Abundance-based management alternatives for Pacific halibut PSC

March 2017[1]

1. Introduction

The Council defined five overarching objectives for potential abundance-based management (ABM) of halibut PSC using relevant indices and associated control rule options. The Council also clarified that stability in annual PSC limits is an objective for this action and should be included in the development of abundance indices and associated control rules. In October 2016, the Council directed the inter-agency workgroup to:

- Develop performance metrics and quantitative tools to evaluate the tradeoffs between the competing objectives for this action.
- Develop abundance indices and associated control rules

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- Develop a broader suite of halibut abundance indices and control rules as outlined by the SSC. Specifically, evaluate different indices that can be used to meet the Council's objectives, which could then be combined in a control rule or decision making framework. The workgroup should also evaluate the index concepts discussed in the AP motion.
- Evaluate developing control rules that could be combined in a 2-or 3-dimensional framework for setting PSC as outlined by the SSC.
- Evaluate developing separate control rules for the hook and line and trawl fisheries that could be used to establish PSC limits.

The Council further requested that a workshop be convened prior to the next Council meeting to provide for input from stakeholders on developing performance metrics appropriate to the Council's objectives for the forthcoming analysis once alternatives have been developed. This discussion paper is intended to address the Council's requests for further development of indices and control rules as well as to incorporate feedback from the workshop held in February 2017.

1.1. Council Purpose and Need (adopted April 2016)

"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, provide an opportunity for the directed halibut fishery, and protect the halibut spawning stock biomass, particularly at low levels of abundance. The Council recognizes that abundance-based halibut PSC limits may increase and decrease with changes in halibut abundance."

Council objectives from the Purpose and Need for this action are used 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.

1.1.1. Relationship of Council objectives/overarching goals to measurable objectives

These overarching goals were used to formulate both questions for stakeholder feedback at a Council workshop as well as draft measurable objectives from which to derive performance metrics. These overarching goals may be in competition with each other. In order to best design and evaluate alternatives which can be compared in a future risk assessment to assist policy-level decision-making, specific measurable objectives for this action must be defined.

Choosing between alternative management measures can be done by comparing how each alternative meets defined objectives. Therefore, it is important to define detailed objectives with measurable outcomes. This can be difficult, and should involve input from stakeholders and decision-makers. 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 or not 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).

Draft measurable objectives were discussed at the February 2017 workshop for stakeholder feedback and input[2]. Additional information on performance metrics is contained in section 6 while feedback from stakeholders has been both folded into draft strawmen alternatives, discussion of incentives and will be further considered in the development of alternatives.

1.2. Strawmen alternatives and relationship to Council decisions

Given public and Council feedback from the two earlier discussion papers, we developed four strawman ABM alternatives/frameworks for halibut PSC limits for Council consideration. We provide rationale and decision-points for each ABM alternative. The following elements were considered in the construction of these alternatives (Table 1):

1. Overarching Council objectives (as noted in section 1.1)
2. Measurable objectives (and corresponding performance metrics for evaluation of these objectives in an analysis) (section 1.1.1)
3. Applicable and available abundance indices (section 2.1)
4. Bycatch control rules (section 2.2)

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[2] Measurable objectives and performance metrics drafted for the workshop are available at: http://npfmc.legistar.com/gateway.aspx?M=F&ID=26243385-0f14-4bc3-b5e6-adc7ef03eadf.pdf

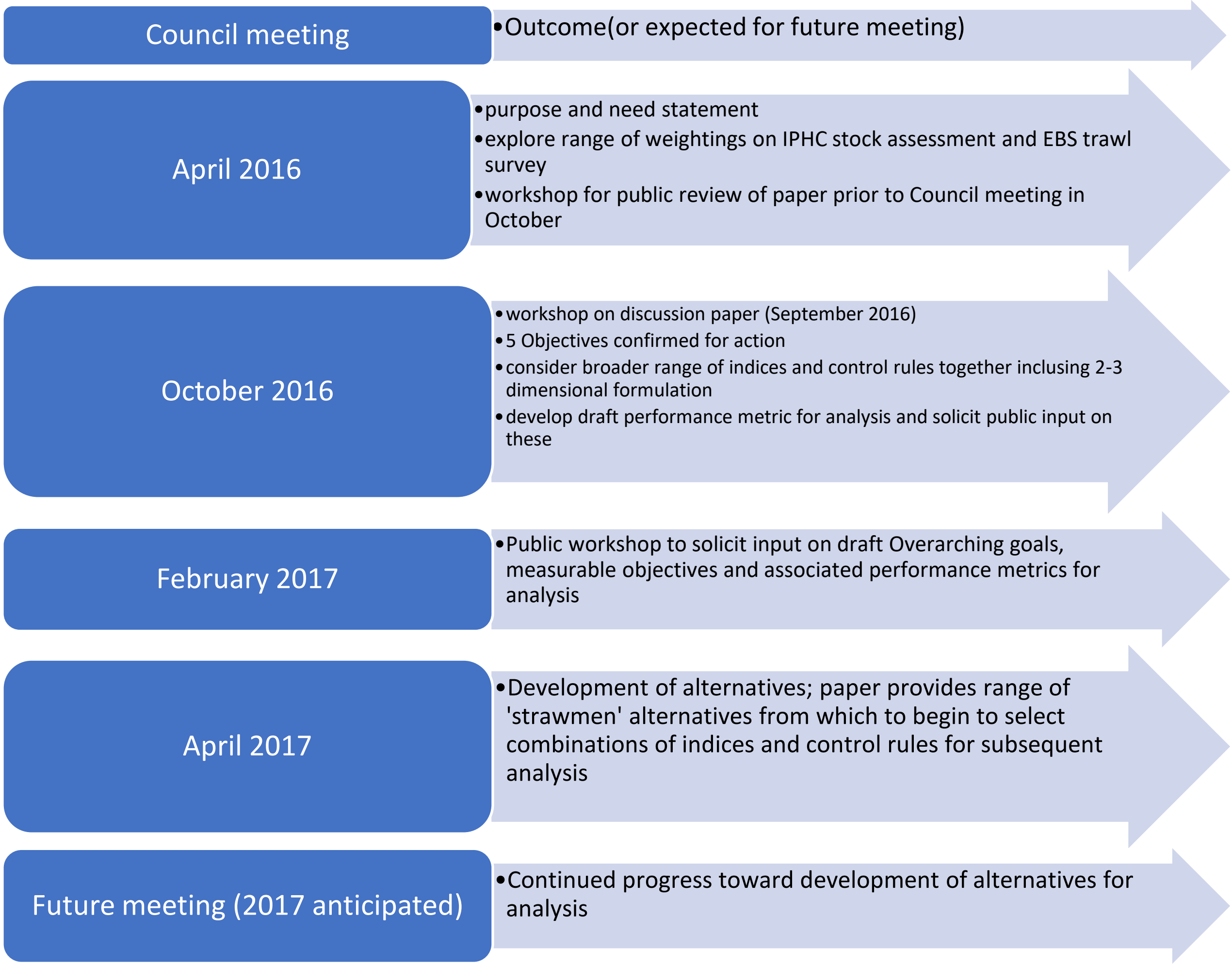
Table 1. Specific sections in the document that relate either generally, or more specifically in computational calculation, to the development of the ABM alternatives.

Description of section as it relates to the development of ABM examples	**Is this a general or detailed (computational) item?**	**Where to locate in the document**
Purpose and Need statement and 5 Objectives (also noted as 'overarching goals')	General used to guide formulations of ABM examples	Section 1.1, Figure 7
Background on previous Council discussion papers and ABM considerations	General to provide context to multi-index/multi-control rule ABM examples	Section 1.3
Principles used to develop and evaluate ABM examples	General (for list) General (as applied to individual ABM examples)	List: Section 1.4 Examples: ABM1: Section 3.2.3 ABM2: Section 3.2.3 ABM3: Section 3.3.3 ABM4: Section 3.4.3
Framework for development of ABM examples	General: includes list of indices, description of what is a control rule	Section 2 (2.1-2.2)
Strawmen alternatives: ABM1, ABM2, ABM3, ABM4	General description of indices within each ABM example	Section 3
ABM examples	Detailed description of indices used and computational equations for the control rules applied	Sections 3.1-3.4
Comparison across the ABM1-ABM4 examples	Detailed based on Sections 3.1-3.4 computations	Section 4.0

The Council also requested information on the applicability of ABM management of halibut PSC in the GOA and how it might differ from the BSAI. We provide a brief comparison of the ABM strawmen and their applicability to the GOA understanding that further development of additional fishery and management issues differing in the GOA from the BSAI will be needed (section 5). We also provide a review of issues related to incentives for the groundfish fleet to minimize halibut bycatch to the extent practicable at all levels of halibut abundance (section 7).

1.3. Council action at this meeting: where are we in the Council process for development of alternatives for an analysis?

The Council is currently in the process of developing alternatives for an analysis. This section provides an overview of the history of this action for purposes of understanding the current ABM strawmen provided here. A timeline of actions by the Council and relative outcomes since April 2016 is shown in Figure 1.



Council meeting	Outcome(or expected for future meeting)
April 2016	purpose and need statement explore range of weightings on IPHC stock assessment and EBS trawl survey workshop for public review of paper prior to Council meeting in October
October 2016	workshop on discussion paper (September 2016) 5 Objectives confirmed for action consider broader range of indices and control rules together inclusing 2-3 dimensional formulation develop draft performance metric for analysis and solicit public input on these
February 2017	Public workshop to solicit input on draft Overarching goals, measurable objectives and associated performance metrics for analysis
April 2017	Development of alternatives; paper provides range of 'strawmen' alternatives from which to begin to select combinations of indices and control rules for subsequent analysis
Future meeting (2017 anticipated)	Continued progress toward development of alternatives for analysis

Figure 1. Timeline of actions taken by the Council since April 2016.

1.3.1. History of this action leading to October 2016 proposed ABM index

In December 2015, the Council initiated a workgroup of Council, NMFS, and IPHC staff to identify and evaluate alternative methods to index halibut PSC limits based on halibut abundance. The Council directed the workgroup to describe potential data and management advantages and challenges provided by alternative methods to index halibut PSC limits based on halibut abundance. The Council also directed the workgroup to evaluate the effects of a number of assumptions on an abundance based approach, such as those related to natural mortality (by size and age), growth rates, size composition of PSC by sector, and the long-term potential spawning capital of juvenile halibut with the goal of returning abundance-based recommendations back to the Council as soon as possible.

In April 2016, the Council reviewed a discussion paper on: (1) the current status of halibut PSC limits and use in the BSAI; (2) indices that may be available to assess the abundance of halibut and the potential strengths and limitations of those indices to setting an abundance based halibut PSC limit; (3) general types, or models, that could be used to set abundance-based halibut PSC limits; (4) different types of control rules that could be used to establish halibut PSC limits (e.g., “stair-step” PSC limits with or without “floors” or “ceilings”); and (5) described the types of policy decisions that the Council would need to consider as this effort progresses. The paper identified areas where Council input would be helpful before proceeding, provided a preliminary work schedule, and presented some ideas and data evaluations that were further developed by individual workgroup members after the workgroup met.

After reviewing the discussion paper, the Council revised its draft purpose and need for this action and directed the workgroup to address additional issues in a discussion paper for October 2016. These Council directed the workgroup to: (1) focus analysis on the use of the NMFS eastern Bering Sea shelf trawl survey and the biomass estimate from the IPHC stock assessment as potentially appropriate indices and explore a variety of assumptions on the appropriate weighting of indices, including using each index as a bookend. If time is available, focus on potential advantages and challenges of incorporating additional surveys (e.g., the Bering Sea shelf, Aleutian Islands, NMFS longline survey, and Gulf of Alaska trawl surveys to develop an Alaska-wide index of abundance), and the Integrated Model-based index approach outlined in that paper; (2) focus on efforts that describe halibut PSC abundance based on both weight and numbers, with DMRs applied to set PSC limits; (3) describe the potential implications of abundance-based halibut PSC allocations using the proportional allocations to the four sectors defined under Amendment 111 as the basis for structure and comparison; and (4) provide further discussion on the potential management and operational implications of control rules (mechanisms for adjusting the PSC limit) that change on an annual basis.

1.4. Indices and ABM index provided in October 2016

The October 2016 discussion paper built upon the approaches and data summaries explored in the April 2016 paper and developed additional approaches. The paper provided an overview of the considerations for developing an abundance index and recommended an integrated abundance-based index. The paper also explored control rule formulations, and provided illustrative control rules applied to the recommended integrated abundance index to lay out the steps and decisions necessary by the Council for moving forward to drafting alternatives for analysis.

The October 2016 discussion paper identified the range of potential abundance indices and determined the strengths and weaknesses of each index. The workgroup then identified a list of principles to consider in developing and evaluating an ABM index[3]:

- Addresses older and younger population components
- Considers the coastwide geographic range
- Considers the coastwide stock status
- Addresses recruitment differences in the BSAI and GOA
- Information to derive the index is available in a timely manner for Council harvest specifications
- Information to derive the index is easily accessible

After evaluating both single and combined indices, the workgroup recommended an ABM index that combined three data sources into an integrated index. The workgroup determined that an integrated index would better address some of the limitations of individual indices and meet the workgroup's objectives for an appropriate index described above. For example, the EBS trawl survey mainly tracks small halibut in the eastern Bering Sea but omits consideration of recruitment in other areas, the directed fishery, and the coastwide status of the halibut stock. The workgroup also determined that the Council likely would develop ABM alternatives that use multiple indices given the number of objectives for the proposed action as well as feedback received from stakeholders suggesting that ABM management should consider several components of the halibut population, including size and area.

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[3] See Table 7 in the October 2016 discussion paper at http://npfmc.legistar.com/gateway.aspx?M=F&ID=515c1f2a-24d0-49aa-b9c1-3717a0b8f230.pdf.

As shown in Figure 2 below, the workgroup's recommended integrated ABM index from October 2016 combined the EBS shelf bottom trawl survey, the GOA bottom trawl survey, and the IPHC standardized stock assessment survey, with the goal to combine them into a single integrated ABM index that can be used to guide the PSC limit. As shown in Figure 2, the workgroup intended the recommended ABM index to be a combination of the three indices which would result in one ABM index to which a control rule would applied to determine the PSC limit. The recommended index did not establish different weights for the three indices (i.e., each index has a weight of 1) because there is no scientific basis for differential weights and the weight given to each index is a policy determination for the Council.

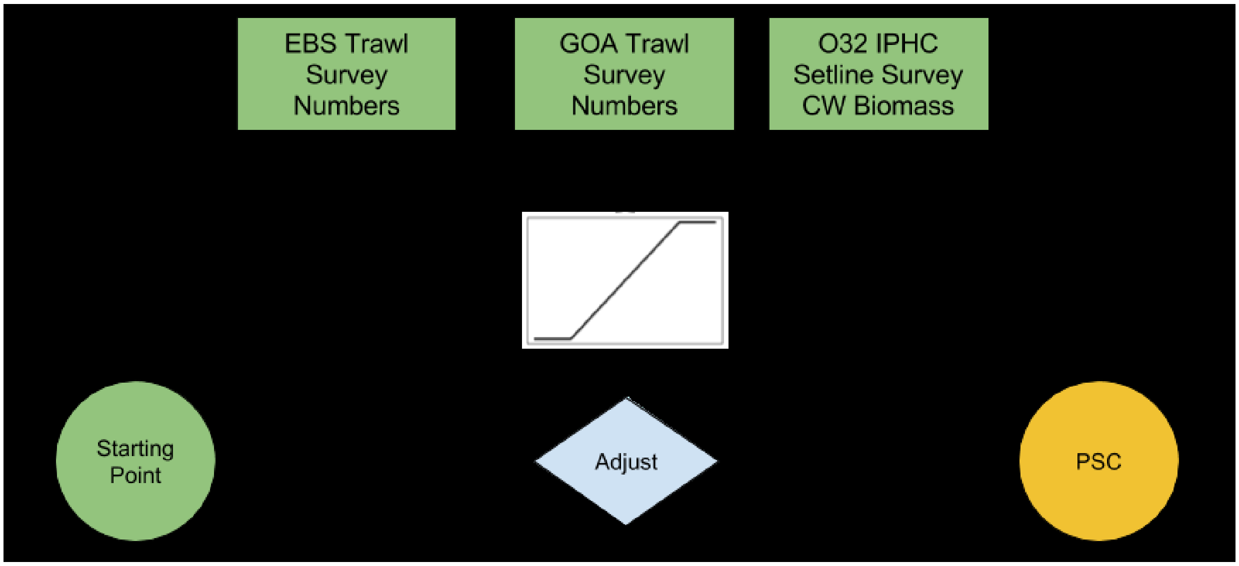

Figure 2. Schematic of the framework laid out and presented at the October 2016 Council meeting; weights for each index were set equal to 1 ($b_k = 1$ for all k) in materials presented at the October 2016 Council meeting.

