IPHC Management Strategy Evaluation to Investigate Fishing Intensity

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PURPOSE

To provide an update on the progress of the IPHC Management Strategy Evaluation process to investigate fishing intensity, and seek recommendations from the MSAB related to the Management Strategy Evaluation simulation framework.

INTRODUCTION

At the 2017 Annual Meeting (AM093) Commissioners supported a revised harvest policy that separates the scale and distribution of fishing mortality (Figure 1). Furthermore, the Commission identified an interim "hand-rail" or reference for harvest advice based on a status quo SPR, which uses the average estimated coastwide SPR for the years 2014–2016 from the stock assessment. The justification for using an average SPR from recent years is that this corresponds to fishing intensities that have resulted in a stable or slightly increasing stock, indicating that, in the short-term, this may provide an appropriate fishing intensity that will result in a stable or increasing spawning biomass.

The Commission provided one request at the 94th Annual Meeting (AM094) in 2018 related to investigation of fishing intensity. This was

> **AM-094, para 31**: The Commission **REQUESTED** that the MSAB look at SPR values consistent with recent estimated SPR values from the assessment model and lower. This would mean expanding the lower range of SPR values to below 40%.

The 2017 stock assessment updated the population estimates and determined that the SPR resulting from actual total mortality from all sources in 2017 was 40%, instead of the 45% decided by Commissioners at AM093. This was an example of estimation error and something that is inherent in the process due to uncertainty in the data. The SPR of 40% was well within the confidence bounds for SPR reported in the 2017 stock assessment (30-59%), and was most likely less than the adopted SPR because of the updated estimation of recent poor recruitment. The estimation may easily go either way (above or below the adopted value).

A brief description of the simulation framework is given below, with many details provided in IPHC document IPHC-2017-MSAB10-09 Rev 1.

FRAMEWORK

The framework of the closed-loop simulations is a map to how the simulations will be performed (Figure 2). There are four main modules to the framework:

1. The **Operating Model (OM)** is a representation of the population and the fishery. It produces the numbers-at-age, accounting for mortality and any other important processes. It also incorporates uncertainty in the processes and may be composed of multiple models to account for structural uncertainty.
2. **Management Procedure**
    a. **Monitoring (data generation)** is the code that simulates the data from the operating model that is used by the estimation model. It can introduce variability, bias, and any other properties that are desired.
    b. The **Estimation Model (EM)** is analogous to the stock assessment and simulates estimation error in the process. Using the data generated, it produces an annual estimate of stock size and status and provides the advice for setting the catch levels for the next time step. However, simplifications may be necessary to keep simulation times within a reasonable time.
    c. **Harvest Rule** is the application of the estimation model output along with the scale and distribution management procedures (Figure 1) to produce the catch limit for that year.

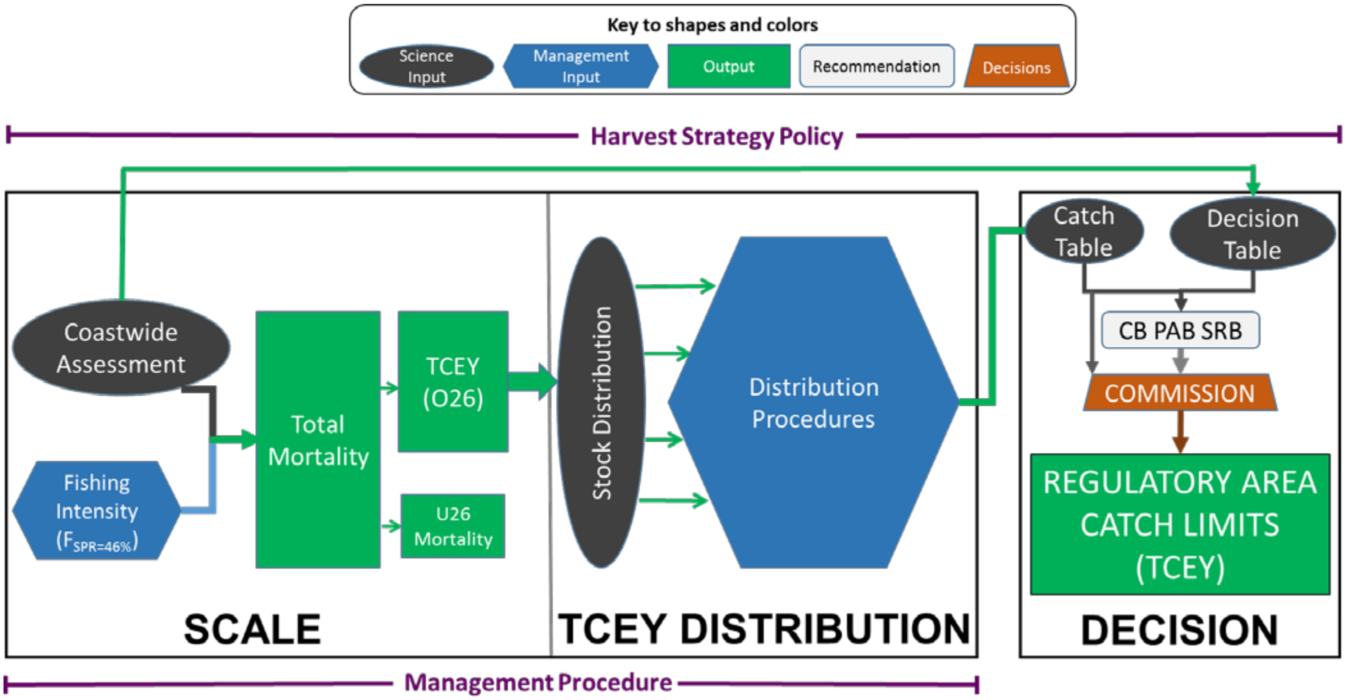

Figure 1: A pictorial description of the interim IPHC harvest strategy policy showing the separation of scale and distribution of fishing mortality. The “decision step” is when policy and decision making (not a procedure) influences the final mortality limits.

