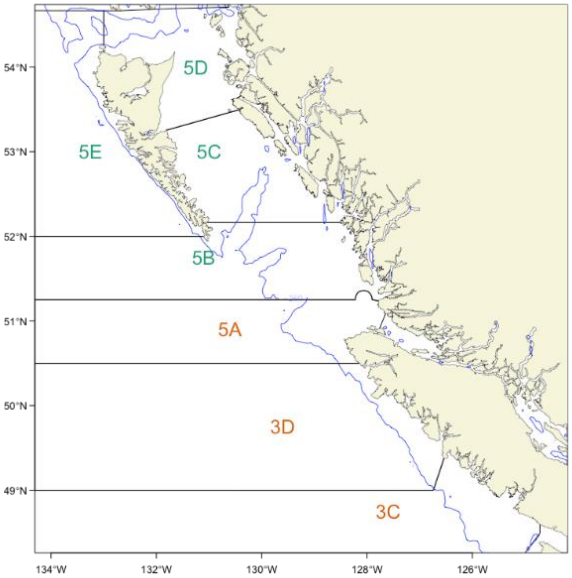

Figure 1. Map of BC groundfish major management areas used to bound the North, (Areas 5BCDE, green) and the South (Areas 3CD5A, orange) areas of the Outside Yelloweye Stock.

Context:

Fisheries and Oceans Canada (DFO) has developed "A Fisheries Decision-Making Framework Incorporating the Precautionary Approach" (DFO 2009), and "Guidance for the Development of Rebuilding Plans under the Precautionary Approach Framework" (DFO 2013). These documents outline the departmental policy and guidelines for applying the precautionary approach (PA) to Canadian fisheries. A key component of the PA Policy requires that when a stock has reached or fallen below a limit reference point (LRP), a rebuilding plan must be in place with the aim of having a high probability of the stock growing above the LRP within a reasonable timeframe. The outside population of Yelloweye Rockfish was last assessed by DFO in 2015 and reference points were established (Yamanaka et al. 2018). The biomass was estimated to be less than the Limit Reference Point (LRP), necessitating the development of a rebuilding plan. DFO Fisheries Management has requested that Science Branch develop advice to inform a rebuilding plan consistent with the DFO (2013) guidance document. This advice will include a review and updating of rebuilding objectives for the outside Yelloweye Rockfish population and fisheries, and development of an analytical framework for evaluating candidate management procedures against the rebuilding objectives.

This Science Advisory Report is from the October 29-30, 2019 regional peer review on the Evaluation of Management Procedures for the Outside Population of Yelloweye Rockfish Rebuilding Plan. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

May 2020

SUMMARY

- This paper provides advice on rebuilding Outside Yelloweye Rockfish (OYE, Figure 1) using closed-loop simulation modelling to test performance of a set of candidate management procedures (MPs) against specific quantitative objectives.
- Due to differences in perceived abundance and exploitation history, the OYE stock was divided into two sub-regions (North and South, Figure 1) for these analyses.
- The key components of this closed-loop simulation work are:
    1. development of a two-area component (North/South) hierarchical age-structured operating model for OYE that represents a range of hypotheses about natural mortality and exploitation history using different data scenarios,
    2. testing MPs comprised of monitoring data, assessments, and harvest control rules (HCR) used to implement rebuilding policies, and
    3. evaluating performance measures that are used in determining the expected conservation performance of alternative MPs relative to stated rebuilding objectives.
- The Rebuilding Objectives being evaluated are:
    1. to grow the spawning stock biomass (SSB) out of the critical zone (i.e., above the limit reference point (LRP) of 0.4BMSY, where BMSY is the operating model biomass at MSY), with a very low (5%) probability of further decline, measured over 1.5 generations (57 years); and
    2. when the SSB is between 0.4BMSY and 0.8 BMSY, limit the probability of decline over the next 10 years from very low (5%) at the LRP to moderate (50%) at BMSY. At intermediate stock status levels, define the tolerance for decline by linearly interpolating between these probabilities.
- A generation time of 38 years for OYE was used, corresponding to the average age of the modeled unfished spawning stock.
- Model estimates of spawning biomass depletion relative to unfished levels (estimated for 1918) range from 29-51% in the North, 21-43% in the South, and 27-48%, coast-wide.
- Alternative data scenarios produced a wide range of estimated stock status, as well as biological and management parameters, from which 4 representative operating model scenarios were selected for simulation testing MPs.
- The candidate MPs evaluated included three different assessment methods:
    1. a catch-at-age assessment model (CAA),
    2. a surplus production assessment model (SP), and
    3. an empirical rule using survey index trends (IDX).
- The three assessment methods were used in combination with different harvest control rules or implementation error scenarios to create a set of candidate MPs that were simulation tested for each of the 4 operating model scenarios for North and South areas independently.
- Simulations of MP performance for setting future OYE Total Allowable Catches (TACs) generally showed robust performance relative to the objectives described above, across the range of operating model scenarios.

- All operating model scenarios implied that OYE is currently above $0.4B_{MSY}$ coast-wide even though OYE biomass declined rapidly by 49-71% in the North, and by 57-79% in the South over the past two OYE generations.
- Several potential MPs were identified that could increase or stabilize OYE biomass in both North and South areas. However, it is not possible at this time to recommend a specific MP for each area without further guidance on fishery objectives and timelines from OYE managers, First Nations, and fishery stakeholders.

INTRODUCTION

Yelloweye Rockfish (*Sebastes ruberrimus*) are a long-lived (aged in BC to 121 years), slow-growing species with a late age-at-maturity (Love et al. 2002). Adults are habitat specialists, preferring demersal, rocky habitats, which have a discontinuous, patchy distribution on the B.C. coast. Genetic analysis has shown that two genetically distinct populations exist in BC: one on the outer coast (Outside), and one in “inside” waters between Vancouver Island and the mainland (Inside) (Andrews et al. 2018, COSEWIC 2008, Siegle et al. 2013). The two populations are considered to be separate “designable units” by the Committee On the Status of Endangered Wildlife In Canada (COSEWIC). COSEWIC designated both populations of Yelloweye Rockfish as a Species of Special Concern in 2008 (COSEWIC 2008) and they were listed under the Species at Risk Act (SARA) in 2011. Readers are referred to the pre-COSEWIC document for additional background on Yelloweye Rockfish (Keppel and Olson 2019).

