Discussion Paper:

BSAI Halibut Abundance-based management (ABM) evaluation methodology[1]

May 30, 2018

Contents

1 Overview

In April 2018 the Council initiated an analysis of several alternatives for setting abundance-based PSC limits for Pacific halibut. In conjunction with this, the Council requested a summary of planned approaches for the analysis of these alternatives for presentation to the SSC. This includes an overview of different tools and their pros and cons and recommendations on simplified methods. The working group seeks input from the SSC on which modeling approach or approaches should be used for this analysis. Additionally, we revisit and review the performance metrics developed for evaluating the alternatives. To advance the Council's objectives for proceeding with preliminary analysis, we propose some

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simplifications to the alternative set (Appendix A). A draft plan of items to include for the October 2018 discussion paper to assist the Council in refining alternatives is provided at the end of this paper.

2 Analytical methods

We discuss three approaches proposed as tools for analyzing the ABM alternatives. The first is the multi-species technical interactions (MSTI) framework (previously presented to the SSC in April 2016). The MSTI framework (Approach 1) is a relatively sophisticated modeling approach, accounting for catch patterns and constraints for EBS halibut, pollock, Pacific cod, and yellowfin sole stock and fleet dynamics. The second proposed approach is a simple single species two-area halibut model (Approach 2). This single-species model is intended to reflect the halibut population dynamics in the BSAI (one area) and allow for simple hypotheses about the relationship to the coastwide (the other area) halibut stock. This approach would evaluate the impact of alternative PSC limits on the halibut stock. Impacts to groundfish fisheries and stocks would be evaluated by comparing these PSC limits to those observed in the past and assume fleet behavior observed at various PSC limits and for various states of the halibut stock. The third model, which we call the two-species model would model 2 species groups: halibut and groundfish (Approach 3). This model would calculate the dynamics of the halibut and single-species groundfish populations and allow for trawl and longline selectivity in both the halibut and groundfish models to account for removals from each population. These approaches are discussed in more detail in the following section. They are structured to note the extent of changes and further development that would be needed to analyze the ABM alternatives (including estimated timelines for completion), Tradeoffs (pros and cons) are also provided.

2.1 Approach 1: Multi-Species Technical Interactions Model (MSTI Framework)

2.1.1 Description

This approach is a framework for conducting management strategy evaluation for the BSAI system that takes into account the ABC-setting process, the constraints that contribute to the TAC-setting process, and broad-scale fleet dynamics. The current implementation includes walleye pollock, Pacific cod, and yellowfin sole, the three target species in the BSAI that together historically compose about 1.7 million t out of the 2 million t OY overall groundfish catch limit. Additional species such as flathead sole and northern rock sole could be added to the model. An additional module, modeling halibut population dynamics is in development. A version of the MSTI framework without the module for halibut population dynamics (modeling a static cap on halibut bycatch as a constraint on catch limits) is in press at the Canadian Journal of Fisheries and Aquatic Sciences (Ono et al. 2018).

The MSTI framework includes an operating model (OM; a representation of our best idea of the true dynamics of the system) that includes age-structured models for the population dynamics of the three target species. These are based on outputs from AFSC stock assessments. Adding an age-structured Pacific halibut model to this framework could mimic those developed as separate tools (described below) but is currently incomplete.

Briefly, the operating model is used to generate data for the three target species assuming observation errors. These data are then fitted using a simplified statistical catch-at-age assessment model for each species (much like the assessment models that are used for AFSC Tier 3 and Tier 1 stock assessments). From the estimation models, ABCs are produced for each of the target species which are then supplied to a constrained optimization module (linear programming or LP model). The ABCs are treated as upper limits in the LP optimization, which together with other constraints and relative values of the species, are part of the optimization used to mimic the TAC-setting process. Specifically, this LP model optimizes net revenue (based on perceived net prices for each species) and takes into account the following constraints:

1) the 1.7-million ton cap (assuming the rest of the 2-million ton cap would be allocated to the excluded other groundfish species),
2) the halibut bycatch limit (the analysts would add code to model the Council alternatives to calculate this limit),
3) the ABCs, and
4) fishery expansion factors that limited changes in the composition of catch by area/sector clusters (métiers) caught together in each year.

The calculation of net revenue includes a simulated net price for each species in each year, multiplied by the catch of each species in each year, where simulated net price is initially calculated such that TACs resulting from the model match those that were implemented in 2014. Future net prices were simulated by a sigmoid curve to be within the range of those that would apply to the TACs observed for each species in 2010–2014.

In the model, the realized catches can differ from the TACs due to accounting for fleet dynamics. Fishery selectivity for each target species is represented by a single asymptotic curve for selectivity-at-age based on outputs from stock assessments. Therefore, it is assumed that the distribution of catches by age by each relevant gear type and sector could be represented by one average relationship for each target species. A second LP model similar to the one described above for determining TAC's was used for determining realized catches for each species, with a couple of adjustments, as follows: (1) the perceived net prices were calibrated based on realized catches rather than TACs for 2010-2014, (2) each species was constrained by its TAC, rather than its ABC, and (3) the catch composition of area/sector clusters (métiers) was adjusted according to proportional changes in the spawning biomass for each species.

2.1.2 Critique

One advantage to using the MSTI framework for the analysis of ABM alternatives is that the framework has gone through peer review and is already published as a proof-of-concept paper. However, the SSC reviewed an earlier version of the MSTI framework in April 2016 and made several recommendations in the meeting minutes. The SSC noted that this is a promising tool for analysis, but that several changes should be made to improve the realism of fleet behavior and economics. Most of the SSC's comments were addressed and appear in the published paper (Ono et al. 2018). However, one recommendation would require substantial work, depending on its interpretation:

> *"The structure and parameterization of the MST is largely informed by and based on empirical observations. To enhance the ability of the model to predict future catches and TACs, the SSC suggests that the developers explore mechanistic interactions where appropriate. The analysts should explore calibrating the model on the basis of past observable characteristics, for instance, allowing changes in catch composition and net prices to be functions of changes in abundance. By doing so, the MST would be readily available for producing out-of-sample predictions (e.g. one-year-ahead predictions). We also note that development of the model could benefit from interactions with AFSC economists."*

The development team has been interacting with AFSC economists to explore this recommendation. One change was made to the model prior to publication such that catch composition and net prices are functions of changes in abundance, so the recommendation has been addressed at a basic level. Currently, three AFSC and university economists are in the midst of a separate project to explore mechanistic relationships between past observable factors and resulting catch composition and net prices. This work is in progress, and in the future its results could be mechanistically modeled within the MSTI framework to improve prediction of fishing fleet dynamics under various harvest policy alternatives. AFSC economists expect to complete their research in approximately two years and at that time could collaborate with model developers to incorporate their findings into the MSTI framework. In the meantime, the framework could be updated to include options for assuming two or three hypotheses for the mechanics of fleet dynamics such that the analysis can show the effects of our uncertainty about drivers of future fleet behavior.

The MSTI framework has the potential to provide quality science advice on the objectives outlined in the Council's Purpose and Needs statement with a completed Pacific halibut module. In addition, the MSTI framework would provide outputs on spawning biomass, catches, and stability of catches for the three target species modeled within the framework; these outputs could be used to calculate any performance metrics related directly to these species that are desired. However, as with many analyses of this type, this approach requires assumptions about fleet dynamics based on historical catch observations. Future conditions and fleet behaviors are likely to differ in ways that are difficult to predict.

The concept of métiers used in this approach is an organizing principle for describing what species are caught together. The métier approach uses a cluster analysis to group NMFS areas and vessels with similar catch composition characteristics. However, as described above, the operating model assumes a single, asymptotic selectivity curve can adequately represent the distribution of catch at age for each species in aggregate. As the ABM alternatives include gear-specific PSC limits with relative proportions changing over time, the current MSTI implementation requires modifications to account for such changes in catch constraints by gear type. Furthermore, while an advantage of the métier approach is to capture the dynamics of the system in aggregate using a simple design, the mosaic of sectors within gear types, each with differing incentives, is unable to be well represented using this approach. Therefore, the ability to predict future system dynamics under sector- or gear-specific harvest policies may be limited. The métiers could be modified to be gear-specific or sector-specific, which could assist in dealing with sector-specific alternatives.

This framework has a reasonable level of detail for tracking target species population and system dynamics compared to the other tools currently available. This approach will inform a broader set of performance metrics, but the higher level of complexity may require more time and work and also complicate interpretation of results. To help with this problem it may be possible to simplify the assessment step. As implemented, a full stock assessment for each target species is conducted in each projection year. For the analysis of the ABM alternatives, the added detail of evaluating the sensitivity of mismatches between the estimation and operating model is less important and could be omitted. Instead, one could replace the species-specific statistical catch-at-age analyses with an error term applied to the spawning biomass in the operating model to represent observation and estimation error.