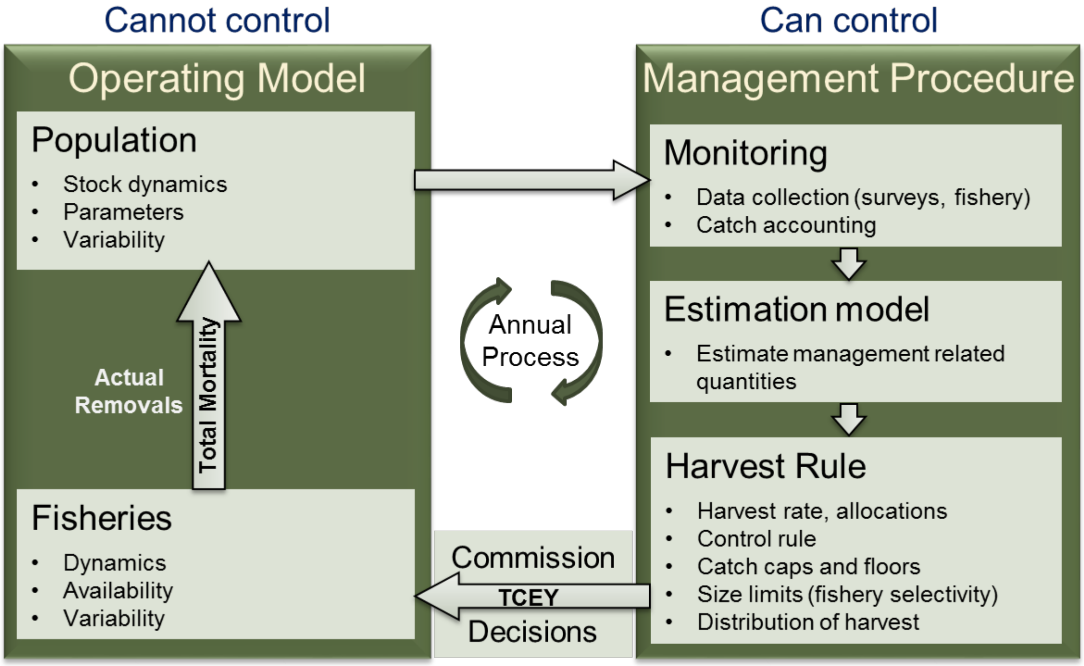

Figure 2: Diagram of the relationship between the four modules in the framework. The simulations run each module on an annual time-step, producing output that is used in the next time-step. See text for a description of operating model, monitoring, estimation model, and harvest rule.

OPERATING MODEL

For the simulations to investigate a coastwide fishing intensity, the stock synthesis (Methot and Wetzel 2013) assessment software was used as an operating model. This platform is currently used for the stock assessment, and the operating model was comprised of the two coastwide assessment models (short and long time-series) currently used in the ensemble. For future MSE evaluations (in particular, investigating the Distribution component of the harvest policy) a more complex operating model will be developed that can provide outputs by defined areas or regions and can account for migration between these areas. This model has been referred to as a multi-area model.

The current stock assessment ensemble, composed of four different assessment models, includes a cross between coastwide or fleets-as-areas structuring of the data, and the length of the time series. Using an areas-as-fleets model would require generating data and distributing catch to four areas of the coast, which would involve many assumptions. In addition, without a multi-area model, there would not be feedback from migration and productivity of harvesting in different areas. Therefore, only the two coastwide models were used, but with additional variability. These models are structured to use five general sources of removals (these are aggregated for modelling purposes and do not necessarily correspond to specific fisheries or sectors): the directed commercial halibut fishery (including research landings), commercial discard mortality (previously known as wastage), bycatch (from non-halibut-target fisheries), recreational, and subsistence. The TCEY was distributed to each source in an ad hoc manner using current available information (see below).

MANAGEMENT PROCEDURE

Monitoring (Data Generation)

It is proposed to use a simplified estimation model due to time constraints, thus no data were generated. However, if a stock assessment was simulated, there are many sources of data to generate (Appendix A).

Estimation Model

Of the four options to simulate an estimation model presented in IPHC-2017-MSAB10-09 Rev1, the No Estimation Model (previously called Perfect Information) option was used in past simulations. The No Estimation Model method assumes that the population values needed to apply the management procedure are exactly known (e.g., spawning biomass). This option is useful as a reference to better understand the performance with and without uncertainty in an estimation model. Due to time constraints, the only other option likely to be considered for simulations in 2018 is the Simulate Error option. This will be suitable to understand the effects of estimation error.

Harvest Rule

The generalized management procedure to evaluate is shown in Figure 1, but the focus will be on the Scale portion to produce results for the MSAB to evaluate before AM095 in 2019. Specifically, the portion of the management procedure being evaluated is a harvest control rule (**Figure 3**) that is responsive to stock status and consists of an SPR determining fishing intensity, a trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a limit that determines when there is theoretically no fishing intensity (SPR=100%). 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 have been used to evaluate a range of SPR values from 25% to 60% and trigger values of 30% and 40% (IPHC-2017-MSAB10-09 Rev 1). Those simulations provided insight into how those different levels of SPR would meet the objectives defined by the MSAB, but few values of SPR below 40% were tested. Future simulations will use a finer resolution of SPR values ranging from 30% to 55% and trigger points of 30% and 40%.

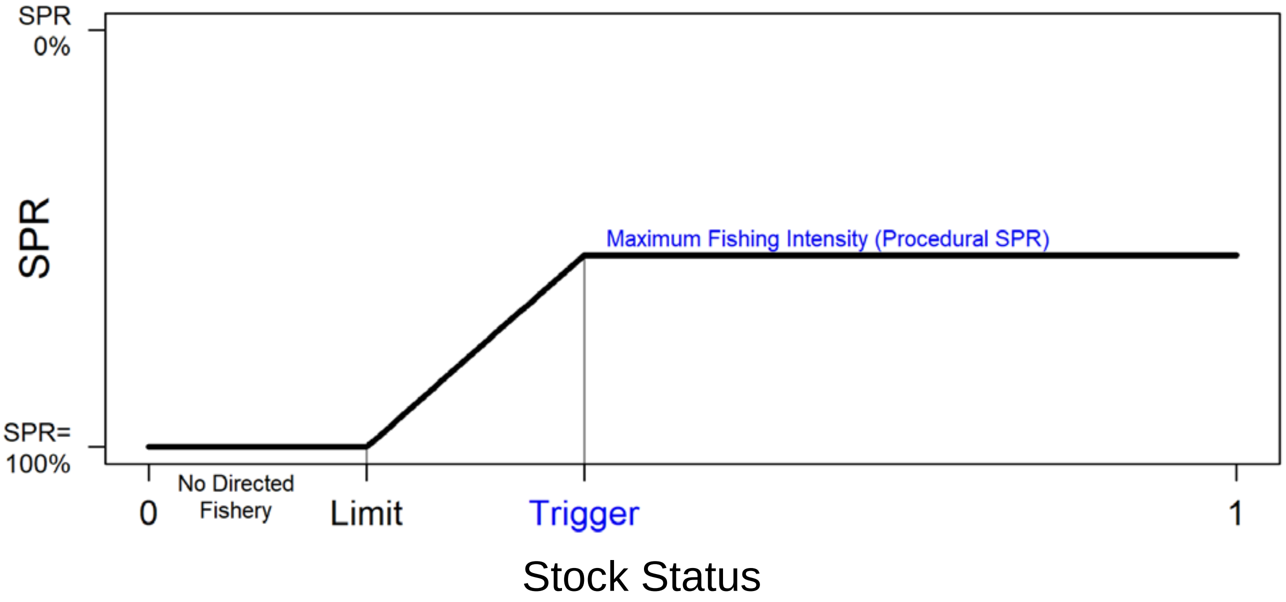

Figure 3: A harvest control rule responsive to stock status that is based on Spawning Potential Ratio (SPR) to determine fishing intensity, a trigger level of stock status that determines when the fishing intensity begins to be linearly reduced, and a limit that determines when there is theoretically no fishing intensity (SPR=100%). In reality, it is likely that only the directed fishery would cease. The Procedural SPR and the Trigger (in blue) are the two values that were evaluated.

SUMMARY OF THE FRAMEWORK

A summary of the major specifications for each component is provided below, with the components listed in a specific order where the next component is dependent on the decisions for the previous components.