The 2014 status assessment of the Outside population of Yelloweye Rockfish (OYE) in British Columbia (BC) concluded that the stock was in the Critical Zone defined by $B_{2014} < 0.4B_{MSY}$, which triggered a rebuilding plan under the Sustainable Fisheries Framework (SFF) (DFO 2009, 2013; Yamanaka et al. 2018). Although Fisheries and Oceans Canada’s (DFO) Guidance Document for the Development of Rebuilding Plans (DFO 2013) does not articulate specific components and objectives of rebuilding plans, it does require a high probability that management actions will lead to stock growth above the LRP within 1.5 to 2 generations. DFO (2013) also recommends that rebuilding plans be re-evaluated every 3 years. The rebuilding plan objective for OYE is to “achieve rebuilding throughout the outside stock’s range and grow out of the critical zone within 15 years, with a 57% probability of success” (DFO 2016). Milestones were also established to “achieve a positive outside stock trajectory trend in each 10-year interval, such that the biomass at the end of each 10-year period is greater than the biomass at the beginning of the same 10-year period” and to “achieve catch reduction targets within three years.” OYE removals were gradually reduced from 287 t in 2014 to 100 t in 2018/2019.

The current OYE Rebuilding Plan does not comply with DFO rebuilding policy for two reasons. First, rebuilding objectives were defined using a 15-year rebuilding period, which is far shorter than 1.5 to 2 OYE generations (~57-76 years). Second, the rebuilding plan was not simulation-tested prior to implementation (DFO 2016). Thus, a more comprehensive analysis of the OYE rebuilding strategy is required than was originally anticipated under the 3-year review cycle described in the Guidance Document for the Development of Rebuilding Plans.

The current assessment aims to provide advice on rebuilding OYE using closed-loop simulation modelling to test performance of a set of candidate management procedures against specific quantitative objectives. The overall approach aims to expose the ecological and fishery consequences of specific analytical (e.g., data collection, assessment methods) and management choices (e.g., harvest control rules, target fishing mortality rates) (Smith 1994, Smith et al. 1999). The key components of this work are:

(i) operating model scenarios (OM) for OYE that represent a range of hypotheses about natural mortality and exploitation history,

(ii) management procedures (MP) comprised of monitoring data, stock assessment model, and harvest control rules (HCR) used to implement rebuilding policies, and

(iii) performance measures that are used in determining the expected conservation performance of alternative MPs relative to stated rebuilding objectives.

Exploitation history is considered via scenarios of commercial and recreational catch. Scientific uncertainty affects management procedures (ii) and performance measures (iii) via the choice of limit reference point (LRP) used to designate a stock as in need of rebuilding, as well as in assessments of stock status relative to the LRP (Milazzo 2012; NRC 2013). Although we do not fully understand the dynamics of OYE populations and fisheries, exploring alternative scenarios and their consequences for rebuilding planning may provide important insights for management of OYE and other stocks considered to be at low abundance.

Objectives for OYE rebuilding emphasized biomass-based objectives over other important aspects such as catch and spatial distribution. The objectives were informed by the 2014 OYE assessment, but have been revised by DFO Fisheries Management to be compliant with DFO rebuilding guidelines. The new primary objectives guiding the rebuilding evaluation are:

1. Grow the spawning stock biomass (SSB) out of the critical zone (i.e. above the LRP of $0.4B_{MSY}$), where B_{MSY} is the operating model biomass at MSY), with a very low (5%) probability of further decline, measured over 1.5 generations; and
2. When the SSB is between $0.4B_{MSY}$ and $0.8\ B_{MSY}$, limit the probability of decline over the next 10 years from very low (5%) at the LRP to moderate (50%) at B_{MSY}. At intermediate stock status levels, define the tolerance for decline by linearly interpolating between these probabilities.

Once the above conservation objectives are satisfied, a preliminary objective for catch is to maximize the probability that annual catch levels remain above a minimum level of 100 t required to operate groundfish fisheries. Further collaborative work is required with First Nations and fishery stakeholders to fully specify conservation and fishery objectives for OYE.

ANALYSIS

Closed loop simulation

Fishery models play two important roles in the design and operation of feedback fishery management systems. Fishery stock assessment models use data obtained from scientific monitoring to estimate past stock abundances and productivity. Inferences derived from the assessment model flow through a decision-making process to determine what future impacts (e.g., harvests) are allowed on the stock. These impacts combine with environmental variability and density-dependent population dynamics to affect characteristics, productivity, and abundance of the stock. Environment-stock interactions are typically the most uncertain aspect of fishery management systems because the dynamics are non-linear and only partially observable. Thus, we may not know the importance of an impact on the stock until long after it occurs. To speed up learning and to avoid putting stocks and fisheries at risk in real experiments, we represent environment-stock hypotheses in operating models and run computer experiments on simulated fishery management systems (Figure 2). Using this type of closed-loop simulation, the authors' evaluated rebuilding management procedures for OYE that attempt to meet the preliminary objectives defined above follows a step-wise approach (Cox et al. 2010). The steps were as follows:

1. Define a range of alternative management procedures (MPs) defined by (i) **data** types and precision, (ii) **assessment methods** for establishing stock status, (iii) **harvest control rules** for setting base catch limits; and (iv) **meta-rules** for modifying base catch limits given pre-defined constraints and conditions as required. Meta-rules might involve time intervals and/or rules for revising the MPs, as well as “exceptional circumstances” that provide trigger points and subsequent actions when MPs are considered unreliable.
2. Specify an operating model (OM) to enable simulation of alternative plausible scenarios for OYE population responses to fishing and data generation mechanisms. This step involves first fitting the operating model to available data to estimate model parameters consistent with the stock history and structural assumptions of OM scenarios.
3. Project OYE stock dynamics and fishery harvesting forward from its current state for each management procedure under each alternative OM scenario. Each year and simulation replicate of the projection involves the following steps:
   a. Simulate the **data** available for stock assessment and append to existing data sets;
   b. Apply the **assessment method** to the data to estimate quantities required by the **harvest control rule**;
   c. Apply the **harvest control rule** to generate a catch limit;
   d. Apply **meta-rules** such as constraints or averaging of catch limits across years;
   e. Subtract the final catch limit from the simulated OYE population as represented by the operating model;
   f. Return to Step 3a until final projection year
   g. Repeat Step 3a-f for 100 independent replicate simulations
4. Calculate a set of quantitative performance measures based on the 100 simulation replicates that can be used to compare and rank MP performance against the conservation and fishery objectives.