At the October 2016 meeting, the Council, SSC and stakeholders identified two primary concerns with the workgroup's recommendation for an integrated ABM index:

- combining three indices with different types of information lacks transparency and is difficult to interpret. Also it is unclear how tradeoffs among multiple, potentially conflicting objectives, could be addressed, and
- the index would likely have been ineffective at constraining PSC during the recent period of decline in coastwide halibut biomass. The ABM index combines a coastwide abundance index of large halibut from the IPHC survey with trawl survey indices of smaller halibut caught in the EBS and GOA trawl surveys. The SSC notes that equally weighting the two trawl-based indices may implicitly put more weight on halibut in the GOA.

The SSC suggested that the Council may need to consider different indices to meet different objectives, which could then be combined in a control rule or decision making framework that allows the Council to evaluate the tradeoffs between protecting spawning stock biomass, constraining PSC, and providing opportunities for a directed fishery.

The SSC suggested that the multiple objectives of the proposed action may require multiple indices, each with its own control rule (reflecting coastwide spawning biomass, encounter rates with the fleet, and availability to the directed fishery, respectively) that allow an evaluation of the tradeoffs between PSC, protecting the stock at low abundances, and providing opportunities for a directed fishery. For example, control rules for setting PSC at different levels of the spawning biomass index and different levels of EBS trawl survey abundance can be combined into a two-dimensional decision table to set a PSC level. The SSC suggested that adding a third dimension may be necessary and would be straightforward. For example, a simple approach could associate low, intermediate and high levels of the spawning biomass with low, intermediate and high levels of PSC (similarly for the abundance index in the EBS trawl survey or the exploitable biomass index). PSC could then, for example, be determined based on the level of the index that is most constraining. The SSC's recommendation for a multi-dimensional control rule is presented below (Figure 3).

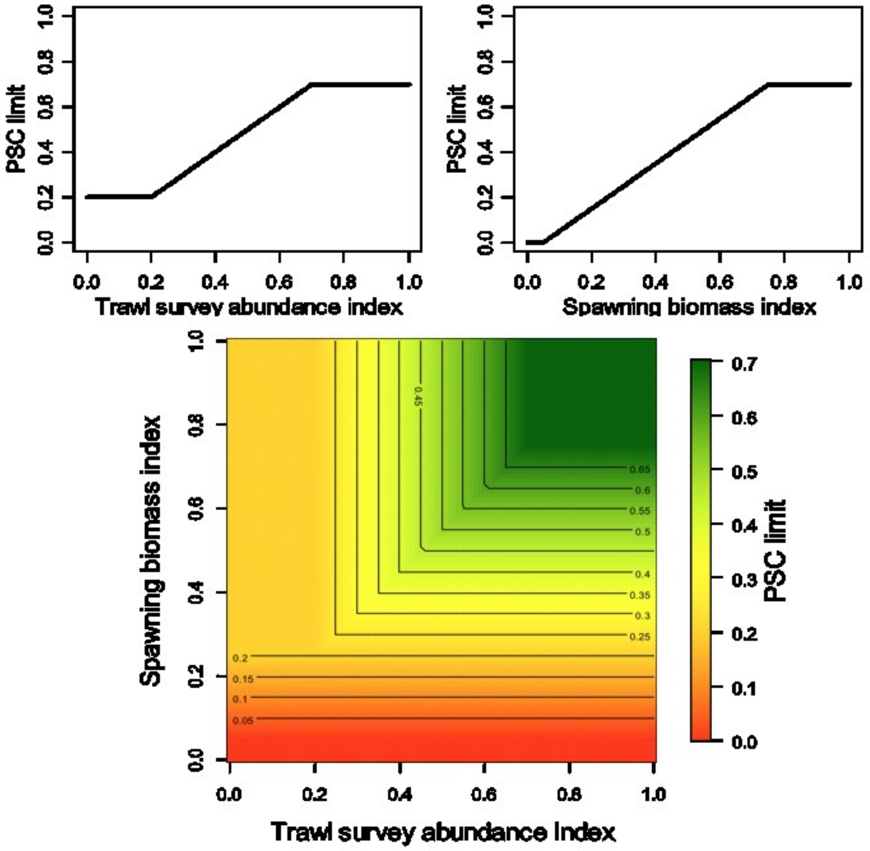

Figure 3. Example "multi-dimension" scenario where one index limit may be constrained on the impact of setting the PSC limit while another (here spawning biomass, vertical scale) affects PSC limit at all levels of spawning biomass (extracted from the October 2016 SSC minutes)

In response to SSC, AP, and public input in October 2016, the Council provided specific direction to the workgroup related to the development of indices and control rules. (see section 1)

In response to this direction, the workgroup revised and expanded the list of principles it developed for consideration in developing and evaluating an ABM index to include objectives for the development of indices and control rules together. The workgroup identified the following principles. The four alternatives presented in this paper were developed based on satisfying some or all the following principles.

1. The ABM index should be independent of management decisions.

2. The ABM index and control rules should be parsimonious, easy to understand, and easy to implement in a timely manner.
3. The ABM index should be free of as many assumptions as possible, and use the data in the best way possible.
4. The ABM index should consider recruitment (e.g., smaller halibut) to ensure future healthy coastwide halibut spawning biomass.
5. The ABM index should consider the biomass of O32 (or O26) halibut in the Bering Sea to provide for opportunity to the directed halibut fishery.
6. The IPHC setline survey provides the best fishery-independent information on the O32 abundance of Pacific halibut, and serves as a proxy for spawning biomass since few females are mature when less than 32 inches.
7. The IPHC setline survey provides the best fishery-independent information on the O26 (or O32) abundance of Pacific halibut in each Regulatory Area.
8. The IPHC stock assessment provides the best scientific information on the coastwide spawning biomass.
9. The PSC limit should be responsive to changes in the total halibut abundance encountered by the groundfish fisheries.

1.5. Example of existing abundance-based PSC limits

The Council has established more simplified abundance-based PSC limits for crab species in the Bering Sea. The original control rules for establishing abundance-based EBS snow crab PSC limit and Tanner crab PSC limits are shown in Figure 4. EBS snow crab trawl PSC limits are based on total abundance of snow crab as indicated by the NMFS standard trawl survey. In recent years, the assessment model estimate of trawl survey crab numbers is used to calculate the limit. The PSC limit is set at 0.1133% of snow crab abundance index (slope), with a minimum PSC limit (floor) of 4.5 million snow crabs and a maximum PSC limit (ceiling) of 13 million snow crabs; the cap is further reduced by 150,000 crabs (Figure 4).

For Tanner crab, proposed lower threshold limits (750,000 for Zone 1 and 2,100,000 for Zone 2) were based upon the average observed bycatch for the stock at that level of abundance (NPFMC 1996). The maximum PSC limit (ceiling) was based on negotiated amounts when the stock was at a high abundance in 1988 (NPFMC 1996). The middle "step" levels were established at an intermediary level between steps 1 and 3. The specific "floor" "slope" and "ceiling" for these crab PSC limits were all established through an iterative process through the Council and based on observed bycatch at the levels of abundance when the measure was considered in 1996. The process by which these crab PSC limits were initially established was a combination of proposals for limits put forward by the State of Alaska, recommendations from the Crab Plan Team, and by committee discussions amongst interested stakeholders.

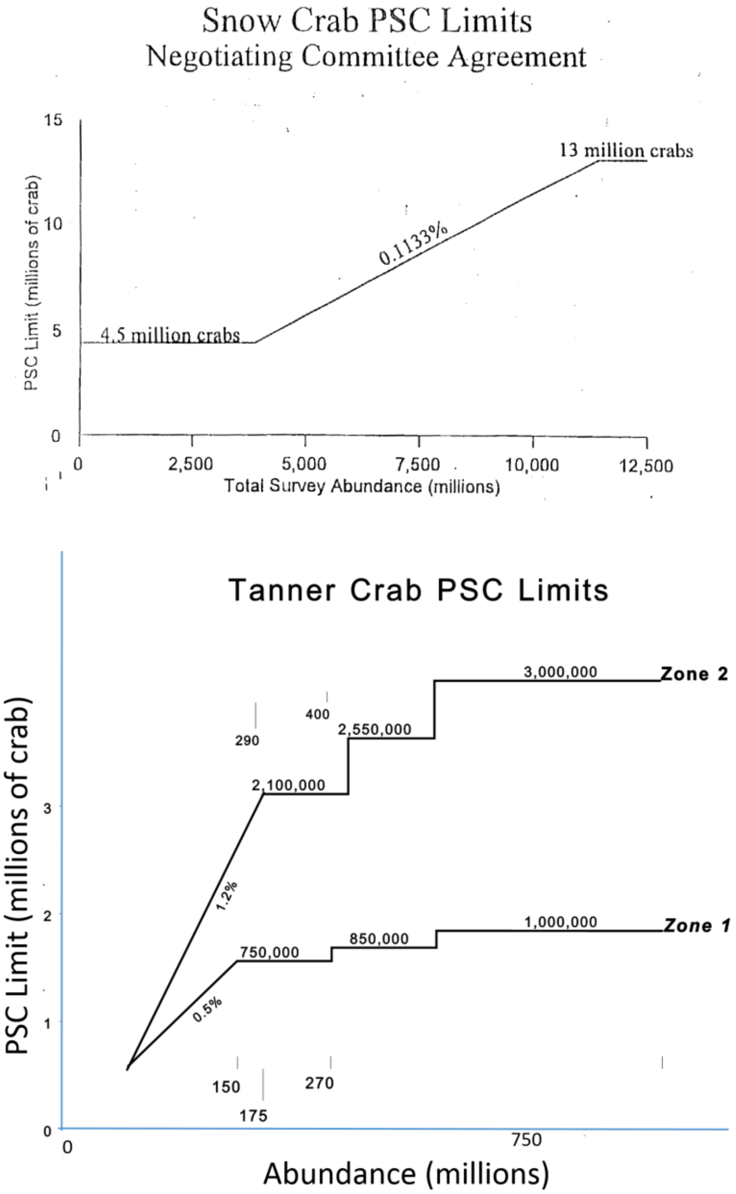

Figure 4. Control rule for snow crab (top) and tanner crab (bottom) PSC limits (from NPFMC 1997).

1.6. What are some of the decision points for halibut ABM alternatives and why is it more complicated?

Index decision point- Using the example for the Crab PSC limits as outlined above, the best estimate of abundance of both Tanner and snow crab was from the annual trawl survey in the BSAI where both stock populations are managed are BSAI area-wide. The decision of what index to use for setting a PSC limit was straightforward. As explained in section 2.1, there are multiple indices for halibut across multiple spatial scales and for different size components of the population, and stakeholder input has suggested that is important for the Council to develop an index that considers halibut stock impacts by area and size. As noted in section 1.1, the Council has identified multiple, often competing, objectives for the proposed action to establish ABM for halibut PSC limits. These include biological objectives such as protecting the halibut spawning stock biomass, and management objectives such as providing opportunities for the directed halibut fishery. These additional objectives have necessarily added to the number of abundance indices that should be considered to develop an ABM program that will satisfy all, or even some, of the objectives. The choice of a single (or combination) of indices to use to best index halibut PSC in the BSAI is more complicated than it was for crab PSC.

Control rule (including starting point, floor, ceiling, and slope) decision point - The general objective for setting crab PSC limits was to reduce the bycatch of the trawl fisheries on crab species while providing opportunity to prosecute those fisheries. As described above, the proposed action to implement ABM for halibut PSC limits includes broader objectives that extend beyond the groundfish fishery. The crab PSC limits established by the control rules (including the floor, ceiling, and slope), were primarily due to a negotiation of appropriate levels between the competing user groups. These negotiations involved agreements to use historical PSC as the "starting point" for developing a control rule, in addition to the other components such as the floor and ceiling. The workgroup anticipates that similar negotiations among halibut user groups likely would benefit the Council in determining appropriate control rule features to analyze for halibut PSC in the BSAI groundfish fisheries. For example, the workgroup has assumed in the strawmen alternatives that the ABM index would result in the 2016 PSC limit (i.e. under each ABM example, the 2016 resulting value is prescribed to be the 2016 PSC limit, 3,515 mt). This is a reasonable approach for the Council to consider as an example, but the Council could also consider other starting points, including other values (e.g., the 2008-2016 average or some higher or lower value for analytical considerations).

2. General framework for developing abundance based management guidance

The following sections outline the set of tools and considerations for developing an ABM for Pacific halibut PSC limits.

2.1. Indices

Indices for the Council to consider should cover the Pacific halibut abundance and age/size specific components similar to how abundance estimates in stock assessments are used to provide management advice. For this work, the group considered the available data for developing the ABM alternatives:

Data sources	Frequency	Characteristics
AFSC EBS shelf bottom trawl survey (EBS BTS)	Annual	Size composition matches observed bycatch Mostly smaller Pacific halibut
AFSC GOA bottom trawl survey	Biennial	May index smaller (recruiting) halibut in the GOA
AI bottom trawl survey	Biennial	Limited halibut occurrence
IPHC setline survey	Annual	Size composition similar to directed fishery Expands to shallower EBS area using calibrations to EBS Trawl data Mostly larger Pacific halibut

The workgroup compiled and standardized (mean = 1) set of available abundance indices over a consistent time-frame to cover aspects of the spatial distribution of Pacific halibut by size. For example, an Alaska-wide recruitment index was developed which included the Gulf of Alaska and the Aleutian Islands along with the eastern Bering Sea. The full set of standardized indices are given in Appendix A.

2.2. Control Rules

A control rule is a function that is driven by data that results in a regulatory control. Here we evaluate simple classes of control rules which is essentially a continuous linear response (responsiveness can vary) and breakpoints (i.e., ceilings and floors). For any approach selected, a critical decision point for the Council will be selecting a baseline starting point (the PSC limit when indices are at their mean value) and alternatives (if desired). Another consideration might include the frequency of PSC changes, the maximum annual change, and alternative configurations by gear type. A general schematic of the index-specific control rules is shown in Figure 5. Decision points for designing alternatives (e.g., starting point for PSC limits) are indicated.

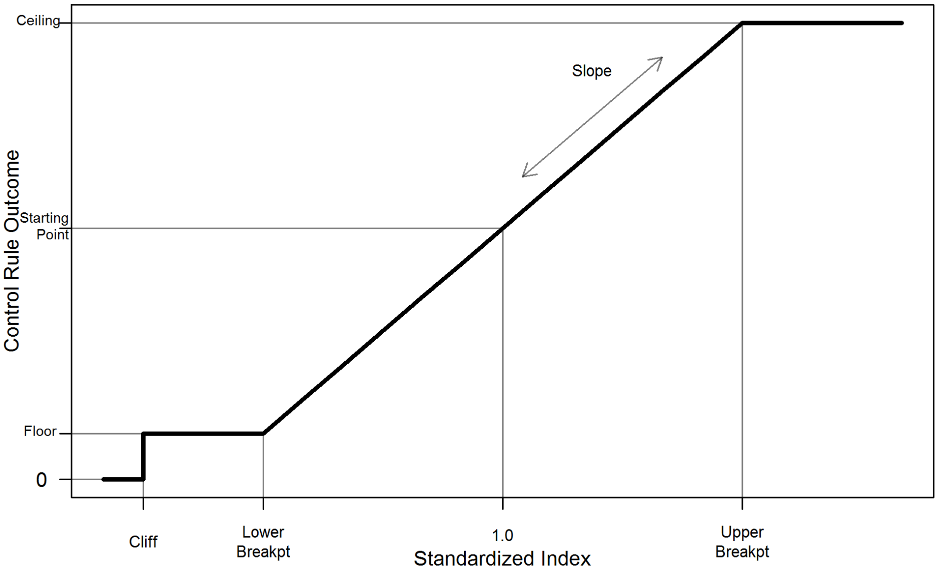

Figure 5. This is an example illustration of a control rule outcome (vertical scale) against a standardized index (horizontal scale) with breakpoints for floor and ceilings etc. as labeled.

2.2.1. Starting point considerations

The starting point for the initial PSC limit will be mandatory for any alternative. For the alternatives presented here, the group selected that each alternative would yield the 2016 PSC limit (3,515 t) as the prediction for that year from the indices/control rule combination.

2.2.2. PSC range considerations

For the alternatives presented here, floors and ceilings were selected at rational, but arbitrary values and apply to all examples that utilize floors and ceilings. For most of these examples the floor and ceiling were chosen to be symmetric around the PSC limit when the indices were at their averages. For the example alternatives shown below the floors and ceilings were set (arbitrarily) one third above and below the starting point for PSC[4].

2.3. Stability considerations

The move to ABM may cause undesirable variability in PSC limits, especially when broken down into fishing sectors. The starting point for establishing a PSC limit under ABM would also be a concern if it represented a significant (and potentially unnecessary) change from the status quo. This can be alleviated to some degree by specifying a maximum annual percentage change, averaging PSC limits over a set of recent years, and/or making changes on a longer than annual basis (biennial, triennial, etc.). In the

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[4] To achieve this with control rules on each, each index had a control rule with a floor and ceiling that were the cube root of the overall floor and ceiling since the adjustments are multiplied together. Note that the individual control rules with floors and ceilings result in the same overall PSC floor and ceiling but with reduced variability (e.g., Figure 7).

examples presented here, stability could be controlled by adjusting the slope of the linear control rules up or down. These types of considerations could be evaluated should the Council wish to evaluate them as component of a management measure. For simplicity in presentation, the examples below omit these types of conditions designed to reduce inter-annual variability of setting PSC limits.