It may be worthwhile to add one or more additional flatfish species to the model (flathead sole or northern rock sole). Historically, the price of flathead sole has been highest of the federally-managed groundfish species, but realized catches have been low historically, presumably because targeting is limited to avoid PSC. If the PSC limit were less limiting, a potential increase in targeting of flathead sole could occur and this could be demonstrated with the MSTI model.

2.1.3 Timeline for use of the MSTI framework as a tool for analyzing ABM alternatives

The following timeline outlines the steps and time necessary to bring the MSTI framework from its current state to that recommended by the SSC for use as an analytical tool for providing science advice on ABM alternatives. Note that difficulties occur when conducting scientific research, especially when working with a complex model such as the MSTI framework, and timelines may need to be adjusted to accommodate unforeseen difficulties.

- **October 2018**:
  - Add rudimentary Pacific halibut model
  - Include option for a simpler assessment step in the MSTI framework
  - Report on issues related to PSC constraints by gear-specific métiers
- **January 2019**
  - Refine Pacific halibut population dynamics model
  - Add any relevant additional species to the MSTI model
- **April 2019**:
  - Complete re-working of métiers to be gear- or sector-specific
  - Complete coding of fleet behavior alternatives
- **October 2019 or April 2020**: Complete of preliminary results using the MSTI model, with additions above only and without incorporating the results of the current study of fleet behavior underway by AFSC and university economists to predict out-of-sample fleet behavior and model dynamics
- **October 2020 or April 2021**: Complete additional scenarios, such as changes in size-at-age and PDO-driven recruitment phases

2.2 Approach 2: Single species two-area Pacific halibut simulations (Halibut PSC Limit Simulation Framework)

2.2.1 Description

This framework is implemented as a single-species MSE that uses an age- and sex-structured population dynamics model of Pacific halibut as an operating model (OM; a representation of our best idea of the true dynamics of the system). Equations for this OM are detailed in Appendix C. The model will be parameterized based on estimates from the current Pacific halibut assessment (which is an ensemble of four statistical catch-at-age assessment models). The OM includes sex-specific natural mortality and fishing mortality. Three age-based selectivity curves are modeled in the OM, each representing a sector (the directed halibut fishery, PSC, and a personal/subsistence use fishery), with discard mortality rates specified for each sector. To replicate model and implementation uncertainty in the Pacific halibut management process, data are simulated and inform a simple stock assessment model that is used to identify exploitable biomass and target harvest rate for defining the Total Constant Exploitation Yield (TCEY). Data are generated from the operating model by simulating random observation errors of appropriate distribution. Two estimation models are available within the framework: a Pella-Tomlinson production model and a simple statistical catch-at-age model. Notably, the estimation model is structurally different than the model ensemble used by IPHC scientists. For an analysis of ABM alternatives, it may be preferable to simulate the estimation error instead of using an estimation model, which would avoid the extra step of simulating and analyzing data. The estimation error could be specified to introduce biases to mimic potential assessment biases.

2.2.2 Critique

The halibut OM described above could easily be adapted to be specific to the BSAI for this analysis. A clear correlation is lacking between recruitment of halibut in the BSAI and recruitment to the coastwide directed IPHC fishery and setline surveys in later years. This could indicate that the recruitment contribution of Pacific halibut observed in the BSAI to the coastwide stock is relatively minor. Alternatively, it could indicate that recruitment sources vary among multiple areas, including the BSAI, depending on conditions in a way that confounds detection/estimation. The model can be configured for these alternative hypotheses, noting that some alternatives for analysis require the coastwide halibut spawning biomass as an input.

1. An adjustment could be made to natural mortality in the BSAI halibut model to account for fish that recruit in the BSAI and then leave the BSAI to join some other area of the halibut stock. Meanwhile, a simple production model could be used to represent trajectories of the coastwide spawning biomass and a downstream correlation coefficient could be applied to represent recruits from the BSAI that contribute to the coastwide stock. This correlation coefficient could be set to zero in one scenario to represent the hypothesis that no downstream effects occur (BSAI recruits do not contribute to the coastwide stock), or to the highest level of correlation seen between BSAI recruitment and downstream coastwide numbers. Aside from the correlation coefficient, the coastwide spawning biomass trajectory would operate independently of the BSAI halibut model.

2. The OM could be expanded to be a two-area model, with the BSAI as one area and the remainder of the coastwide stock as the second area. Immigration and emigration rates could then be modeled between the two areas and the spawning stock biomass in each area would be summed to obtain the coastwide spawning biomass.

The Pacific halibut catch limit (TCEY) needs to be determined within the model for the BSAI area, and then allocated to the various fisheries (e.g., PSC and directed). For all of the approaches, modeling of the IPHC's management procedure would require careful consideration, as the IPHC catch limit specification process is currently being developed, and historically has involved complex and non-formulaic considerations. Instead of attempting to model the IPHC catch limit specification process consisting of a coastwide fishing intensity and the distribution of catch limits to IPHC Regulatory Areas, the TCEY could simply be related to available biomass in the modeled area. Previous years could be analyzed to determine the relationship between the harvest policy recommended coastwide TCEY for Pacific halibut and the estimated biomass. Furthermore, the variability in the TCEY that results after decision making for the regulatory areas within the BSAI could also be determined. Quantifying this relationship and the interannual variation therein, it would be possible to incorporate this variation in our simulations. It may also be necessary to model various scenarios to represent the potential future relationships between estimated biomass and the resulting TCEY allocated to the BSAI, given possible changes to the IPHC harvest policy. All of these sources of uncertainty can easily be included in the analysis.

Quantifying the impacts to groundfish fisheries, including calculating performance metrics associated with the Council objective stating that "There should be flexibility provided to avoid unnecessarily constraining the groundfish fishery particularly when halibut abundance is high" would be assessed using model results for PSC limits and an empirical approach based on past patterns. The PSC limits resulting from the halibut simulation model would be compared to the available biomass of halibut to the groundfish fisheries as a measure of how many halibut may be encountered compared to the available PSC limit. The empirical approach would involve examining simulated PSC limits in the context of historical PSC use, limits, and halibut abundance, along with historical responses to those limits and proportion of TAC achieved by relevant species and sectors in the groundfish fishery. This empirical accounting for impacts to groundfish is similar to the methodology used by Marcus Hartley in his 2015 analysis of changes to PSC caps, but the halibut population dynamics model included in our approach is more sophisticated. Relative net revenue achieved by each sector in the groundfish fishery under historical conditions could also easily be included. One disadvantage of this approach is that it is not very informative about what would happen in the event of unprecedented low or high PSC limits, along with unprecedented halibut population states, in relation to groundfish TACs and groundfish population states.

Currently the halibut simulation model lumps the PSC fishery into one category using a single selectivity curve. To analyze gear-specific PSC limits it will be necessary to distinguish longline from trawl PSC. In addition, time-varying selectivity could be modeled and parameterized based on recent observations to allow for the model to account for changes in size-at-age that have occurred in recent years.

Pacific halibut experience high and low phases of recruitment that appear to be linked to the Pacific Decadal Oscillation. Pacific halibut stock status may be substantially different during a high recruitment phase than for a low recruitment phase and these would be important scenarios to model for the ABM analysis. Likewise, size-at-age of halibut have fluctuated substantially over the years. Currently, size-at-age is particularly low in some regions relative to historical norms. High size-at-age and low size-at-age scenarios will be important to model in the analysis as well.

2.2.3 Timeline for use of the Halibut PSC Limit Simulation Framework as a tool for analyzing ABM alternatives

The following timeline outlines the steps and estimated time necessary to update the two-area halibut simulation model for use as a suitable analytical tool for providing science advice on ABM alternatives. Note that difficulties occur when conducting scientific research, especially when working with complex modeling tools, and timelines may need to be adjusted to accommodate unforeseen difficulties.