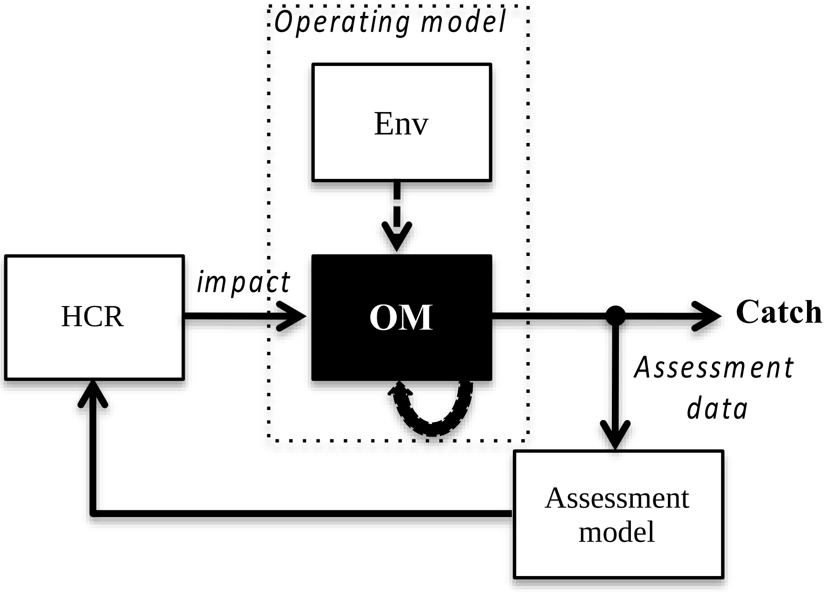

Figure 2. Schematic of the closed loop simulation approach taken here comprises operating model (OM) scenarios that represent alternative hypotheses of OYE biology, ecology, exploitation history and environmental conditions (Env) that are fit to historic data (dotted box). The operating model scenarios are used to simulate future estimates of the data which are fit after applying a Harvest Control Rule (HCR) to set the catch under each management procedure at each annual time step. The simulation repeats until the end of the projection period. The assessment model is run at each time step to evaluate management performance against the objectives (adapted from Cox et al. 2010).

Operating Model

The previous stock assessment assumed a single OYE stock (Yamanaka et al. 2018), which raised concerns among stakeholders about how future catch should be allocated among the areas used to manage the commercial groundfish fisheries. In particular, stakeholders were concerned that in particular, stakeholders were concerned that (i) not enough catch would be allocated to northern areas where OYE appeared to be relatively abundant and (ii) too much catch would be allocated to southern areas where OYE were less abundant and possibly declining. Concern (i) implies that low TACs on OYE in the north would interfere with other directed fisheries (e.g., Pacific Halibut), while concern (ii) implies that too high TACs in the south could exacerbate OYE declines, leading to even more restrictive coast-wide TACs. Such positive feedback could lead to future problems for both OYE and groundfish fisheries in general.

To help address these management concerns, the authors developed a two-area, age-structured OM for OYE in which North (Groundfish Management Areas 5B, 5C, 5D, and 5E) and South (Groundfish Management Areas 3C, 3D, and 5A) (Figure 1) were assumed to be independent, closed populations, but with shared population dynamics parameters. The two areas allowed the authors to represent the key spatial issues related to stock sizes and population trends without having to model biological exchange between populations (i.e., there is no basis for assessing movement given lack of tagging). Modelling North and South OYE areas simultaneously allowed information to be shared about uncertain parameters (i.e., natural mortality, selectivity, productivity). Current understanding of OYE life history is that movement rates are extremely low once fish settle to rocky bottom habitats, which means that the independence assumption is plausible, at least at the gross North-South scale.

Preliminary meetings of the OYE Technical Committee identified model start dates (1918 or 1960), alternative historical catch series, and prior assumptions about natural mortality as the main axes of uncertainty that should be reflected in OYE operating model scenarios. Therefore, the authors derived 24 OM scenarios from combinations of the two start dates, two commercial catch series, two recreational catch series, and 5 aggregate-level prior means for natural mortality. Each model scenario was fitted to the same survey and age-composition datasets and then models were clustered into 4 representative groups within which model fits and biological properties were similar. A final set of 4 individual OM scenarios were selected for the north and south area to represent the broad set of characteristics shown across the 24 OM scenarios. These final 4 OM scenarios were further classified into a "most plausible" base model (defined below) and three alternatives.

The base OM scenarios (Group 1) for North (base_North) and South (base_South) used the same 1918 start year, upper bound (reconstructed) commercial and recreational catch series, and the base prior mean for aggregate-level natural mortality $\overline{M} = 0.0345$/yr. This model configuration reflected Group 1 fits, which were statistically superior, in general, and also biologically plausible in suggesting coast-wide MSY < 500 t (Table 1).

Three alternative OM scenarios were chosen for each area in an attempt to cover the range of plausible OM scenarios given the input data and assumptions about natural mortality.

1. The OM2 (Group 2) scenario uses (i) 1960 model start year, (ii) lower bound commercial catch series, and (iii) base prior mean for aggregate-level natural mortality $\overline{M} = 0.0345$/yr.
2. The OM3 (Group 3) scenario uses (i) 1960 model start year, (ii) reconstructed catch series, and (iii) prior mean for aggregate-level natural mortality $\overline{M} = 0.03$/yr.
3. The OM4 (Group 4) scenario uses (i) 1918 start year, (ii) lower bound commercial catch, and (iii) base prior mean for natural mortality rate $\overline{M} = 0.0345$/yr.

As noted above, these particular combinations are generally representative of the range of properties across the 13 OM scenarios with coast-wide MSY < 500 t, which include natural mortality estimates ranging from $\overline{M} = 0.031 - 0.044/\mathrm{yr}$, but excluded the scenarios for $\overline{M} > 0.05$/yr.

The authors then weighted the base model 50% and the alternatives 16.67% for the purpose of evaluating rebuilding procedures and providing a single, concise summary of MP performance (as requested by DFO Fisheries Management).

Management Procedure

The assessment components of candidate MPs use historical data for the pre-MP period (1918-2018) and simulated data for the evaluation period (2019-2076). For the projection period, we assume that catch is known exactly in the assessments regardless of the method (i.e., catches are equal to the TAC, uncertain catches (recreational and FSC) are doubled, there is no unreported catch, or unreported discarding).

The authors specify three candidate methods for the assessment component of management procedures for OYE:

1. A statistical catch-at-age model (with base label CAA in figures and tables) utilizes the most comprehensive catch, survey, age-composition, and life history data available;

2. A Schaefer surplus production model (SP) provides a reduced approach to assessing OYE based only on catch and survey indices, which is consistent with previous OYE assessments; and
3. An empirical survey index (IDX) trend estimator for tracking proportional changes in OYE biomass over time.

Each of the assessment components of the MP has a different HCR. The model-based management procedures (CAA and SP) use assessment model estimates of stock status (B_t/B_{MSY}) relative to lower/upper control points to determine the target fishing mortality via the familiar hockey stick HCR (Figure 3). When stock status is estimated below the lower control point ($0.4B_{MSY}$) the target exploitation rate equals zero and, when stock status is above the upper control point ($0.8B_{MSY}$), the target exploitation rate is equal to some reference removal rate (e.g., maximum fishing mortality or exploitation rate). The IDX MPs set TACs by adjusting the previous year's TAC according to the estimated proportional change in stock biomass (Figure 4).

