Risk and Uncertainty in the Groundfish and Crab Harvest Specifications Process and Development of Alternative Harvest Control Rules
May 2026[1]

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For definition of acronyms and abbreviations, see online list: https://www.npfmc.org/library/acronyms

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1 Introduction

In December 2024, the Council established a climate resilience work plan to guide near-term actions for enhanced climate resilient federal fisheries management in the GOA and the BSAI. The work plan focuses on 1) expanding the Council's existing processes, collaborations, and partnerships that facilitate inclusion of multiple knowledge systems in climate planning, and 2) considering management tools and options focused on the inclusion of existing and emergent climate information[2]. Some key aspects of the climate resilience work plan include on-going stock assessment work and work towards developing ecosystem indicators for informing stock assessment parameters and ecosystem models to evaluate connectivity between stock productivity and environmental variability. The Council requested that staff develop the work plan, and as an initial step the Council identified several near-term actions including the following elements:

A. Incorporate climate-forecast-linked management advice;
B. Incorporate climate-driven interactions and cascading impacts through the use of ecosystem indicators and models;
C. Consider and incorporate dynamic management tools to increase in-season adaptation capacity; and
D. Review tier systems, consider climate-informed biomass targets and limits, and climate-robust or forecast-informed harvest control rules.

These initial elements form the basis of the Climate work plan, understanding that additional longer-term and priority actions may be considered in the future. At the June 2026 Council meeting, the Council will review and provide feedback on the work plan and progress towards the initial items identified, and may consider augmenting the work plan with additional items at that time.

1.1 One element of the Climate work plan

This paper focuses on Element D of the climate resilience work plan: *Consider climate-informed biomass targets and limits and climate-robust forecast-informed harvest control rules (HCRs) for specifying Acceptable Biological Catch (ABC) limits*. While this is related to other elements of the work plan such as (A) '*Incorporating climate forecast linked management advice*" and (B) "*Incorporate climate-driven interactions and cascading impacts through use of ecosystem indicators and models*" this paper is focused solely on the current harvest specifications process and HCRs and the consideration of alternative HCRs as a means to advance climate resiliency[3]. Ongoing work at the AFSC by the Alaska Climate Integrated Modeling (ACLIM) and Gulf of Alaska Climate Integrated Modeling (GOACLIM) teams indicates that alternative HCRs and modified biomass targets and limits for some or all stocks may be more responsive over a longer time frame to changing environmental conditions. The North Pacific has already experienced multiple marine heat waves in the last decade and associated biological and economic impacts on fish and shellfish stocks, notably EBS snow crab and GOA Pacific cod. Climate-resilient HCRs have the potential to perform better to protect spawning biomass for some species and stocks during climate shocks and longer-term changes that impact stock productivity under rapidly changing marine environmental conditions than the current HCRs that are specified under the BSAI and GOA Groundfish and BSAI Crab fishery management plans (FMPs).

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[2] Council motion on Climate Work Plan December 2024

[3] See agenda item E2 on the Council's June 2026 meeting eAgenda for additional information on the Climate work plan elements and progress to date

1.2 Risk and uncertainty in harvest specifications and moving towards climate-resilient HCRs

The Council is interested in understanding and potentially improving the treatment of risk and uncertainty in establishing harvest specifications for BSAI and GOA Groundfish and BSAI Crab stocks.[4] Risk considers the likelihood that an adverse effect will occur and the severity of the consequences, while uncertainty indicates a relative lack of information or confidence in the reliability of that information. Risk and uncertainty are addressed in multiple levels of the NPFMC harvest specifications process. The Council's Science and Statistical Committee (SSC) is responsible for recommending overfishing levels (OFL) and acceptable biological catch (ABC) levels to the Council for BSAI/GOA groundfish stocks and BSAI crab stocks[5]. These OFL and ABC catch levels form limits on the amount of catch of a specified stock. For BSAI and GOA groundfish an additional step in the harvest specifications process is recommendations for total allowable catch (TAC) levels (directed fishery catch) by the Council. HCRs are used to specify an OFL and an ABC. HCRs are an operational component of a harvest strategy whereby a formula is applied to a biomass estimate to calculate a limit based upon a pre-determined analysis of risk and uncertainty.

1.3 Roadmap for this discussion paper

This paper contains the following information on the current NPFMC treatment of risk and uncertainty in establishing harvest specifications for BSAI and GOA Groundfish and BSAI Crab stocks as well as rationale and progress to date for moving towards more climate resilient HCRs. This includes the following:

- Detailed description of the purpose and structure of HCRs in general and more specifically the current HCRs employed for groundfish and crab stocks (Section 2).
- Details on where different components of risk and uncertainty are considered in stock assessments, ABC setting and TAC setting to better understand what benefits could be conveyed by considering modified HCRs (within the current harvest specifications process) at this time (Section 3).
- Modifications which can be made within the current HCRs or through FMP amendments to adopt modified HCRs (Section 3.4)
- Modified HCRs under development to enhance climate resilience under environmental changes[6] and determining goals and objectives for these modifications (Section 4.2 and 4.3).
- Council decision points (Section 4.5)

A series of appendices are included which provide additional technical details on HCRs under development and contextual information for moving forward with analyses of HCRs and climate informed management advice.

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[4] While the Council may also consider additional measures to address risk and uncertainty in the harvest specifications process for Cook Inlet Salmon stocks and Alaska Scallop stocks this paper is currently focused on BSAI and GOA Groundfish and BSAI Crab stocks.

[5] The SSC also recommends OFL and ABC to the Council for Cook Inlet salmon stocks and Alaska scallop stocks. This paper

[6] Given previous direction by the Council, modifications are not envisioned to the OFL HCRs thus an explanation of how they are set is included but proposed modifications to HCRs are restricted solely to ABC and the overall treatment of risk and uncertainty in the harvest specifications process.

2 Overview of the harvest specifications process

The annual harvest specifications process establishes catch limits through a structured, hierarchical approach. The process begins with stock assessments that estimate current biomass and productivity, proceeds through application of HCRs to derive OFL and ABC, and concludes with Council action to recommend TACs (TAC recommended for groundfish stocks only; BSAI crab stocks have TAC set by the State of Alaska). The procedure used to set these catch limits is one of the Council's primary functions, and an "onramp" for using ecosystem and climate information in the management process.

Harvest specifications differ in timing for groundfish and crab due to the timing of fisheries and available information, but the process of categorizing stocks by available information and using a harvest control rule (HCR) to set these catch limits is largely similar between the two FMPs. However, the FMPs differ in the current process for setting ABC below maximum permissible as well as TAC-setting[7]. Each step of this process addresses different aspects of risk and uncertainty, and Section 3.4 summarizes the benefits and drawbacks of each approach.

2.1 Harvest Control rules

This section provides a general overview of HCRs and their function. More details on the specific HCRs used in setting OFLs and ABCs in the North Pacific are provided in Sections 2.2 and 2.3. Harvest control rules (HCRs) are an operational component for developing the harvest specifications. They are predetermined guidelines regarding how much fishing can take place, based on indicators of the targeted stock's biological status. HCRs can range in complexity. The simplest form is a constant catch strategy—under which catch levels do not change with biomass or stock status. More complicated forms include multistep rules that set allowable catch based on biomass and stock status triggers.

Figure 1 shows a measure of spawning stock biomass plotted against a fishing mortality rate. The spawning stock biomass (SSB) is the best estimate of the sexually mature biomass capable of reproducing. A target SSB is identified (SSB_{target}) above which the stock is considered 'healthy' and below which the stock needs additional protection to rebuild back to the target stock size. Fishing mortality is plotted with both a target fishing mortality (F_{TARGET}) and a limit fishing mortality (F_{LIMIT}). Fishing above the limit fishing mortality would indicate overfishing while biomass dropping below the SSB limit may constitute a depleted stock in need of further protection. Management is ideally intended to maintain the stock at or above the SSB target with fishing mortality at or below the target (fishing below the target decreases during the 'rebuilding[8] phase' to allow for stock size to increase back to the SSB target; See Appendix 1 for a glossary of terms). These concepts of targets, limits and decreasing fishing mortality below a biomass threshold are all included in HCRs for groundfish and crab stocks in NPFMC FMPs.

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[7] The Council recommends TAC levels to the Secretary of Commerce for Groundfish stocks. For BSAI crab stocks the Council recommends the ABC levels at or below those set by the SSC but under the delegated management framework the State of Alaska sets the TAC levels according the BSAI Crab FMP framework (Category 2) measures. Section 8.2 of the BSAI Crab FMP provides an overview of Category 2 Framework management measures.

[8] Here the term 'rebuilding' is used in the context of providing reduced fishing mortality until a stock returns to (or above) it's target stock size. This term is not used in the context of the legal requirements under the Magnuson Stevens Act (MSA) for a rebuilding plan when a stock is declared overfished or approaching an overfished condition.