- **October 2018**
    - Complete coding option for a simpler assessment step in the framework
    - Complete adaptation of model to represent both BSAI and coastwide stock separately
    - Add sector-specific selectivity to the OM
    - Complete coding current ABM alternative set
    - Complete a “perfect information” scenario for Alternatives 1-4 for a subset of elements and options
- **February 2019**: Refine and build on the “perfect information” scenario
- **October 2019**: Complete results for a subset of the alternative and scenario set
- **April 2020**: Complete additional scenarios, such as changes in size-at-age and PDO-driven recruitment phases

2.2.4 The April 2017 Halibut Simulation Model

A halibut simulation model was presented at the April 2017 meeting, which could be adapted to conduct an analysis of alternatives. It was determined that the “Two-area halibut simulation model” is similar to the model that was presented in April 2017 but incorporates a couple of key elements that would need to be added to the April 2017 model (for instance, making the model sex-specific, as halibut males and females grow to different sizes and at different rates). Therefore, we focus on describing the two-area halibut simulation model described above (Approach 2) in lieu of the model presented in April 2017. However, merging ideas from this simple model into the two-area halibut simulation model (e.g., a single-area model with a simplified “outside” area, as described above) could possibly quickly produce a useful model for analysis on ABM alternatives.

2.3 Approach 3: The Two-Species (halibut and groundfish) Framework

2.3.1 Description

This approach would need to be developed for this analysis. It would use the two-area halibut simulation model described above as a starting point and would include an OM that is a halibut population dynamics model linked to a population dynamics model for a generic groundfish species. The groundfish OM could be conditioned based on estimates from assessments of any desired groundfish species. Scenarios could be run for pollock, Pacific cod, and yellowfin sole separately. Both population dynamics models would include trawl and longline fishery selectivity curves. The relative amount of catch that was PSC vs a particular groundfish species in total in a recent year or set of years could be used to initialize the model. AFSC economists have conducted a simple regression analysis to estimate the proportion of ABC that is specified as a TAC for a particular species, and for estimating the amount of realized catches resulting from a TAC for a particular species. This information is currently being used in the ACLIM model (which focuses on biological interactions among key species in the BSAI). This regression analysis could be expanded to consider halibut stock status and halibut PSC limits and its results could be used in the two-species model as a tool for predicting likely TACs and realized catches for ABM analysis. A simplified estimation step could be included in this framework, which would involve multiplying spawning biomass for each species by an error term meant to represent observation and estimation error (as suggested for the other modeling frameworks described above).

2.3.2 Critique

This approach would require the changes discussed above for the two-area halibut simulation model, the difficulties described above in modeling the IPHC's management procedure and would require development of an age- (and possibly sex-structured) groundfish population dynamics model. Harvest control rules would need to be simulated for groundfish based on Tier 1 or Tier 3 management as specified in the BSAI Fishery Management Plan; this should be fairly straightforward.

An advantage of the two-species model is that potential impacts to groundfish species and fisheries could be quantified through modeling and additional economic analysis of model outputs. This may provide more information on potential impacts to the groundfish fleet than is possible using the two-area halibut simulation model, while maintaining a model that is as parsimonious as possible, given the problem at hand. However, the two-species model would make the assumption that historical relationships between PSC, halibut stock status, groundfish species' stock status, and TAC's and realized catches would remain the same under future scenarios. That is, the two-species model does not include sophisticated fleet behavior and a mechanistic model of fleet behavior to provide for robust out-of-sample prediction. In addition, changes in targeting decisions cannot be taken into account by the two-species model; tracking changes in targeting decisions would require the use of the MSTI Framework.

2.3.3 Timeline for Two-Species Framework

- **October 2018**:
  - Complete tasks scheduled for the two-area halibut simulation model
- **February 2019**:
  - Complete a rudimentary a generic groundfish simulation model
  - Refine the two-area halibut simulation model
  - Refine the perfect information scenario for the two-area halibut model
- **October 2019 or April 2020**
  - Complete perfect information scenario for two-species model
  - Complete preliminary results for a subset of the alternative and scenario set
- **April 2020 or October 2020**:
  - Complete results for a subset of the alternative and scenario set
  - Complete additional scenarios, such as changes in size-at-age and PDO-driven recruitment phases

3 Synthesis of modeling approaches

The working group seeks input from the SSC on which modeling approach or approaches should be used for this analysis. The MSTI model would require a longer timeline for analysis but would provide outputs to inform impacts to both halibut and groundfish populations that would take into account potential changes in targeting decisions in the groundfish sector and resulting effects on population dynamics of halibut and groundfish. Performance metrics could be calculated directly from the MSTI model to assess the ability of alternatives to meet Council objectives whether impacts to groundfish populations would occur. The two-area Pacific halibut simulation framework would be available to produce results for a "perfect information" scenario (which assumes that the spawning stock biomass estimates which uses exact quantities without estimation error from the simulated population are used in control rules to determine catch limits) in October 2018 and would provide outputs to inform whether Council objectives were being met. Impacts to groundfish populations would be assessed based on a comparison of expected encounter rates of Pacific halibut throughout history as compared to the PSC limits produced by the model. The two-area Pacific halibut simulation framework would not model groundfish populations and out-of-sample predictions of groundfish population dynamics could not derived. The two-species model would require an intermediate timeline for analysis and would provide a model of both halibut and groundfish population dynamics for use in evaluating whether Council objectives could be met by each alternative. Outputs on groundfish population dynamics could be used to assess potential impacts to groundfish populations but would not take into account changes in targeting decisions within the groundfish fleet that would likely occur with changes PSC limits and changes in the relative biomass of groundfish species.

One way to move forward while also responding to the timeline for analysis specified by the Council (to provide a preliminary analysis at the October 2018 Council meeting) would be to use the two-area halibut simulation model for preliminary analysis to refine the alternative set and corresponding elements and options and to report performance metrics related to Council objectives. Subsequently, and on a longer timeline, the MSTI framework could be used for an analysis that reports on outcomes related to Council objectives as well as impacts to fleets and groundfish populations in the context of an Environmental Impact Statement (EIS).

Alternatively, the SSC could select one of the modeling frameworks described above as a sole framework for analysis to be used both for reporting on the ability of alternatives to meet Council objectives and to provide information on impacts to fleets and groundfish populations in the context of an EIS.

The Pacific halibut catch limit (TCEY) needs to be determined within the model for the BSAI area, and then allocated to the various fisheries (e.g., PSC and directed). For all of the approaches, modeling of the IPHC's management procedure would require careful consideration, as the IPHC catch limit specification process is currently being developed, and historically has involved complex and non-formulaic considerations. Instead of attempting to model the IPHC catch limit specification process consisting of a coastwide fishing intensity and the distribution of catch limits to IPHC Regulatory Areas, the TCEY could simply be related to available biomass in the modeled area. Previous years could be analyzed to determine the relationship between the harvest policy recommended coastwide TCEY for Pacific halibut and the estimated biomass. Furthermore, the variability in the TCEY that results after decision making for the regulatory areas within the BSAI could also be determined. Quantifying this relationship and the interannual variation therein, it would be possible to incorporate this variation in our simulations. It may also be necessary to model various scenarios to represent the potential future relationships between estimated biomass and the resulting TCEY allocated to the BSAI, given possible changes to the IPHC harvest policy. All of these sources of uncertainty can easily be included in the analysis.

4 Performance metrics

The Council and stakeholders began the process of developing performance metrics for this analysis in 2017 (February 2017 workshop, June 2017 Council meeting). The Working Group continues to modify these for the preliminary analysis of alternatives.

Choosing between different ABM management alternatives can be done by comparing how each alternative meets defined objectives. Therefore, it is important to define detailed objectives with measurable outcomes. Typically, overarching goals are defined first and translated into measurable objectives, and there may be multiple measurable objectives for each goal. Sometimes it is helpful for analysts to ask stakeholders and decision-makers questions which can then lead to measurable objectives.

For example, a question related to an overarching goal of "maintaining a healthy fish stock" may be "Is there a minimum spawning stock abundance that is desired?" which may lead to a measurable objective of "keeping the spawning stock above a certain abundance for a specified number of years with a specified probability." This measurable objective has an outcome ("a certain abundance"), a time-frame ("a specified number of years") and a probability or acceptable risk level. A performance metric can then be defined to evaluate whether a measurable objective has been achieved (e.g., the probability that the spawning stock abundance is above a certain level over a specific number of years).

A draft list of performance metrics is provided in the table below in conjunction with the current suite of alternatives and the Council's overarching 5 objectives for this action. The purpose and need statement for this analysis, overarching objectives and draft of revised measurable objectives and performance metrics are provided below. These will continue to be developed as the preliminary analysis moves forward.