1) Operating Model
    a) Stock synthesis, based on coastwide assessment models (short and long models).
    b) Five fleets, as in the assessment models (commercial, discards, bycatch, sport, personal use).
    c) Uncertainty incorporated through parameter uncertainty and model uncertainty. See Scenarios.
2) Management Procedure
    a) Estimation Models
        i) Perfect Information (as a reference if we knew population values exactly when applying the harvest rule).
        ii) Simulate error from the simulated time-series to mimic a stock assessment.
    b) Data Generation
        i) Not needed at this time.
    c) Harvest Rule
        i) Coastwide fishing intensity (F_{SPR}) with SPR ranging from 30% to 55%.
        ii) Trigger to reduce the fishing intensity (increase SPR) when stock status is below 30% or 40%
        iii) A limit to cease directed fishing when the stock status is less than 20%.
        iv) Catch assigned to sectors based on historical information (with variability)

SCENARIOS AND UNCERTAINTY

Scenarios are alternative states of nature in the operating model, which are represented by parameter and model uncertainty, as described in Appendix A. These alternative states of nature integrate over the uncertainty in the system that we cannot, or choose not to, control. The scenarios for the MSE simulations include variability in the operating model processes as described in Table 1.

Table 1: Processes and associated variability in the operating model (OM). TM refers to total mortality.

Process	Uncertainty
Natural Mortality (M)	Estimate appropriate uncertainty when conditioning OM
Recruitment	Random, lognormal deviations
Size-at-age	Annual and cohort deviations in size-at-age with bounds
Steepness	Estimate appropriate uncertainty when conditioning OM
Regime Shifts	Autocorrelated indicator based on properties of the PDO for regime shift
TM to sectors	See section on allocating TM to sectors
Proportion of TCEY	Sector specific. Sum of mortality across sectors may not equal coastwide TM

ALLOCATING SIMULATED TOTAL MORTALITY TO SECTORS

The simulated management strategy returns a coastwide recommended TCEY, which is then allocated to each of the five sectors, with variability. In reality, there is a slight difference between the Total Mortality (TM) and the TCEY because of shortfalls and overages, but those should be dealt with on a sector basis. The MSAB09 meeting in May 2017 noted that catch history, in conjunction with uncertainties and sensitivities, can be used to allocate TM to each sector. Recent sector-specific mortality or proportions of TM for each sector were used to guide the allocation using relationships between the sector specific mortality or proportions to the TM. For example, at low TM the bycatch is likely a larger proportion. Figure 4 shows the percentage of TM attributed for each sector for the past 40 years.

A summary of the methods used to allocate total mortality to the five sources is provided in Table 2. Additional details can be found in IPHC-2017-MSAB10-09.

Due to specified minimum levels of subsistence and bycatch mortality, as well as random variability, it is possible that, at low levels of total mortality, there is no directed commercial mortality and that the actual total mortality exceeds the mortality determined from the management procedure. Expected values of the mortality and proportion by source plotted against Total Mortality is shown in Figure 5.

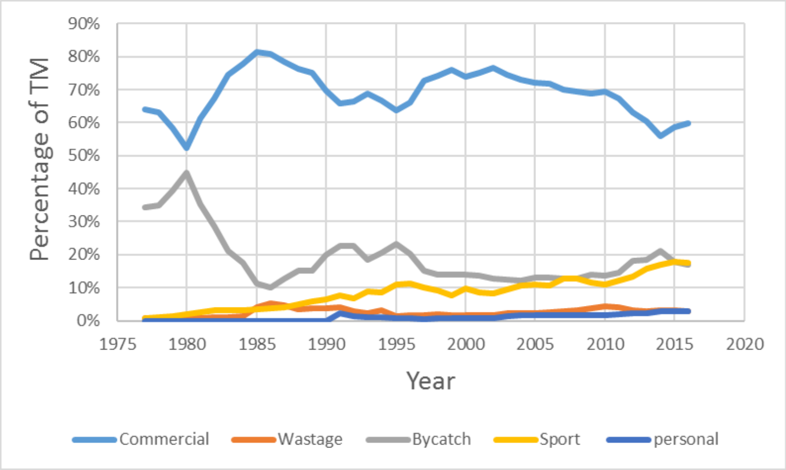

Figure 4: Percentage of Total Mortality (TM) for each sector used in the assessment model from 1976 to 2016.

Table 2: A summary of the methods to allocate total mortality to each of the five sources used in the operating model.

Source	**Method of allocating Total Mortality**
Subsistence	Randomly drawn from a lognormal distribution with a median of 1.2 million pounds (544 t) and a coefficient of variation (CV) of 15%. The 5th and 95th percentiles are approximately 0.9 million pounds (410 mt) and 1.5 million pounds (680 mt), respectively.
Bycatch	The non-directed component of the total mortality is randomly drawn from a lognormal distribution with a median of 7.0 million pounds (3,175 mt) and a CV of 20%. The 5th and 95th percentile are approximately 5.0 million pounds (2,300 mt) and 9.7 million pounds (4,400 mt), respectively. Potential improvements to the simulation of bycatch mortality will be discussed.
Recreational	The percentage of recreational mortality was linearly decreasing with total mortality when the total mortality was less than 57 million pounds (25,855 mt). The recreational mortality was randomly drawn from a lognormal distribution with a median of 7.7 million pounds (3,493 mt) and a CV of 20% when the total mortality was greater than 57 million pounds (25,855 mt).
Discard Mortality	The discard mortality was modelled as a function of the commercial plus discard mortality (total mortality minus subsistence, bycatch, and recreational mortality) and the size at age 8 for a male Pacific halibut (smaller fish likely results in more discard mortality).
Commercial	The commercial mortality is the remainder of the total mortality after subtracting the subsistence, bycatch, sport, and discard components.

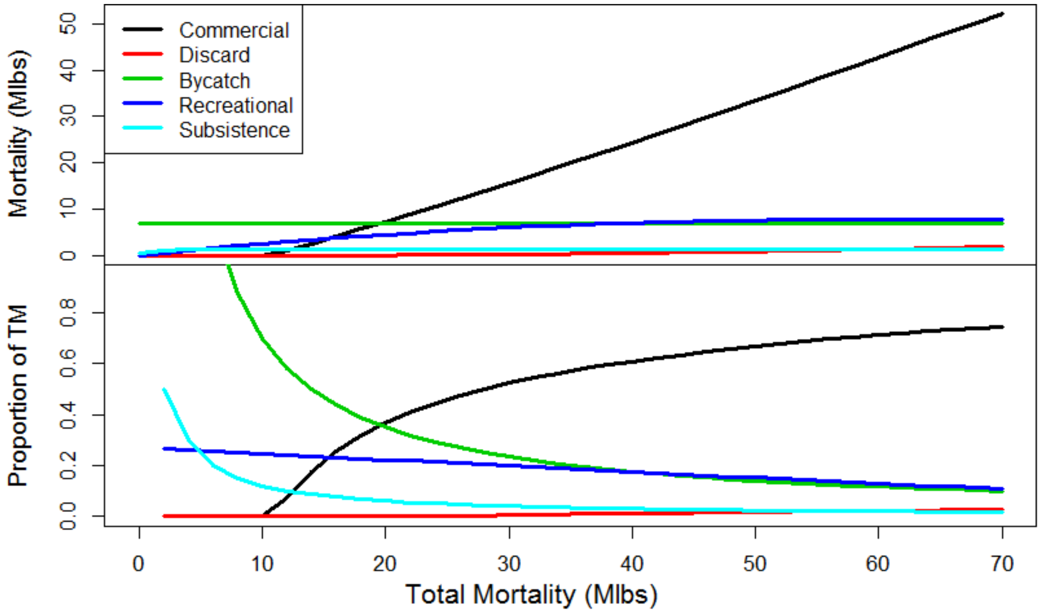

Figure 5: Average sector specific mortality (top, millions of pounds) and the sector-specific proportion of Total Mortality (TM) plotted against TM. For plotting purposes, age 8 males are 6 pounds and random variability is not included.