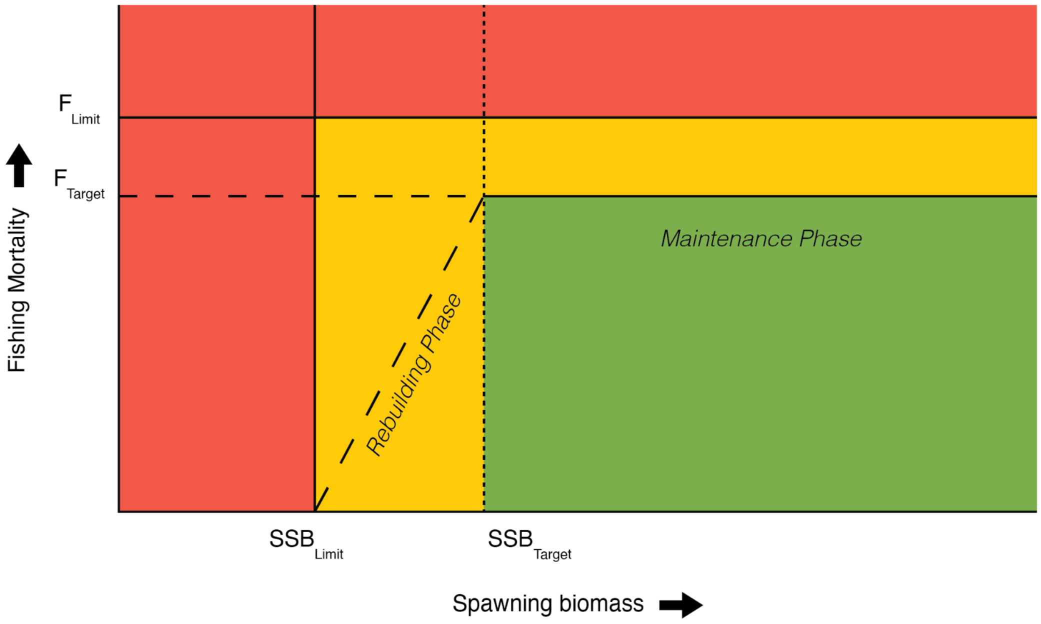

Figure 1 HCR similar to those used for North Pacific Groundfish stocks where green indicates a healthy stock above its SSB target, yellow indicates fishing either above the target fishing mortality (*FTARGET)* or below the SSB target. Red indicates a stock below its SSB limit and/or fishing mortality above the *FLIMIT*.

2.2 NPFMC system of HCRs

The regulations governing the setting of HCRs outlined in the NPFMC FMPs have been in place for many years with numerous revisions[9]. The HCR frameworks comply with the Magnuson Stevens Act (MSA), National Guidelines for implementation of the MSA (National Standards) and guidelines for use of the Best Scientific Information Available (BSIA).

An Overfishing Limit (OFL) control rule and an Acceptable Biological Catch (ABC) target control rule are specified for North Pacific stocks (BSAI and GOA Groundfish, BSAI Crab, Cook Inlet Salmon and Alaska Scallops). Therefore, while Figure 1 shows a single HCR, per MSA requirements (and according to National Standard1 guidelines), both an OFL and an ABC are specified in the NPFMC system. Additional details on the OFL and ABC specified for BSAI/GOA Groundfish and BSAI crab stocks are contained in Sections 2.3 and 2.4 respectively. For BSAI and GOA groundfish and BSAI crab, a hierarchy based on available information for that stock categorizes them into tier levels ("Higher" tiers, which are lower numbers, indicate more information is available). Stock status within that tier (e.g., at, above or below a target stock size) determines the HCR to be applied.

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[9] In 1999, the NPFMC revised their frameworks for setting HCRs for groundfish in the Bering Sea-Aleutian Islands (BSAI FMP Amendment 56) and Gulf of Alaska (GOA FMP Amendment 56). These groundfish HCRs were reviewed by an independent panel in 2002 (Goodman et al., 2002). The NPFMC revised their HCRs for managing Bering Sea-Aleutian Islands crab (BSAI Crab FMP Amendment 24) in 2008. In 2011, the crab HCRs were revised to comply with revisions to the Magnuson Stevens Fishery Conservation and Management Act (in short, the Magnuson Stevens Act, MSA) that required setting Annual Catch Limits (ACLs, BSAI Crab FMP Amendment 38).

At their core, the current HCRs acknowledge that when viewed over long time-frames, most animal populations are governed by sustainable population dynamics (i.e., population growth rates decline as they reach their carrying capacity such that a sustainable, equilibrium population size can be estimated and represent carrying capacity under “average” conditions) with associated concepts of maximum sustainable yield (MSY) or the highest average catch that can be removed continuously from a population without depleting it. Based on these concepts, scientists can identify biomass targets, limits, fishing mortality, and biomass reference points for sustainable management. These reference points and biomass targets are set by the NPFMC Scientific and Statistical Committee (SSC) based on information regarding the reproductive potential of the stock.

2.3 Groundfish Tier System and current OFL and ABC control rules

The groundfish harvest specifications process (Figure 2) begins with stock assessments that estimate current biomass and productivity and proceeds through a rigorous and iterative scientific review process including the Plan Teams and SSC to establish final assessments and OFL and ABC recommendations from the SSC[10].

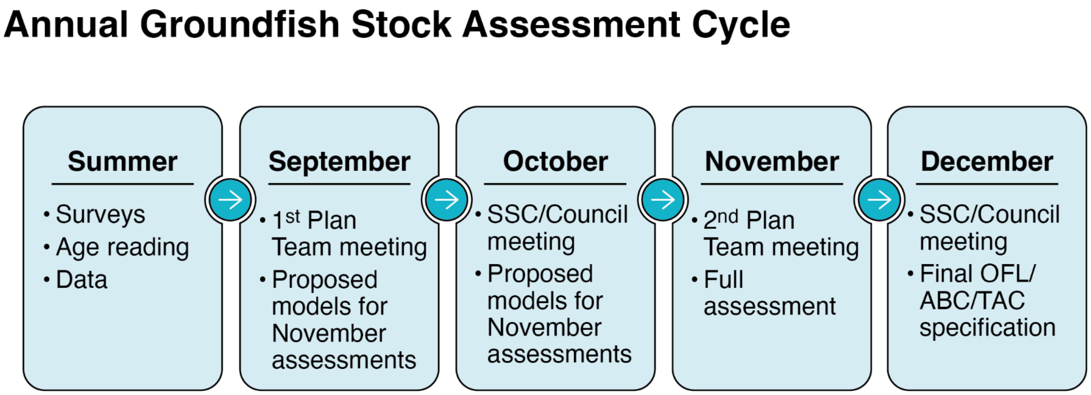

Figure 2 **Schematic of annual Groundfish stock assessment and scientific review process. Note not all new data are available by September and not all stocks are assessed annually.**

The amount of information used to assess stock status varies substantially across managed stocks, ranging from full age-structured assessments with decades of survey and fishery data (e.g., EBS pollock) to data-limited stocks assessed with survey biomass indices alone to stocks for which reliable biomass information is not available and catch data is used to inform specifications. The current groundfish management framework in the NPFMC uses a tier system (Tiers 1–6) that reflects the quality and quantity of information available for each stock (Figure 3). This heterogeneity in data richness directly affects the tools available for incorporating climate considerations at each stage of the specifications process.

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[10] As noted in Section 3.3 once the OFL and ABC have been recommended by the SSC the Council then recommends TAC levels for each stock with the condition that TAC ≤ ABC.