2.4. Gear considerations

The Council directed the workgroup to evaluate the possibility of applying separate control rules to the ABM index for the hook and line and trawl fisheries in order to establish PSC limits. The working group discussed this approach and noted that complications will arise if gear-specific control rules are specified. For instance, the flatfish trawl fishery targeting northern rock sole generally has different bycatch patterns compared to flatfish trawl gear targeting yellowfin sole (Figure 6). The Pacific cod longline fishery has caught larger halibut than the yellowfin trawl fishery on average over time. These differences in gear selectivity and target will impact different age groups of halibut. Because of these differential selections of sizes of halibut, halibut PSC mortality from longliners targeting cod may have a different "footprint" on the halibut stock compared to trawlers that are targeting flatfish. In addition, if PSC limits are established by gear-specific control rules, the status quo proportional allocations of PSC to the groundfish sectors likely would change because the sector PSC limits would no longer be determined as a proportion of the total PSC limit. Because the Council directed the workgroup to maintain the current PSC allocation to sectors for purposes of the ABM action, the workgroup did not develop alternatives to apply separate control rules to the ABM index for hook and line and trawl fisheries.

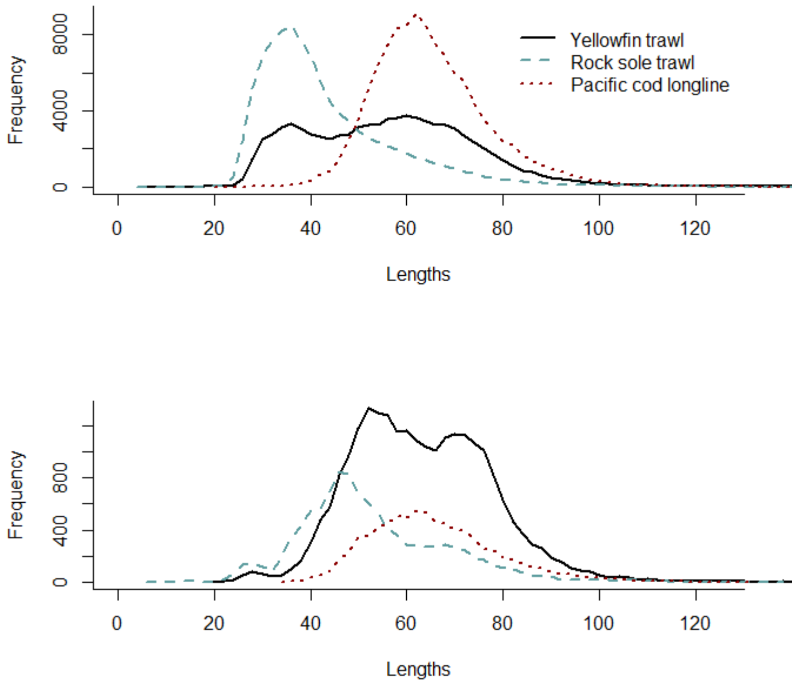


Figure 6. Pacific halibut length distributions for NMFS Alaska Regional Office defined target fisheries for all years combined (2008-2016; top panel) and for 2016 (bottom panel).

3. ABM strawman alternatives

Given the framework and components outlined above, the following strawman alternatives were developed by the workgroup. Note that the individual components of these examples are interchangeable; here they are packaged to help illustrate some of their characteristics.

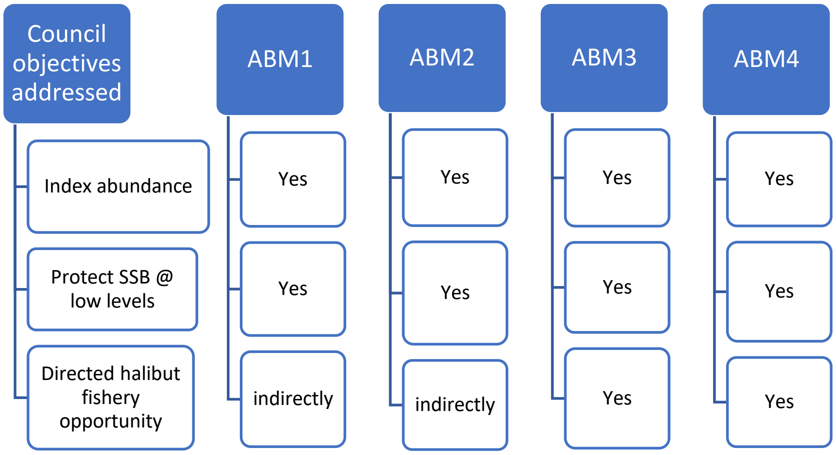
ABM1 This alternative uses the integrated index with equal weights (proposed in October 2016) re-formulated into a multi-dimensional control rule. The eastern Bering Sea (EBS) Shelf trawl survey indexes halibut numbers available to the bycatch and directed fisheries in the EBS. The GOA trawl survey in numbers indexes recruitment and the downstream success of young fish initially occurring in the EBS. The coastwide O32 IPHC setline survey indexes the health of female spawning biomass because this size component is dominated by female fish that are partially mature.

ABM2 This alternative is a refinement to ABM1 to respond to feedback from the February 2017 workshop indicating that the abundance indices should consider the size structure of the halibut stock. Two indices comprise halibut above and below 12 inches (O12 and U12); this is roughly the cutoff for 2 year old halibut. The O12 EBS trawl survey indexes numbers of O12 available in the EBS. To address incoming recruitment and predict small fish entering the fisheries, we used Alaska wide (GOA/AI/EBS) combined trawl survey numbers of U12 halibut. The coastwide O32 setline survey indexes the health of female spawning biomass because this size component is generally dominated by mature female fish.

ABM3 This alternative applies the O26 weight per unit effort (WPUE) from the IPHC setline survey. It also includes adjustments based on a U26 halibut index from the EBS trawl survey and the coastwide spawning biomass from the IPHC assessment. This is intended to address issues related to maintaining the directed halibut fishery while using relative spawning biomass benchmarks established by the IPHC.

ABM4 This alternative is a refinement to ABM3 and applies the O26 WPUE from the IPHC setline survey and the U26 halibut numbers from the EBS trawl survey. These two indexes are weighted to account for differences in selectivity/encounters with O26 and U26 halibut. This self-weighted component is combined with a 3rd component based on the relative spawning biomass benchmarks established by the IPHC. The weight of this latter component would be specified by the Council.

To summarize alternatives and partially reflect how they have evolved based on feedback from the Council, SSC, and stakeholders a set of strawman alternatives were developed and compared across the Council objectives (Figure 7). The subsequent sections provide the detail of how these components are specified and addressed in each of the alternatives.



Council objectives addressed	ABM1	ABM2	ABM3	ABM4
Index abundance	Yes	Yes	Yes	Yes
Protect SSB @ low levels	Yes	Yes	Yes	Yes
Directed halibut fishery opportunity	indirectly	indirectly	Yes	Yes

Figure 7. Summary of strawmen alternatives provided and which address aspects of Council objectives. Note that the remaining objectives of providing for groundfish flexibility and stability of limits directly depend upon the selection of Control rule formulations (slope, ceilings, floors, cliffs) and thus are not yet addressed by the ABM examples provided. They will depend upon choices made in the development of alternatives.

3.1. ABM1

The modifications suggested by the SSC led to developing the "ABM1" framework. This differs somewhat in the indices used and the way the control rule may or may not apply within the indices as shown in the equations (and Figure 8) below. This notion follows the guidance provided by the SSC in their October 2016 SSC minutes (Figure 9).

3.1.1. Indices and control rules

ABM1 involves data from the following data sources:

1) The EBS Shelf trawl survey indexes halibut numbers available to bycatch and directed fisheries in the EBS; in ABM1, this index covers all size ranges available to the trawl survey gear; this index applies primarily to **Principle 9** (groundfish fisheries in the EBS)
2) The GOA trawl survey indexes halibut numbers available of a size range that is not fully covered by the setline survey so helps determine successful overall recruitment; this index covers all size ranges available to the trawl survey gear; this index applies primarily to **Principle 4** (recruitment)
3) The O32 IPHC coastwide setline survey is a proxy for female spawning biomass. The 50% length at maturity presently is approximately about 32 inches, and as fish exceed 32 inches they are increasingly female.; this index applies primarily to **Principle 6** (amount of female spawning biomass)

3.1.2.Application to control rule

The SSC requested that each index have separate slopes (i.e., sub-control rules) which could then be re-combined to determine the PSC limit. The sub-control rule applied to each index determines the proportional change in its contribution to PSC (b_k =1). If the value of b_k is 1, changes in the index will have a 1:1 impact on the PSC limit (i.e., the control rule would exert a 10% increase in the PSC limit for a 10% increase in the index). If the value of b_k is greater than 1 it will have a higher impact on the PSC limit (e.g., for a $b_k = 2$, the control rule would exert a 20% increase for a 10% increase in the index). If the value of b_k is less than 1 it will have a smaller impact on the PSC (e.g., for a $b_k = 0.5$, the control rule would exert a 5% increase for a 10% increase in the index). For this alternative, the workgroup established floors and ceilings that are 2/3rd and 4/3rd the overall PSC limit when the indices average 1 (PSC_0 or the "Starting point" on Figure 8).[5]

The example application in Figure 9 shows how the multipliers[6] for each index (each index's proportional impact on the resulting PSC limit, indicated as the "Adjustment" in Figure 8) propagate to result in the combined adjustment to the PSC limit. Figure 10 presents the PSC limits that would result from applying the combined adjusted indices as described for ABM1 and also shows the sensitivity of the PSC range constraints.

Figure 8 presenting a schematic of the process for determining a PSC limit using ABM1. The workgroup used the 2016 PSC limit (3,515 t) as the *Starting Point* in all of the strawman alternatives, including ABM1. The first step in the process is to adjust 3,515 t by the outcomes of the sub-control rules applied to each index (*Adjustment* in the bottom line of the figure) to determine the PSC limit (*PSC* in the bottom line of the figure).

$$c_t = PSC_0 \prod_k \left[1 - (1 - x_{k,t})\, b_k\right]$$

$$PSC_t = \begin{cases} PSC_{min} & c_t < PSC_{min} \\ c_t & PSC_{min} < c_t < PSC_{max} \\ PSC_{max} & c_t > PSC_{max} \end{cases}$$

$$x_{k,t} = \begin{cases} x_{k,min} & x_{k,t} < x_{k,min} \\ x_{k,t} & x_{k,min} < x_{k,t} < x_{k,max} \\ x_{k,max} & x_{k,t} > x_{k,max} \end{cases}$$

where these and all variables used in the alternatives are described in Table 2.

Table 2. Parameters used in the ABM equations.

Parameter	Description
k	Index for abundance time series
t	Index for year
$x_{k,t}$	Normalized value of abundance index *k* in year *t*
b_k	Proportionality constant for index *k*
PSC_0	Prohibited species catch limit when all indices are average (1)
PSC_t	Prohibited species catch limit in year *t*
PSC_{min}	Floor (minimum value) of the prohibited species catch limit
PSC_{max}	Ceiling (maximum value) of the prohibited species catch limit
c_t	Defines the PSC limit prior to application of floors and ceilings
$x_{k,min}$	Floor (minimum value) of index *k*
$x_{k,max}$	Ceiling (maximum value) of index *k*
ρ_t	Proportional weight of index 1 (used in ABM4)

---

[5] To achieve this with control rules on each, each index had a control rule with a floor and ceiling that were the cube root of the overall floor and ceiling since the adjustments are multiplied together.
[6] Simple scaling factors or adjustments to the starting point (here specified as PSC_0).

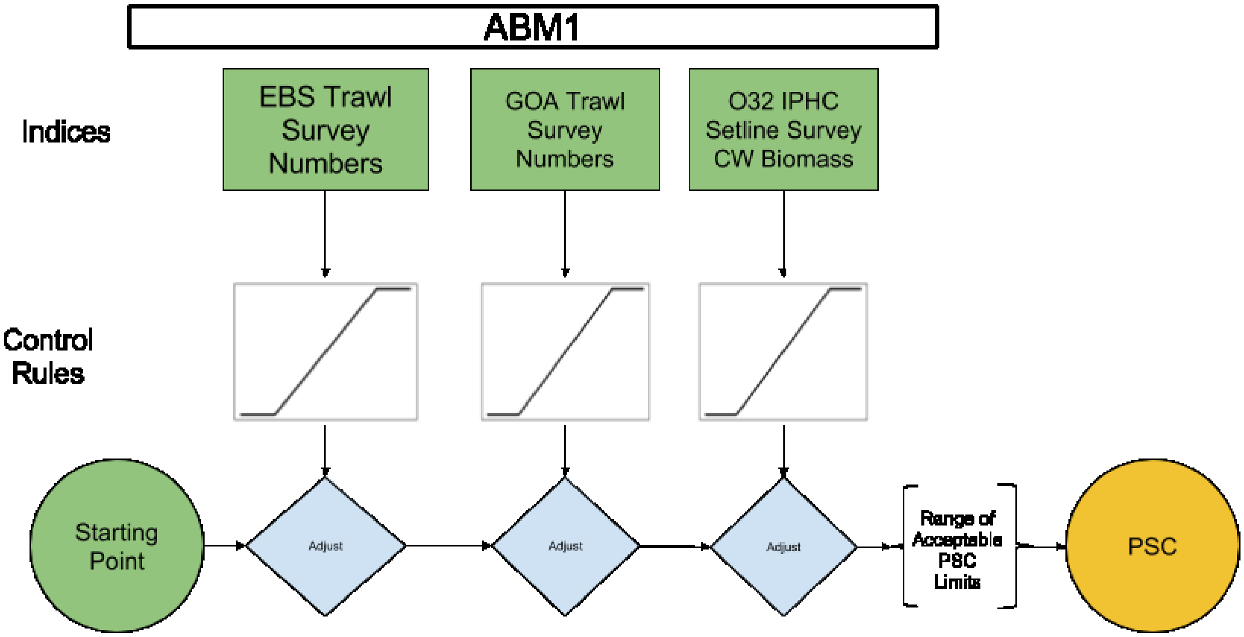


Figure 8. Schematic of the framework “ABM1”.

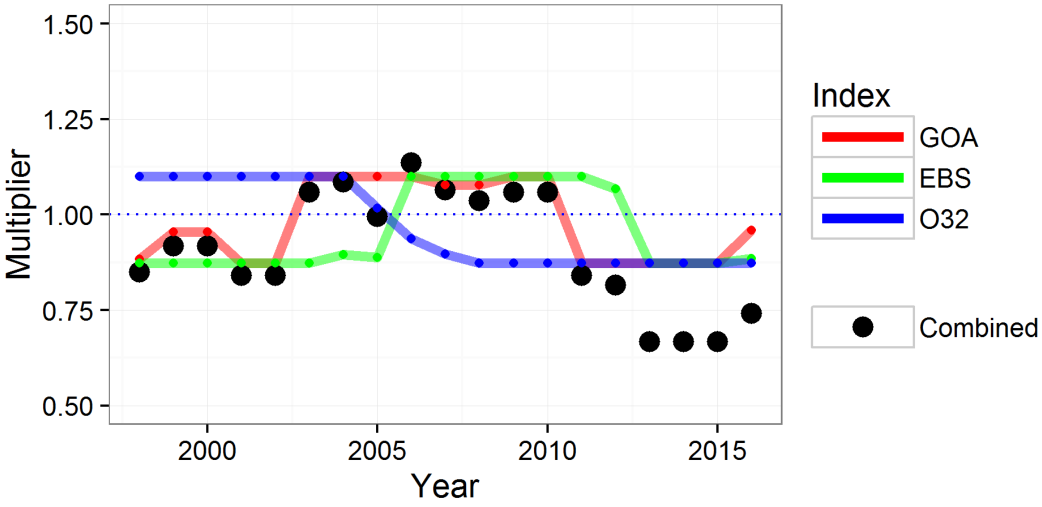


Figure 9. Example indices for ABM1 with control rules and combined effect (treated as multipliers).