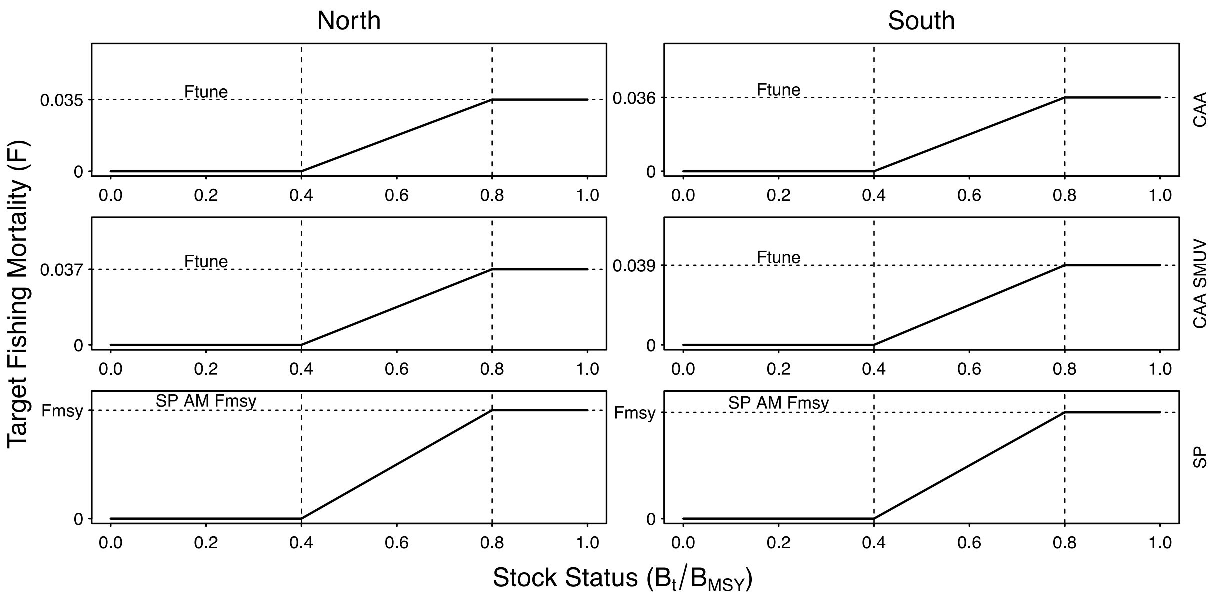

Figure 3. Harvest control rules for CAA (top row), CAA SMUV (middle row), and SP (bottom row) MPs for North and South areas. The CAA MPs use a target F (Ftune) tuned to provide relatively stable OYE biomass over the projection period and the SP MPs use the assessment estimate of Fmsy (SP AM Fmsy) as the maximum removal rate.

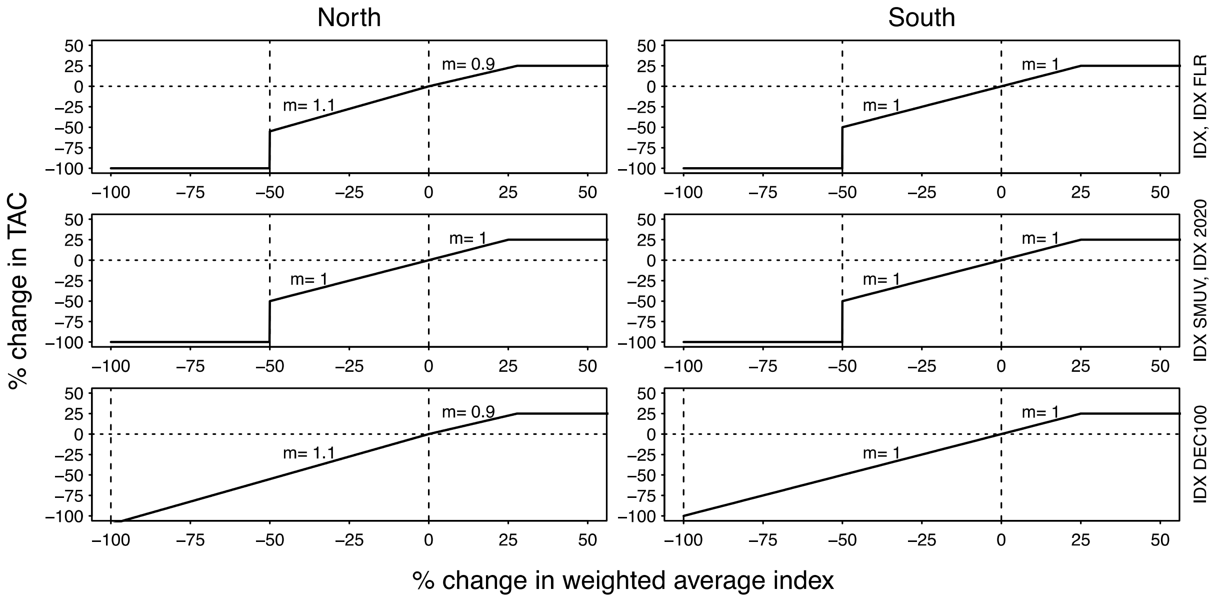

Figure 4. Harvest control rules for survey index based MPs (IDX, IDX_FLR, IDX_SMUV, IDX_2020, IDX_DEC100) in North and South areas with up/down slopes (m) indicating TAC change in proportion to index change.

The authors applied an additional smoothing step to output TACs from MPs using IDX and CAA assessment components to limit inter-annual variation in TACs caused by high survey index variability (IDX) and a short-term jump from existing TACs for OYE to those implied by the CAA-based MP (i.e., which aims to stabilize biomass near current levels). Preliminary simulations showed that TACs generated from CAA-based MPs make a large jump in the first projection year; therefore, a smoother provides an option for a more gradual transition to those TAC levels.