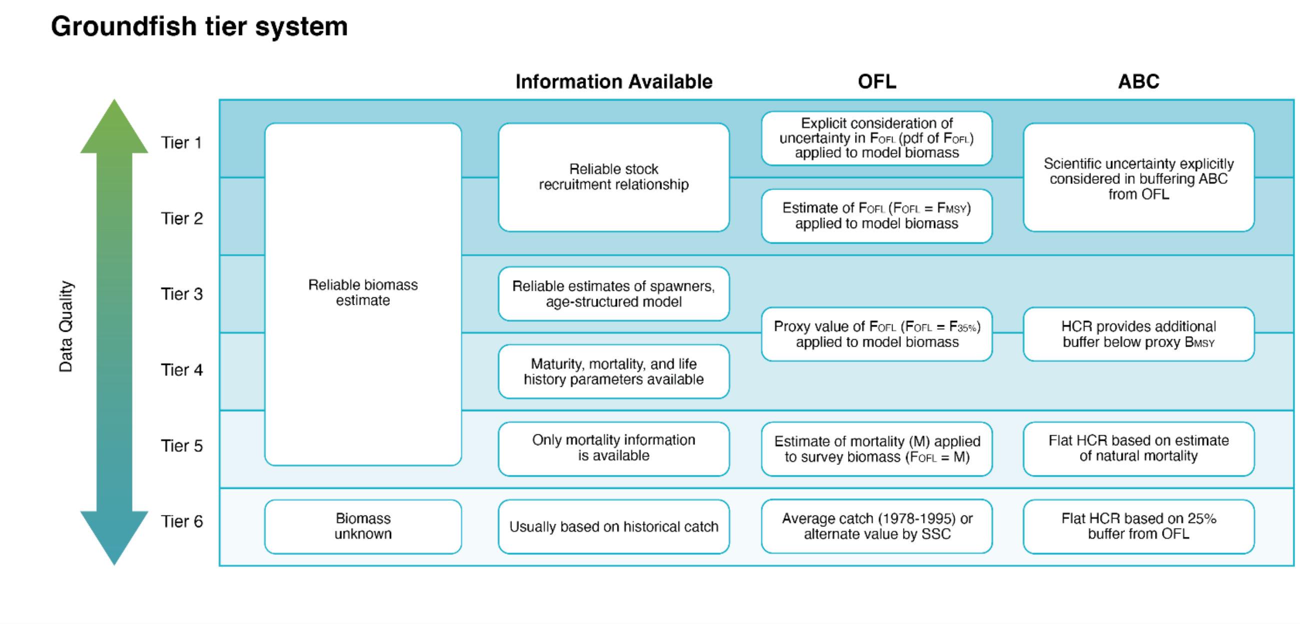

Figure 3 **Schematic of the BSAI and GOA Groundfish 6 tier system for categorizing stocks based on varying levels and precision of information available and the resulting harvest control rule (HCR) used to specify OFL and maxABC. Note that 'pdf' refers to the probability density function to estimate the uncertainty in the F_{OFL} parameter. Tiers 3 and 4 differ in the OFL in that the sloping HCR is only applicable to Tier 3.**

Higher tiers (1–3) use age-structured assessment models and spawner-per-recruit analyses; lower tiers rely on survey biomass estimates and more precautionary default reference points to accommodate the increased uncertainty. The tier placement determines which HCR formula applies and the associated level of precaution. Each tier has a defined HCR that maps estimated stock status within that tier to an OFL HCR and a maximum permissible ABC (maxABC) HCR (Figure 3). For higher tiers, the rules are functions of estimated spawning biomass relative to reference points (B/B_{MSY} or proxy). For groundfish stocks where estimation of the biomass capable of producing maximum sustainable yield (MSY[11]) (or proxy thereof) is possible (Tiers 1-3), B_{MSY} is based on the estimated stock recruitment parameters (Tier 1) while for Tier 3 and lower, B_{MSY} is defined at $B_{35\%}$. A minimum stock size threshold (MSST) is defined as ½ B_{MSY} below which a stock is considered overfished and a rebuilding plan must be developed and implemented to comply with the provisions of the MSA.

For Tier 4-5 stocks, the rules apply fixed fishing mortality rates to survey-based biomass estimates to derive OFL and a maxABC (Figure 3). Where no reliable estimates of biomass exist (Tier 6) average catch estimates are generally used to estimate an OFL and ABC however recent work by the AFSC has proposed alternative methods for Tier 6 catch specifications[12]. The current HCRs were designed to be risk-neutral in aggregate and do not explicitly account for environmental variability or regime shifts.

For additional precaution (Tiers 1-3), when a stock goes below $B_{40\%}$ an automatic rebuilding provision is applied by decreasing fishing mortality linearly below that level (Figure 4). An additional precaution is applied by the slope of the control rule lines intersecting the biomass measure (x-axis) at a level (noted as

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[11] The BSAI and GOA Groundfish FMP's define "Maximum sustainable yield (MSY) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions, fishery technological characteristics (e.g., gear selectivity), and distribution of catch among fleets'.

[12] A report from the AFSC data-limited methods (DLM) working group was presented to the Groundfish Plan Teams in September 2025. Modified Tier 6 methods do not require an FMP amendment to be adopted for use in specifications.

α) greater than 0[13]. This provides for a steeper rate of fishing mortality decline below the inflection point at $B_{40\%}$ (shown in dotted line in Figure 4) than if the intersection was at 0. Additionally for Steller sea lion (SSL) prey stocks (pollock, Pacific cod and Atka mackerel) there is a provision whereby directed fishing for these species is 0 at or below a biomass threshold at $B_{20\%}$.

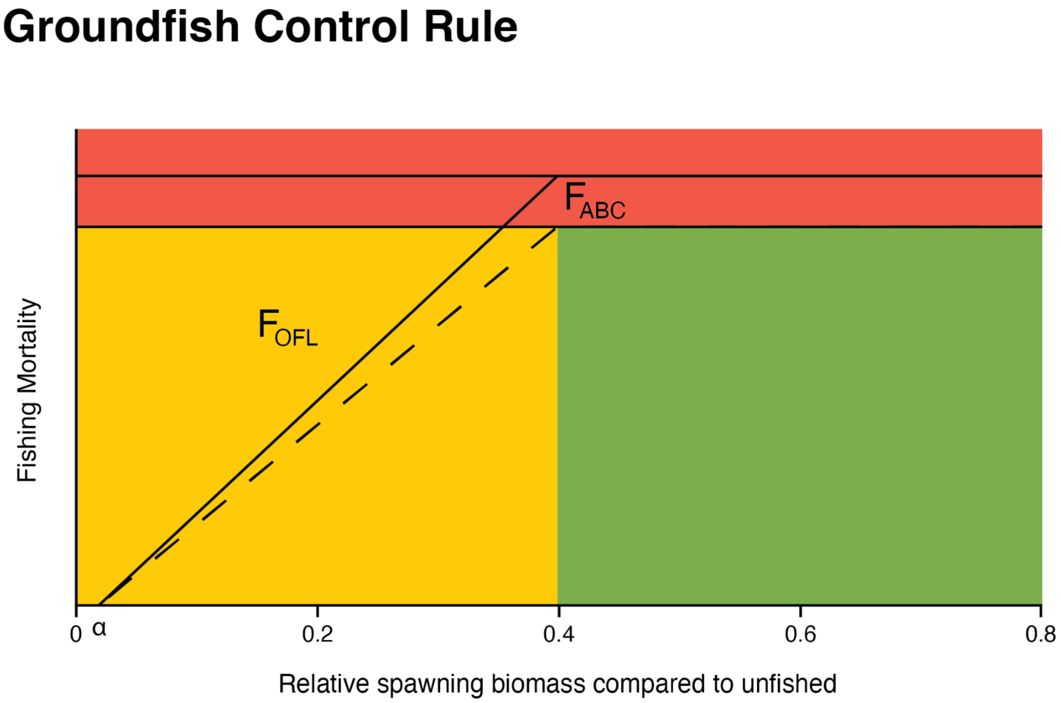

Figure 4 **Harvest control rules for OFL and ABC (Tiers 1-5) where fishing mortality is on the Y-axis and biomass is shown as a proportion of the estimated unfished biomass on the X-axis. Fishing mortality decreases when estimated biomass is below $B_{40\%}$ (denoted by '0.4' on the X-axis). α = 0.05. Green shading indicates biomass above target while yellow shading is biomass below target and red indicates fishing rates above the limit (indicated by F_{ABC} and F_{OFL}).**

In the BSAI there are 23 managed stocks and stock complexes for which OFL and ABC are specified (Table 1) while in the GOA there are 24 stocks and stock complexes (Table 2). There are currently two Tier 1 stocks in the BSAI and no Tier 1 stocks in the GOA. OFL and ABC are specified at the level of the stock or stock complex. Further finer scale spatial management below the stock level is accomplished with designated area-specific Biologically-informed Recommended Distributions (BRDs)[14]. Within stock complexes, some stocks may be assessed at different Tier levels due to information availability. The Tier levels are determined by the SSC. Modifications to Tier levels are proposed in individual assessments and reviewed by the Plan Teams prior to review and final recommendations by the SSC (Figure 2).

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[13] For Tiers (1-3), the coefficient 'α' is set at a default value of 0.05, with the understanding that the SSC may establish a different value for a specific stock or stock complex as merited by the best available scientific information.

[14] See Council motion from Oct 2025

Table 1 **BSAI Stocks and Tier levels by region.**

Stock	Assessment Region	Tier
Pollock	BS	3
	AI	3
	Bogoslof	5
Pacific cod	BS	3
	AI	3
Sablefish	BSAI/GOA	3
Yellowfin sole	BSAI	1
Greenland turbot	BSAI	3
Arrowtooth flounder	BSAI	3
Kamchatka flounder	BSAI	3
Northern rock sole	BSAI	1
Flathead sole	BSAI	3
Alaska plaice	BSAI	3
Other flatfish	BSAI	5
Pacific Ocean perch	BSAI	3
Northern rockfish	BSAI	3
Blackspotted/Rougheye rockfish	BSAI	3
Shortraker rockfish	BSAI	5
Other rockfish	BSAI	5
Atka mackerel	BSAI	3
Skates	BSAI	3,5[1]
Sharks	BSAI	6
Octopuses	BSAI	6

[1] Alaska skates are assessed as a Tier 3 stock while the remaining ‘other skates’ in the complex are assessed as Tier 5 stocks

Table 2 GOA stocks and Tier levels by region.