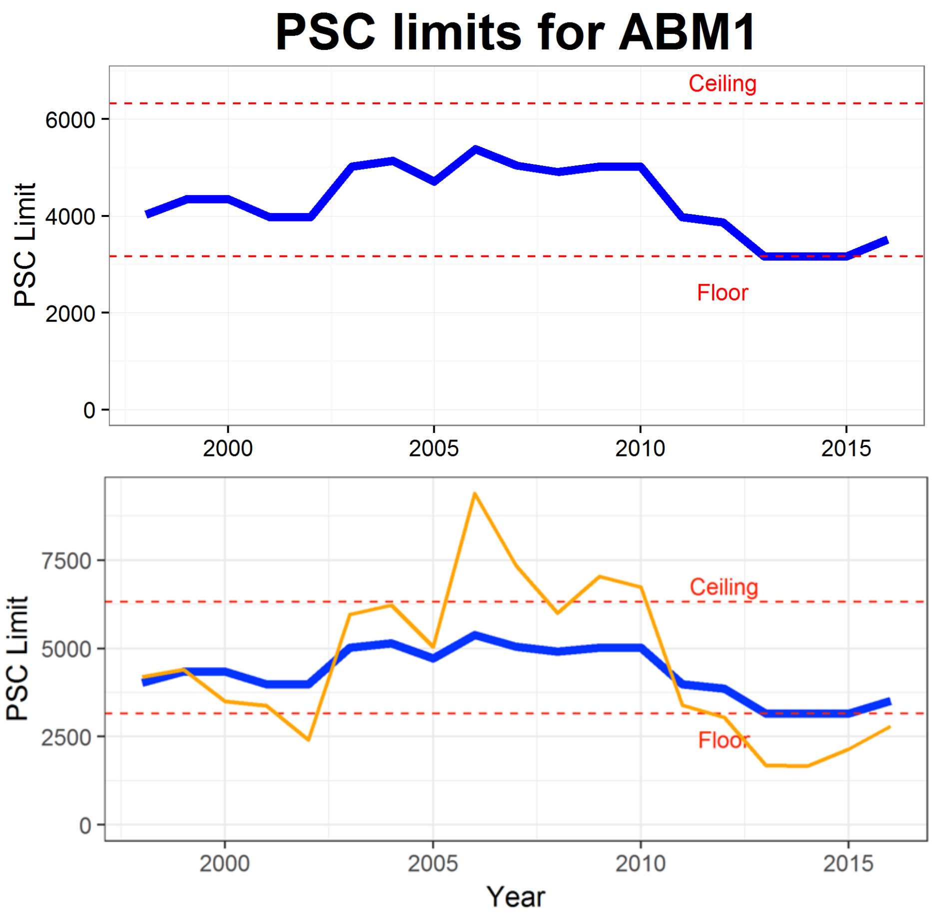


Figure 10. PSC limit based on example combined indices for historical PSC limits for ABM1 (top) and including result without any constraint on range for indices and PSC (i.e., zero or infinite for floor and ceiling; thinner gold line, bottom). Note vertical scaling differs between these figures.

3.1.3.Discussion

ABM1 uses survey data only, and uses data that are routinely calculated by their respective survey groups and hence is transparent. This alternative satisfies **Principles 1, 2 and 3** of the features described above which are related to transparency.

The slope of the control rule for each index can be adjusted to control the percent change in the indices compared to the percent change in the PSC limit which provides stability. In addition, the floors and ceilings could be adjusted to as wide or narrow a range as risk tolerance accepts which would contribute to stability (or instability).

The range of PSC limits available under this control rule is determined by the floors and ceilings imposed on this example. These limits are an arbitrary example, but we can see that ABM1 is affected by the floor and not the ceiling and the range is approximately 3500 – 5300 t.

This alternative attempts to address the issue of recruitment and ontogenetic movement between areas by looking at trawl survey numbers in both the EBS and GOA. However, the AI, Canada and the West Coast are not included and without a rich tagging data set and a complex model, fully capturing the spatial dynamics and effects of harvest would be speculative at best. Although the trawl data when used in numbers are more focused on smaller fish, these data were not restricted in ABM1.

The use of the coastwide O32 setline survey is appealing because it is data-based and addresses the overall stock status of Pacific halibut (which is considered to be one stock). The stock assessment likely estimates stock status more accurately, but is also subject to occasional method changes which may change perceptions quickly which can be detrimental to stability.

This alternative makes no attempt to address which indices (designed to address diverse factors) have greater importance. However, the method is transparent and the control rules can readily be adjusted to Council objectives on stability and risk tolerance.

Finally, ABM1 does not specifically consider **Principles 7** and **8** for using IPHC data by area or the stock assessment advice, but it does make some consideration for **Principle 5** (directed fishery) through the EBS trawl survey and the coastwide O32 index.

3.2. ABM2

This alternative uses three indices to calculate a PSC limit. This alternative has a set of equations and schematic that is identical to that shown in ABM1 above. The only difference is in the indices used. The ABM2 indices incorporate feedback from the February 2017 workshop suggesting that abundance indices should consider halibut size structure. ABM2 uses the combined GOA/AI/BS trawl survey index to reflect Alaska-wide recruitment. By comparing the relative abundance between the GOA and EBS for smaller halibut, a cut-off point at 12 inches showed that the abundance of Pacific halibut less than 12 inches (U12) was qualitatively similar. This size group is also considered mainly to comprise 1 and 2 year old fish. The schematic with the indices is shown in Figure 11. below.

3.2.1.Indices and control rules

ABM2 uses data from the following data sources:

1) The EBS Shelf trawl survey indexes halibut numbers available to groundfish and directed fisheries in the EBS; this index is now restricted to the O12 component; this index applies primarily to **Principles 5** and **9** (directed and groundfish fisheries in the EBS)
2) Summed trawl survey numbers of halibut under 12 inches (U12) from GOA/AI/EBS shelf trawl surveys (not the EBS Slope trawl survey because the goal is to index small halibut as incoming recruitment); this index applies primarily to addressing **Principle 4** (recruitment)
3) The O32 IPHC coastwide setline survey is a proxy for female spawning biomass. The 50% length at maturity presently is approximately about 32 inches, and as fish exceed 32 inches they are increasingly female.; this index applies primarily to **Principle 6** (amount of female spawning biomass)

3.2.2.Application to control rule

The SSC recommended that each index have separate slopes (i.e., sub-control rules) which could then be re-combined. Each index is proportional to the change in its contribution to PSC (b_k =1). For this option we set floors and ceilings that are 2/3rd and 4/3rd the overall PSC when the indices average 1 (PSC_0). To achieve this with control rules on each, each index had a control rule with a floor and ceiling that were the cube root of the overall floor and ceiling since the adjustments are multiplied together.

An example application shows how the multipliers for this propagate (with their constraints by indices (Figure 12). Combined with the PSC limits (as examples) are provided in Figure 13.

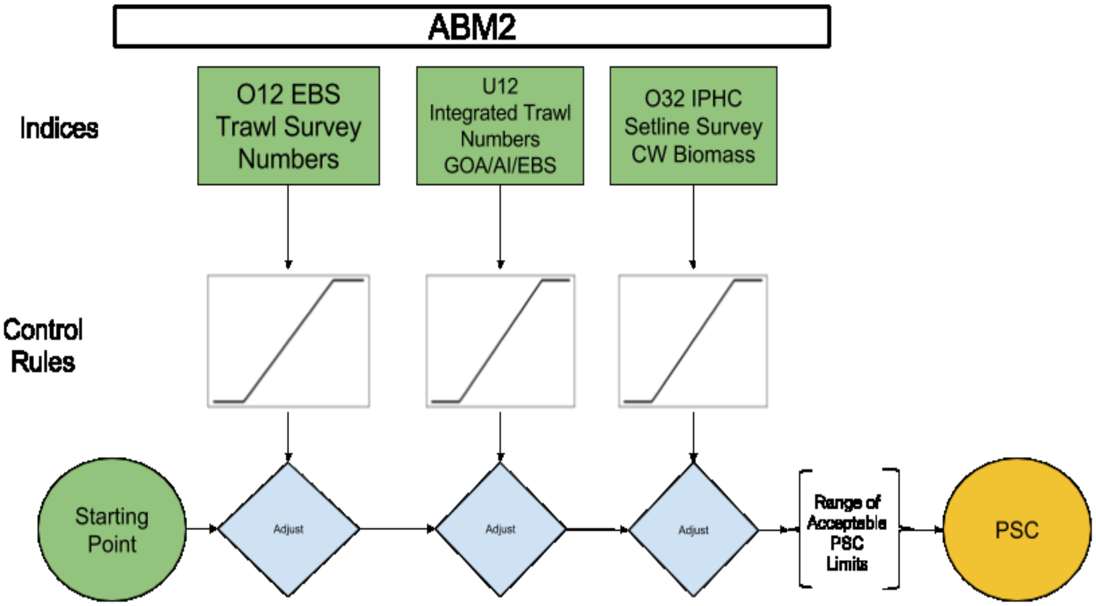


Figure 11. Schematic of the framework “ABM2”.

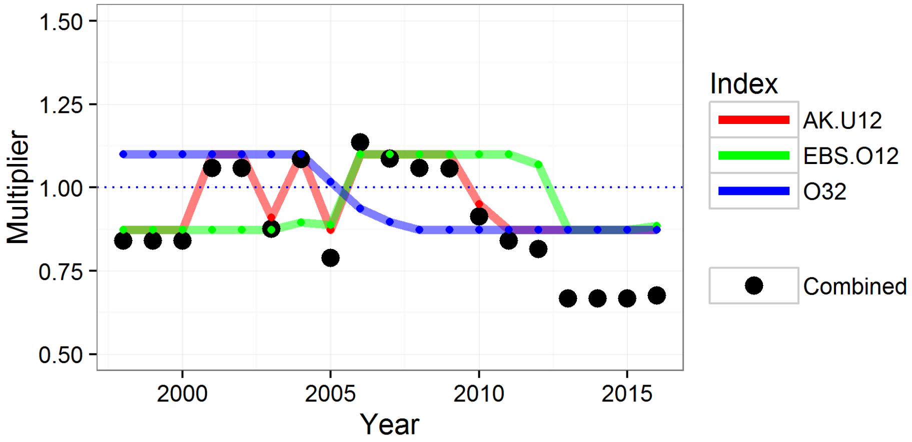


Figure 12. Example indices for ABM2 with constraints and combined effect (treated as multipliers).

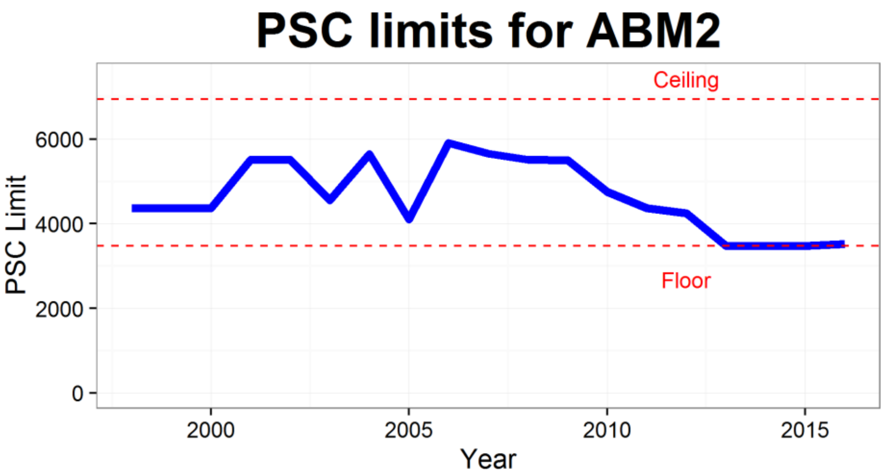


Figure 13. PSC limit based on example combined indices for historical PSC limits for ABM2.

3.2.3. Discussion

ABM2 uses survey data only, and uses data that are routinely calculated by their respective survey groups and hence is transparent. This alternative satisfies **Principles 1, 2 and 3** of the features described above which are related to transparency.

The slope of each control rule can be adjusted to control the percent change in the indices compared to the percent change in the PSC limit which provides stability. In addition, the floors and ceilings could be adjusted to as wide or narrow a range as risk tolerance accepts which would contribute to stability (or instability).

The range of PSC limits available under this control rule is determined by the floors and ceilings imposed on this example. These limits are an arbitrary example, but we can see that ABM2 is affected by the floor and not the ceiling and the range is approximately 3500 – 6000t.

This alternative was designed to address the issue of recruitment and ontogenetic movement between areas by looking at small fish abundance throughout Alaska. However, Canada and the West Coast are not included and without a rich tagging data set and a complex model, fully capturing the spatial dynamics and effects of harvest would be speculative at best.

The coastwide O32 setline survey is data-based and addresses the overall stock status of Pacific halibut (which is considered to be one stock). The stock assessment likely estimates stock status more accurately, but is also subject to occasional large method changes which may change perceptions quickly which can be detrimental to stability. The EBS U12 index should capture the availability of the middle age/size range of halibut which are important both to directed and non-directed fisheries.

This alternative makes no attempt to address which indices (designed to address diverse factors) have greater importance. However, the method is transparent and the control rules can readily be adjusted to Council objectives on stability and risk tolerance.

Finally, ABM2 does not specifically consider **Principles 7,** and **8** for using IPHC data by area or the stock assessment advice, but it does make some consideration for **Principle 5** (directed fishery) through the EBS trawl survey and the coastwide O32 index.

3.3. ABM3

This alternative uses three indices to calculate a PSC limit.

1. O26 WPUE from the IPHC setline survey. O32 is currently being used in the example for this discussion paper because O26 WPUE is not currently available. O26 WPUE can be made available in the Council chooses to evaluate an ABM alternative using O26 WPUE as an index. This index is a direct link to the abundance available to the directed halibut fishery (**Principle 5)**.
2. U26 halibut numbers observed in the EBS shelf trawl survey. This is an index of the smaller/younger fish that may contribute to future spawning biomass or directed fishery opportunities (**Principle 4**) . Including this index also ensures that the PSC is adjusted to reflect what the groundfish fisheries may encounter (**Principle 9**). It may be desirable to be consistent with the first index of WPUE from the setline survey (i.e., O26/U26 or O32/U32).
3. Coastwide stock status from the IPHC assessment (**Principle 8**). This is assumed to be the same as the current IPHC control rule on relative spawning biomass (i.e., ramp down adjustment between 30% and 20% relative spawning biomass, and zero PSC below 20% relative spawning biomass).

The equations and the schematic for this framework are shown below (Figure 14).

Equations describing how the PSC in year *t* is determined are as follows, including the IPHC “30:20” control rule (with floors and ceilings).

$$c_t = \begin{cases} 0 & x_{3,t} <= 20\% \\ PSC_0 \prod_{k=1}^{2} [1-(1-x_{k,t})b_k][-2+10x_{3,t}] & 20\% < x_{3,t} < 30\% \\ PSC_0 \prod_{k=1}^{2} [1-(1-x_{k,t})b_k] & x_{3,t} >= 30\% \end{cases}$$

then

$$PSC_t = \begin{cases} PSC_{min} & c_t \leq PSC_{min} \\ c_t & PSC_{min} < c_t < PSC_{max} \\ PSC_{max} & c_t \geq PSC_{max} \end{cases}$$

$$x_{k,t} = \begin{cases} x_{k,min} & x_{k,t} < x_{k,min} \\ x_{k,t} & x_{k,min} < x_{k,t} < x_{k,max} \\ x_{k,max} & x_{k,t} > x_{k,max} \end{cases}$$

Note that in this case $x_{3,t}$ is the index of relative spawning biomass in year *t.*

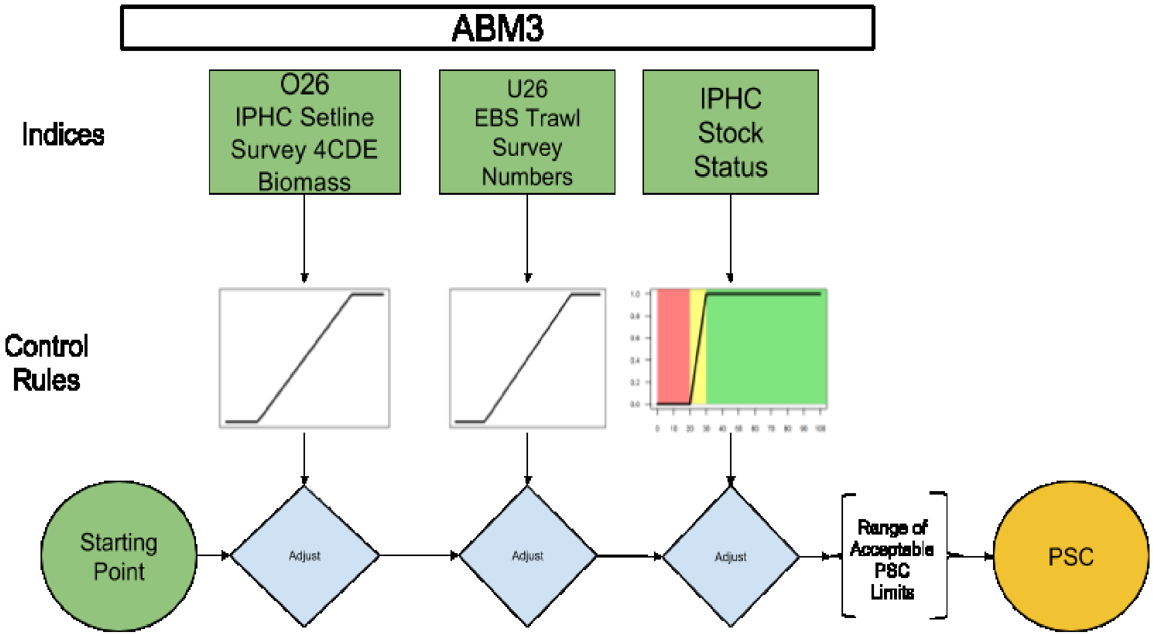


Figure 14. Schematic of the framework “ABM3”.