Although the SP and CAA models produce similar estimates of MSY and B_{MSY}, the relationship of B_{MSY} relative to B_0 as well as current stock size relative to B_{MSY} are very different (Figure 5). These results are largely due to differences in how B_{MSY} is estimated; the SP model lacks information on stock productivity and sets B_{MSY} equal to 0.5 B_0 whilst the CAA model estimates $B_{MSY,}$ from the stock production function, in this case, to be ~ 0.27 $B_{0.}$ Consequently when the coast-wide stock status is estimated to range between 0.27- 0.48 B_0, perception of stock status is very different due to the difference in the estimated value of $B_{MSY.}$

Evaluating MPs by simulation requires quantitative performance indicators for each fishery objective. Stock status indicators are all measured using the true operating model spawning stock biomass and, where necessary 1.5 generations (57 years) calculated using the base OM natural mortality estimates of $M = 0.038 - 0.039$/yr.We use the average age of the unfished spawning stock to calculate a generation time (*G*) of 38 years for OYE (Cox et al. 2011). Objective 1 can be stated probabilistically as $P(B_{2076} > LRP) \geq 0.95$, which the authors simply compare to the proportion of 100 simulation replicates for which the condition is true; that is, operating model spawning biomass in Year 2076 is greater than $0.4B_{MSY}$.

Performance statistics for the biomass-based rebuilding Objective 2, were calculated for each simulation replicate. The expected MP performance was then summarized using the median of the 100 replicate statistics. Performance measures are calculated separately for the 4 OMs for each area and then weighted to generate one weighted-performance table for North (Table 2) and South (Table 3) areas.

The 4 OM scenarios range in current biomass from approximately 3,100 to 10,100 t in the North and 2,400 to 5,500 t in the South (Figure 6). This range is considerably wider than the statistical uncertainty within any particular OM. No single factor clearly explains the range of biomasses because natural mortality, absolute catch levels, and historical recruitments all affect biomass and recruitment estimates either directly or indirectly. The 1960 start year generally has the higher unfished and current biomass, while the lower bound commercial catch leads to the lower unfished and current biomass.

Table 1. Biological parameter and management reference point estimates for base, alternative (2,3,4), and weighted (wtd) operating models for north, south, and coast-wide areas. The Limit Reference Point, LRP=0.4B_{MSY}.

North

OM	Unfished Biomass (kt)		Natural Mortality		Reference Points				Current Status			
	B_0	95% CI	M	95% CI	B_{MSY}	LRP	F_{MSY}	MSY	B_{2018}	B_{2018}/B_0	B_{2018}/B_{MSY}	P(B_{2018}>LRP)
base	14.2	13.1 - 15.4	0.039	0.037 - 0.040	3.6	1.4	0.053	0.21	4.5	0.31	1.23	100.0%
2	16.0	11.8 - 21.8	0.044	0.043 - 0.046	4.4	1.8	0.052	0.26	8.2	0.51	1.85	100.0%
3	17.4	15.6 - 19.5	0.034	0.034 - 0.035	4.8	1.9	0.042	0.22	5.3	0.30	1.11	99.9%
4	8.8	8 - 9.7	0.039	0.037 - 0.040	2.3	0.9	0.051	0.13	2.6	0.29	1.12	100.0%
wtd	14.1	12.4 - 16.2	0.039	0.038 - 0.040	3.7	1.5	0.051	0.21	4.9	0.35	1.33	100.0%

South

OM	Unfished Biomass (kt)		Natural Mortality		Reference Points				Current Status			
	B_0	95% CI	M	95% CI	B_{MSY}	LRP	F_{MSY}	MSY	B_{2018}	B_{2018}/B_0	B_{2018}/B_{MSY}	P(B_{2018}>LRP)
base	10.8	10 - 11.7	0.038	0.036 - 0.039	2.8	1.1	0.052	0.16	3.3	0.30	1.18	100.0%
2	10.3	8.7 - 12.2	0.041	0.040 - 0.043	2.9	1.2	0.048	0.15	4.4	0.43	1.54	100.0%
3	11.6	10.8 - 12.5	0.031	0.031 - 0.032	3.2	1.3	0.038	0.13	2.4	0.21	0.75	91.8%
4	7.5	6.7 - 8.5	0.038	0.036 - 0.039	2.0	0.8	0.050	0.11	1.9	0.26	0.98	94.6%
wtd	10.3	9.4 - 11.4	0.037	0.036 - 0.038	2.8	1.1	0.049	0.14	3.1	0.30	1.13	98.0%

Coastwide

OM	Unfished Biomass (kt)		Natural Mortality		Reference Points				Current Status			
	B_0	95% CI	M	95% CI	B_{MSY}	LRP	F_{MSY}	MSY	B_{2018}	B_{2018}/B_0	B_{2018}/B_{MSY}	P(B_{2018}>LRP)
base	25.0	23.1 - 27.1	0.039	0.037 - 0.040	6.4	2.6	0.053	0.37	7.8	0.31	1.22	100.0%
2	26.3	20.5 - 34.0	0.043	0.042 - 0.045	7.3	2.9	0.050	0.41	12.6	0.48	1.73	100.0%
3	29.0	26.4 - 32.0	0.033	0.033 - 0.034	8.0	3.2	0.040	0.35	7.7	0.27	0.96	99.8%
4	16.3	14.7 - 18.2	0.039	0.037 - 0.040	4.3	1.7	0.051	0.24	4.5	0.28	1.05	99.7%
wtd	24.4	21.8 - 27.6	0.039	0.037 - 0.039	6.5	2.6	0.050	0.35	8.0	0.33	1.24	100.0%

Table 2. Weighted-average management procedure performance over 4 operating model scenarios for the ***North****. The 2020 TACs and catches are the same across all replicates for CAA and IDX MPs, while median values are shown for SP MPs.*

	Conservation Objectives		Other Performance Measures									
MP	1	2	Long-term depletion		Short-term Catch (5 years)			Medium-term Catch (10 years)			2020 Catch (t)	
	P(B_{2076}>LRP)	P(B_{2029}<B_{2020})	B_{2076}/B_0	B_{2076}/B_{MSY}	P(C_t>62t)	Median (t)	AAV	P(C_t>64t)	Median (t)	AAV	TAC	Catch
Sp	1	0	0.55	1.89	0.20	43	45	0.34	54	39	38	38
sp_2xRec	1	0	0.52	1.79	0.25	46	48	0.38	60	42	38	41
Caa	1	0.48	0.36	1.25	1.00	190	13	1.00	193	7	166	166
caaSmuv	1	0.48	0.35	1.21	1.00	181	15	1.00	195	7	124	124
caa_2xFSC	1	0.57	0.35	1.21	1.00	199	13	1.00	201	7	166	175
caa_2xRec	1	0.72	0.33	1.14	1.00	216	14	1.00	218	8	166	190
Idx	1	0.43	0.43	1.48	1.00	185	22	0.99	184	19	166	166
idxSmuv	1	0.26	0.33	1.13	1.00	162	16	1.00	168	12	120	120
idx_2xFSC	1	0.65	0.40	1.38	1.00	210	21	1.00	207	19	166	175
idx_2xRec	1	0.88	0.36	1.24	1.00	256	24	1.00	250	21	166	190
idx_2020	1	0.00	0.46	1.59	0.94	96	14	0.94	105	15	85	85
idx_dec100	1	0.43	0.43	1.48	1.00	185	22	0.99	184	19	166	166
idxFlr	1	0.44	0.42	1.46	1.00	185	22	1.00	184	19	166	166