4.1 Council Purpose and Need

"The current fixed yield-based halibut PSC caps are inconsistent with management of the directed halibut fisheries and Council management of groundfish fisheries, which are managed based on abundance. When halibut abundance declines, PSC becomes a larger proportion of total halibut removals and thereby further reduces the proportion and amount of halibut available for harvest in directed halibut fisheries. Conversely, if halibut abundance increases, halibut PSC limits could be unnecessarily constraining. The Council is considering linking PSC limits to halibut abundance to provide a responsive management approach at varying levels of halibut abundance. The Council is considering abundance-based PSC limits to control total halibut mortality, particularly at low levels of abundance. Abundance based PSC limits also could provide an opportunity for the directed halibut fishery, and protect the halibut spawning stock biomass. The Council recognizes that abundance-based halibut PSC limits may increase and decrease with changes in halibut abundance."

Council objectives inferred from the Purpose and Need for this action to form overarching goals:

1. Halibut PSC limits should be indexed to halibut abundance.
2. Halibut spawning stock biomass should be protected especially at lower levels of abundance.
3. There should be flexibility provided to avoid unnecessarily constraining the groundfish fishery particularly when halibut abundance is high.
4. Provide for directed halibut fishing operations in the Bering Sea.
5. Provide for some stability in PSC limits on an inter-annual basis.

These overarching goals were used to formulate draft measurable objectives from which to derive performance metrics, building upon work by the Council and stakeholders in 2017. These overarching goals may be in competition with each other.

4.2 Summary of performance metrics

Table 1 lists performance metrics and features relative to Council objectives (and how they might be measured).

Table 1. Council objectives and overarching goals (first column) and measures and characteristics of performance metrics that might apply for contrasting future alternative PSC management measures.

Council Objectives	Measurable objective	Threshold	Time Frame	Performance metric
There should be flexibility provided to avoid unnecessarily constraining the groundfish fishery particularly when halibut abundance is high	Average PSC limit	NA	short and long term	Average (PSC limit)
	The PSC limit is below the 2016 PSC limit a certain percentage of time.	3,515 t	short and long term	P(PSC limit < 3,515t)
	The PSC limit is below the 2016 PSC catch a certain percentage of time.	2,337 t	short and long term	P(PSC limit < 2,337t)
	Maintain catch above a minimum value to reach the TAC (and below PSC)		short and long term	Ratio of PSC limit to exploitable (groundfish fishery) halibut biomass
Provide for some stability in PSC limits on an inter-annual basis.	Achieve a level of inter-annual variability in PSC levels that is below an acceptable level	NA	short and long term	Average annual variation (AAV) in halibut PSC limitP(AAV < ???%)
Halibut spawning stock biomass should be protected especially at lower levels of abundance	Maintain the Coastwide spawning biomass above critical levels	20% of equilibrium	short and long term	$P(SB_{coastwide} < 20\%)$
	Maintain the Bering Sea spawning biomass above critical levels	20% of equilibrium	short and long term	$P(SB_{BSAI} < 20\%)$
Provide for directed halibut fishing operations in the Bering Sea.	A minimum FCEY in 4CDE			P(FCEY < minimum)
	A target FCEY in 4CDE		short and long term	P(FCEY < target)
	NOTE: a minimum and a target will have to be determined from consultation with stakeholders. In the meantime, the average (TCEY minus the PSC) will be reported.			
Halibut PSC limits should be indexed to halibut abundance	The range of the index for which a minimum level of variation is achieved.		short and long term	P(floor used) P(ceiling used)
	PSC is proportional to halibut abundance		short and long term	PSC limit change relative to halibut biomass

4.2.1 Glossary of terms

Council Objectives A list of overarching goals for abundance-based halibut PSC management that were inferred from the Council's Purpose and Need Statement.

Measurable Objective An objective that can be specified explicitly (e.g., ensure the spawning biomass stays above a minimum threshold) and evaluated with a performance metric (e.g., ensure the spawning biomass stays above 20% of the unfished spawning biomass with 90% probability) which reflects and is linked to the Council objectives. Performance metrics are used to judge policy alternatives relative to these objectives. An additional quantity as part of the measurable objective may be a probability (level of tolerance) which to evaluate against. Probabilities are framed as a risk (something undesirable happening).

Threshold A value or range of values that must be achieved to meet a measurable objective.

Time Frame	There are two concepts here. The first is how far into the future is considered (e.g., short-term or long-term). The second is a range of years over which the measurable objective is to be evaluated. This can be short-term, long-term, annual, a period of 10 years, etc.
Performance Metric	Metric or statistic that is used to evaluate whether a measurable objective is achieved. Performance metrics are used in scientific analysis to gauge success in meeting measurable objectives. The Performance Metric is determined from the Threshold and Time Frame.

Other Terms:

AAV	Average Annual Variability
ABM	Abundance based management specifically for Pacific halibut
Control Rule	A function relating a metric of stock status to a resulting management limit, such as a catch, fishing mortality, or effort limit
BCR	Bycatch control rule; a control rule for setting the limit of a bycatch (PSC) species based on a specified metric of stock status
PSC	Prohibited species catch (for halibut, synonymous with bycatch)
SPR	Spawning potential ratio; the ratio of spawning biomass per recruit at a particular level of fishing mortality to the spawning biomass per recruit under an assumption of no fishing. Spawning biomass per recruit is the amount of future spawning biomass that can be expected as the result of a fish spawning over the course of its lifetime, assuming a particular level of constant fishing mortality.
SSB	Spawning stock biomass

5 Plans for October

As described above a complex model is unlikely to be available for use in preliminary analysis for October. However, in an effort to continue to move the process along while the methodology for impact analysis is being developed, the working group has some suggestions for analyses which could be brought forward in October to inform the alternative set. The preliminary analysis of a subset of alternatives is proposed using the two-area Pacific halibut simulation framework to estimate the PSC limits to assist in the refinement of alternatives for analysis. Pending SSC direction on modeling approaches, the EIS analysis would move forward with a smaller sub-set of alternatives to be analyzed in a more complicated approach to account for groundfish and halibut population dynamics and economic impacts.

For October the following would be brought back in a discussion paper to assist in refining alternatives:

- Description of Alternatives (draft Chapter 2) including:
    - Recommendations for the low, medium, high index values and their biological basis.
    - Biological basis for the baseline index years to be used.
- Description of groundfish and halibut fisheries -- This is a first iteration of the EIS section that provides context for evaluating alternatives' relative benefits and costs. This section will describe how the fishery operates in terms of harvest participation (vessels, crew, and processors) and target species selection (TAC utilization, markets, spatial/temporal effort, market factors, and business/fishing constraints including but not limited to bycatch). This section will also begin to develop the components of the EIS social impact assessment, including descriptions of affected

communities and non-fishing stakeholders, as well as scoping of metrics to analyze reliance on fisheries that are directly and/or indirectly affected by this action.

- Preliminary analysis of alternatives: As noted this analysis would use of the two-area Pacific halibut simulation framework with 'perfect information' to provide preliminary analysis of Alternatives 2,3, and 4 (see proposed subset of elements and options in Appendix A). This would include:
  - Contrast of historical and future PSC limits against status quo PSC limits (Alternative 1).
  - Discussions of the pros and cons of the current Alternative 3 and 4 approaches with a goal towards recommending one instead of both.
  - Working Group suggestions for a more simplified range of alternatives based upon preliminary analysis.
- Following feedback in June on the proposed modeling approach, the discussion paper would provide a list of the exact alternatives that will be simulated, which will not include all possible combinations listed in the April Council motion (Appendix A) but will provide explanations for how each element and option will be able to be evaluated using combinations of elements and options.
- Descriptions of the performance metrics that will be reported to evaluate results and how they relate to the Council objectives. Note: this is also contingent on the modeling approach recommended.

Appendix A. ABM Alternatives and proposed simplifications for preliminary analysis

Alternative Set from April

The Council moved the following set of alternatives for analysis in April 2018.

Alternative 1: No action

Alternative 2: Index trawl PSC to EBS trawl survey biomass. Index longline PSC to setline survey biomass.

Alternative 3 (former ABM 4): Index trawl gear PSC and fixed gear PSC to both EBS trawl survey (primary index for trawl, secondary index for longline) and setline survey (primary index for longline, secondary index for trawl). The secondary index modifies a multiplier on the starting point of the control rule when the secondary index is in a "high state" or a "low state" (e.g., the PSC is multiplied by 1.1 when the secondary index is at a "high" value and by 0.9 when the secondary index is a "low" value).

Alternative 4 (former ABM 4): Index trawl gear PSC and fixed gear PSC to both EBS trawl survey (primary index for trawl, secondary index for longline) and setline survey (primary index for longline, secondary index for trawl). The secondary index modifies the multiplier on the final PSC limit after the primary index is applied when the secondary index is in a "high state" or a "low state" (e.g., the PSC is multiplied by 1.1 when the secondary index is at a "high" value and by 0.9 when the secondary index is at a "low" value).