3.3.1. Indices and control rules

The biomass of large fish encountered by the directed fishery (O32 or O26) in the Bering Sea/Aleutian Islands is directly linked to the population available for directed halibut fisheries. Smaller Pacific halibut taken as PSC in other groundfish fisheries appear to have higher variability due to availability and selectivity issues relative to survey gear. The IPHC space-time model output using the setline survey and other survey observations provides an index of biomass or abundance for halibut over 26” (O26) or over 32” (O32) that may be more precise and accurate compared to survey data on smaller fish. Linking the PSC limit to the O26 or O32 biomass estimated by the survey in 4CDE (and possibly including other areas in the Bering Sea such as a portion of 4A) would result in values more closely related to the trends in biomass available to the directed fishery.

The PSC catch of Pacific halibut is generally smaller than O26 (the size range managed for directed halibut fishing) and changes in abundance of those U26 fish are important for PSC allowances in groundfish fisheries. These smaller fish will eventually contribute to and maintain the directed fisheries and the coastwide population as they age. Therefore, the PSC limit should also be responsive to the abundance of these smaller fish for conservation purposes and to minimize bycatch to the extent practicable and provide for groundfish opportunities.

A third and important component of ABM3 is the index of the coastwide spawning biomass of Pacific halibut. Here the PSC limit is adjusted based on the relative spawning biomass (RSB) of Pacific halibut using the same underlying control rule presently applied by the IPHC in setting Pacific halibut allowable catch rates. Specifically, if coastwide RSB is greater than 30% then no adjustment is needed. As the RSB drops below 30% the rate falls linearly and is set to zero when the RSB is at or below 20%. Consistent with the halibut fishery management, when the Pacific halibut stock is below 20% of the unfished spawning biomass estimate, PSC and directed fishing is curtailed (Figure 15).

The Council may wish for this control rule to be closely aligned with the IPHC practice/policy of protecting spawning biomass. Should the IPHC practice change, the Council may wish to adopt the same changes (note that this would be challenging to analyze for impacts) or remain with the current 30:20 policy.

3.3.2. Application of the three components of this alternative to determine the PSC limit

The O26 WPUE, the U26 abundance, the relative spawning biomass, and their associated control rules would simply result in multipliers to a starting PSC limit. This starting PSC limit would remain the same every year, and deviations in these indices would simply result in deviations to the starting PSC limit. An example application (using O32 WPUE from the IPHC space-time model since that is the only index currently available) shows how the multipliers for this propagate (with their constraints by indices (Figure 16). Combined with the PSC limits (as examples) are provided in Figure 17.

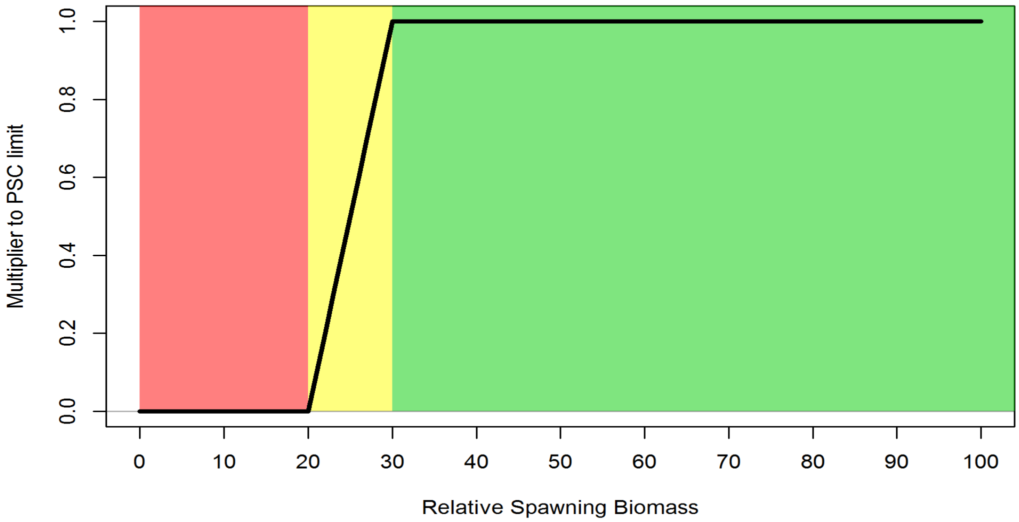


Figure 15. Determination of a multiplier for a control rule related to relative spawning biomass with a decline from one above 30% to zero below 20%.

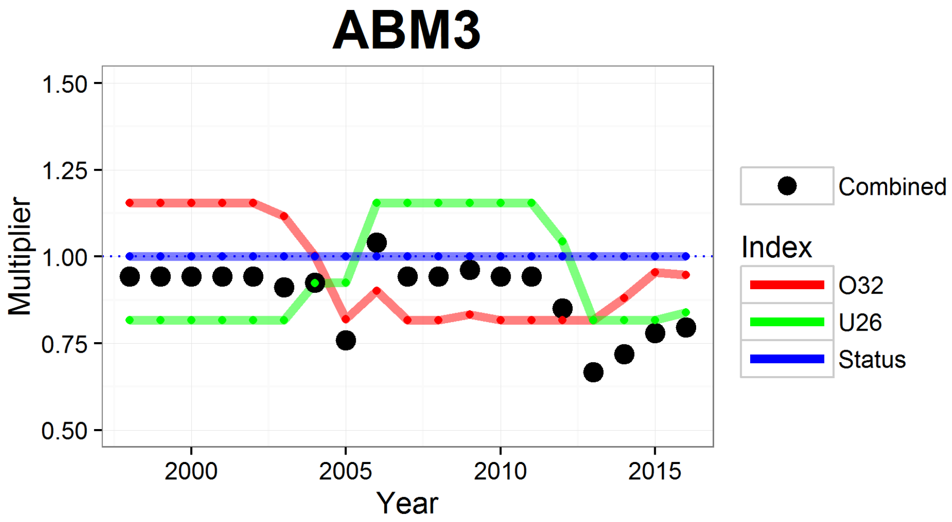


Figure 16. Example indices for ABM3 with constraints and combined effect (treated as multipliers on PSC_0).

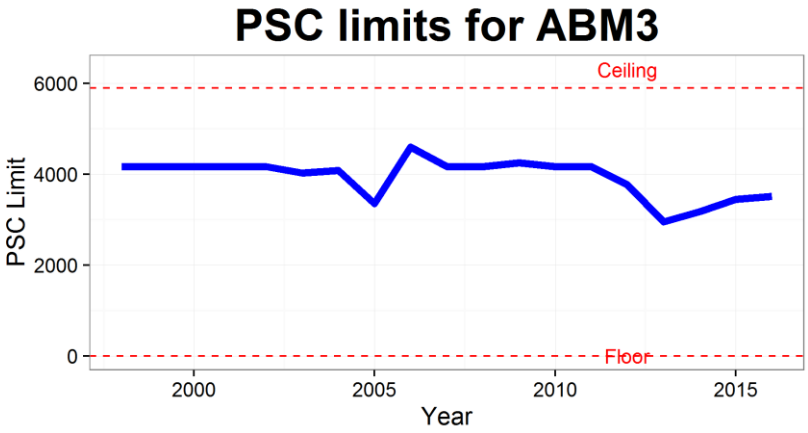


Figure 17. PSC limit based on example combined indices for historical PSC limits for the ABM3 framework, with implied floor and ceiling determined from the individual floors and ceilings on each index.

3.3.3. Discussion

This alternative provides for a response in the PSC limit when the O26 biomass and the U26 abundance change, which provides a direct relationship to the larger fish that are important to the directed halibut fishery, and a direct relationship to the small fish. This satisfies **Principle 5** (directed fishery)**, Principle 7** (O26 abundance by area), and **Principle 9** (halibut encountered in groundfish fisheries), and attempts to balance providing opportunity for the groundfish fisheries and providing for a healthy halibut population in the future. It partially satisfies **Principle 4** (recruitment) by including an index of small halibut in the BS/AI. Separating these two components allows for more detailed control on the response to each. The coastwide status is introduced to protect the Pacific halibut stock when the spawning biomass is reduced, thus satisfying **Principle 8**. Historically, the stock status has never been estimated to have been below 30%, thus this control rule would never have been retrospectively applied.

It may be important to monitor the encounter ratio of U26 to O26 in the groundfish fisheries to make sure that the combined response to the two indices is appropriate. For example, and hypothetically, if a lot of weight is given to the O26 index, but the groundfish fishery is mostly encountering U26 halibut, the PSC limit may not be appropriately responsive to what the groundfish fishery is encountering. Furthermore, if a large recruitment event occurs, the combination of the indices may not be responsive enough to provide opportunity to the groundfish fisheries.

Lastly, this alternative accounts for coastwide spawning biomass, but does not consider the potential, or lack of potential, from recruitment outside of the BSAI. The inclusion of an additional index for GOA U26 or replacing the U26 BSAI index with an Alaska-wide U26 index may provide the necessary protection. **Principle 3** (minimize assumptions) **and Principle 4** (recruitment) may not be entirely satisfied for this alternative, as outlined here.

3.4. ABM4

This alternative uses three indices to calculate a PSC limit. Two of them are “self-weighting” and based on size categories. For simplicity, we propose to have one index on the O26 component and a separate index on the U26 component, as in ABM3. These two components can be combined with weights that are specific to a fishery to account for differences in selectivity/encounters with different size classes. These weights proposed here are data driven. i.e., the weighting between O26 and U26 indices are based on their relative abundance and in this example, were specified as follows:

1. O26 WPUE from the IPHC setline survey. O32 is currently being used in the example for this discussion paper because O26 WPUE is not currently available. O26 WPUE can be made available in the Council chooses to evaluate an ABM alternative using O26 WPUE as an index. This index is a direct link to the abundance available to the directed halibut fishery (**Principle 5**).
2. U26 halibut numbers observed in the EBS shelf trawl survey. This is an index of the smaller/younger fish that may contribute to future spawning biomass or directed fishery opportunities (**Principle 4**). Including this index also ensures that the PSC is adjusted to reflect what the groundfish fisheries may encounter (**Principle 9**). It may be desirable to be consistent with the first index of WPUE from the setline survey (i.e., O26/U26 or O32/U32).
3. Coastwide spawning biomass from the IPHC assessment.

3.4.1.Indices and Control rules

This framework is set up to use indices based on abundance measures of U32 and O32 as in the examples, but can be based on U26 and O26, or any other size definition. For this example, the O32 and U26 indices are the same as in ABM3, and are motivated for similar reasons. The third index, coastwide spawning biomass, is another example of how the coastwide population can be incorporated. This index would modify the PSC limit with a control rule, just as other indices do.

The equations and schematic (Figure 18) for ABM4 are shown below.

$$c_t = PSC_0 \times x_{1,k}\rho_t \times (1 - \rho_t)\, x_{2,t} \times b_3 x_{3,t}$$

$$\text{then}$$

$$PSC_t = \begin{cases} PSC_{min} & c_t \le PSC_{min} \\ c_t & PSC_{min} < c_t < PSC_{max} \\ PSC_{max} & c_t \ge PSC_{max} \end{cases}$$

$$x_{k,t} = \begin{cases} x_{k,min} & x_{k,t} < x_{k,min} \\ x_{k,t} & x_{k,min} < x_{k,t} < x_{k,max} \\ x_{k,max} & x_{k,t} > x_{k,max} \end{cases}$$

Where x_k is the k^{th} index and ρ_t is the proportional weight of index 1.

$$\rho_t = \frac{x_{1,t}}{x_{1,t} + x_{2,t}}$$

The weights, ρ_t consequently are determined as a function of the proportion of U26 fish in the population. The weight, ρ_t, may include other variables that limit the responsiveness or include a floor or ceiling, similar to the features of a control rule.

3.4.2.Application to control rule

An example application shows how the multipliers, with floor and ceilings on each index, propagate for ABM4 (Figure 19). These scaling factors or multipliers, when combined with PSC_0 give historical PSC limits as examples (Figure 20).

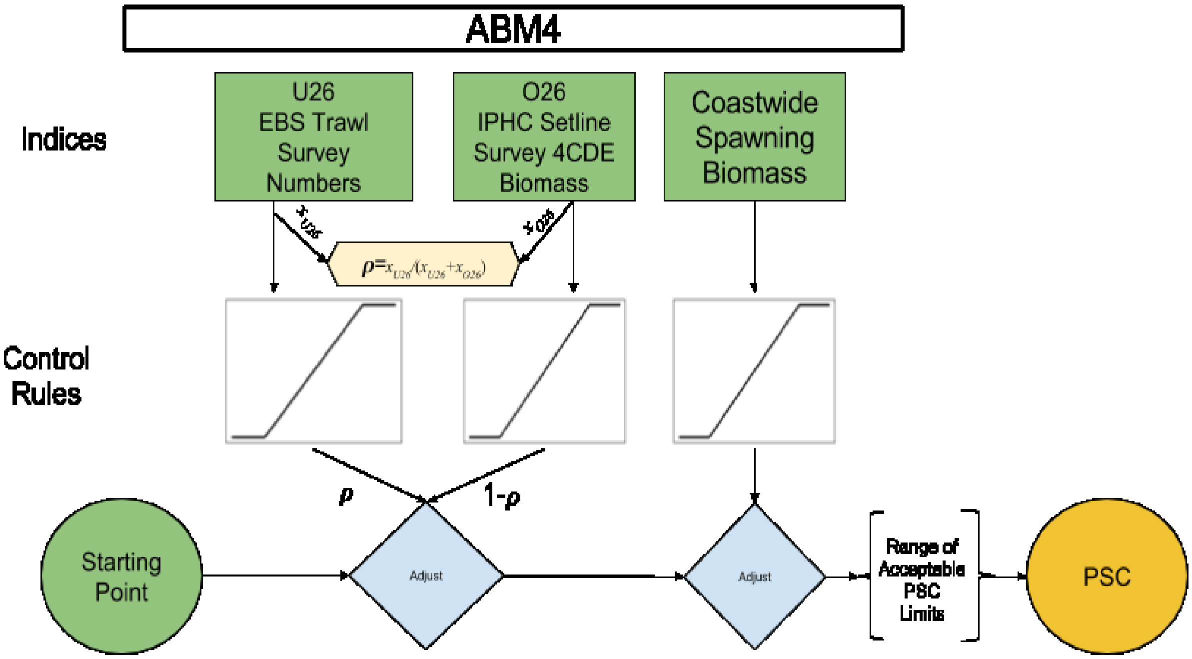


Figure 18. Schematic of the framework “ABM4”. This includes a weighting factor for the U32 and O32 indices (ρ), which may be a different functional form that incorporates a different slope, floor, and/or ceiling.

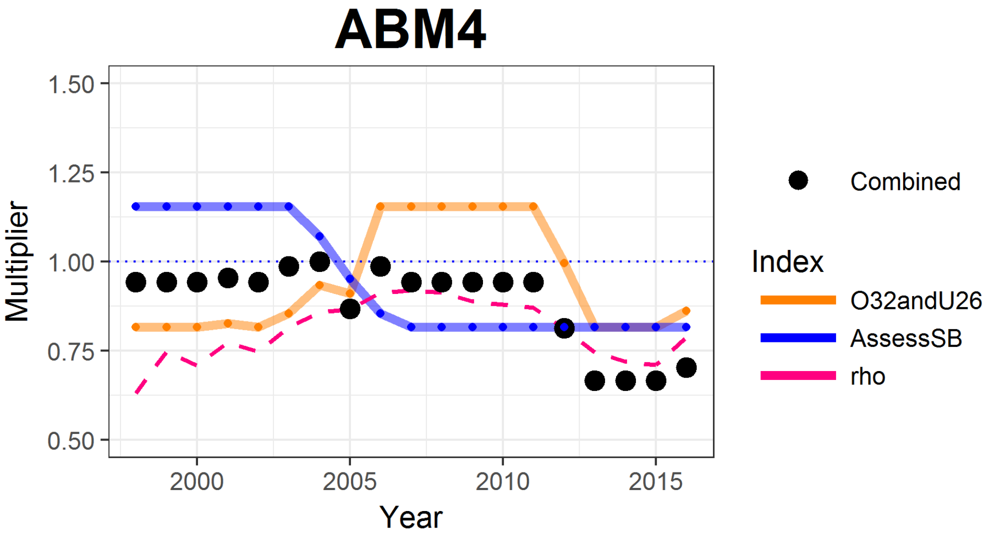


Figure 19. Example indices for ABM4 with constraints (treated as multipliers on PSC_0). Black dots are the three indices multiplied together to show the deviation on PSC_0.