Stock	Assessment Region	Tier
Pollock	W/C/WYAK	3
	SEO	5
Pacific cod	GOA	3
Sablefish	BSAI/GOA	3
Shallow-Water flatfish	GOA	3,5[1]
Deep-Water flatfish	GOA	3,6 [2]
Rex sole	GOA	3
Arrowtooth flounder	GOA	3
Flathead sole	GOA	3
Pacific Ocean perch	GOA	3
Northern rockfish	GOA	3
Shortraker rockfish	GOA	5
Dusky rockfish	GOA	3
Rougheye and Blackspotted rockfish	GOA	3
Demersal Shelf rockfish	W/C/WYAK	6
	SEO	5,6[3]
Thornyhead rockfish	GOA	5
Other rockfish	GOA	4,5,6[4]
Atka mackerel	GOA	6
Big Skate	GOA	5
Longnose Skate	GOA	5
Other Skates	GOA	5
Sharks	GOA	5,6 [5]
Octopuses	GOA	6

[1] Dover sole is assessed as a Tier 3 stock, Greenland turbot, Kamchatka flounder, and Deepsea sole are assessed as Tier 6 stocks
[2] Northern/Southern rock sole is assessed as a Tier 3 stock while the remaining stocks in the complex are assessed as Tier 6 stocks
3 Yelloweye rockfish in SEO is assessed as a Tier 5 while the remaining DSR species in SEO are Tier 6
4 Sharpchin rockfish is assessed as a Tier 4 stock, four other rockfish species are assessed as Tier 5 stocks while the remaining 14 species in the complex are assessed as Tier 6 stocks.
5 Spiny dogfish is assessed as a Tier 5 stock, while the remaining shark species in the complex are assessed as Tier 6 stocks.

Tier level modifications can arise by improved information availability resulting in modifying a stock by moving to a higher Tier (more information) such as with a new age-structured assessment (e.g. AI cod) or a possible decrease in Tier level (less information) due to improved understanding of the relative reliability of model parameters or estimates such as stock recruitment relationships (e.g. EBS Pollock). The process by which assessment changes and the implications thereof to biological reference points and resulting catch specifications is discussed further in Section 3.1.2. Once the OFL and ABC have been recommended by the SSC, the Council then recommends TACs at or below ABC.

2.4 Crab Tier System and current OFL and ABC control rules

The BSAI Crab harvest specification framework also uses a Tier system format (Tiers 1-5) similar to groundfish for OFL and maxABC based upon information availability (Figure 5). The five-tier system incorporates new scientific information and provides a mechanism to continually improve the status determination criteria as new information becomes available.

Crab tier system

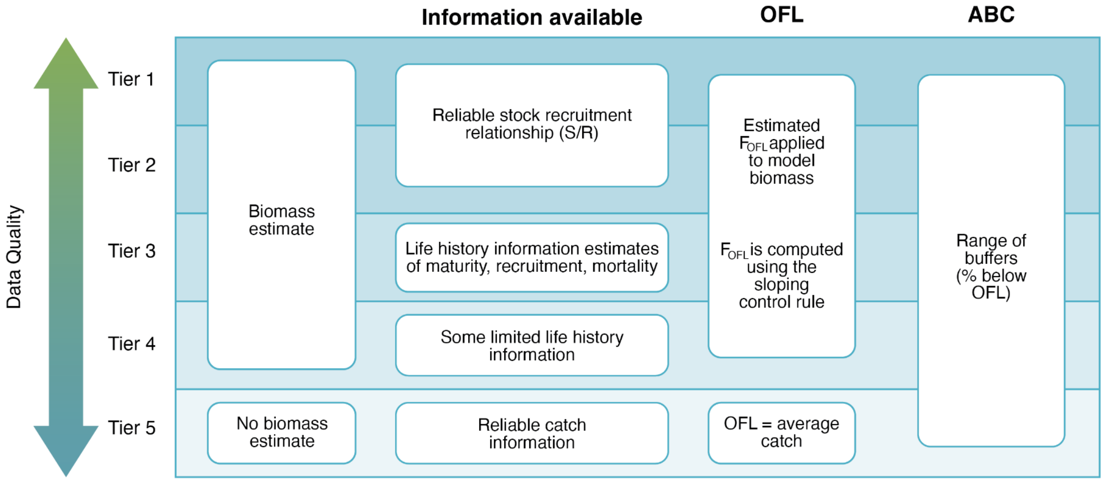
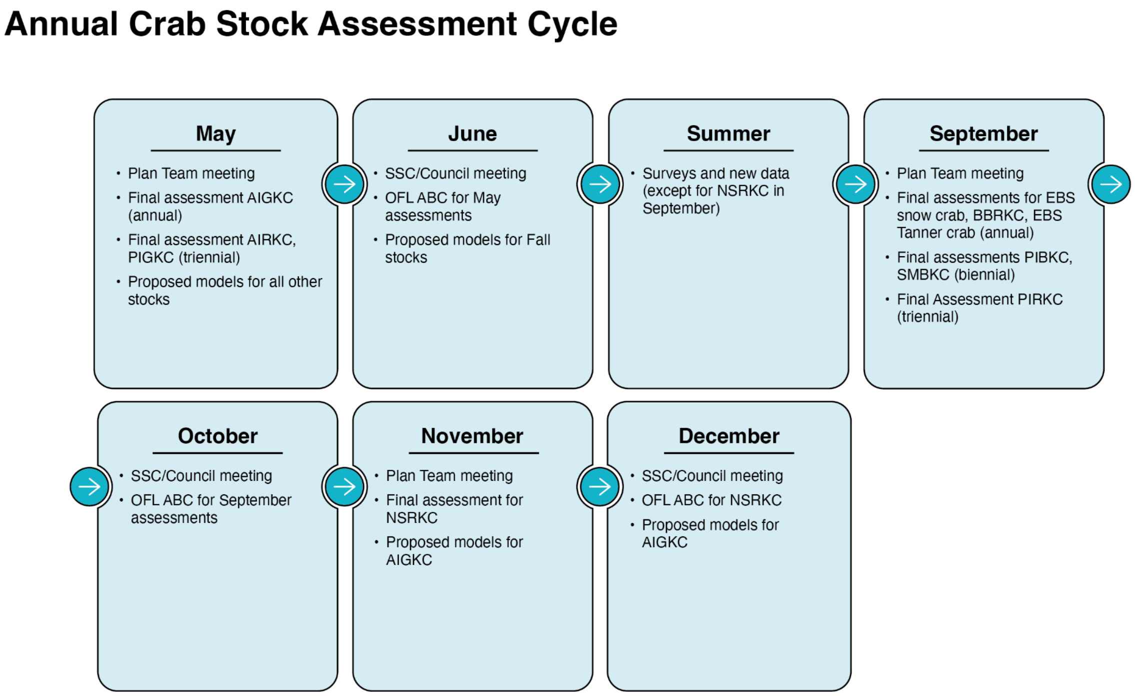


Figure 5 **Schematic of the 5 tier system under the BSAI Crab FMP which categorizes stocks according to information availability with an OFL Control rule derived by each tier. As the maxABC for BSAI crab stocks is approximately equal to the OFL the ABC is shown with a qualitative buffer system (<maxABC) which has been used since 2011.**

As with groundfish, the crack stock assessment process begins with stock assessments that estimate current biomass and productivity and assessments are then iteratively reviewed by the Crab Plan Team and SSC, with final OFL and ABC recommendations made by the SSC. Due to the timing of crab fisheries these reviews are scheduled in May(Plan Team)/June (SSC) for some stocks and September (Plan Team)/October (SSC), November (Plan Team)/December (SSC) for others (Figure 6).



Annual Crab Stock Assessment Cycle

May
- Plan Team meeting
- Final assessment AIGKC (annual)
- Final assessment AIRKC, PIGKC (triennial)
- Proposed models for all other stocks

June
- SSC/Council meeting
- OFL ABC for May assessments
- Proposed models for Fall stocks

Summer
- Surveys and new data (except for NSRKC in September)

September
- Plan Team meeting
- Final assessments for EBS snow crab, BBRKC, EBS Tanner crab (annual)
- Final assessments PIBKC, SMBKC (biennial)
- Final Assessment PIRKC (triennial)

October
- SSC/Council meeting
- OFL ABC for September assessments

November
- Plan Team meeting
- Final assessment for NSRKC
- Proposed models for AIGKC

December
- SSC/Council meeting
- OFL ABC for NSRKC
- Proposed models for AIGKC

Figure 6 Schematic of annual crab stock assessment and scientific review process. Note not all stocks are assessed annually.

Similar to groundfish, the HCR for determining the OFL provides for automatic rebuilding by decreasing fishing mortality at a level equivalent to the estimate of B_{MSY} (Figure 7). Here the biomass (B) represents the measure of the productive capacity of the stock (similar to SSB for groundfish). Due to lack of information on the effective spawning biomass currency for crab stocks, mature male biomass (MMB) has been used as a proxy for the spawning biomass. For crab the inflection point in the control rule is at a value of B_{MSY} or proxy thereof. Similar to groundfish, an α value (>0) is used to increase the slope of the line such that F decreases more rapidly as biomass declines (than if α = 0) while at a value of β the directed fishing mortality is set equal to 0.[15].