For each alternative above the slope of the control rule is fixed at a value of 1.0

The following elements and options are exclusive to Alternatives 2-4:

Element 1 – PSC limit responsiveness to abundance changes
- Option 1. PSC limit varies no more than 5% per year
- Option 2. PSC limit varies no more than 15% per year
- Option 3. PSC limit varies no more than 25% per year

Element 2 – Starting point for PSC limit
- Option 1. 10% below 2016 PSC use (2,119 t)
- Option 2. 2017 use (1,958 t)
- Option 3. Average of 2016 PSC use and limit (2,935 t)
- Option 4. 2016 PSC limit (3,515 t)

Element 3 – Maximum PSC limit (ceiling)
- Option 1. 2016 PSC limit (3,515 t)
- Option 2. 2015 PSC limit (4,426 t)
- Option 3. No ceiling

Element 4 – Minimum PSC limit (floor)
- Option 1. No floor (PSC goes to 0)
- Option 2. 2016 use (2,354 t)
- Option 3. ½ of 2016 PSC limit (1,758)
- Option 4. PSC limit is zero at IPHC 20% Coastwide stock status (or proxy)

Element 5 – High and low values for secondary index (Only applies to Alternatives 3 and 4)
Option 1. High = 2nd highest value of time series, Low = 2nd lowest value of time series
Option 2. Index is 25% below or above average
Option 3. Index is above or below average

Element 6 – Multiplier for secondary index (only applies to Alternative 3 and 4)
Option 1. High = range of 1.1 to 1.5
Option 2. Low = range of 0.5 to 0.9
Option 3. Other high, medium and low ranges to be selected between 0.5 and 1.5

Alternative 5: Index fixed gear PSC to combination of IPHC Area 4 all sizes survey and EBS shelf trawl survey. BSAI fixed gear PSC limit is presented in a look-up table based on halibut abundance from the IPHC Area 4 setline survey and the EBS trawl survey.

The following elements are exclusive to Alternative 5:

Element 1 – PSC limit responsiveness to abundance changes

A reduction (options 25-50%) in the EBS halibut index for either survey triggers a reduction from the existing cap to the floor. Also, SB 20 coastwide halibut control rule (or proxy) triggers going to the floor (independent of the two surveys).

Element 2 – Starting Point
Option 1. 2016 limit (710 mt)
Option 2. 10% below 2016 limit (639 mt)
Option 3. 20% below 2016 limit (568 mt)
Option 4: 2016 PSC use (205 mt).

Element 3 – Maximum PSC limit (ceiling)
Option 1. 2015 PSC limit (833 mt)
Option 2. 2016 PSC limit (710 mt)
Option 3. Option 3. No ceiling

Element 4 – Minimum PSC limit (floor)
Option 1. 2002-2016 avg. PSC use = 462 mt
Option 2. 50% of 2016 PSC limit = 355 mt
Option 3. PSC limit is zero at SB 20% Coastwide stock status (or proxy)

In this analysis, the Council also tasks staff to evaluate the following items, and other comments from the SSC as practicable:

- Time series of the indices used. Provide the Council biological considerations for selecting the baseline years for the index, as described by the SSC.
- Index values for high, medium and low. In Alternatives 3 and 4 a secondary index may modify the PSC limit based on the secondary index being high, medium or low. The Council request a biological basis for determining when an index is high or low, as well as guidance on how to the response associated with each value.
- Alternative PSC limits. A small number of fixed PSC values should be included in the analysis to allow investigation of the performance of ABM alternatives relative to differences in the scale of the starting points, as outlined by the SSC.

- Evaluate using a 3- to 5-year rolling average of PSC limits, as described by the SSC.
- Consider how to allocate CDQ PSC between fixed gear and trawl gear.
- Describe the steps and process that produces the EBS trawl IPHC survey index values.

Proposed simplifications for preliminary analysis

Based on the following selection of a subset of the Elements and Options from the Council, the Work Group proposed a bookend analysis (bolded items below) for preliminary review. The overarching goal of the preliminary review is to assist the Council in refining alternatives. Alternatives to be used for preliminary analysis are 2, 3 and 4 (contrasted against Alternative 1).

The following elements and options are exclusive to Alternatives 2-4:

Element 1 – PSC limit responsiveness to abundance changes
- **Option 1: PSC limit varies no more than 5% per year**
- Option 2: PSC limit varies no more than 15% per year
- **Option 3: PSC limit varies no more than 25% per year**

Element 2 – Starting point for PSC limit
- Option 1. 10% below 2016 PSC use (2,119 t)
- Option 2. 2017 use (1,958 t)
- Option 3. Average of 2016 PSC use and limit (2,935 t)
- **Option 4. 2016 PSC limit (3,515 t)**

Element 3 - Maximum PSC limit (ceiling)
- Option 1. 2016 PSC limit (3,515 t)
- **Option 2. 2015 PSC limit (4,426 t)**
- **Option 3. No ceiling**

Element 4 - Minimum PSC limit (floor)
- **Option 1. No floor (PSC goes to 0)**
- **Option 2. 2016 use (2,354 t)**
- Option 3. ½ of 2016 PSC limit (1,758)
- Option 4. PSC limit is zero at IPHC 20% Coastwide stock status (or proxy)

Element 5 – High and low values for secondary index (Only applies to Alternatives 3 and 4)
- **Option 1. High = 2nd highest value of time series, Low = 2nd lowest value of time series**
- **Option 2. Index is 25% below or above average**
- Option 3. Index is above or below average

Element 6 – Multiplier for secondary index (only applies to Alternative 3 and 4)
- **Option 1. High = range of 1.1 to 1.5 (bookends of 1.1 and 1.5)**
- **Option 2. Low = range of 0.5 to 0.9 (bookends of 0.5 and 0.9)**
- Option 3. Other high, medium and low ranges to be selected between 0.5 and 1.5

Appendix B. SSC Recommendations for the MSTI Model from the April 2016 SSC Meeting Minutes

We received an overview of the multispecies technical interactions model (MST) that was developed for management strategy evaluations, which includes Pacific cod, walleye pollock and yellowfin sole, and is being modified to include simplified halibut population dynamics. The SSC was encouraged by this development and the model provides a promising tool to evaluate the impacts of different harvest control rules for setting halibut PSC limits on groundfish fisheries and, to a limited degree, on the halibut stock. The SSC was excited to see a number of improvements to the MST model and its adoption for this purpose and encourages further development of the model. The MST models the Council’s decision-making process, whereby the Council chooses TACs to maximize “net profits”, subject to a number of constraints, across multiple ‘métiers’ (combination of fishing grounds, gear, and fish assemblages). Fleet behavior is subsequently modeled using linear programing, whereby the fleet assigns effort to métiers to maximize profits, subject to the TACs chosen by the Council. Métiers were empirically identified based on catch composition data for the BSAI from 2011-2014. The SSC had the following recommendations regarding the model:

- The profit function in the Council’s linear programming model uses “net prices”, which are determined through a calibration exercise that compares realized to predicted catches. The SSC recommends calibrating the model on the basis of realized and predicted TACs (‘intended’ catches) rather than actual catches.
- The profit function in the fleet’s linear program uses the same net prices as the Council linear program, implicitly assuming that the fleet and Council have the same preferences over métiers. The SSC recommends that different net prices should be used for the fleet linear program, which could be determined through a separate calibration exercise comparing, for instance, realized and predicted catches or métier choices.
- The structure and parameterization of the MST is largely informed by and based on empirical observations. To enhance the ability of the model to predict future catches and TACs, the SSC suggests that the developers explore mechanistic interactions where appropriate. The analysts should explore calibrating the model on the basis of past observable characteristics, for instance, allowing changes in catch composition and net prices to be functions of changes in abundance. By doing so, the MST would be readily available for producing out-of-sample predictions (e.g. one-year-ahead predictions). We also note that development of the model could benefit from interactions with AFSC economists.
- The SSC noted some issues with the proposed implementation of the halibut quota determination that need to be corrected. Specifically, the IPHC reduces total allowable catch for each regulatory area (TCEY) by subtracting all anticipated removals (such as PSC in other fisheries) to determine catch limits for the directed fishery (FCEY). This process can be reasonably approximated in the MST model for evaluating the effects on the directed halibut fishery in the Bering Sea, but results in reduced feedback of changes in PSC to the halibut stock dynamics.
- The SSC noted that in addition to recruitment variability at the coastwide level, and relative to the Bering Sea, size-at-age is an important driver of the dynamics of the halibut stock. The variability in size-at-age should be included in the MST.