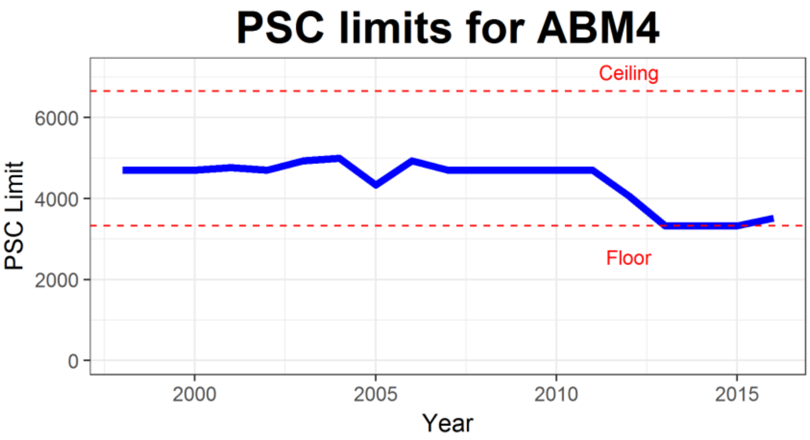


Figure 20. PSC limit based on example combined indices for historical PSC limits for the ABM4 framework.

3.4.3.Discussion

This alternative allows for the PSC limit to be weighted based on data so that the weighting is proportional to what is likely to be encountered by the non-directed fishery. It also allows the PSC to respond to recruitment failures or successes. For example, if there was a big recruitment, that would result in a larger proportion of U26 halibut, which would change the length composition observed in the fishery, meaning that the fishery would be encountering more U26 fish. Because of the big recruitment, there would be many U26 fish and the PSC would increase to account for that increase in population size. This alternative satisfies **Principle 5** (directed fishery)**, Principle 7** (O26 abundance by area), and **Principle 9,** and partially satisfies **Principle 4** (recruitment)**. Principles 3** (minimize assumptions) **and 4** (recruitment) may not be entirely satisfied for the specific formulation of this alternative.

The proportion of U26 would likely be determined from the fishery-independent trawl survey so that there are no unforeseen incentives for the non-directed fishery participants to change behavior and target specific size classes. However, this could result in bias, especially as the fishery changes selectivity (e.g., using excluders or avoiding specific areas). The function for ρ can incorporate similar features as control rules to adjust how it responds to changes in each component, allowing it to mimic how the fishery selectivity may respond to changes in abundance of each component (e.g., the availability of a specific size class increasing as abundance increases).

4. Comparison of alternatives

To compare reasonably over the different alternatives, the floors and ceilings are set so that the combined floor and ceilings are +/- 33% from the 2016 PSC limit (Figure 21). A similar comparison of ABMs to address Council objectives is shown in Table 3.

Table 3. Comparison across alternative ABMs for the indices and cross checking on the Council's stated objectives. "Mod" means that modifications would be necessary.

	Alternative ABMs			
Size Area Type	1	2	**3**	4
Total numbers in GOA trawl index	X			
Total numbers in EBS shelf trawl survey index	X			
O32 coastwide WPUE from the IPHC setline survey (space-time model)	X	X		
U12 recruitment index from combined GOA/AI/BS trawl VAST or simple sum		X		
O12 EBS shelf trawl survey		X		
IPHC stock status (function of IPHC SSB)			X	
O26 EBS setline survey index			X	X
U26 EBS shelf trawl survey index			X	X
SSB coastwide IPHC Stock assessment				X
U26 (EBS trawl survey) and O26 (EBS setline) proportional dynamic weighting*				X
Council objectives				
Indexes abundance	X	X	X	X
Protects SSB at low levels	X	X	X	X
Groundfish flexibility	-	-	-	-
Directed halibut fishery opportunity			X	X
Stability of limits	-	-	-	-
Suited to GOA?	Yes	Yes	Mod	Mod

ABM 1 includes the halibut encountered by the groundfish fishery, considers recruitment from the GOA and the setline survey for larger fish (as a proxy for female spawning biomass) coastwide without including the assumptions embedded in the assessment. ABM 2 improves upon the assumptions and considerations under ABM1 by focusing upon specific size classes, and considering recruitment Alaska-wide based upon a statistical approach of combining different surveys, addresses abundance of halibut in the Bering Sea that the fishery will encounter without double-counting any observations and accounts for the Coastwide spawning biomass by using a different index than the assessment. ABM3 has similar qualities as ABM2 but focuses more directly on the conditions encountered by the directed fishery within the Bering Sea, includes explicit consideration of stock status from the assessment, and addresses the size range between O26 and O32 as brought forward by stakeholder input. Unlike ABM1 and ABM2, ABM3 uses O26 to index the fishable biomass rather than spawning biomass. ABM4 is similar to ABM3 but introduces dynamic weightings on the U26/O26 based upon observations with the purpose of allocating more PSC when there are more of one size component available than the other.

Each of these alternatives is an example of how different components (indices and control rules) can be combined to meet various objectives. For example, the way that stock status is used in ABM3 can easily be introduced or substituted in the other alternatives to address the objective of protecting spawning biomass at low levels, but in a slightly different way. Also, an additional index and control rule can be added to any of these examples, such as adding a GOA index of recruitment to ABM3. An alternative does not necessarily need to have exactly three indices.

Example PSC limits for the four ABM scenarios given the example "starting point", indices, and relative floors and ceilings are shown in Figure 22. Projections of the Pacific halibut population considering some "what-if" future Pacific halibut recruitment scenarios and the responsiveness of the PSC limit to the ABM alternatives is given in Appendix B.

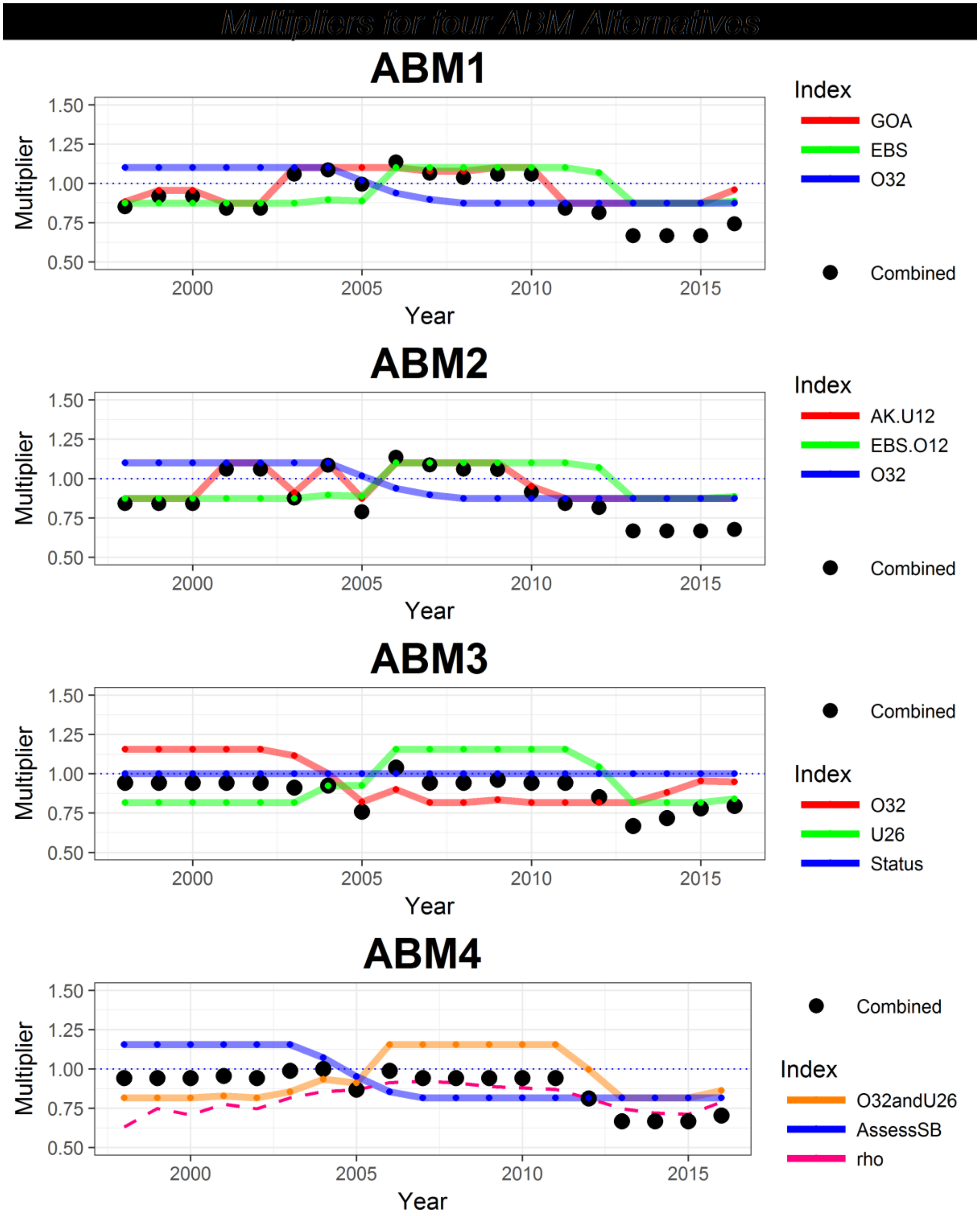


Figure 21. Comparing multipliers across alternatives.

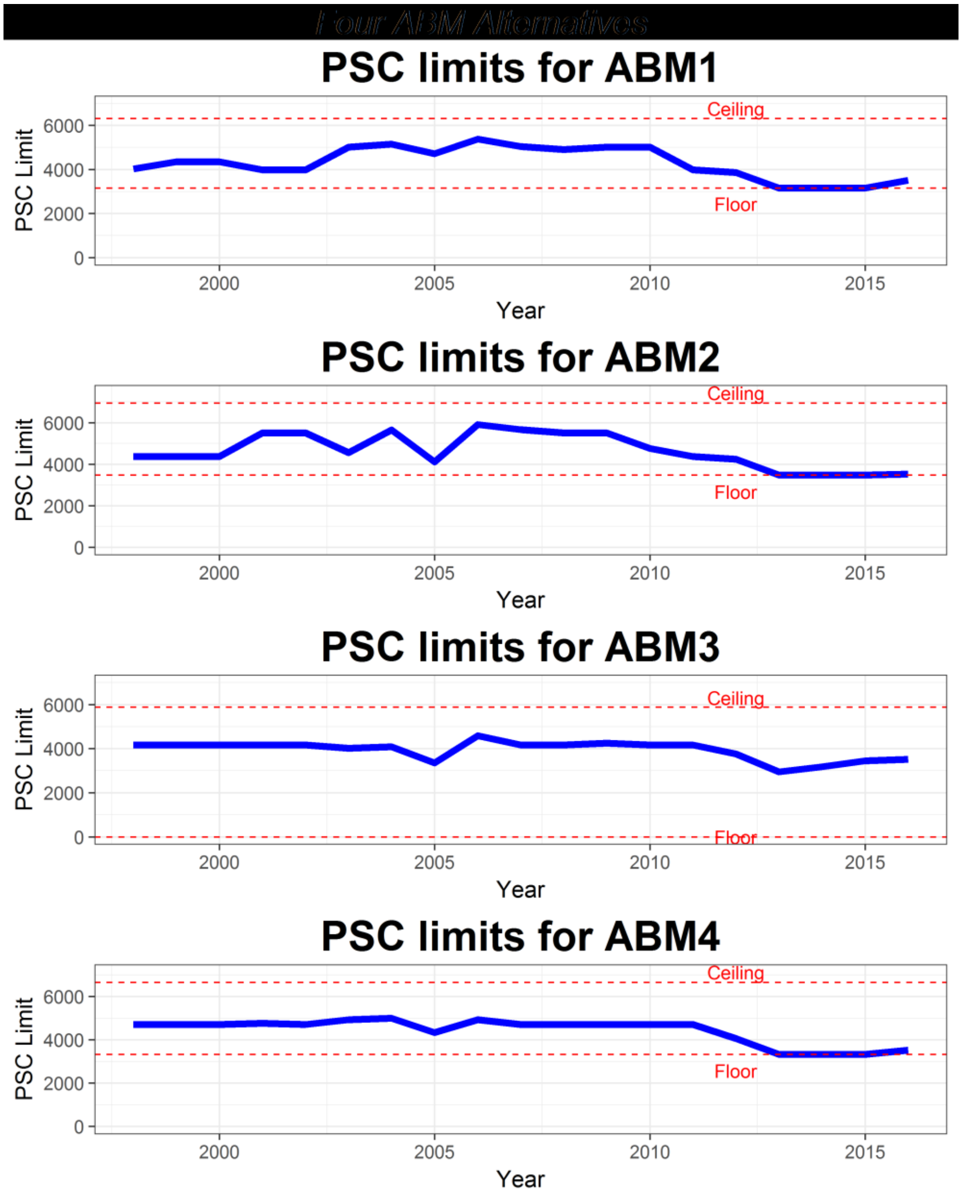


Figure 22. Comparing PSC limits for the different example alternatives.

5. Expansion to GOA

ABMs 1 and 2 would work apply with main modification being the "starting point" or scale of PSC control rule. ABMs 3 and 4 would be the same but would require modifications of the indices (and also the scale of the CR). There are multiple other considerations outside of simply the ABMs themselves and the data that should be further considered including the differences in fleets, observer coverage differences, differing management constraints etc.

6. Performance Metrics

Performance metrics are quantities that help to evaluate whether management alternatives are likely to achieve the objectives specified by the Council. For example, a performance metric may be the expected average catch over a 10-year period based on a simulation model of population dynamics and management alternatives; this would provide information about which alternatives would be most likely to achieve catch and opportunity objectives. Similarly, the probability that the catch exceeds a certain amount over the same 10-year period could be compared to a pre-defined measurable objective about desired catch to determine if that alternative is likely to meet the catch objective (e.g., a measurable objective may be that the catch exceeds X with a probability of Y%). Other possible performance metrics could address the stability of the catch or PSC limit (e.g., Average Annual Variation, AAV), or the stock status of Pacific halibut such as the probability that the coastwide spawning biomass is above a threshold).

A workshop with stakeholders and managers was held on February 2, 2017 to outline and solicit feedback on the goals and objectives for the abundance-based management of PSC limits in the BSAI, and to identify components of measurable objectives to later form into performance metrics. The Councils overarching goals are:

- there should be flexibility provided to avoid unnecessarily constraining the groundfish fishery particularly when halibut abundance is high,
- provide for some stability in PSC limits on an inter-annual basis,
- halibut spawning stock biomass should be protected especially at lower levels of abundance,
- provide for directed halibut fishing operations [in the Bering Sea], and
- halibut PSC limits should be indexed to halibut abundance.

The workshop identified many measurable objectives and provided useful feedback for further development of performance metrics that will be used to evaluate the alternatives once analyses have started. The working group will continue to develop performance metrics throughout this process to make sure that results can be adequately evaluated against all important objectives. The workshop comments were also useful for creating the frameworks and components for the ABM alternatives presented here and will be useful in identifying appropriate tools for analysis of alternatives.

7. Incentives

Stakeholder input at the February 2017 workshop also noted the need for consideration of appropriate incentives when designing alternatives for analysis. The section below provides some further comments by stakeholders, analysts and other potential considerations. Minimizing halibut bycatch to the extent practicable involves balancing a number of national standards, with the goal of efficiently minimizing bycatch while achieving optimum yield. Halibut bycatch rates vary significantly across time and space in a manner that has both predictable and unpredictable characteristics. Halibut and target groundfish populations have different degrees of co-mingling and the cost of avoiding halibut is therefore not consistent across time. This means a well-designed bycatch management system will enable groundfish vessels to decide the best times and methods to reduce bycatch and providing for the best incentives to do so is an important consideration.

The Council and NMFS have implemented a number of management programs that provide sector-level and vessel-level incentives to minimize bycatch to the extent practicable. These include the Chinook Salmon Bycatch Management Program developed under Amendments 91 and 110, which combines a cap with additional incentives to minimize bycatch at all times, including at lower levels of Chinook salmon encounters. Here the intention is to provide an incentive to consider the bycatch impacts, even if the PSC limit is not going to be reached.

There are currently several measures in place that provide incentives to the groundfish fleet to minimize halibut bycatch to the extent practicable, especially for the Amendment 80 fishery. The total halibut PSC limit sets an upper limit to halibut bycatch by sector, but each vessel in the sector encounters significant change in incentives throughout the year, especially for the fisheries where halibut can be individually allocated within the cooperative(s), such as Amendment 80. Vessels have to adjust their fishing plans throughout the year to ensure that they stay below the limit. Reductions to the limit, therefore, affect individual fishing plans and each vessel's ability to stay below its limit. More frequent changes to the PSC limit under ABM may require substantial changes to already complex multi-species groundfish fishing plans.

Research on the Amendment 80 fleet has shown that halibut bycatch rates have come down significantly after implementation of Amendment 80 (Abbott, Haynie, and Reimer 2015, Reimer, Abbott, and Haynie 2017). Vessels have been able to choose where and when to fish – and when to target different species in light of evolving bycatch conditions. They have moved more in reaction to the high-bycatch events and reduced fishing at night at times when halibut bycatch is higher.

Finally, in response to a June 2015 Council request, the Amendment 80 Halibut Bycatch Avoidance Plan was developed and implemented in 2016. The Plan developed best practices for halibut avoidance tools including fleet communication, excluder usage, and other fishing practices. The plan is similar to the Vessel Incentive Program (VIP) that was implemented in 1992 but ultimately repealed due to enforcement challenges, but because of contractual agreements within the Amendment 80 fishery, this system is viable and not subject to the enforcement limitations that faced the VIP.