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[15] Since the five-tier system was adopted in 2008 the default values for α (= 0.1) and β (= 0.25) have been used.

Crab control rule

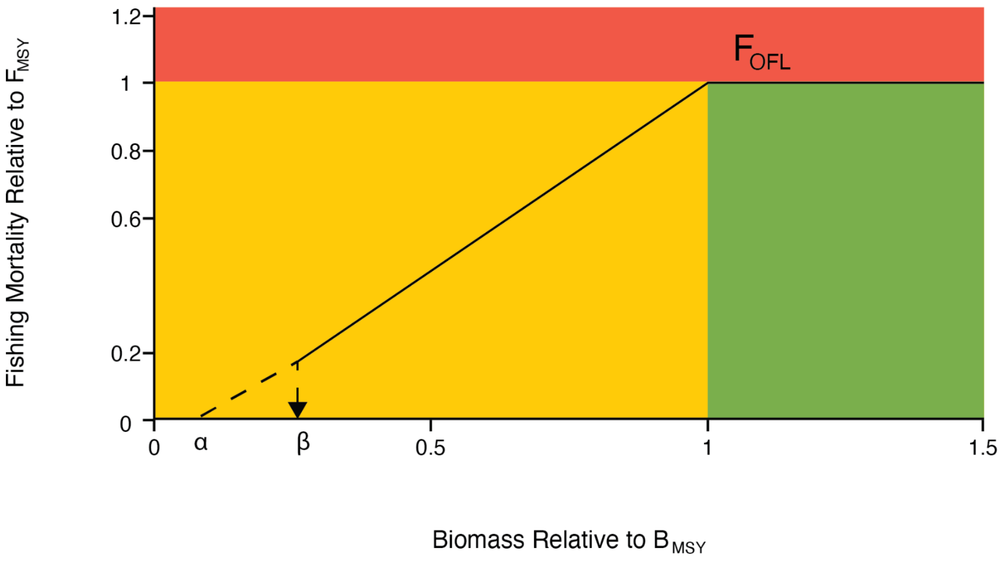

Figure 7 Sloping OFL Control rule employed for Crab stocks in Tiers 1-4 where biomass is shown as a proportion of the estimated B_{MSY} (or proxy). Fishing mortality decreases when estimated biomass is below B_{MSY} (or proxy) (denoted by '1' on the X-axis). Directed fishing mortality is 0 below β (0.25). α is 0.1. Green shading indicates biomass above target while yellow shading is biomass below target and red indicates fishing rates above the limit (indicated by F_{OFL}).

Differences in the OFL and the maxABC for BSAI crab stocks.[16] are negligible and therefore accommodation doesn't exist to account for scientific uncertainty in the point estimate of the OFL. The consideration of risk and uncertainty in setting an ABC for crab stocks (given concerns of considerable uncertainty for these stocks) is discussed further in Section 3.2.2. Due to the concern that there is considerable scientific uncertainty for crab in the point estimate of the OFL, qualitative buffers have been used to set ABC<maxABC for all crab stocks since the ABC HCR was adopted in 2011. Examples of the buffer level changes per year and stock are discussed further in Section 3.2.2.

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[16] BSAI Crab FMP amendment 38 established a maximum ABC HCR for BSAI crab stocks in Tiers 1-4 whereby ABC≤(1-by) * OFL. The parameter, by, is the value for the annual buffer calculated from a P* of 0.49 and a probability distribution for the OFL that accounts for scientific uncertainty in the estimate of OFL. For Tier 5 stocks ABC≤0.90 * OFL

3 How risk and uncertainty are addressed in the harvest specifications process

Uncertainty and risk are considered both in ABC and TAC recommendations for groundfish and crab while uncertainty (alone) is also captured in stock assessments. The OFL sets the absolute limit on catch for each stock, meaning if the annual catch exceeds the OFL, overfishing is occurring. The OFL is set as a point estimate and does not include any uncertainty around that point estimate. The ABC however is intended to reflect the scientific uncertainty around the true and unknown OFL point estimate (see 600.310(f)(2)(ii) “The ABC control rule must articulate how ABC will be set compared to the OFL based on the scientific knowledge about the stock or stock complex and taking into account scientific uncertainty”). This is to avoid overfishing (i.e., exceeding the OFL) due to the uncertainty in the true value of the OFL. Risk, on the other hand, is a consideration of how much scientific uncertainty is acceptable in establishing the ABC so as not to exceed the OFL value. If the scientific uncertainty is considered to be very small then an approach to set a low buffer value below the OFL may be an acceptable risk. For stocks with considerably more uncertainty, a more risk averse approach (resulting in higher buffers) may be more appropriate.

The balance of risk and uncertainty is both a scientific and policy decision-making process (Figure 8). For many years the ABC control rule used for groundfish and the resulting buffer values from the application of that HCR were considered sufficiently risk averse. For BSAI crab stocks, however, the approved maxABC HCR was not considered risk averse, as it did not take into account sufficient scientific uncertainty. Thus qualitative buffers to set the ABC have been utilized since 2011 when Amendment 38 was approved and ABCs for crab stocks were first established.

Management uncertainty accounts for the uncertainty that arises not from scientific uncertainty but from uncertainty in the ability of managers to constrain catch so that the annual catch limit (ACL; defined as ABC in the North Pacific) is not exceeded (e.g., inaccurate reporting of catch, late catch reporting, regulations not being enforced). Management uncertainty is considered in setting the TAC levels (recommended by the Council for groundfish and set by the State of Alaska for crab). TAC cannot exceed ABC. As with the ABC if management uncertainty is considered to be very low and catch can be managed to the TAC level very precisely, a TAC = ABC can be set as the risk of exceeding the ABC is considered low. For stocks where management uncertainty is high, a more risk averse approach is recommended by setting TAC < ABC to accommodate this.

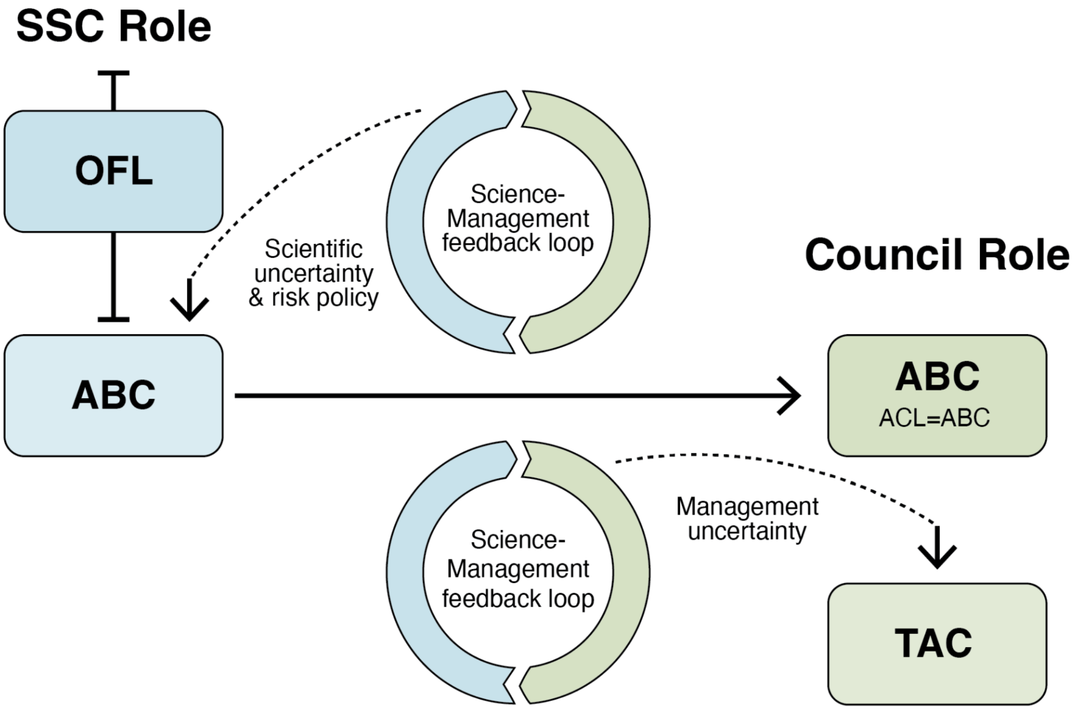

Figure 8 **Relative considerations of scientific uncertainty and risk in setting an ABC control rule (left side) and the roles of both the SSC and the Council in balancing scientific and management decisions in doing so. Also shown (to right) is the policy role in using management uncertainty considerations in setting TAC (for groundfish, for crab see Figure 10). Note that ACL is defined at the ABC for North Pacific groundfish and crab stocks under the respective FMPs.**

3.1 Assessment

Stock assessments are designed to be risk-neutral, producing point estimates of biomass and fishing mortality along with measures of statistical uncertainty. Assessment authors make numerous modeling choices (e.g., natural mortality, selectivity, growth parameters, recruitment assumptions) that implicitly address some sources of scientific uncertainty. While investigation of environmental linkages (including their impacts on time-varying parameters) is on-going and there is nothing that prevents incorporation of them to assessments, most assessments have not yet incorporated environmental drivers of productivity change, and these changes may not be captured except when observed in fishery and survey data (e.g., abundance and growth changes).