Appendix C. Details of the Current Configuration of the Halibut PSC Limit Simulation Framework

Background

A simulation framework for comparative evaluation of alternative methods for implementing Pacific halibut prohibited species catch (PSC) limits in the Bering Sea and Aleutian Islands regions has been developed by Dr. Curry Cunningham (NOAA AFSC) and Dr. Matt Reimer (UAA ISER) as part of a separate Saltonstall-Kennedy Grant funded project. This biological-management simulation framework is intended to connect with a model under development by Dr. Matt Reimer quantifying the impact of annual PSC limits on the behavior and profitability of groundfish fleets. However, this biological-management simulation framework may provide a useful option for the proposed analyses currently under consideration.

Model Structure

The biological simulation model is age and sex structured, tracking cohorts of Pacific halibut forward in time across successive age classes on an annual time step. The model is not spatially explicit and generally describes dynamics of the entire pacific Halibut stock. The structure of the simulation model is based on the International Pacific Halibut Commission (IPHC) coast-wide assessment models and Martell et al. (2015) white paper describing initial explorations of index-based PSC limits.

Natural and Fishing Mortality

Annual survival for sex-specific cohorts of halibut is a function of time and age-invariant, but sex-specific natural mortality ($M_{female} = 0.15, M_{male} = 0.16$), and fishing mortality. Fishing mortality imposed on the halibut stock is modeled as the cumulative impact of four fishing sectors.

Name	Sector	Discard Mortality Rate
IFQ	Directed fishery – Individual fishery quota	0.16
PSC	Prohibited species catch	0.8
SPT	Sport fishery	0.2
PER	Personal use fishery	0.0

Each of the four fishing sectors has independent age-specific selectivity, which is the joint probability of both size-at-capture and size-at-retention, and assuming separate discard mortality rates for each sector. Capture probability at age is defined as an exponential logistic function with parameters derived from the 2014 assessment in Martell et al. (2015) and assumes equal capture probability for ages 15 in the PSC, SPT, and PER sectors. Retention probability at age is modeled as a logistic function, where size at retention is a function of a minimum and upper size limits and accounting for a standard deviation in length-at-age.

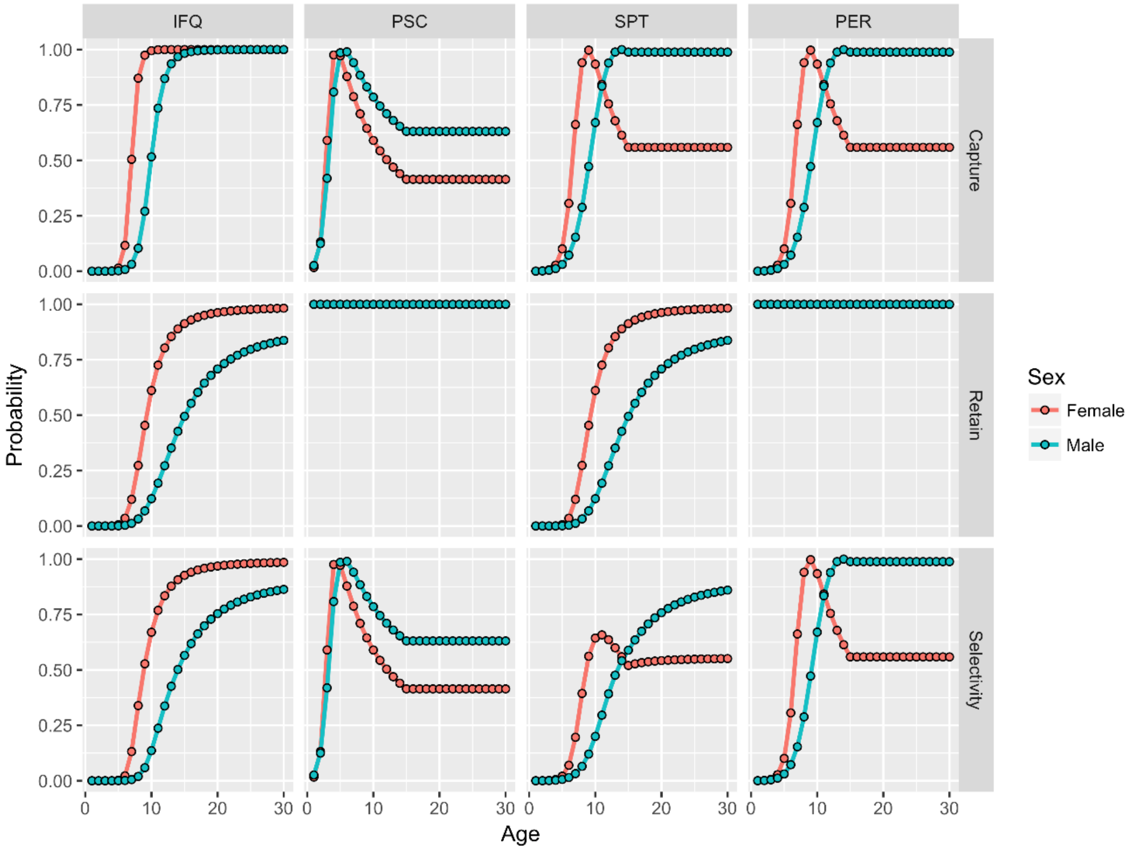


Figure 1. Age and sex-specific probability of capturing and retaining pacific Halibut, and the resulting overall fishery selectivity by sector.

Growth and Allometry

Pacific halibut growth (length-at-age) is described by sex-specific von Bertalanffy growth functions and weight-at-age is represented a standard power function of allometric relationship between weight and length. Parameters for these relationships come directly from Martell et all. (2015) and reflect average coast-wide growth and allometry relationships estimates as of 2014.

Further development of the growth component of simulation model could include random or correlated variation in growth parameters. Alternatively, Ian Stewart (IPHC) suggested that sensitivity trials could include three trends in growth: stable, increasing, and decreasing.

	Growth (length-at-age) $l_a = l_\infty\left(1 - exp\left(-k(a - t_0)\right)\right)$			**Allometry (weight-at-age)** $w_a = \alpha(l_a)^\beta$	
Parameter	L_∞	K	t_0	α	β
Female	150.84	0.0795	-0.597	6.92E-06	3.24
Male	102.97	0.0975	-1.234	6.92E-06	3.24