Incentives can take any form, as long as they provide benefits or costs associated with an action. Skippers may win a prize, there may be a list of high-bycatch vessels, etc. Money or quota may result. Providing incentives that are always present will provide the incentive to industry to constantly innovate and to choose the halibut avoidance methods that work best. Besides avoiding bycatch, the ABM program could be developed to provide incentives for not overharvesting a specific segment of the population, whether spatial or size-based, or allowing for ingenuity and continuing to encourage innovative solutions,

7.1. General issues for designing PSC management programs

This section is intended to provide some general context on developing bycatch avoidance incentives should the Council choose to consider including incentive measures as specific components of the ABM management program.

- **Flexibility is a desirable characteristic of any program**. The cost of avoiding halibut is extremely different across time and groundfish vessels. Developing a bycatch management program that allows vessels to be flexible about when they work most aggressively to avoid halibut will achieve be more likely to achieve bycatch management objectives at a lower cost to the groundfish sectors. Similarly, enabling vessels that can more easily avoid bycatch to do more of the avoidance is likely to reduce total avoidance costs. Vessels may be different because of their target fishery, amount of quota held, when they fish in other fisheries, gear, vessel type, and other factors.

- **Rigidity is also tool that can be part of a program.** Allowing transfers of PSC among vessels will lead to more efficient usage of PSC, but may take the pressure off some vessels to avoid bycatch in the context of uncertainty with seasons. The Inshore Salmon Savings Incentive Program (SSIP) has restricted PSC transfers to encourage all vessels to as aggressively avoid Chinook as possible.

- **The Council could provide more or less design control to the sectors.** For example, the Council could request the sectors develop plans rather than placing specific bycatch avoidance plan components in regulation. Sectors would then be able to design a plan that meets the general goals of the Council and National Standard 9 while ensuring that the plan is compatible with the needs of each sector.

- **Industry can provide great insight into how systems would work and public discussion is also essential.** The groundfish industry actively participated in the development of the Chinook salmon PSC management programs implemented by Amendments 91 and 110. Several rounds of Council, analyst, stakeholder, and public discussion led to a more transparent and better program. Similarly, the Amendment 80 sector has developed a halibut avoidance plan that displays a thoughtful understanding of the vessel-level incentives for avoiding halibut bycatch. A process to develop a plan would benefit from multiple rounds of stakeholder input.

- **There are likely to be trade-offs between simplicity and effectiveness.** Managers and industry have to balance trade-offs between as effective as possible and being simple to understand and implement. The system that is developed should "make sense" to the people participating in it. Again, iterative development can be effective for encouraging the development of a system that balance the Council's objectives and making everyone more comfortable with how programs would function.

- **Punishing vessels or sectors for past bycatch reduction may provide incentives that are inconsistent with Council objectives.** If allocation or incentives are based on recent annual bycatch rates in the context of some vessels/sectors having already taken action to reduce bycatch, this may discourage future work by sectors to voluntarily improve avoidance plans. Different groundfish species have had different historical halibut bycatch rates due to a combination of where bycatch occurs in different target fisheries AND the way that each sector has been managed.

- **Fisheries with cooperatives are in very different positions and have different tools to avoid halibut.** Cooperatives can coordinate and enforce information sharing, detailed rules, civil penalties, and take collective action to address problems. Sectors that are not managed under cooperatives or other programs that provide vessel-level responsibility and accountability sectors may struggle to coordinate. However, this may mean that the best halibut avoidance tools for sectors may be quite different – or it may signify that larger or other management changes (e.g., target fishery rationalization or the formalization of entities) should be considered to implement some types of bycatch management programs.

- **Fishers respond to incentives, so it is important to incentivize the Council's primary goals.** Bycatch avoidance incentives should NOT be equal where we recognize that there are real differences across the sizes and ages of halibut being caught, for example. Similarly, seasonal limits should not be established if the timing of groundfish harvests do not impact halibut bycatch rates or there are no other clear reasons to do so.

- **Halibut differs from "rare" bycatch species, but is encountered more regularly as part of fishing operations in groundfish fisheries.** This is important because it means that vessels do encounter halibut and then can move–one bad tow does not ruin the season or exceed an allocation as it can with rare bycatch species like Chinook salmon in the pollock fisheries. This fact, combined with observed changes after Amendment 80, indicate that vessels will be able to respond to flexible incentives through a variety of tools. How expensive and challenging different levels of avoidance would be is less clear.

If the Council decides to consider development of specific incentive structures in conjunction with the ABM action, future analyses will review examples of the types of structures that have been used in other fisheries as well as other options for the Council to consider.

8. Next steps for Council action

The Council is in the process of developing a suite of alternative ABM PSC alternatives for a forthcoming analysis of a BSAI Groundfish FMP amendment. To do so, the Council must begin to **make iterative decisions on appropriate combinations and numbers of indices** (here presented as ABM1-4 example combinations) with control rules applied to them. Selecting a set of indices, control rule configurations, and starting point options should weigh against Council's objectives, some of which are clearly competing. Given a narrowed specification set, subsequent analysis can be geared to more fully evaluate their relative performance.

For example, it would be helpful for development of control rule alternatives for the Council to **specify a set of PSC values (i.e., floor and ceiling)** for consideration. The Council should also consider **selecting a range of appropriate starting points (e.g., 2008-2016 average PSC, 2014-2016 average PSC, the 2016 PSC limit of 3,515 t, or other combinations of years from which to determine a starting point)** to apply to any of the aggregated indices. The examples provided here by the working group (and from the October 2016 discussion paper) illustrate some of the characteristics of applying sources of Pacific halibut abundance trends to compute PSC limits.

9. References

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10. Appendix A. Abundance indices

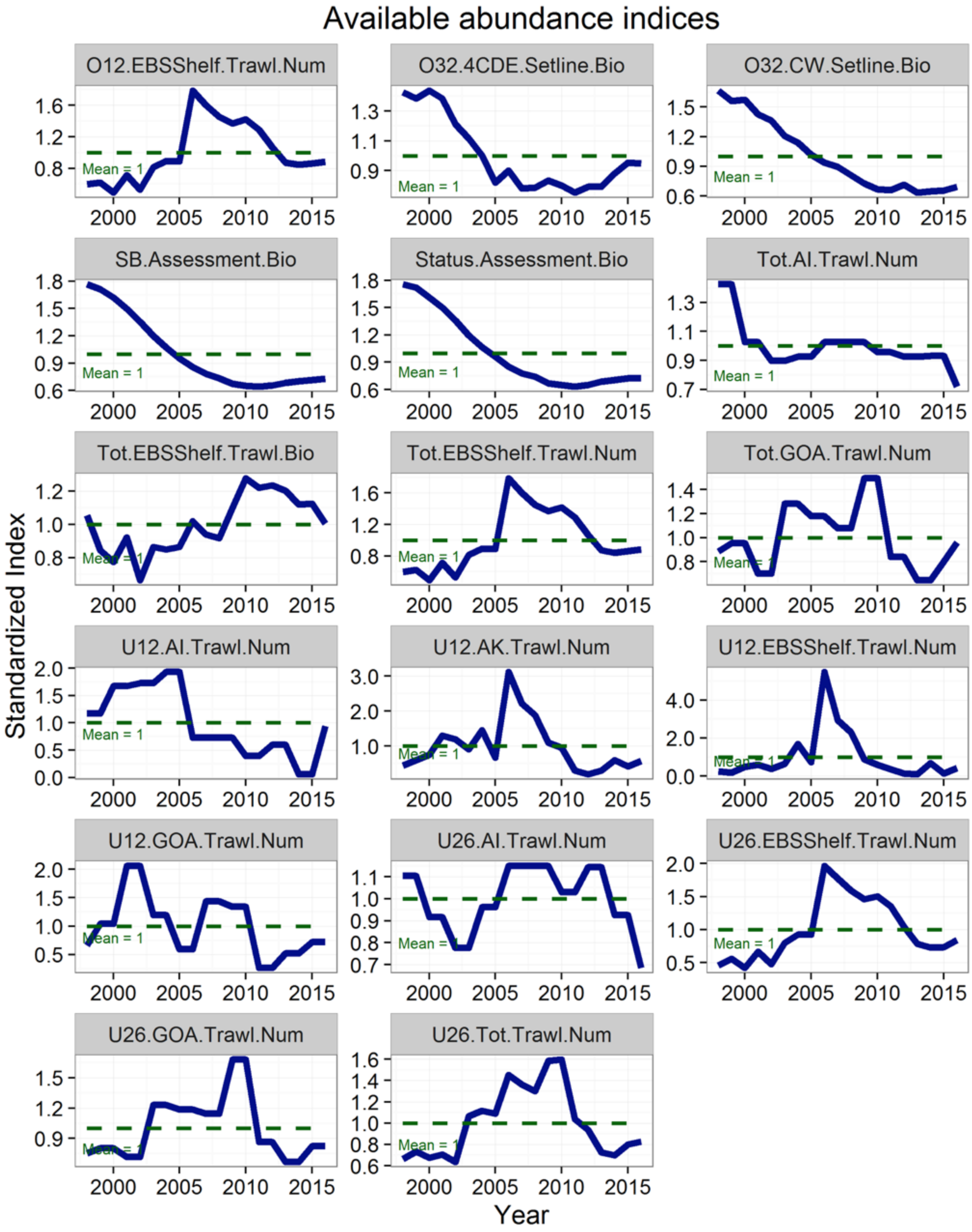

Figure A1. Suite of indices developed for consideration in creating alternative control rule frameworks.

Table A1. Description of indices developed for consideration in creating alternative control rule frameworks. Note column labeled "2016 value" represents the "multiplier" or value from the standardized index defined as the index value divided by the index mean from 1998-2016. Also note that the naming convention follows roughly the size:area:gear:units format for Pacific halibut .

Pacific halibut Index Name	Description	Units	2016 Value	Variability (CV)
O12.EBSShelf.Trawl.Num	Numbers over 12 inches on the EBS Shelf trawl survey	Numbers	0.88	38%
O32.4CDE.Setline.Bio	Biomass of halibut over 32 inches from the IPHC setline survey in Regulatory Area 4CDE	Biomass	0.95	25%
O32.CW.Setline.Bio	Biomass of halibut over 32 inches from the IPHC setline survey in all areas	Biomass	0.69	36%
SB.Assessment.Bio	Current estimates of spawning biomass from the stock assessment model	Biomass	0.73	40%
Status.Assessment.Bio	Current levels of spawning biomass relative to unfished from the stock assessment	Biomass	0.72	40%
Tot.AI.Trawl.Num	Biomass of all sizes on the AI Shelf trawl survey	Numbers	0.72	17%
Tot.EBSShelf.Trawl.Bio	Biomass of all sizes on the EBS Shelf trawl survey 2016	Biomass	1.00	17%
Tot.EBSShelf.Trawl.Num	Numbers of all sizes on the EBS Shelf trawl survey 2016	Numbers	0.88	38%
Tot.GOA.Trawl.Num	Numbers of all sizes on the GOA trawl survey 2016	Numbers	0.96	27%
U12.AI.Trawl.Num	Numbers under 12 inches on the AI trawl survey	Numbers	0.94	62%
U12.AK.Trawl.Num	Combined numbers under 12 inches on the GOA/AI/EBS trawl surveys	Numbers	0.57	75%
U12.EBSShelf.Trawl.Num	Numbers under 12 inches on the EBS Shelf trawl survey	Numbers	0.43	133%
U12.GOA.Trawl.Num	Numbers under 12 inches on the GOA trawl survey	Numbers	0.72	53%
U26.AI.Trawl.Num	Numbers under 26 inches on the AI trawl survey	Numbers	0.68	15%
U26.EBSShelf.Trawl.Num	Numbers under 26 inches on the EBS Shelf trawl survey 2016	Numbers	0.84	47%
U26.GOA.Trawl.Num	Numbers under 26 inches on the GOA trawl survey	Numbers	0.83	31%
U26.Tot.Trawl.Num	Combined numbers under 26 inches on the GOA/AI/EBS trawl surveys	Numbers	0.83	33%

11. Appendix B

A simple preliminary simulation analysis of Pacific halibut to explore properties of ABM alternatives

To examine the ABM alternatives and the effects of recruitment events on the indices and abundance-based PSC limits, a very simple age-structured simulation model was written in R. It is basically a single-area, single-sex population model for the Pacific halibut population, but accounts for out-of-area movement through increased natural mortality and recruitment multipliers that only affect the population outside of the single area; federally-managed groundfish populations are not modeled in this exercise. The outside area is not directly influenced by the simulated halibut abundance because fish leaving the area are assumed to die and are not tracked. The single area is referred to as BS and the outside area is referred to as GOA. For now, this simple model provides the opportunity to isolate and investigate the effects of various perturbations in the population.

The simple population model simulates the abundance at age (N_a) as

$$N_{a,y} = \begin{cases} R_y & a = 0 \\ N_{a-1,y}e^{-Z_{a-1}} & 0 < a < A \\ \dfrac{N_{a-1,y}e^{-Z_{a-1}}}{1-e^{-Z_{a-1}}} & a = A \end{cases} \tag{1}$$

$$B_{a,y} = w_a N_{a,y} \tag{2}$$

where R_y is recruitment to the BS area in year y and Z_a is total mortality-at-age. The maximum age, A, is 30 years and recruitment occurs at age 0. Biomass-at-age (B_a) is the product of numbers-at-age and weight-at-age (w_a).

Total mortality (Z_a) is the combination of natural mortality-at-age (M_a) and fishing mortality-at-age (F_a). Natural mortality is 0.15 for all ages 8 and older, and is inflated at younger ages to mimic migration out of the BS. It is 0.20 for ages 0–3, then declines from 0.19 at age 4 to 0.16 at age 7.

Fishing mortality is the product of fishing effort in year y for fleet k ($f_{k,y}$) and selectivity-at- age for fleet k ($s_{a,k}$); total mortality at age a in year y ($Z_{a,y}$) is the sum of natural and fishing mortalities-at-age.

$$F_{a,k,y} = f_{k,y}s_{a,k} \tag{3}$$

$$Z_{a,y} = M_a + \sum_k F_{a,k,y} \tag{4}$$

There are two fleets: one that is intended to mimic the directed fishery and the other the groundfish fishery. Selectivity for the directed fishery is logistic, but forced to be zero at age 4 or younger, and forced to be one at ages 16 and greater. Selectivity for the groundfish fleet is double normal and introduces dome-shaped selectivity to include the possibility of reduced mortality on older fish due to excluders and increased survivability. The selectivity curves are shown in Figure B1.

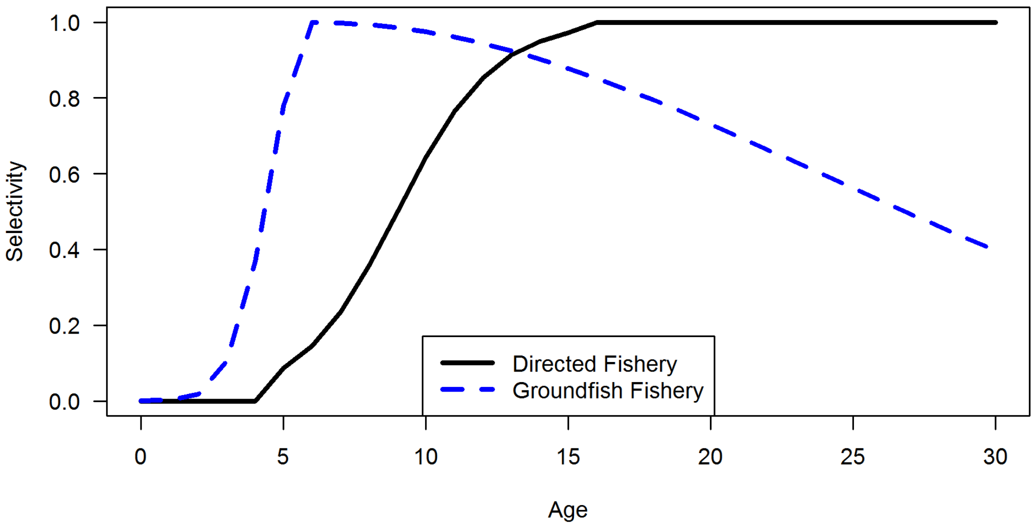

Figure B1 Selectivity curves for the two fisheries in the simulated population.