Table 3. Weighted-average management procedure performance over 4 operating model scenarios for the ***South****. The 2020 TACs and catches are the same across all replicates for CAA and IDX MPs, while median values are shown for SP MPs.*

	Conservation Objectives		Other Performance Measures									
MP	1	2	Long-term depletion		Short-term Catch (5 years)			Medium-term Catch (10 years)			2020 Catch (t)	
	$P(B_{2076}>LRP)$	$P(B_{2029}<B_{2020})$	B_{2076}/B_0	B_{2076}/B_{MSY}	$P(C_t>62t)$	Median (t)	AAV	$P(C_t>64t)$	Median (t)	AAV	TAC	Catch
sp	1	0	0.42	1.45	0.44	38	33	0.65	56	30	32	32
sp_2xRec	1	0	0.36	1.21	0.50	44	43	0.70	68	37	32	34
caa	1	0.45	0.31	1.07	1.00	146	16	1.00	154	8	107	107
caaSmuv	1	0.47	0.29	1.01	1.00	138	19	1.00	156	9	79	79
caa_2xFSC	1	0.58	0.30	1.01	1.00	154	15	1.00	162	8	107	116
caa_2xRec	1	0.88	0.25	0.86	1.00	187	18	1.00	193	10	107	136
idx	1	0.05	0.56	1.9	1.00	103	27	0.98	104	23	107	107
idxSmuv	1	0.03	0.45	1.56	1.00	100	19	1.00	105	14	74	74
idx_2xFSC	1	0.19	0.50	1.73	1.00	125	23	0.99	126	21	107	116
idx_2xRec	1	0.81	0.42	1.45	1.00	191	25	0.98	193	24	107	136
idx_2020	1	0	0.63	2.15	0.88	51	18	0.87	53	18	52	52
idx_dec100	1	0.05	0.56	1.9	1.00	103	27	0.98	104	23	107	107
idxFlr	1	0.05	0.53	1.79	1.00	103	27	1.00	104	23	107	107

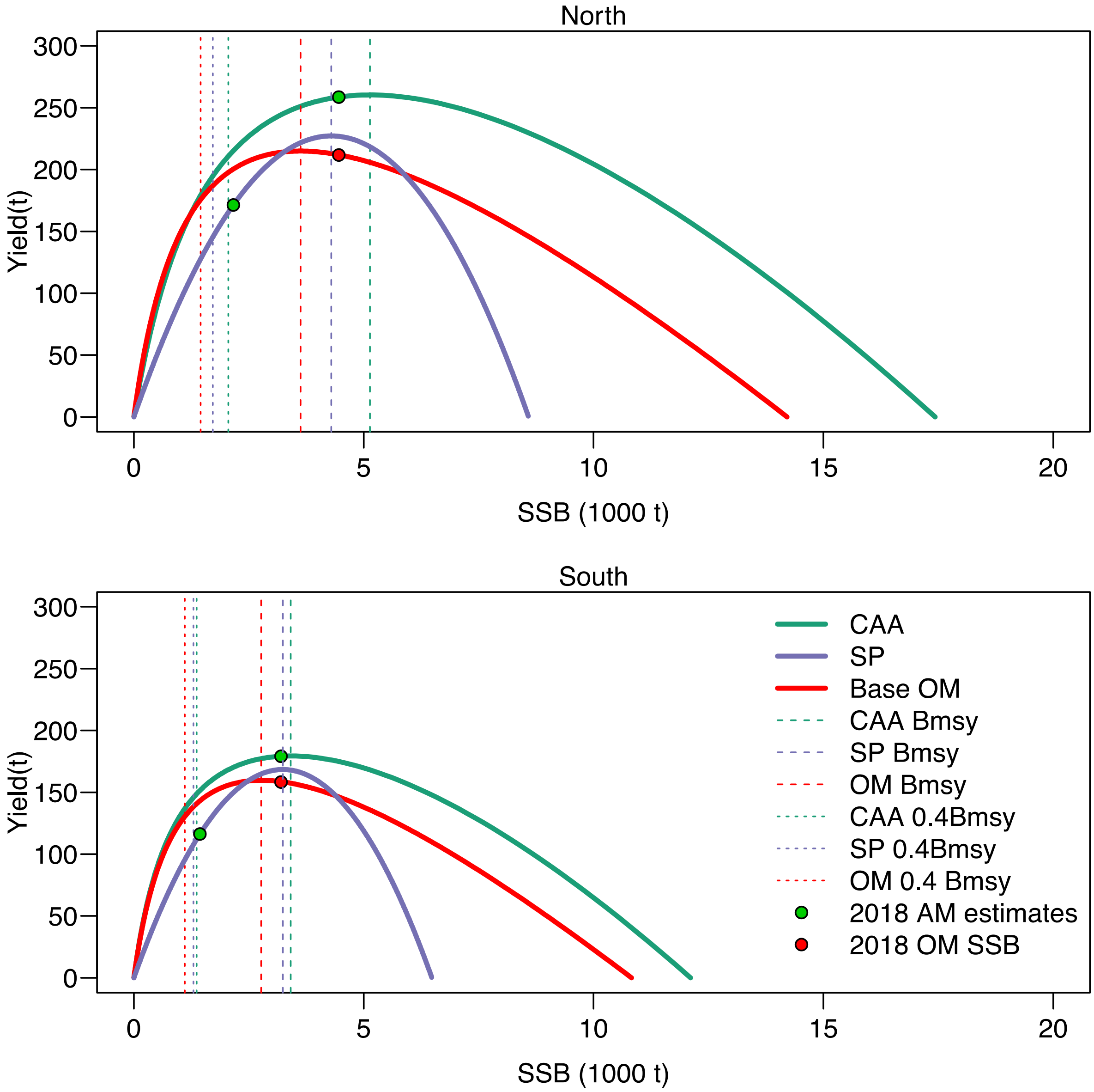

Figure 5. Equilibrium yield vs spawning stock biomass curves for the base OM and estimates from the catch-at-age (CAA) and surplus production (SP) assessments used in MPs for the first year fit in simulations (i.e., 2018).