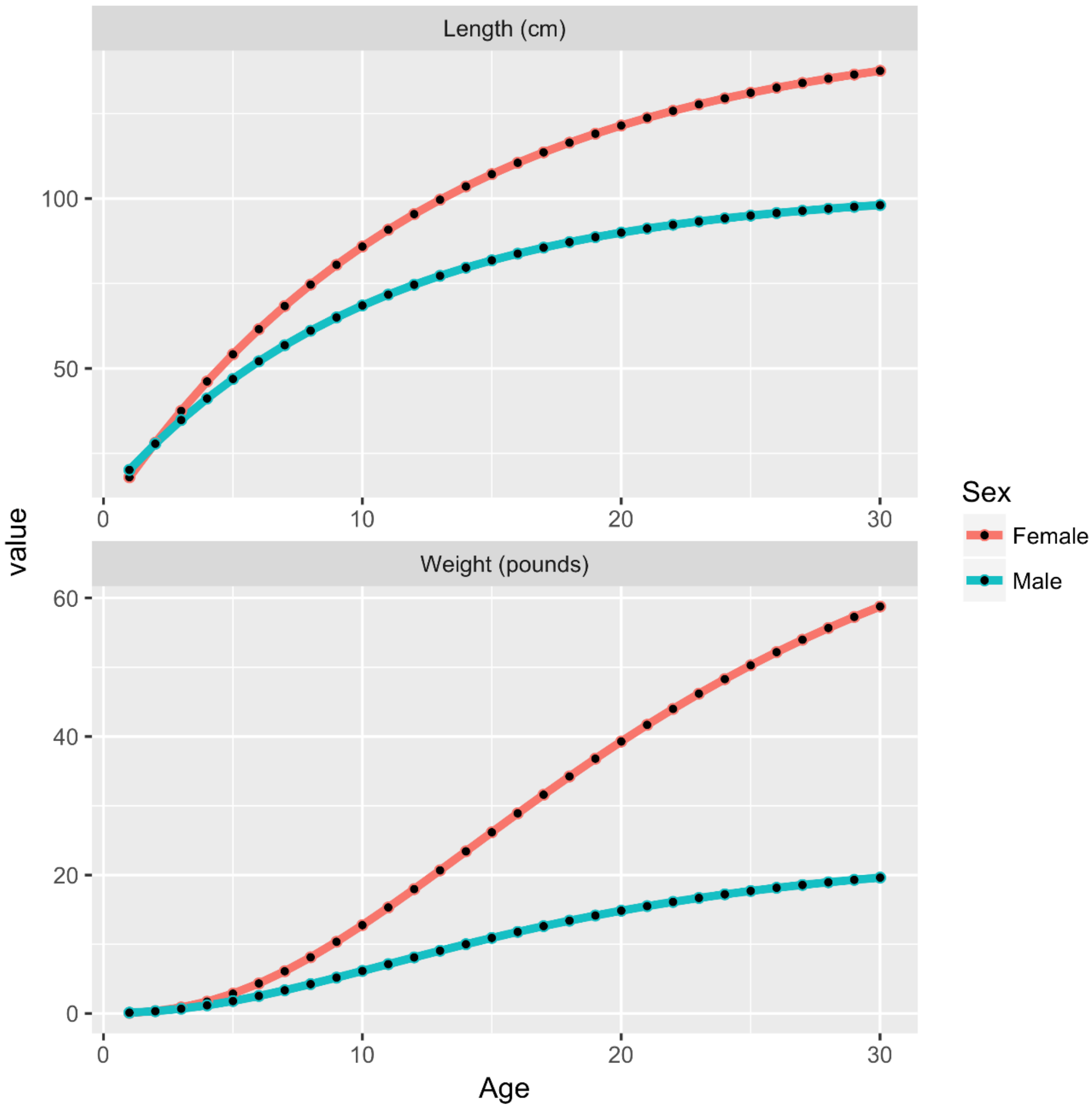


Figure 2. Pacific halibut length and weight at age by sex assumed in the simulation model.

Recruitment

A Beverton-Holt stock-recruitment relationship is assumed for the pacific Halibut stock, with a steepness of $h = 0.75$. Lognormal process variation in recruitment was random with standard deviation of $\sigma_{rec} = 0.6$. Recruitment parameters were taken directly from the 2015 IPHC Coastwide Long (1888-2015) assessment model, as described in the appendix to the 2015 assessment.

The recruitment of pacific Halibut was originally shown by Clark and Hare (2002) to correlate with regimes of the Pacific Decadal Oscillation (PDO). During forward simulation it would be ideal to represent these low frequency changes in stock productivity. The current IPHC Coastwide Long and Areas As Fleets Long assessment models estimate an offset associated with the PDO phase that could be used directly in our simulations in conjunction with a hidden Markov approach to simulating regime occupancy.

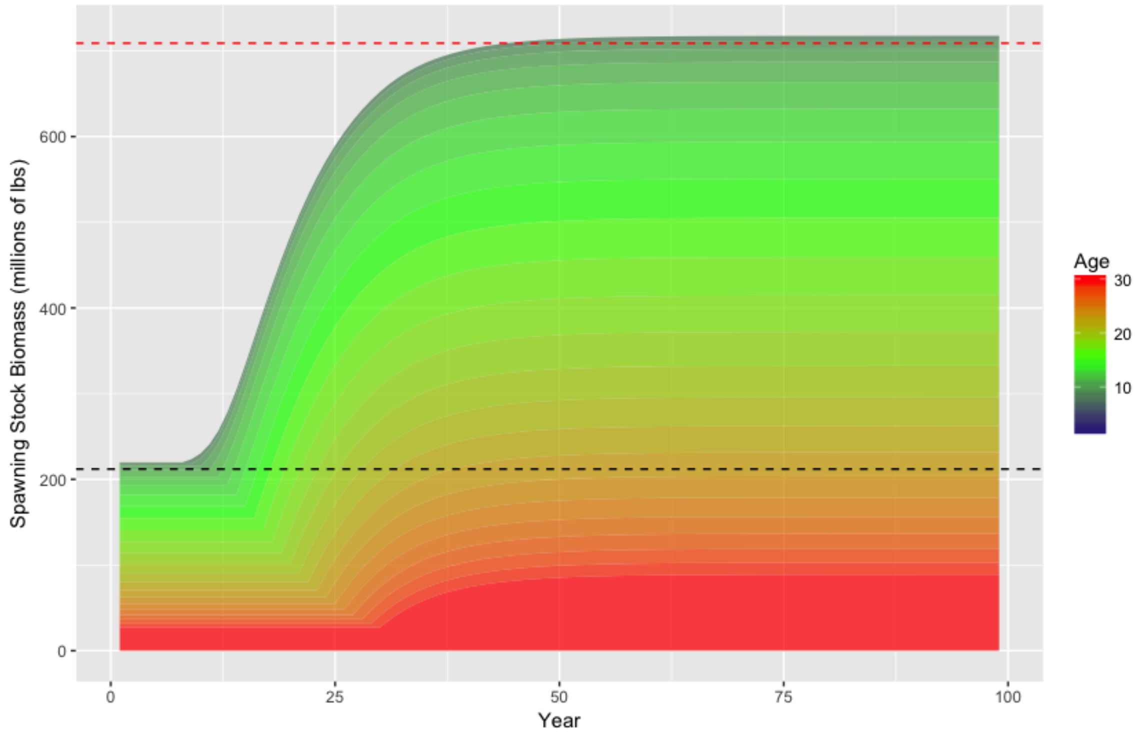


Figure 3. Simulation model conditioning exercise to ensure population smoothly moves from the 2016 SSB to unfished SSB0, when no fishing mortality is present and there is no process variation in recruitment.

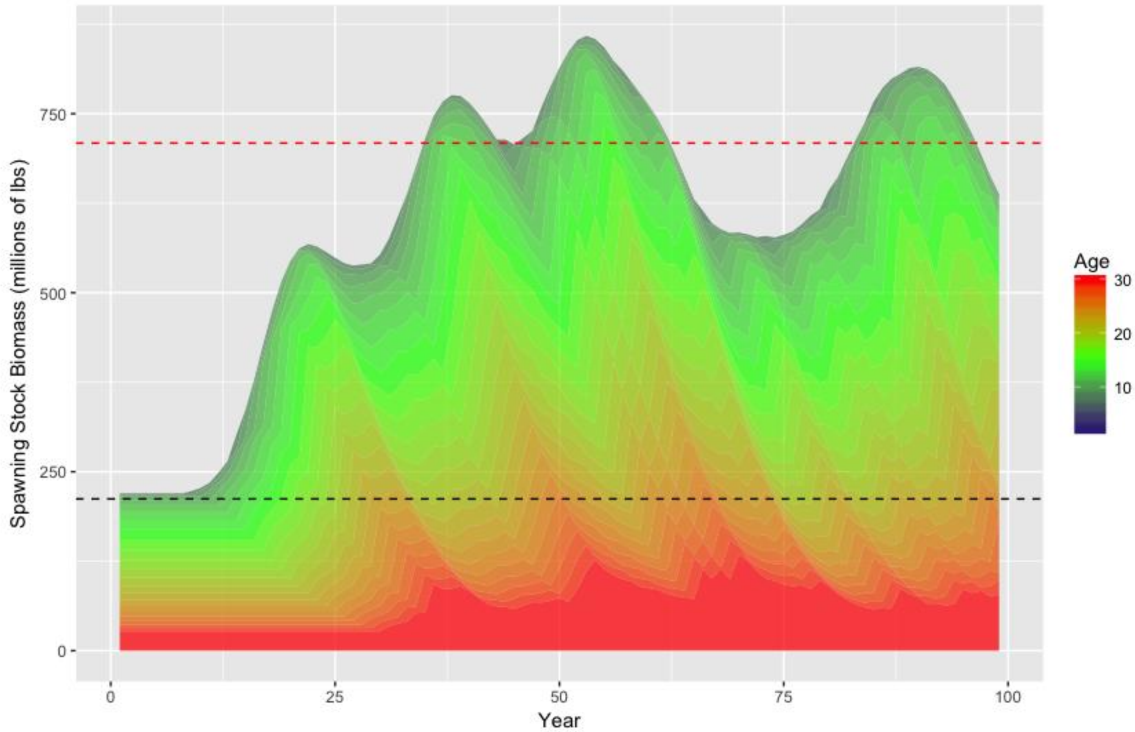


Figure 4. Change in spawning stock biomass at age from a single simulation, forward from the 2016 SSB, with process variation in recruitment and no fishing mortality from any sector.