SIMULATING WEIGHT-AT-AGE

It is important to simulate time-varying weight-at-age because it is an influential contributor to the yield and status of Pacific halibut. There are 82 years of weight-at-age observations in the long time-series assessment models, with an observed wide range over the years (Figure 6 and Figure 7). Many years of these data have been estimated from sparse data, and the entire time-series has been smoothed to eliminate large deviations from year to year.

Important behaviors of the historical weight-at-age time-series to consider when simulating future weight-at-age are

1. the age-specific weights-at-ages tend to increase and decrease in the same year (little evidence of lags due to specific cohort effects; Figure 6 upper plot),
2. the time-series appears to be similar to a random walk with smooth trends and few large jumps in observations (partly due to the smoothing that was done; Figure 6), and
3. there appears to be some ages that do not strictly follow the general trend (evident at the end of the time series where the sampling was likely greater; Figure 6 lower plot).

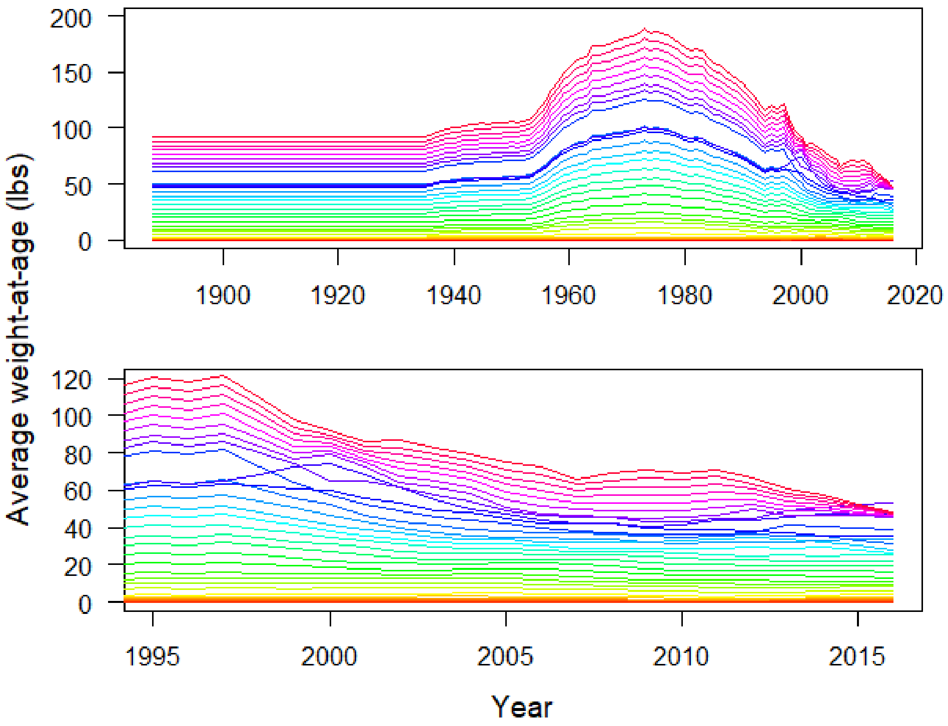

Figure 6: Historical female weight-at-age as used in the long time-series assessment models. Note that the observations are smoothed over years to reduce spurious observations.

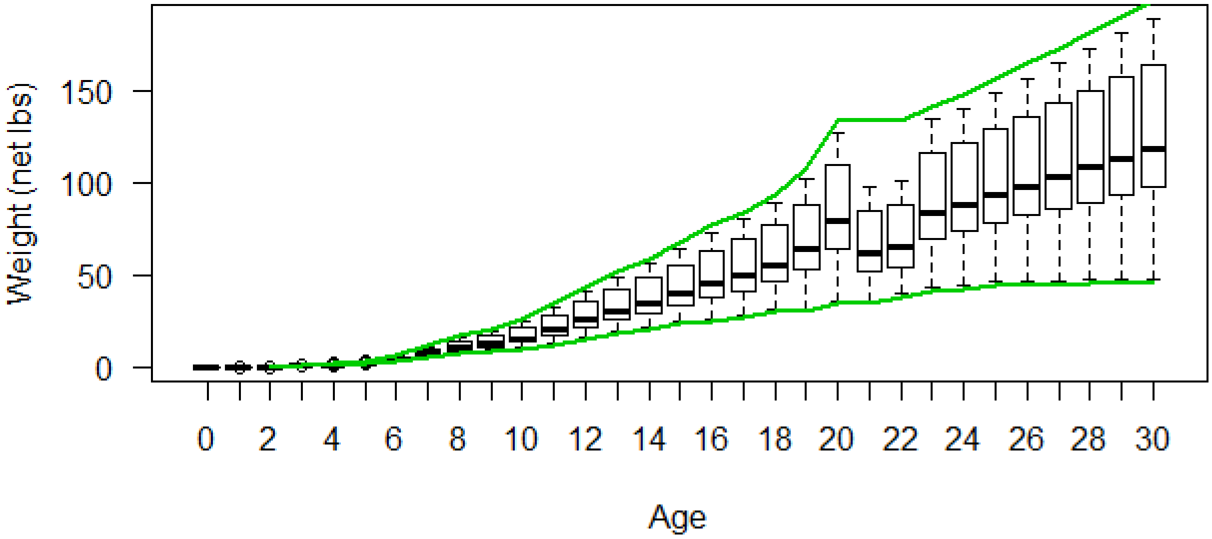

Figure 7: Boxplots of female weight at ages 0 to 30 over all historical years. The green line shows the lower and upper bounds used in the simulations.

The method used to simulate weight-at-age addressed each of these behaviors in the following ways.

1. A single deviation was generated from a normal distribution with a constant standard deviation (0.05), and was a multiplier on the current year's weight-at-age to determine the weight-at-age in the next year. This made all weights for each age increase or decrease similarly.
2. A random walk was used where the weight-at-age in the next year was generated from the weight-at-age in the current year. The deviation in (1) was also correlated with past deviations to simulate periods of similar trends (ρ=0.5).
3. Deviations for each age 6 and greater were generated from a normal distribution with a constant coefficient of variation for each age (0.01), resulting in standard deviations scaled by the mean weight-at-age observed over all historical years with observations. This allows for larger deviations for older fish and provides a mechanism for the mean weight of a specific age to depart from the overall trend simulated in step 1.

The random walk could potentially traverse to extremely high values or low values (obviously negative weight-at-age is not valid). Therefore, boundary conditions were set to limit the range over which weight-at-age could vary. The boundary limits were determined from the observed range of weight at each age, and expanded 5% beyond the minimum and maximum weight at each age observed. Two upper boundaries (ages 21 and 22) were expanded further to equal the upper boundary of age 20 (Figure 7). The random walk simulations remained within the bounds by applying the following algorithm.

1. If a weight-at-age was simulated to be beyond the bounds, the deviations for only the ages where the age-specific bounds were exceeded were reduced by one-half and applied again to determine if it still exceeded the bounds.
2. Repeat step (1) until no age-specific bounds were exceeded.