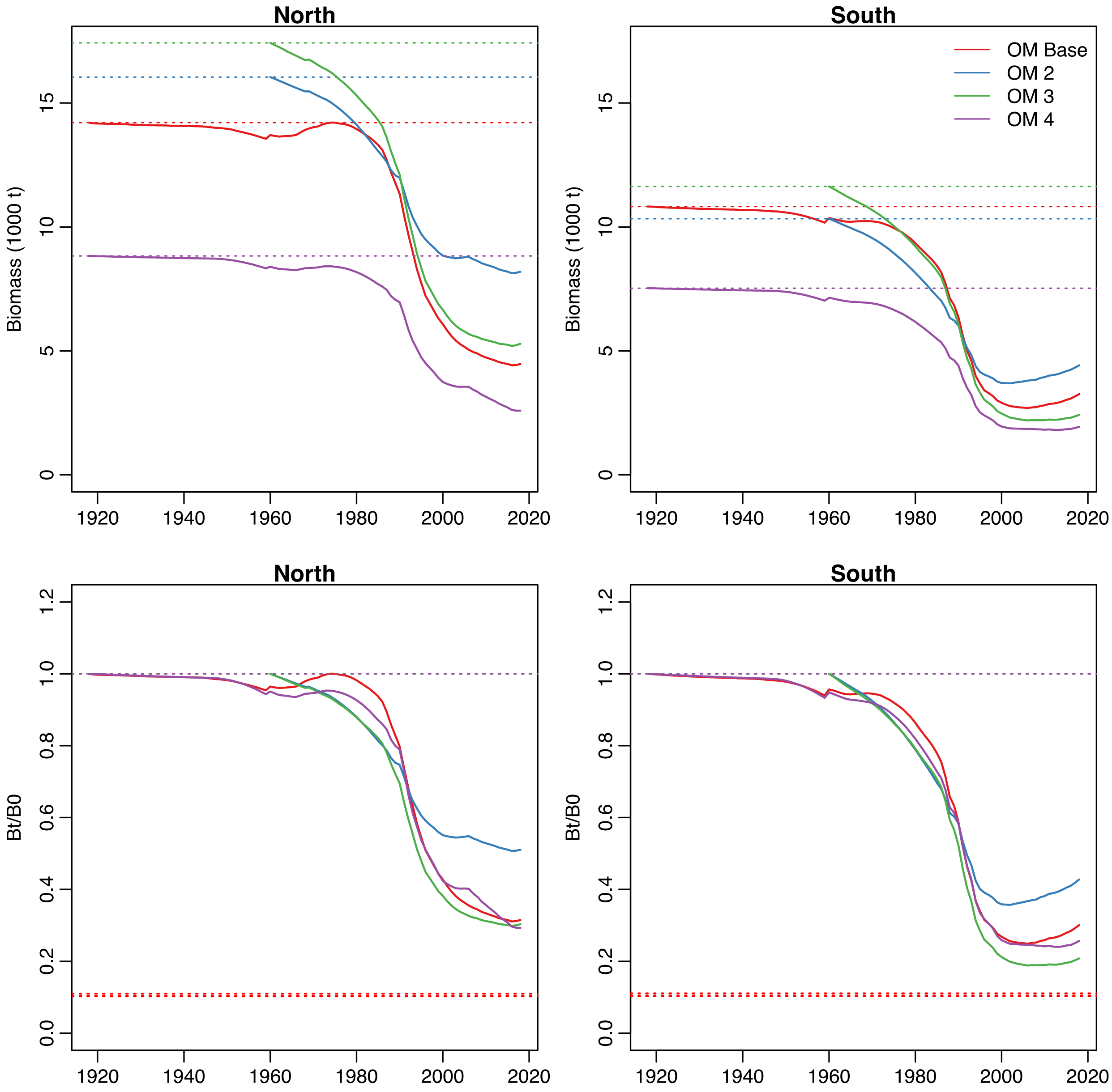

Figure 6. Absolute spawning biomass depletion (top) and relative depletion (bottom) for operating models using i) a 1918 start year and reconstructed commercial catch (OM Base), ii) a 1960 start date and lower bound on commercial catch (OM 2), iii) a 1960 start year and reconstructed commercial catch (OM3), and iv) a 1918 start year and lower bound on commercial catch (OM4)). The red dotted lines in the bottom plots indicate the LRP for each OM, which range from 0.10B_0-0.11B_0.

Sources of Uncertainty

The suite of OM scenarios explored does not necessarily encapsulate all possible sources of uncertainty. Although survey indices and age-composition data were used, the amount and quality of these data remain limited relative to the longevity of OYE and time span over which groundfish fisheries have operated in B.C. This means that certain parameter assumptions – via prior distributions – could have considerable influence on the results. Informative or weakly informative priors on high natural mortality rates lead to high estimated natural mortality and unrealistically high biomass estimates. There is not much additional information in the way of unfished age-composition or tagging data to estimate M for OYE, which means that natural mortality scenarios will continue to be necessary for OYE assessments and MP evaluation.

The operating models show some lack of fit, particularly over-estimating the age 65+ class (Figure 7) in the age-composition and under-estimating the downward trend in the IPHC_South survey index. Exploring the size of the age plus group could stabilize model behaviour and future work should explore different plus age groups. The robustness of trends in the IPHC survey should be explored given that it is designed for Pacific Halibut and could therefore lead to trends in the survey that do not accurately reflect changes in OYE abundance. Alternate methods, such as a delta-model to explore the presence-absence as well as the abundance data, should be explored to verify trends in the IPHC survey.

The operating models use an age-specific fecundity that is correlated with age, but this relationship should be explored further in future work given that the body size-fecundity relationships are exponential in rockfishes (Dick et al. 2017).

The estimated growth curves appear positively biased for young ages (age-1 to age-6), which could lead to over-estimation of exploitable biomass and under-estimation of fishing mortality. This bias may be minor given that these fish are not recruited for several years to either exploitable or spawning components and by that time, the growth model is a bit more accurate.

Age composition data from the commercial fishery are limited and potentially biased, and absent from the recreational and FSC fisheries. Developing a way to collect commercial ageing data should be considered. Selectivity functions used in the commercial, recreational and FSC fisheries are very uncertain and novel methods of data collection should be developed to improve selectivity functions.

An important consideration for future research would involve more detailed testing of the OM scenarios for OYE to specifically include simulation testing for bias and precision properties. This would help establish the robustness of conclusions drawn about MP performance.

Additional sources of uncertainty that could not be fully addressed include high uncertainty in recreational and FSC catches, including suspected misidentification of Yelloweye Rockfish in historical and contemporary data.

The impact or benefit of Rockfish Conservation Areas (RCAs) on stock growth could also not be evaluated or included in this work as a result of a lack of monitoring within RCAs.