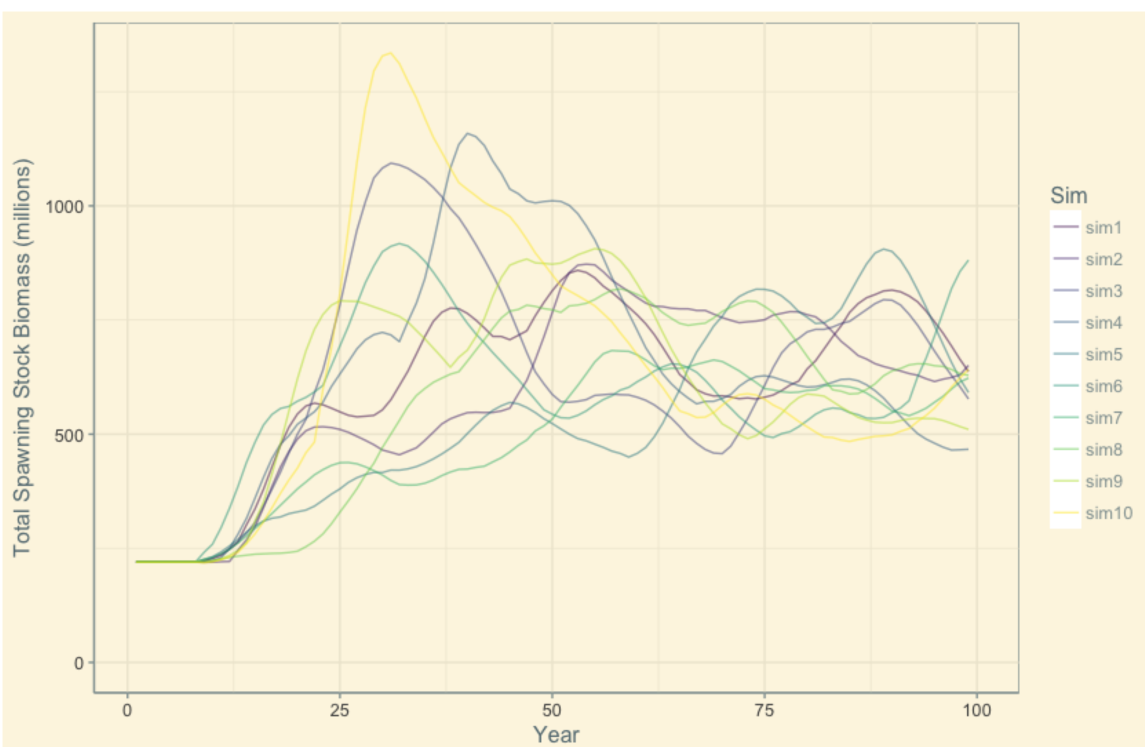


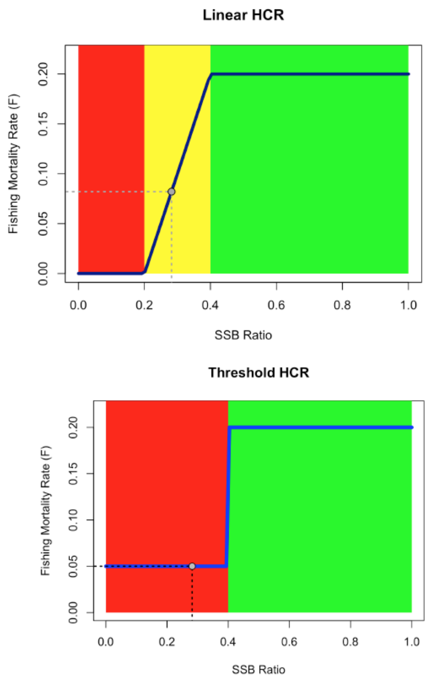
Figure 5. Change in total spawning stock biomass from replicate simulations, forward from the 2016 SSB, with process variation in recruitment and no fishing mortality from any sector.

Assessment Model

To specify Total Constant Exploitation Yield (TCEY) in a given year, it is necessary to conduct a simple assessment of the halibut stock. Although the IPHC uses a sophisticated ensemble of age-structured assessment models informed by a wide array of data sources to estimate population status and reference points, we have elected to implement two forms of simplified assessment models a potential proxies. The first is a Pella-Tomlinson surplus production model (Polacheck et al. 1993), taking catch and an index of abundance as the only data streams. The second is a generalized statistical catch at age model, with age composition of catch, catch numbers and an index of abundance as data streams. Neither of these models is designed to in any way replicate the IPHC assessment, simply to add implementation uncertainty to simulations.

Simulation Cycle

1. Simulate recruitment.
2. Conduct “stock assessment” to calculate SSB proxy.
3. Determine Total Constant Exploitation Yield (TCEY) based on approximated IPHC harvest control rule, as a function of SSB relative to unfished level SSB0.
4. Determine PSC based on static cap or harvest control rule.
5. Convert to F-rate for the PSC sector.
6. Determine Personal Use and Sport harvest biomass.
7. Convert to F rate for SPT and PER sectors.
8. Calculate Fishery CEY as: $\mathrm{FCEY} = \mathrm{TCEY} - \mathrm{B_{PSC}} - \mathrm{B_{SPT}} - \mathrm{B_{PER}}$
9. Directed fishery harvestable biomass to F-rate.
10. Cohort survival is simulated one year and age forward.



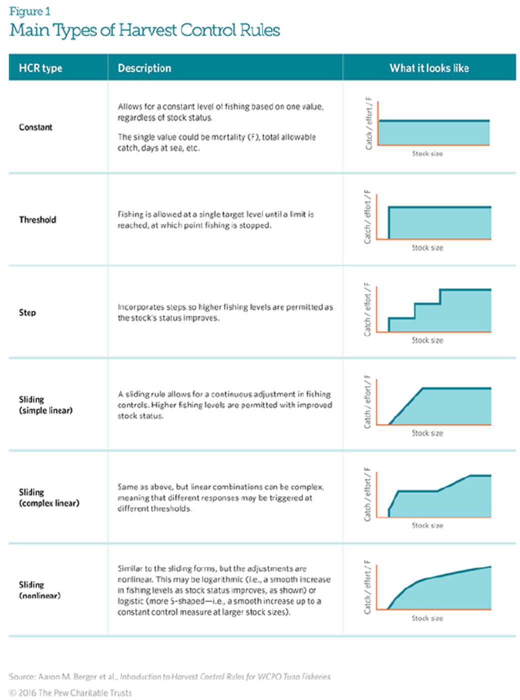


Figure 1

Main Types of Harvest Control Rules

HCR type	Description	What it looks like
Constant	Allows for a constant level of fishing based on one value, regardless of stock status. The single value could be mortality (F), total allowable catch, days at sea, etc.	
Threshold	Fishing is allowed at a single target level until a limit is reached, at which point fishing is stopped.	
Step	Incorporates steps so higher fishing levels are permitted as the stock's status improves.	
Sliding (simple linear)	A sliding rule allows for a continuous adjustment in fishing controls. Higher fishing levels are permitted with improved stock status.	
Sliding (complex linear)	Same as above, but linear combinations can be complex, meaning that different responses may be triggered at different thresholds.	
Sliding (nonlinear)	Similar to the sliding forms, but the adjustments are nonlinear. This may be logarithmic (i.e., a smooth increase in fishing levels as stock status improves, as shown) or logistic (more S-shaped—i.e., a smooth increase up to a constant control measure at larger stock sizes).	

Source: Aaron M. Berger et al., *Introduction to Harvest Control Rules for WCPO Tuna Fisheries*

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Figure 6. Example harvest control rules for TCEY.

Progress

- The structure of the dynamic simulation model is complete and can easily be used to run replicate forward simulations across a 100-year time horizon with process variation in recruitment.
- Functions are available for specifying *basic* harvest control rule types.
- Simple surplus production and age-structured models are used as a ***crude*** proxy for the ensemble of age-structure assessment models used by the IPHC.
- Functions are available which add observation uncertainty to abundance indices and age composition samples.

Potential Next Steps:

- Explicitly formulate harvest control rules.
- Consider process variation in growth and natural mortality.
- Consider including PDO-correlated recruitment.

References

Clark, W.G., and Hare, S.R. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut. Journal of Fisheries Management 22: 852-862.

Martell, S., Stewart, I.J., and Wor, C. 2015. Exploring index-based PSC limits for Pacific halibut. C9: Abundance-based BSAI Halibut PSC. December 2015. North Pacific Fishery Management Council, Anchorage, A.K.

Polacheck, T., Hilborn, R., and Punt, A.E. 1993. Fitting Surplus Production Models - Comparing Methods and Measuring Uncertainty. Canadian Journal of Fisheries and Aquatic Sciences 50(12): 2597-2607.