Changes in assessments generally fall into several categories (not mutually exclusive): model changes, biological reference point changes, data changes, modifications to time frames for time-varying processes (such as recruitment, growth and/or selectivity), and Tier level changes for a variety of reasons (Table 3).

3.1.1 Model structure modifications

Model modifications are proposed by the assessment team and are reviewed by the Plan Teams and SSC at least one meeting prior to being utilized in the assessment for that year. Model structure changes can be explored incrementally with multiple models brought forward for consideration within the assessment cycle (Figure 2). For example, in 2023 in moving from an ensemble model approach for EBS Pacific cod, the author provided several models in September moving from a simplified single model approach to models with incremental added complexity such as annually varying growth, annually varying survey selectivity, and fixed natural mortality. Authors explore sensitivity to various model configurations in conjunction with the previously approved status quo model. The authors, Plan Team and SSC provide recommendations on a model approach for use in setting final specifications. The SSC recommended model is then used in December to set OFL and ABC for the subsequent year.

3.1.2 Biological reference point (BRP) changes and incorporation of new or revised data

Changes in data inputs or parameters are sometimes but not always reviewed prior to incorporation within-year in the assessment process. Some of these changes are based upon incorporation of new data (e.g., new age-growth data) into an assessment model, revised time series for recruitment from an assessment model, or a new study to better inform modeling parameters (e.g., maturity information). Incorporation of these changes does not indicate a modification in model structure but may nonetheless have a profound impact on the relative references points as well as biomass and stock status implications. Changes in assessment parameters can also lead to modified biological reference points (BRP) and the maxABC

3.1.3 Tier level changes

Tier level changes are driven by considerations such as improved understanding of the reliability of data available for that stock (e.g., EBS Pollock in 2024) or changes in the assessment product (e.g. moving from a survey-based assessment to an age-structured assessment as with Aleutian Islands Pacific cod in 2024). Tier level decreases can also be driven by a lack of data such as the potential for less age data available for many stocks. Tier level changes are proposed for consideration at least one Plan Team and SSC meeting prior to being adopted and have an immediate impact on the maxABC HCR applied due to the modification in the quantitative treatment of uncertainty by Tier level (Table 3).

Table 3 Examples of how maxABC specifications can change within the existing Tier system formulas and modification to model parameters

Stock	Proposed change/ rationale	Change in resulting maxABC	Time frame from proposal to adoption for use in specifications
EBS Pollock	Change Tier 1 to Tier 3, lack of data at low stock sizes results in uncertain Stock-Recruit relationship (SRR)	-1,666,000 t	Discussion paper reviewed in September/October 2024; Tier level change by SSC in December 2024
BSAI Yellowfin sole	Change Tier 1 to Tier 3,lack of data at low stock sizes results in uncertain SRR	Not yet available	Discussion paper September/October 2025; change pending 2026 assessment cycle
AI Pacific cod	Change from Tier 5 to Tier 3; approved age-structured model	-3,134	Multiple years in development and 2024 approval of age-structured model
BSAI Atka mackerel	Estimate of F_{OFL} and F_{ABC} 25% higher relative to previous year due to changes in the fishery selectivity	+10,290 t	Assessments in 2021 relative to 2020
Various	Revised Tier 3 proxies, age-(or sex) specific schedules updated. E.g., selectivity, weight-age, and maturity	Varies	Generally proposed in September, if approved by SSC, will be included for December meeting

3.2 Acceptable Biological Catch (ABC)

3.2.1 Groundfish ABC

For groundfish, the Tier-specific HCR (a formula that uses the best available estimate of the reproductive potential of the stock (e.g., spawning biomass), an estimate of or proxy for B_{MSY}, and an estimate of or proxy for F_{MSY}) produces a maxABC that represents the upper bound on ABC. Therefore, given the specified Tier level and the assessment outputs, the HCR (a fishing mortality rate applied to the biomass estimate) yields a specific numerical ABC result. As with the OFL, the maxABC HCR for groundfish specifies that a maximum fishing mortality target rate is used to calculate maxABC when relative spawning biomass is at or above $B_{40\%}$ and the fishing mortality target rate decreases with decreasing relative spawning biomass values when relative spawning biomass is below $B_{40\%}$ (Figure 4). A target fishing mortality rate of zero applies when relative spawning biomass is below a specified value ($\alpha = 0.05$ in the current groundfish FMPs). The current maxABC does not incorporate qualitative information about stock health, ecosystem conditions, or socioeconomic factors.

Stocks under Tier 6 have no reliable biomass estimate available for setting OFL or ABC and the default is to use average catch over the years 1978-1995[17] with the maxABC specified as 75% of the OFL. However, there is considerable flexibility in the SSC recommending an OFL and ABC for Tier 6 based upon alternative criteria. As such, most groundfish stocks in Tier 6 do not have harvest specifications based upon this average catch calculation and instead use a range of modified values. Recent work by the data-limited methods (DLM) working group on a range of methodologies for catch specifications for Tier 6 stocks was presented at the 2025 Groundfish Plan Team and may be considered in the 2026 Groundfish specifications cycle[18]. None of the alternative Tier 6 specification methods require an FMP amendment to implement.

While the ABC control rule as specified in the Groundfish FMPs provides a ceiling on the maximum permissible ABC, the SSC (with appropriate justification) has the latitude to recommend a value below the maxABC. As addressed in the Groundfish FMPs, a stock assessment author first develops a recommendation for a value below maxABC that is then reviewed by the Plan Team and the SSC for consideration and documented as such. This reduction is based on “whether conditions exist that warrant setting ABC at a value lower than the maximum permissible value” and accounts for “any other scientific uncertainty” (as ABC is defined in the Groundfish FMPs and consistent with National Standard 1 guidelines). The SSC provides the final recommendation on a reduction from the maxABC for any stock.

There have been periodic ABC recommendations below maxABC historically for a variety of different rationales. A quantitative example is the GOA pollock ABC HCR (Figure 9) during the early 2000s where the stock assessment author instituted a different HCR with an inflection point at $B_{47\%}$ (i.e., beginning the fishing mortality decrease sooner than the maxABC HCR inflection at $B_{40\%}$), largely due to concerns that the stock was rebuilding too slowly and that allowing for faster rebuilding would address concerns about prey availability for Steller sea lions.

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[17] Unless the SSC recommends a different time period for appropriately characterizing catch

[18] NPFMC Tier 6 harvest control rules and data-limited stock assessment methods, September 2025

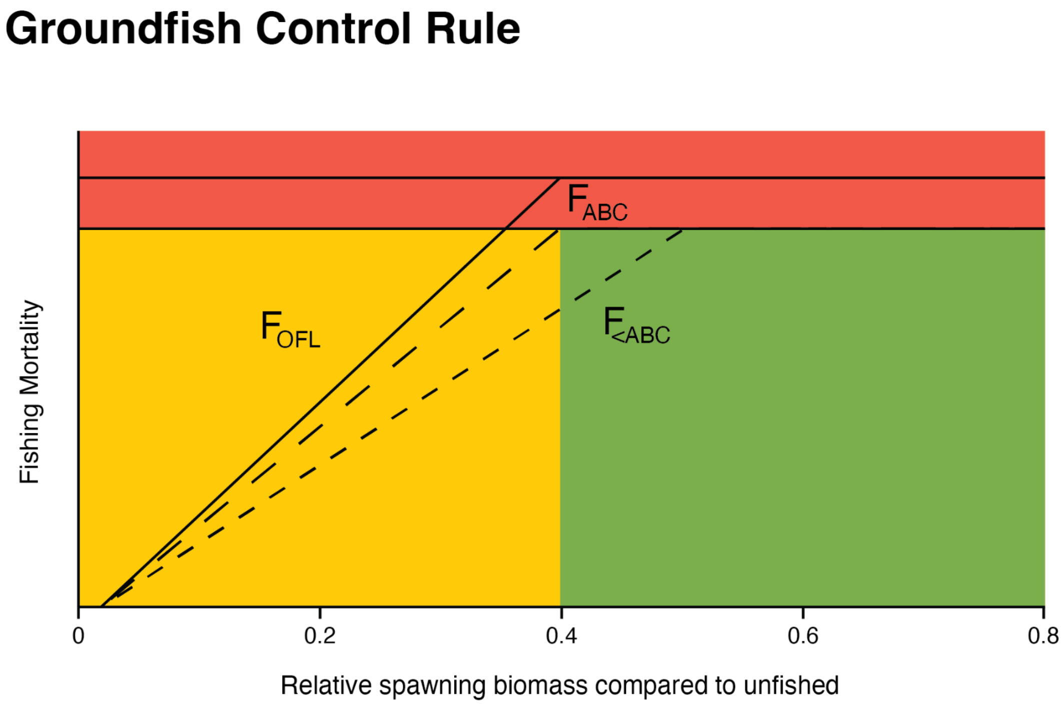

Figure 9 **Harvest control rules for OFL and ABC (Tiers 1-5) as with Figure 4 but with the additional below maximum F_{ABC} HCR employed historically in the GOA Pollock assessment denoted as $F_{<ABC}$**

A more recent quantitative example was for the 2022 BSAI Northern rock sole stock assessment, where the ABC was reduced from maxABC due model structural uncertainty indicating that a plausible alternative model existed for which the OFL was smaller than the base model's maxABC. Therefore, the ABC was reduced to the value of the OFL for this alternative model. Qualitative recent examples include the use of "risk" tables to evaluate additional non-assessment-related scientific uncertainty to justify recommending a larger ABC buffer, which we discuss in Section 3.2.3 below.