Example simulated weight-at-age time series are shown in Figure 8.

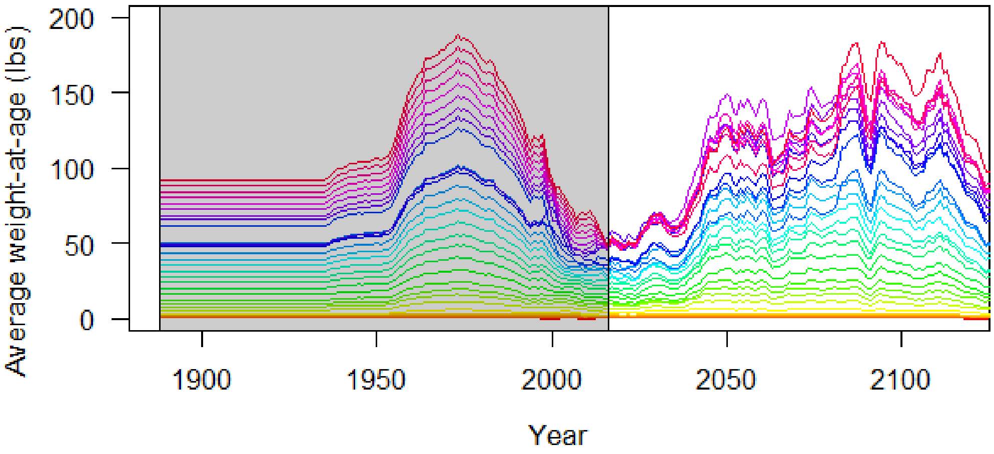

Figure 8: One potential simulated female weight at age in the historical period (1888-2016, shaded) and the simulated period (2017-2116).

SIMULATING REGIME SHIFTS

An environmental regime is used in the stock assessment to determine if average recruitment is high or low. This is based on the Pacific Decadal Oscillation (PDO, http://research.jisao.washington.edu/pdo/, Mantua et al. 1997, Figure 9) and the value is 0 or 1 depending on classified cool or warm years, respectively (Figure 10).

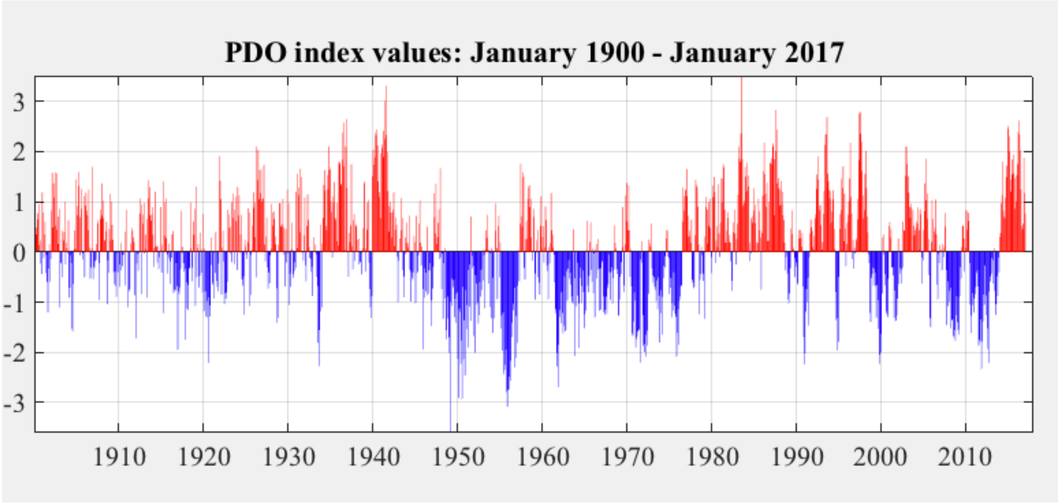

Figure 9: Pacific Decadal Oscillation (PDO) (figure from http://research.jisao.washington.edu/pdo/).

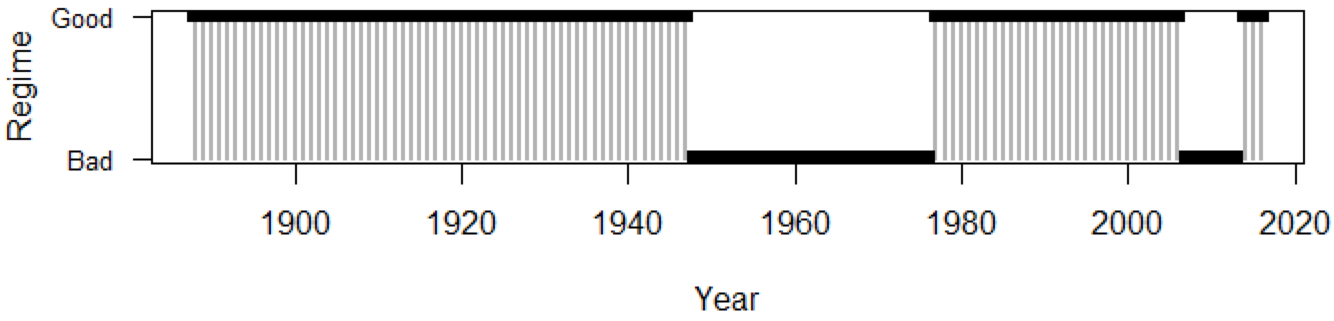

Figure 10: Good and bad regimes in the Pacific halibut stock assessment for 1888-2016.

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

The simulated length of a regime was most often between 20 and 30 years, with occasional runs between 5 and 20 years.

SOME ADDITIONAL SCENARIOS NOT CURRENTLY CONSIDERED

Some scenarios that were not considered, but will likely be considered in the future are:

Selectivity: It may be desirable for the time-varying selectivity for at least commercial gears to be linked to changes in weight-at-age.

Migration: Migration will require a multi-area model and hypotheses about movement. A multi-area model is being developed with four regions. Migration hypotheses will be informed by tagging data as well as other observations from various fisheries and surveys.

CONDITIONING THE OPERATING MODEL

The operating model (OM) should be a reasonable depiction of reality with an appropriate level of uncertainty. The OM consists of two stock synthesis (Methot and Wetzel 2013), models parameterized similarly to the short and long coastwide assessment models for Pacific halibut (Stewart 2015 appendix of RARA). Each model is conditioned by fitting to the same data used in the 2016 stock assessment (Stewart & Hicks 2017). To evaluate and choose management procedures that are robust to uncertainty in future states of the population, many assumptions in the assessment model were freed up to characterize a wider range of possibilities in the future. Estimating natural mortality for both sexes in both models and estimating steepness were the only changes to estimated parameters from the assessment model when conditioning.

Parameter variability was characterized by randomly sampling parameters for each simulation from a truncated multivariate normal distribution conditioned to data. Unrealistic simulated historical trajectories (e.g., the population could not support the observed catch) were eliminated.

The conditioned OM has a considerable amount of extra variability compared to the ensemble stock assessment (Figure 11). The assessment ensemble contains four individual models while the OM contains only two, which is why the trend at the end of the time series is slightly different, although well within the uncertainty.