Many of these uncertainties should be evaluated in future iterations of the MSE process. Alternate objectives for OYE should also be developed including fishery objectives and the maintenance of large size and old age structure due to the population-level importance of big, old, fecund females (see “Other Considerations”).

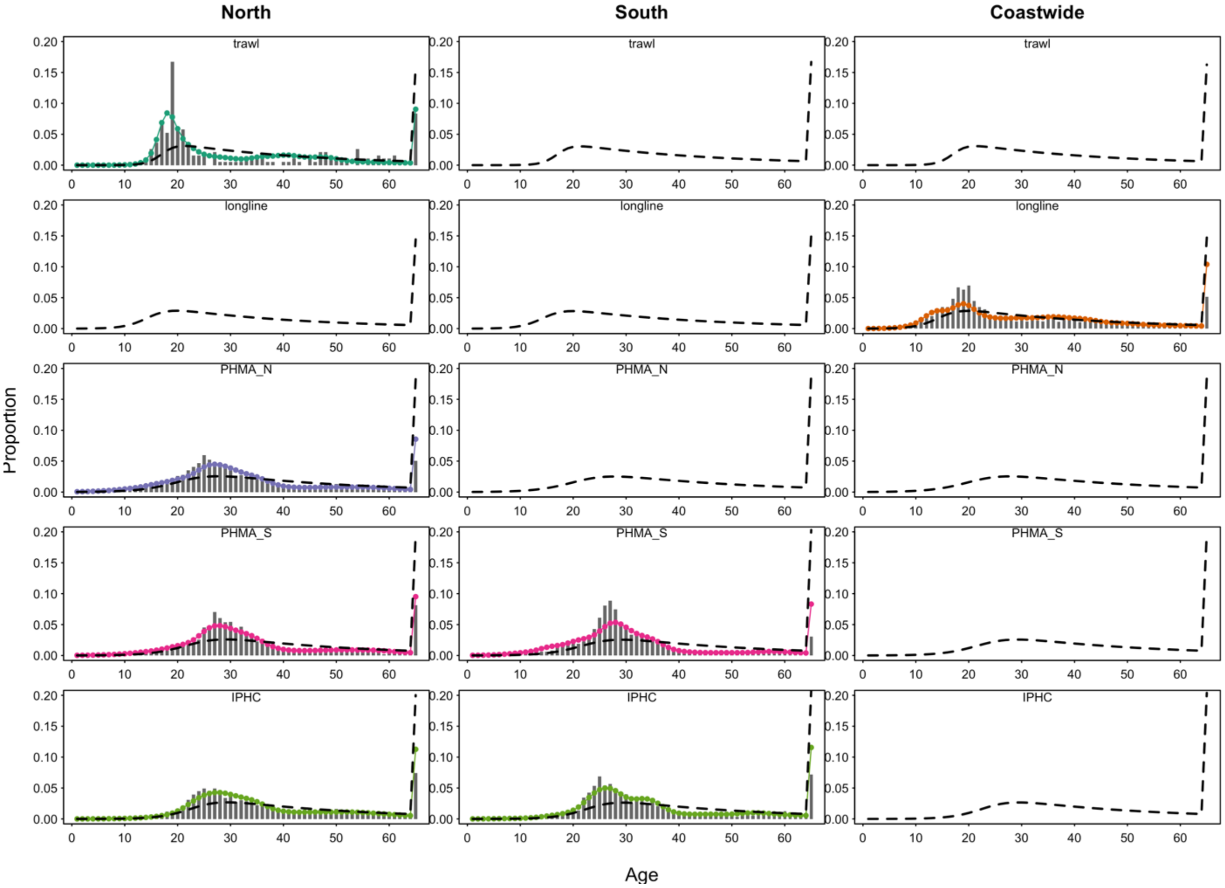

Figure 7. Average observed and fitted age-compositions under the base operating models for fleets contributing age-composition data. Black dashed lines indicate unfished equilibrium age composition adjusted by selectivity in each fleet.

CONCLUSIONS AND ADVICE

- This paper provides advice on rebuilding Outside Yelloweye Rockfish (OYE) using closed-loop simulation modelling to test performance of a set of candidate management procedures (MPs) against specific quantitative objectives.
- A management-oriented approach was initially intended to develop rebuilding plans for OYE; however, in identifying and conditioning operating models for OYE, the authors concluded the stock is probably not in need of rebuilding above the LRP.
- All operating models implied that OYE is currently above $0.4B_{MSY}$, coast-wide, even though OYE biomass declined by 49-71% in the North and 57-79% in the South, and 52-73% coast-wide over the past two OYE generations.
- Current objectives for OYE rebuilding emphasize biomass-based objectives over other important aspects such as catch and spatial distribution. Several potential MPs were identified that could increase or stabilize OYE biomass in both North and South areas. For example, the CAA MPs were tuned to achieve a target fishing mortality rate that would provide relatively stable OYE biomass over the short term.
- Additional guidance from OYE managers, First Nations, and fishery stakeholders should be sought to further develop fishery objectives and subsequently identify tradeoffs between MPs.
- Any MP that is implemented in the interim should seek to increase or stabilize OYE biomass while fishery objectives are developed further. An interim MP could be selected and implemented from the MPs evaluated through this process to provide harvest advice in the short term.

OTHER CONSIDERATIONS

Ecosystem considerations and climate change were not explicitly included in this analysis; however, differences in productivity amongst areas may be driven by ecosystem or environmental effects. Yelloweye Rockfish are harvested in a multi-species fishery and maintaining a minimum catch to allow the operation of those fisheries was used as a catch floor in our simulations. The impact or benefit of Rockfish Conservation Areas (RCAs) on stock growth could also not be evaluated or included in this work as a result of a lack of monitoring within RCAs. It is expected that as RCAs mature and size-age structures stabilize within them, that they will begin to have a positive effect on OYE biomass. Moving towards a management strategy evaluation offers a way to consider or operationalize an Ecosystem Approach to Fisheries Management by incorporating ecosystem considerations, climate uncertainty, and other conservation measures into MP selection. Groundfish stocks that are fished down to apparently sustainable biomass levels may have truncated size and age structures (Hixon et al. 2014) and declines in OYE body sizes (and age) were recently documented on BCs central coast (Eckert et al. 2017; McGreer & Frid 2017). Although the scope of this project was to determine whether we could meet the objectives related to biomass, future work could include analyses about spatial, age-structured distributions and other aspects of a healthy rebuilt stock. Management and rebuilding objectives would be strengthened by explicitly addressing the restoration of large size and old age structures.

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SOURCES OF INFORMATION

This Science Advisory Report is from the October 29-30, 2019 regional peer review on the Evaluation of Management Procedures for the Outside Population of Yelloweye Rockfish Rebuilding Plan. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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