3.2.2 Crab ABC

For crab, as noted in Section 2.4, qualitative buffers have been used to set the ABC (below maxABC) for each stock annually in consideration of the scientific uncertainty in the OFL not captured by the assessment model or the maxABC HCR (Figure 10). Crab ABC buffers are intended to be as consistent as possible across levels of uncertainty for each stock, noting that within Tier 3 there is considerable variation in uncertainty across crab stocks. Table 4 shows the relative change in buffers across crab stocks for the last 5 years, which is a qualitative reflection of relative increases or decreases in the level of scientific uncertainty for each stock in the estimate of the OFL.

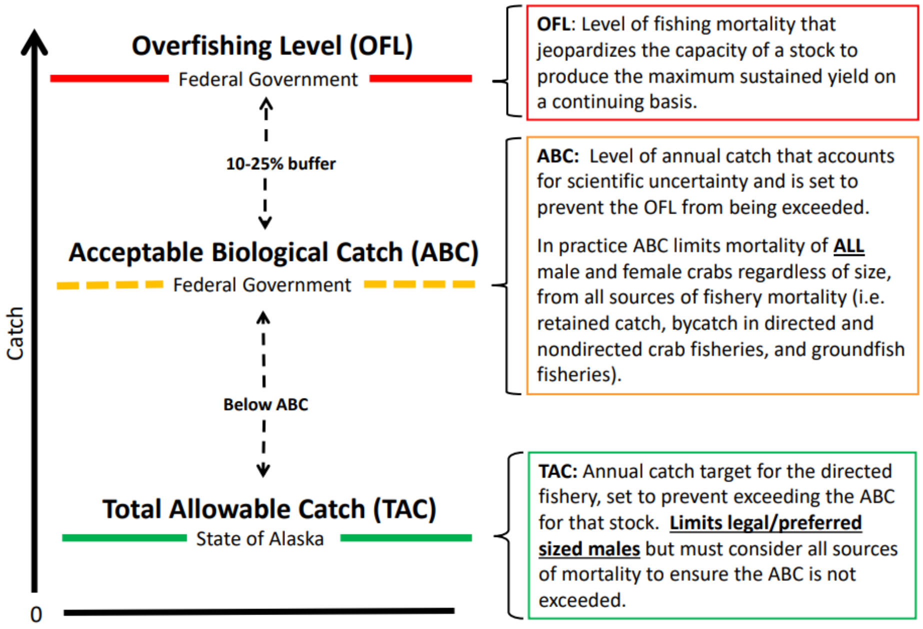

Figure 10 **Federal process for setting OFL (red) and ABC (yellow dashed line) and State process for establishing TAC (green) for BSAI Crab stocks.**

Table 4 **BSAI Crab stocks by Tier and relative ABC buffer (i.e. percentage below the OFL point estimate) over the last 5 years (2021/22 – 2025/26)**

Crab Stock	**Tier**	**ABC Buffer by year**				
		2021/22	2022/23	2023/24	2024/25	2025/26
EBS Snow Crab	3	25%	25%	50%	65%	40%
Bristol Bay Red King Crab	3	20%	20%	20%	20%	20%
EBS Tanner Crab	3	20%	20%	20%	20%	20%
Pribilof Islands red king crab	4	25%	25%	25%	25%	25%
Pribilof Islands blue king crab	4	25%	25%	25%	25%	25%
St. Matthew blue king crab	4	25%	25%	25%	25%	25%
Norton Sound red king crab	4	40%	40%	30%	30%	30%
Aleutian Islands golden king crab	3	30%	25%	25%	25%	25%
Pribilof Islands golden king crab	5	25%	25%	25%	25%	25%
Western Aleutian Islands red king crab	5	75%	75%	75%	75%	75%

3.2.3 Risk tables

More recently, reductions from maxABC for groundfish have been documented through the use of risk tables for many stocks[19]. The risk table framework provides a structured process for the stock assessment

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[19] Additional information on SSC discussion of risk tables can be found in SSC minutes from December 2024, April 2025 and the SSC Risk Table Workshop in February 2021

authors, Plan Teams, and SSC to recommend ABC reductions below maxABC based on contextual information not captured in the stock assessment model.

Risk tables evaluate concerns across four categories: assessment considerations, population dynamics, environmental/ecosystem factors, and fishery performance. A general description of guidance and the risk table template that applies to all risk tables in the assessment chapters, is provided in Table 5. The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. Examples of the types of concerns that might be relevant include the following:

1. "Assessment-related considerations"—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.
2. "Population dynamics considerations"—those not already captured by the assessment model including decreasing biomass trends, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance, population dynamics that are atypical or outside of the historical range for the stock.
3. "Ecosystem considerations"—adverse trends in environmental/ecosystem indicators, ecosystem modeling results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. "Fishery-informed stock considerations"—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings."

The risk table categories describe scientific uncertainty not directly captured in the stock assessments and rank them based upon relative levels of concern. The risk tables can be used to document and justify recommendations of ABC below maximum permissible ABC. Authors vary in how they develop their stock specific discussions using the general guidance from Table 5.

Table 5 Description of relative considerations in determining levels of concern for risk table categories

Risk Table Levels of Concern

	Assessment-related considerations	*Population dynamics considerations*	*Ecosystem considerations*	*Fishery-informed stock considerations*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are typical for the stock and recent trends are within normal range.	No apparent ecosystem concerns related to biological status (e.g., environment, prey, competition, predation), or minor concerns with uncertain impacts on the stock.	No apparent concerns related to biological status (e.g., stock abundance, distribution, fish condition), or few minor concerns with uncertain impacts on the stock.
Level 2: Increased concern	Substantially increased assessment uncertainty/ unresolved issues, such as residual patterns and substantial retrospective patterns, especially positive ones.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are unusual; trends increasing or decreasing faster than has been seen recently, or patterns are atypical.	Indicator(s) with adverse signals related to biological status (e.g., environment, prey, competition, predation).	Several indicators with adverse signals related to biological status (e.g., stock abundance, distribution, fish condition).
Level 3: Extreme Concern	Severe assessment problems; very poor fits to important data; high level of uncertainty; very strong retrospective patterns, especially positive ones.	Stock population dynamics (e.g., recruitment, growth, natural mortality) are extremely unusual; very rapid changes in trends, or highly atypical patterns compared to previous patterns.	Indicator(s) showing a combined frequency (low/high) and magnitude(low/high) to cause severe adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock) that are likely to impact the stock.	Multiple indicators with strong adverse signals related to biological status (e.g., stock abundance, distribution, fish condition), a) across different sectors, and/or b) different gear types.

3.2.3.1 Application of risk tables for groundfish stocks

For groundfish stocks, since application of the risk tables beginning in 2018, several stocks with elevated risk table scores resulted in a reduction from the maxABC in the specification cycle (Table 6). For additional explanation on the overarching rationale for the reduction see Shotwell and Bryan, 2024. It should be noted that categories and scoring levels have been modified iteratively from 2018-2022 and therefore consistent use of the current categories[20] and scoring levels are from 2023 to present.