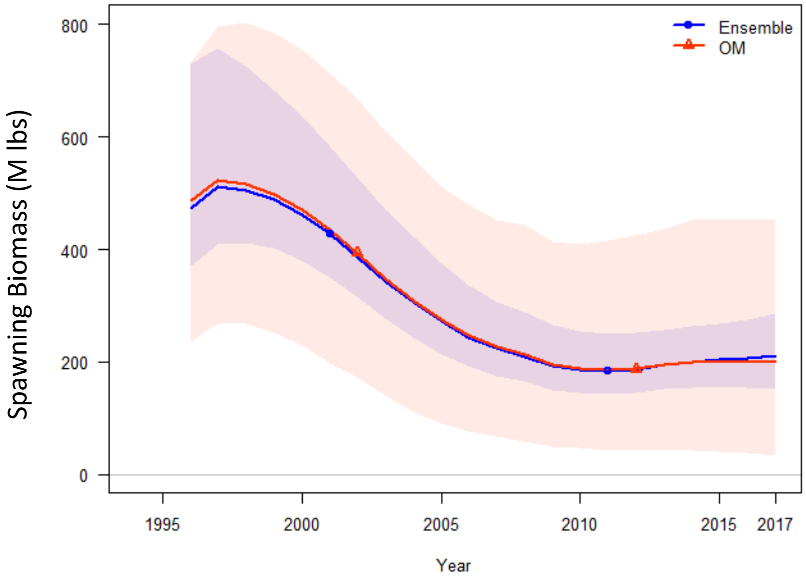

Figure 11: The conditioned operating model (red) compared to the stock assessment ensemble (blue) with 95% confidence intervals.

A potential issue highlighted at SRB11 was that starting the OM in 2017 with such a wide range of uncertainty will not adequately characterize our best knowledge of the near future (short-term) and the medium-term. However, the long-term results are appropriate since the current state would not have an effect, and the wide range of uncertainty is a result of the chosen uncertainties to evaluate harvest strategies against. One solution to provide short-term results would be to start the OM from the assessment model and its uncertainty (the blue shaded region in Figure 11). However, this may not be indicative of our best predictions for the short-term or medium-term because of the wider range of uncertainty in the parameters that will result in large deviations at the start of the simulations and because the OM is not the best representation of the current state of the population (i.e., the ensemble assessment is with four models).

Instead, we present results for the long-term to identify management procedures that meet the goals and objectives defined by the MSAB. These management procedures can then be further investigated using short-term predictions directly from the assessment model (1-3 years from the end of the time-series; 8-11 years from the most recent information on recruitment) to identify how they may affect the fishery now. For example, the decision table already presents risk metrics for various SPR values, and these results can be used to evaluate the immediate consequences to the fishery of a change in the harvest policy. Additionally, transitory behavior from the short-term to the long-term can be highlighted in future analyses. This may be describing the trends of various trajectories (e.g., catch or spawning biomass) between the short-term or long-term. For example, the short-term may indicate low catches with a higher catch on average in the long-term, but to get there, it appears that catches may be low for a short time before increasing.

The reason that it is difficult to quantify medium-term results is that we have very little predictive power for that time-period. In the short-term, we have an idea of where we currently are and what may occur in the next few years (e.g., we have some data indicating recruitment and weight-at-age). In the long-term, we are summarizing statistics over a wide range of uncertainty and all possible states (we do not need to know anything about the current state of the population). However, that uncertainty is not well described in the medium-term because it is partially dependent on the current state, but also affected by the wide range of possibilities. Therefore. it could be very misleading to present medium-term results as unbiased and informative predictions.

MSE RESULTS

Results from initial simulations were provided at MSAB010. Additional results will be presented at the MSAB011 Meeting.

RECOMMENDATION/S

That the MSAB:

1) **NOTE** paper IPHC-2018-MSAB011-08 which provided an overview of the simulation framework to evaluate the harvest control rule (fishing intensity and trigger) in the IPHC Harvest Strategy Policy.
2) **CONSIDER** the simulation framework and assumptions as described, including introducing variability to the OM, simulating weight-at-age and an environmental regime, and distribution of the Total Mortality to different sources of mortality.
3) **CONSIDER** the interpretation of short-term, medium-term, and long-term results.
4) **RECOMMEND** modifications to the simulation framework and assumptions.
5) **AGREE** on additional management procedures to evaluate in 2018 and report at AM095.

ADDITIONAL DOCUMENTATION / REFERENCES

Clark WG. 1993. The Effect of Recruitment Variability on Choice of Spawning Biomass per Recruit. Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Eds: G. Kruse, R. J. Marasco, C. Pautzke and T. J. Quinn. University of Alaska, Alaska Sea Grant College Program Report. 93-02: 233-246.

Harley SJ, Davies N, Tremblay-Boyer L, Hampton J. McKechnie S. 2015. Stock assessment for south Pacific albacore tuna. WCPFC-SC11-2015/SA-WP-06 Rev 1 (4 August 2015)

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APPENDIX A: A REVIEW OF THE HARVEST CONTROL RULE

The harvest control rule defines the fishing intensity on the coastwide stock (Figure 3) and incorporates a maximum fishing intensity and a control rule to reduce that fishing intensity when needed. It consists of a maximum fishing intensity (defined as a procedural SPR), a trigger defined by a stock status here the fishing intensity begins to be reduced (increase the procedural SPR), and a limit where theoretically the fishing intensity is set to zero. These are defined in more detail below.

MEASURES OF FISHING INTENSITY

Fishing intensity is a measure of how fishing is affecting the coastwide stock, and it is the element of the management procedure in determining the scale of the current harvest policy shown in Figure 1. An intuitive measure of fishing intensity is an exploitation rate, which is simply the catch divided by the exploitable biomass. Less intuitive, but similar, is instantaneous fishing mortality, which is used in an exponential function, as is M. These are obvious measures of fishing intensity for a single fleet, but become very complicated when considering multiple fleets with different selectivities or annual changes in selectivity.

Measures of fishing intensity have been developed that are more holistic and provide a meaningful measure of fishing effort on the stock of fish, rather than a specific portion. Many of these metrics focus on the effect of fishing on the spawning biomass, and often measure the long-term effects after fishing consistently at the same intensity. The following are some of the desired properties of a fishing intensity metric (many from pers. comm., Owen Hamel, NWFSC).

- As fishing effort increases, the fishing intensity metric also increases appropriately.
- Applies to simple as well as complex (i.e., multiple areas and fleets) models.
- Metric changes with changes in selectivity, and captures systematic changes in selectivity.
- Easy to compute.
- A scale that is easy to understand.

A commonly used metric is the spawning potential ratio (SPR), which is a measure of the effect of fishing on the long-term reproductive potential of the stock. This metric is currently used in the IPHC interim harvest policy.

SPR (spawning potential ratio) is a measure of the effect of fishing on the long-term reproductive potential of the stock. More specifically, it is the percentage of long-term, equilibrium spawning output-per-recruit when fishing at a constant fishing intensity (F_{SPR}), divided by the long-term, equilibrium spawning output-per-recruit without fishing. Spawning output for Pacific halibut is measured by spawning biomass. The higher the fishing intensity (F_{SPR}), the lower the SPR (Figure 12). For example, SPR=100% is, by definition, no fishing; and SPR=40% is a fishing level that reduces the equilibrium spawners-per-recruit (i.e., spawning potential) to 40% of the unfished level. The general equation for SPR is

$$SPR = \frac{\widetilde{SB}_F \big/ R_F}{\widetilde{SB}_{noF} \big/ R_{noF}} \tag{1}$$

where $\widetilde{SB}$ is the spawning biomass simulated forward to equilibrium with fishing (F) or without fishing (noF), and R is recruitment.