The population was initialized using an equilibrium fishing mortality rate of 16.125% and then simulated for 5 years at the same rate. This determined the TCEY in each year (a 16.125% harvest rate for the BS area has been applied as part of IPHC harvest policy calculations historically). After year 5, the PSC limit was calculated from the indices for the specific alternative and subtracted from the TCEY to give a directed fishery catch. It was assumed that the entire PSC limit was caught by the groundfish fishery. The total fishing mortality-at-age was calculated from the fleet specific exploitation rates and equations 3 and 4 based on catches for the directed and groundfish fishery,

Recruitment is fixed and deviations are not drawn from a probability distribution. Increases and decreases in recruitment are implemented by multiplying or dividing by 3 and the value 3 was chosen arbitrarily. The concept of outside recruitment is used to mimic recruitment occurring outside of the BS which later contributes to the spawning biomass and can be used to determine an index for outside recruitment. A vector of recruitment multipliers is supplied to the simulation and is used to drive the spawning biomass and outside indices up or down. The spawning biomass is calculated using the biomass-at-age in year *y*, the multiplier of recruitment for the year appropriate for that age, and a maturity ogive.

$$SB_y = \sum B_{a,y} O_{y-a} V_a \tag{5}$$

where O_{y-a} is the outside recruitment multiplier for the recruitment corresponding to the age in that year, and V_a is the maturity-at-age. Outside recruitment for cohorts before the start of the simulations was set equal to the multiplier in year 1. Maturity-at-age is zero for ages 0–5, 0.3, 0.6, and 0.8 for ages 6–8, and 1 for all ages greater than 8. The exploitable biomass of halibut available to each fleet *k* in year *y*, $EB_{k,y}$, is defined as

$$EB_{k,y} = \sum_a B_{a,y} s_{a,k} \tag{6}$$

11.1. Simulated indices for the ABM alternatives

The ABM alternatives include some indices based on size, but length-at-age was not modelled in these simulations. Therefore, the indices are all age-based, but calculated to include ages that typically correspond to the size classes intended by the indices. Simulated indices were standardized to a specific year (typically year 4), but were not standardized to a mean from a range of years.

11.1.1. Spawning biomass and stock status

Spawning biomass was determined as described above (Equation 5), with outside recruitment multipliers allowing the spawning biomass to change independently of the population in the modelled area (BS). The simulations were started with outside multipliers less than 1 to mimic a fished population. The spawning biomass and the stock status in each year were standardized to their respective values in year 1. Spawning biomass was used in ABM1, ABM2, and ABM4. Stock status was used in ABM3.

11.1.2. EBS area indices

Indices for the eastern Bering Sea were calculated for each alternative. For ABM1, the EBS index was simply the sum of numbers-at-age for ages 2 and greater. ABM2 uses Alaska-wide indices for U12, but the large (O12) index was the biomass at ages 3 and greater from the BS area. The outside recruitments were used in the calculation of the U12 index and are described below. ABM3 used the sum of numbers at ages 1–7 for small halibut, and biomass at ages 7 and greater for large halibut from the BS area. There is a slight overlap of these indices. ABM 4 used the same indices as ABM3, but determined weights (ρ) from the proportion of numbers-at-ages 1–7 compared to numbers at ages 1 and older.

11.1.3. Outside area indices

ABM1 and ABM2 are the only two alternatives that use indices from outside of the BSAI. The GOA index for ABM1 was calculated from the outside recruitment multipliers for all corresponding ages, and then standardized. The Alaska-wide recruitment index for ABM2 (U12) was calculated as the standardized sum of numbers at ages 1 and 2 for small halibut from the BS area, and then adding in the outside recruitment multiplier and standardizing again. This Alaska-wide recruitment index will respond to fluctuations in the BS halibut population and well as the outside halibut population.

11.2. Simulating recruitment events

Three events were implemented in the simulations (Figure B2).

1. A large BS recruitment in year 20, while GOA recruitment remains equal to average recruitment,
2. a low recruitment in year 50, while GOA recruitment remains equal to average recruitment and
3. very low recruitment outside of the Bering Sea (BS) in years 65-80 while BS recruitment is at its average value

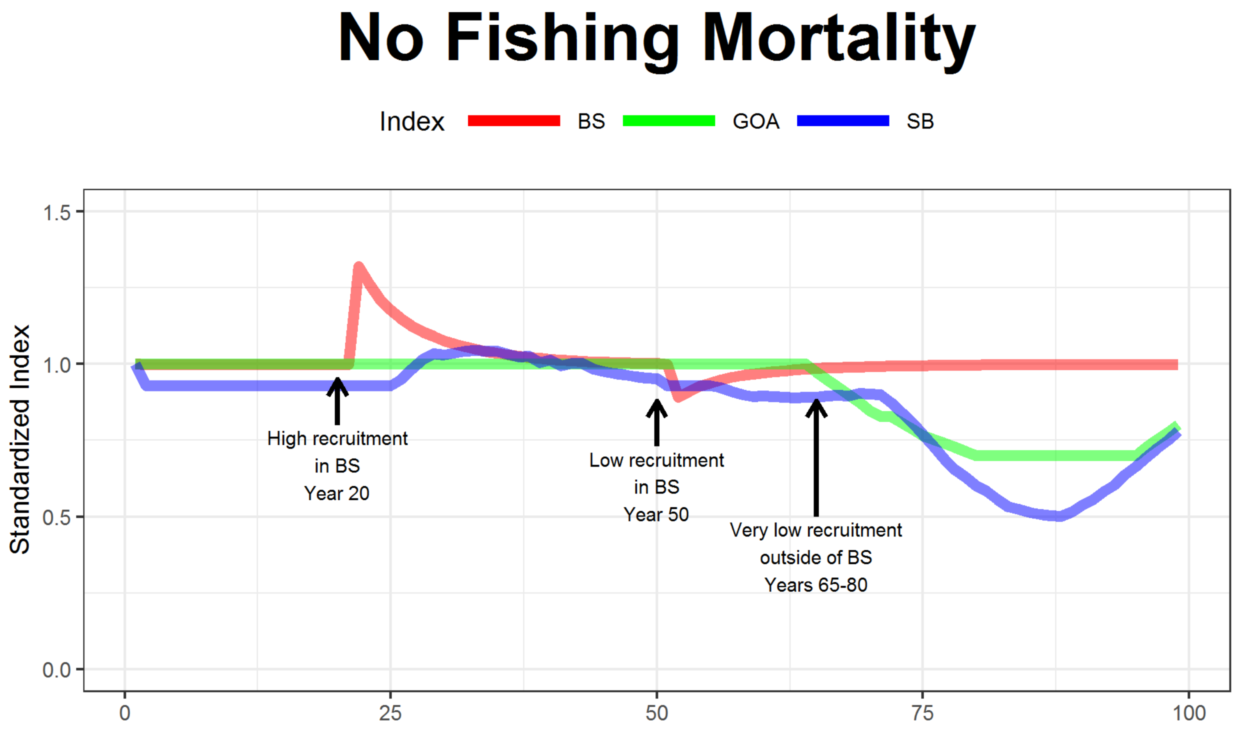

Figure B2. Standardized indices from simulations with no fishing and three recruitment events shown by the arrows. The BS index is an index of the age 2 and older population in the BS area, the GOA index is an index of the population outside of the BS area (the outside recruitment multipliers), and SB is the spawning biomass as described in Equation (5).

Standardized indices for the BS area, the GOA area (outside), and the spawning biomass, simulated without fishing, show the response to these recruitment events (Figure B2). The BS index increases sharply shortly after the high recruitment in year 20, and is followed by a moderate increase in spawning biomass and no change to the GOA index. The low recruitment event in year 50 shows a sharp decline in the BS index with a slight decrease in the spawning biomass and no change to the GOA index. The very low outside recruitment series results in no change to the BS index, a sharp and steady decline in the GOA index followed by a decline in the spawning biomass with recovery occurring once recruitment returns.

11.2.1. Simulations with fishing mortality for each alternative

The population was simulated with the three events described above, and including fishing mortality where the PSC limit was abundance-based and determined from one of the four alternatives described earlier. Figure B3 shows the standardized indices, the multiplier from the control rule (with floors and ceilings), and the resulting PSC limit. These simulations are not meant to represent reality, but to show the responsiveness of each alternative to various recruitment events, and to compare between alternatives.

Each alternative shows a response in the indices to changes in the population, with lags to indices of larger fish. The PSC limit has the potential to undulate with the rise and fall of each index when using an index of small fish and an index of large fish. This undulation can likely be controlled with adjustments to the control rules or by introducing some overlap of the indices (e.g., O26 and U32). A large decrease in spawning biomass affects each index, but influences the PSC limits in ABM3 differently since it is based on stock status. The multiplier for spawning biomass in ABM3 declines quickly once the status drops below 30%, and has the potential to reach zero if the status declines to 20% or less (dashed lines in the top row indicate 20% and 30%). The abundance indices generally increase after the spawning biomass declines because the PSC limit is reduced, and thus fishing mortality is reduced.

The proportion of small fish in ABM4 (ρ or rho) is not highly variable (which was also seen in the historical examples shown in the main document). It may be desired to associate a control rule with it or standardize it in some way to increase its range, and its effect on the weighting.

The PSC limit may be too responsive in these simulations, and changing the slope, floors, and ceilings in the control rules would change the responsiveness of the PSC limit to the indices. A more shallow slope would reduce the magnitude of changes in the PSC limit over time, while floors and ceilings would change the extremes. Changing how ρ is calculated in ABM4 would change the responsiveness to one or the other index used.

Overall, the simulations show that the PSC limit responds similarly to all of the alternatives, and many of the slight differences between the alternatives could probably be aligned with changes to the control rules. Two of the most noticeable differences between alternatives are the effect of the outside recruitment in ABM2 and the effect of the spawning stock status in ABM3. The response of ABM2 to the reduced outside recruitment is much more variable than for the other alternatives because the recruitment index is composed of two age classes and the recruitment event is an extreme and occurs over multiple years. Therefore, it may be slightly exaggerated. The comparison between coastwide spawning biomass indices is interesting; using stock status with a 30:20 control rule results in a large, quick reduction in the PSC limit when the coastwide spawning biomass is below the 30% threshold. The PSC limit could go to zero when using stock status, whereas all indices would have to be zero before the PSC limit was zero in the other alternatives. A floor on the 30:20 control rule would maintain the PSC limit above zero even as the coastwide spawning biomass approached zero.

A benefit of investigating these alternatives through a simulation of the population dynamics is that you can see the feedback of changes in the PSC limit on the halibut population. A reduction in the PSC limit often results in an increase in the abundance in the BS because the groundfish fisheries select smaller fish (Figure B1), which then results in an increase to the PSC limit in later years (as can be seen when the coastwide spawning biomass declines).

The effect that this may have on the groundfish fisheries can be seen by comparing the PSC limit to the exploitable biomass of halibut available to the groundfish fisheries in the BS ($EB_{groundfish,y}$ Figure B4). The exploitable biomass time series is similar across alternatives, but mainly differs after the low outside recruitment event. Because the PSC limit is not reduced as quickly in ABM3, the exploitable biomass does not increase as soon, resulting in a shorter period of time that both the PSC is low and $EB_{groundfish,y}$ is high. The indices for smaller fish seem to result in a response to the PSC limit before $EB_{groundfish,y}$ responds, but it would be interesting to contrast this with abundance (numbers) instead of biomass since the weight-at-age of young fish is small.

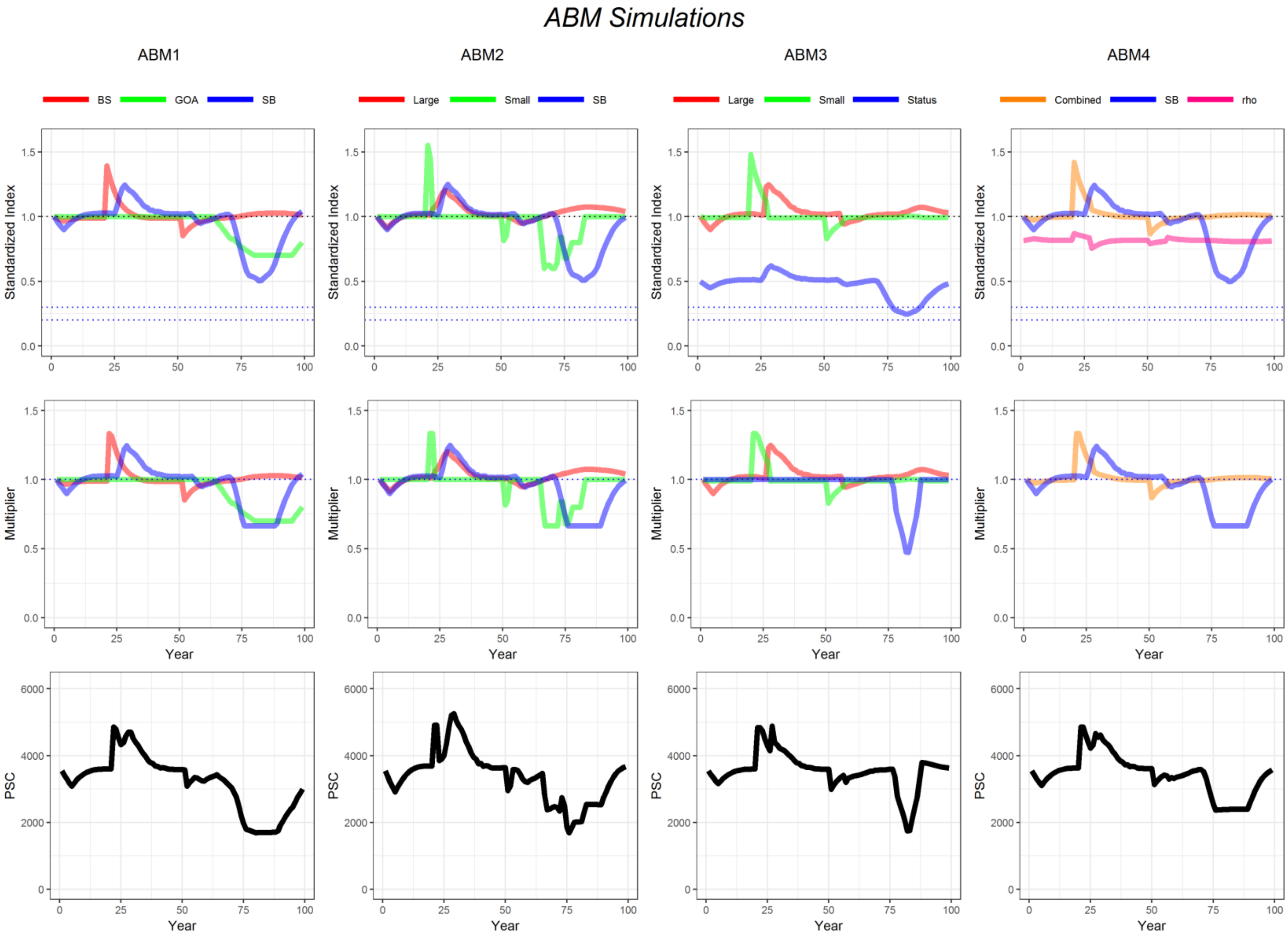

Figure B3. Indices (top row), multipliers (middle row), and abundance-based PSC limit (bottom row) from a simulated population with fishing for each ABM alternative.

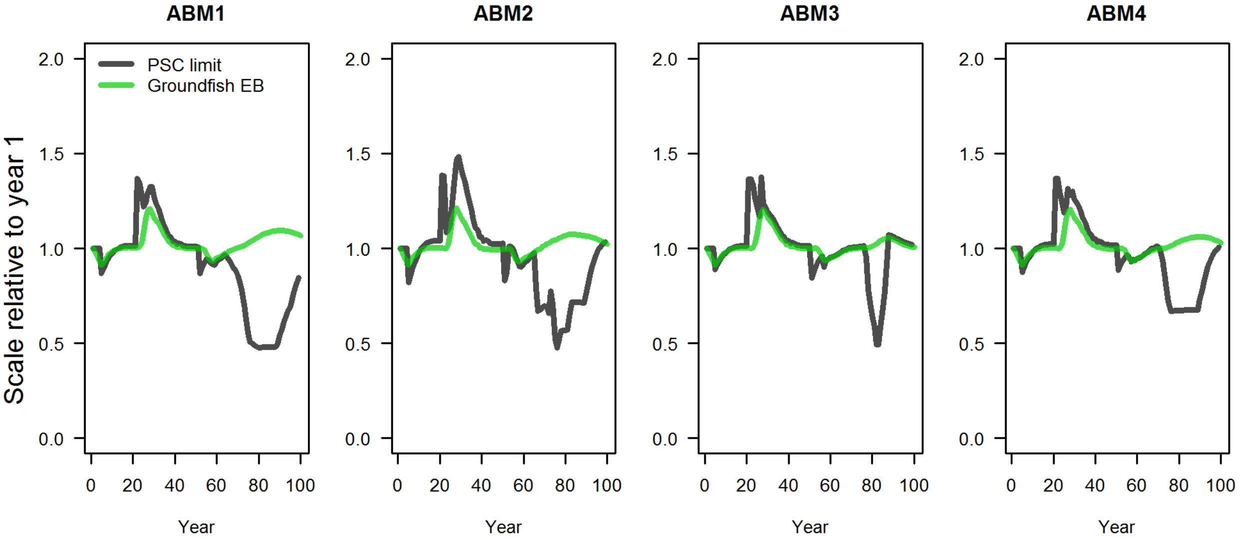

Figure B4. The relative PSC limit (scaled to year 1) and the relative exploitable biomass available to the groundfish fisheries ($EB_{groundfish,y}$) for the simulations of each alternative.