SPR, in general, is slightly different than simply dividing equilibrium spawning biomass when fishing by unfished equilibrium spawning biomass because SPR is on a per-recruit basis, thus eliminating the density-dependent effects of the spawner-recruit curve and simply measuring equilibrium spawning potential. In other words, SPR is the relative spawning potential of a recruit when faced with natural and fishing mortalities. SPR-based harvest policies are commonly used in the management of many fisheries around the world, including fisheries under U.S. fishery management council jurisdiction. An $F_{SPR=46\%}$ policy is currently the interim harvest policy at IPHC. Clark (1993) recommended that a $F_{SPR=40\%}$ for groundfish fisheries would maintain a high average yield.

To calculate SPR, the biology of the species (e.g., natural mortality, maturity, etc.), the selectivity for each fishery, and an overall fishing intensity (or fishing intensities for each fishery) are needed. The calculation of SPR always uses the biology and selectivities in the year of interest, thus accounts for changes in these parameters. However, an appropriate SPR for management should be robust to these changes.

This calculation of SPR is called static %SPR by Mace et al. (1996), and we will simply refer to it as SPR. Mace et al (1996) also presented the concept of “transitional SPR”, which looks at the impact of fishing on existing cohorts in the stock (those that were present back in time) and thus is more of a retrospective measure, rather than quantifying current or future impacts. We do not consider transitional SPR metrics because those metrics are better suited to determine the level at which a stock has been fished, rather than providing a metric of how the stock is to be fished. The static %SPR (from now on simply called SPR) provides a measure of SPR given the current biological regime, fishery patterns, and a fishing intensity (F_{SPR}). See Mace et al. (1996) for further discussion of the difficulties calculating transitional SPR.

The metrics SPR and F_{SPR} has been reported in previous Pacific halibut assessments and are commonly calculated in many stock assessments around the world. It is a useful metric because it accounts for complex and temporally changing population dynamics and selectivities. It can be thought of as a measure of the spawning potential given fishing under the current conditions.

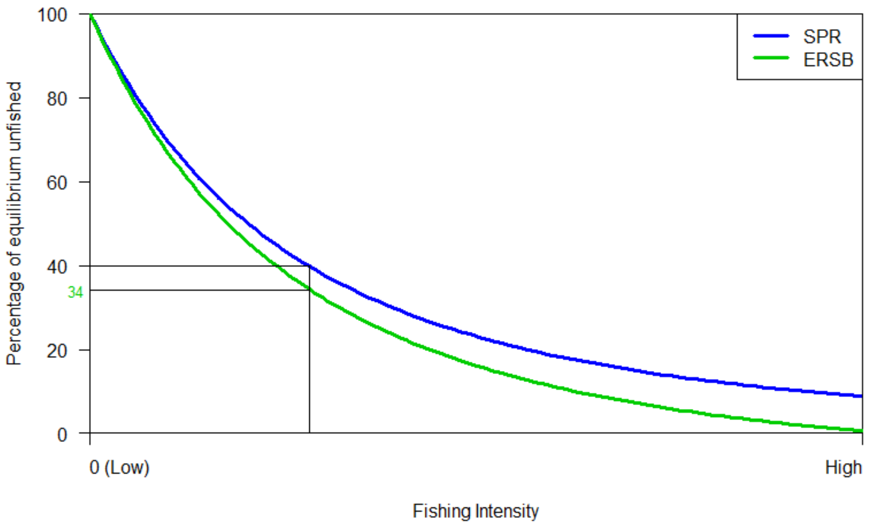

Figure 12: SPR (spawning potential ratio) and ERSB (equilibrium relative spawning biomass) plotted against fishing intensity for a generic equilibrium model with constant recruitment (unweighted SPR) and time-invariant biology and selectivity.

ERSB (Equilibrium Relative Spawning Biomass): the long-term equilibrium relative spawning biomass given a level of fishing. Relative spawning biomass (RSB) is the percentage of equilibrium spawning biomass with fishing ($F_{XX\%}$) relative to that without fishing. ERSB was called ESD, or Equilibrium Stock Depletion, by Cordue (2012), but the term relative spawning biomass is used at the IPHC instead of depletion. The calculation is simply the equilibrium spawning biomass when fishing divided by unfished equilibrium spawning biomass. The calculation uses constant recruitment, and accounts for density-dependence of the stock-recruit relationship. In other words, this is the effect of fishing on the deterministic spawning potential of the stock, which reflects the decline in recruitment as the spawning biomass declines.

$$ERSB = \frac{\widetilde{SB}_F}{\widetilde{SB}_{noF}}$$

where $\widetilde{SB}$ is the spawning biomass simulated forward to equilibrium with fishing (*F*) or without fishing (*noF*). The only difference from SPR is the division by the number of recruits, and ERSB can be easily calculated from SPR using the following equation (with a Beverton-Holt stock-recruit relationship).

$$ERSB = \frac{4hSPR + h - 1}{5h - 1} \tag{2}$$

where h is steepness in the Beverton-Holt stock-recruit relationship. Notice that when steepness is equal to one (constant recruitment at all spawning stock sizes), ERSB is equal to SPR.

As with SPR, when temporal trends are present, the biology and selectivity used when calculating ERSB can affect the outcome. It is proposed to use the current conditions and project forward to determine the equilibrium spawning biomass with and without fishing. This keeps ERSB consistent with SPR and maintains the relationship in Equation (2). However, SPR and ERSB are similar metrics that can be calculated from one another, thus only one should be used for setting fishing intensity. RSB is currently used in the 30:20 control rule of the harvest policy, which may be a useful place in the harvest policy to use ERSB as a translation of the SPR value to a target RSB. However, RSB is slightly different than ERSB because the denominator in RSB is consistently B_0, which does not consider current biological conditions (but defined equilibrium conditions) when calculating. We'll discuss this more in the Control Rule section below.

CONTROL RULE

The control rule is an additional part of the harvest policy that affects the fishing intensity or FCEY. The premise of a control rule is that if the stock declines below a **trigger** reference point (typically measured using stock status) the fishing intensity is reduced, and if the stock declines below a **limit** reference point there is no harvest. This is used to avoid low stock sizes by acting in a precautionary manner when the stock size begins to approach the limit reference point. The current IPHC control rule is called a 30:20 rule because the trigger is 30% RSB and the limit is 20% RSB (Figure 13).

The multiplier can act on the fishing level (i.e., fishing intensity) or the catch (i.e., FCEY), and it would be somewhat straightforward for the fishing intensity to be adjusted. For example, if $F_{SPR=46\%}$was the fishing intensity, the F could be adjusted, or the SPR could be adjusted. The relationship between SPR and FI is nonlinear (Figure 12) thus a linear adjustment to one would result in a nonlinear adjustment to the other. It is most straightforward for the SPR to be adjusted.

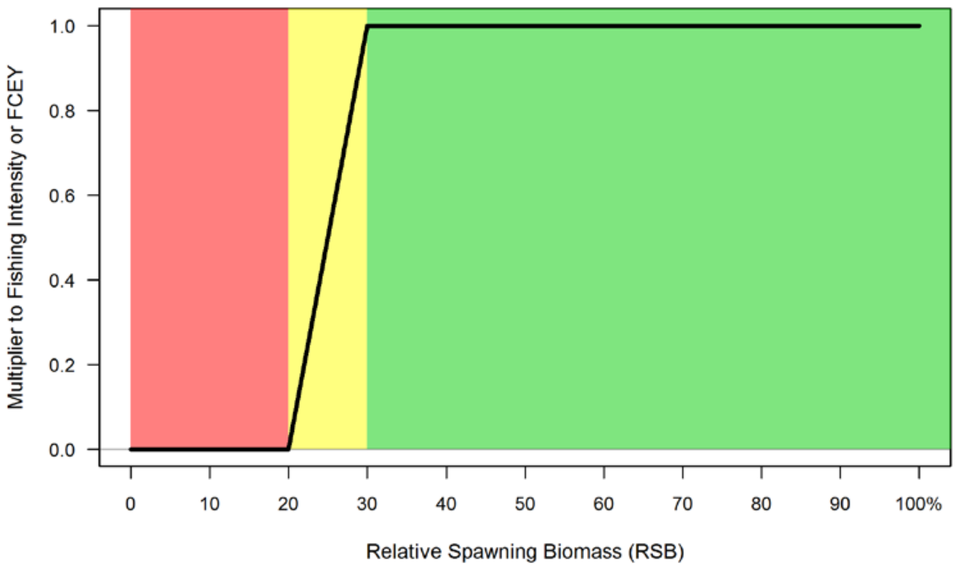

Figure 13: Control rule for the IPHC harvest strategy policy. It is commonly called a 30:20 control rule because the downward adjustment begins at a relative spawning biomass (RSB) of 30% (trigger reference point) and no harvest occurs when the RSB is below 20% (limit reference point). The adjustment may apply to the fishing intensity or to the FCEY.

Adjusting the catch may be more difficult because there are portions of the catch that are not directly controlled by the IPHC. It would be possible to adjust the FCEY, but the other components of the TCEY as well as the U26 mortality would not be adjusted. This also brings up an important point about adjusting the fishing intensity, which defines the total mortality, some of which is not controlled by the IPHC. Therefore, the fishing intensity would not decline to zero when below the limit threshold unless cross-agency management measures were agreed upon.

The current IPHC assessment used RSB to determine stock status with a static unfished equilibrium biomass (B_0), calculated assuming good size-at-age and poor recruitment, as the reference. This static definition has many potential problems. First, it is not necessarily reflective of current conditions. Second, if fishing were to stop and current conditions remained constant, the RSB would not go to one, but could be less than or greater than one. Lastly, a change in conditions could potentially result in a RSB below the trigger even without fishing. In some cases a specific static reference point may be the desired target, but not accounting for current conditions may be misleading when managing a dynamic stock subject to changing conditions.

SPR is currently used to define fishing intensity, which is an equilibrium concept using current conditions. When a target SPR is defined, a target ERSB is also defined (assuming the Beverton-Holt stock-recruit curve and a value for steepness). With a target related to stock status one may also define a trigger and limit in relation to that target (Figure 14). However, the x-axis of the control rule (stock status) should also be based on current conditions instead of a static definition.

A dynamic quantity to define current stock status is needed to be consistent with SPR and ERSB, and could be used to determine at what stock status fishing intensity is reduced. A desirable property for the current status may be that if fishing had not occurred on all age classes in the population, then the calculation of the status would result in a value of one. In other words, the current status would be a measure of the effect of fishing and not include the effect of changing conditions or recent deviations in recruitment. Dynamic B_0 (McCall et al. 1985) is a dynamic calculation of stock status that uses the conditions and recruitment deviations that the stock has recently experienced. It also corrects for the reduction in average recruitment due to the stock-recruit function. This quantity has also been used in tuna assessments (Harley et al 2015).

Using SPR and translating that to ERSB results in consistent equilibrium quantities for fishing intensity and target stock status. Dynamic B_0 is the consistent link to determine the current fishing effect on stock status, which we call dynamic RSB (dRSB). Using these three quantities (SPR, ERSB, and dRSB) provides for a control rule where each component relates to each other in a meaningful way. For example, a stock would be expected to fluctuate around a target ERSB due to natural variability in recruitment. It is likely that dropping below the trigger is not a highly desired state due to a curtailing of fishing effort, and if the trigger was near the target, it would be crossed often due to variability in the population. Setting the trigger less than the target reduces the probability of curtailing fishing effort and builds the stock back to expected levels when the current stock status is lower than desired. However, if the desire is to build back to the target as quickly as possible, a trigger closer to the target may be useful.

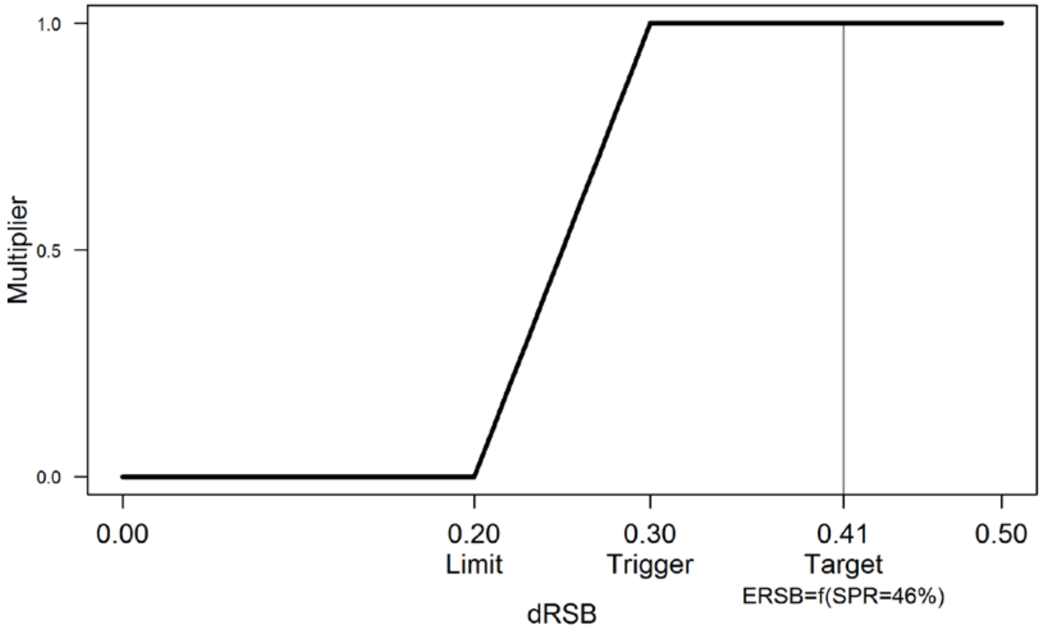

Figure 14: Components of the control rule (expressed as a multiplier on fishing intensity).

A concern may be that in extreme cases where non-fishing related influences result in a static stock status below a trigger, the dynamic approach would not reduce the fishing intensity appropriately to maintain a minimum spawning biomass or spawning abundance. Using SPR to define a fishing intensity helps to alleviate this concern since it determines a relative spawning potential. Even though SPR is based on current conditions, it still maintains a minimum spawning potential.

A consistency between reference points is useful because it helps to relate the different components of the harvest control rule to each other and define meaningful values.