Table 6 **Groundfish ABCs set below maxABC due to concerns noted in assessment's risk table [note these are SSC recommendations and do not include examples where the Plan Teams and or assessment author had a recommendation below maxABC that was not endorsed by the SSC]. For more information on author-recommended reductions and justifications see Shotwell and Bryan, 2024. Note that for the risk table categories the following conventions are used for abbreviation: 'A'(assessment-related), 'P' (Population dynamics), 'E'(Ecosystem) and "F' (Fishery-informed). Note that the Fishery-informed stock considerations category was added in 2019 and scores were adjusted to a maximum of '3' for any category beginning in 2023. The 'Rollover' in risk table score column indicates that no assessment model was run in that year and the previous ABC reduction was rolled over to that year.**

Stock	Assessment Year(s)	Risk Table Scores > 1	SSC reduction from maxABC
EBS Pollock	2018	P-2, E-2	30%
	2019	P-2, E-2, F-2	43%
	2020	E-2, F-2	30%
	2021	A-2, E-2, F-2	11%
	2022	A-2	43%
	2023	E-2	18%
EBS Pacific cod	2019	E-2	3%
AI Pacific cod	2023	P-2, E-2	10%
AK Sablefish	2018	A-2, P-4, E-2	45%
	2019	A-2, P-3, E-2, F-3	50%
	2020	A-3, P-3, E-2, F-3	44%
BSAI Yellowfin sole	2021	P-2, E-2	24%
BSAI Greenland turbot	2024	A-3, P-2, E-2	25%
BSAI Northern rock sole	2022	A-3	23%
	2023	rollover	23%
BSAI Blackspotted / Rougheye rockfish	2022	A-3, P-2, F-2	11%
	2023	rollover	11%
BSAI Sharks	2022	A-3, P-2	13%
	2023-2024	rollover	13%
GOA Pollock	2023	A-2	18%
GOA Pacific cod	2018	NA*	14%
	2019	A-2, P-2, E-2	NA**
GOA Dusky Rockfish	2020	A-2	24%
	2021	Rollover of stair-step	24%
GOA Rougheye/Blackspotted rockfish	2023	A-2, P-2	20%
	2024	NA***	10%
GOA Demersal shelf rockfish	2021	A-2, P-2, F-2	22%
	2022	A-2, P-2, F-2	15%

* No risk table; recommendation to keep SSB > B20% in subsequent year
** Set at maxABC but with catch assumed to be at a level below 2019 ABC as directed fishery closed
*** Rollover of method to set below maxABC

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[20] Note that in 2024 the name of the category "Fishery-informed stock considerations' was modified from previously used "Fishery performance indicator' however this change did not impact how the category was characterized.

There is considerable flexibility allowable under the current tier system within the Groundfish FMPs and consistent with the National Standard 1 regulations for recommending ABC levels below the maxABC. There is no flexibility to recommend an ABC higher than the maximum permissible.

3.2.3.2 Application of risk tables for crab stocks

Draft risk tables are under development for some crab stocks (Table 7). As qualitative buffers are already being used to set ABC, these risk tables are intended to provide a more formalized description of the categories of uncertainties included to justify the relative buffer level by stock rather than explicitly considered in the development of the buffer values themselves (as buffer levels for crab stocks preceded the use of risk tables). Should action be taken to consider a quantitative maxABC HCR for crab stocks (via an FMP amendment process), the risk tables could then be used in a similar manner as with groundfish whereby diverging from the maxABC is the exception rather than the rule with the risk tables providing sufficient justification and scored appropriately for that consideration.

Table 7 BSAI Crab stocks by Tier level and years in which a risk table was most recently included in the assessment as well as the relative scores by category. Here NA indicates no risk table developed for that stock.

Crab Stock	Tier	Risk Table/Year	Risk Table Score			
			Assessment	Population dynamics	Ecosystem	Fishery
EBS Snow Crab	3	Y 2025	2	2	1	1
Bristol Bay Red King Crab	3	Y 2025	1	2	2	1
EBS Tanner Crab	3	Y 2025	2	1	1	1
Pribilof Islands red king crab	4	Y 2025	2	2	1	1
Pribilof Islands blue king crab	4	Y 2025	1	1	1	1
St. Matthew blue king crab	4	N				
Norton Sound red king crab	4	N				
Aleutian Islands golden king crab	3	Y 2025	1	2	1	2
Pribilof Islands golden king crab	5	N				
Western Aleutian Islands red king crab	5	N				

3.3 Total Allowable Catch (TAC)

TAC levels for both groundfish and crab are set on an annual basis. For crab stocks this is under the jurisdiction of the State of Alaska as a Category 2 measure under the Crab FMP (framework management measures)[21]. For groundfish however, the Council recommends final harvest specifications to the Secretary of Commerce annually. The sum of the recommended TACs for all groundfish stocks within each FMP must fall within the optimum yield (OY) range (for GOA the range is 116,000-800,000 mt, for the BSAI the range is 1.4 – 2.0 million mt); these values are specified in the groundfish FMPs and in implementing regulations. TAC must be set at or below ABC. In the BSAI, the top range of the OY (referred to as the 2 million metric ton OY 'cap') frequently results in TACs well below ABC for many stocks. In the GOA, markets and bycatch concerns also result in TACs for some stocks frequently below

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[21] Section 8.2 of the BSAI Crab FMP discussed the Category 2 Framework Management Measures including the process to set TAC (Section 8.2.2).

ABC[22] and the upper range of the OY has not been reached (see the discussion on Optimum Yield in Example 2 of Appendix 3). The Council retains broad latitude to recommend TAC below ABC on an annual basis, consistent with the Groundfish FMPs and implementing regulations (50 CFR 679.20(a)(3)) , drawing on socioeconomic information and concerns not addressed in the ABC-setting process provided the sum of the TACs is within the ranges specified in the respective FMPs[23].

3.4 Benefits and Drawbacks across the three approaches and time frame for changes

Three current approaches to address risk and uncertainty as detailed in Sections 3.1 - 3.3can be accomplished within the current assessment review process. The benefits, drawbacks and relative timing of modifying these approaches are shown in Table 8.

Table 8 Summary of approaches for modified management advice under the current specification process, relative benefits and drawbacks of each approach and relative timing for enacting changes.

Approach	Benefits	Drawbacks	Timing
Assessment changes	Highly targeted; can address stock-specific dynamics; scientific peer review provides quality control	Less transparent to the public; extended development time; changes within scientific purview, not direct Council action	Depends upon scope and scientific concurrence on modifications; can be done within two meetings of Plan Teams and SSC; sometimes may take multiple iterations of changes to eventually get approved (e.g., AI Pacific cod model and resulting Tier level change)
ABC changes from maxABC	Can be done within an assessment cycle drawing on information within the assessment (e.g., where recruitment estimates are modified) or with the use of risk table scoring and justifications for out of assessment model uncertainties	Qualitative; scoring and resulting reductions may be inconsistent across assessments; it is not possible to recommend an ABC above the maxABC	Modified by the SSC during their annual stock assessment review and ABC recommendations
TAC adjustments	Flexible and responsive on annual timescales; can draw on a broad range of information; no FMP amendment needed but sum of TACs must fall within the OY range by FMP.	Does not create lasting structural change; ad hoc; may lack analytical basis; subject to annual political dynamics; and structure (e.g., use of HCRs and risk tables)	Modified within a Council meeting cycle without additional analysis

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[22] Note more information on the factors that inform the specification of TAC below ABC in the GOA are provided in the final rule implementing the GOA specifications (91 FR 11902, March 11, 2026)

[23] Note that in conjunction with the Climate agenda item at the June 2026 SSC meeting, the SSC will address an agenda items to review 'Economic and community indicator reports' which may be relevant to continued discussions of socio-economic information available for the TAC-setting process.

4 Council considerations for revising treatment of risk and uncertainty

In conjunction with the Climate work plan, the Council has expressed an interest in continuing to refine the treatment of risk and uncertainty in the harvest specifications process. The previous section has described the current process and structure (e.g., use of HCRs and risk tables) and components of the process and structure where risk and uncertainty are addressed. In establishing a climate resilience work plan, the Council moved forward on several items that are on-going[24] including the consideration of the current tier systems, climate informed biomass targets and climate-robust or forecast-informed harvest control rules.

Should the Council choose to augment what is currently available by considering alternative HCRs to better address climate shocks and environmental variability (to set max ABC) it will be necessary to articulate the goals and objectives to be achieved by undergoing this evaluation.

While the frameworks governing the HCRs for groundfish and crab have been static for many years, as discussed in Section 3.1, the calculation of the biological reference points (and resulting ABCs) within individual assessments can change frequently in response to:

- new information on the key vital rates governing population dynamics of the stock
- shifts in information availability and management tiers
- shifts in spatial distribution of the stock that influence availability and/or catchability
- changes in the selectivity and catchability of the stocks to fishing resulting from gear changes, time-area-gear regulations that influence selectivity, and other factors governing harvest practices of the fleet (including changes in prohibited species mortality caps and discard mortality restrictions).

The NPFMC's HCR framework has proven flexible enough to accommodate these changes. The NPFMC's current system of management has sustained fishing opportunities for many stocks historically. In recent decades shifts in ocean conditions have had profound impacts on some groundfish and crab with associated impacts on the fisheries and communities that depend on them (Bigman et al., 2023; Suryan et al., 2021). These impacts are harbingers of future changes in fish and crab abundance under future environmental scenarios and thus inform consideration of more adaptive HCR frameworks.

4.1 Foundational Elements for alternative BRPs and HCRs

The following discussion of alternative management control rules and assessment advancements assume continued investment in the foundational elements of responsive management. This includes ongoing surveys and data collection along with subsequent data processing (both fishery dependent and independent data) which are essential for status determination and to detect changes in ecosystem carrying capacity or baseline conditions that can impact the distribution and productivity of a given stock. Additionally, effective management depends on continued support for a network of data access and information exchange, partnership building, and a sustained and transparent process for decision making[25]. Any advancements in this process should be towards reinforcing the predictability and accessibility of decision-making information, tools, and resources and could include continued development of open access tools, reproducible data flows and assessment methods and code, and continued two-way dialog with decision makers and Alaskan communities of place, practice, and

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[24] Council motion on Climate work plan December 2024

[25] Effective EBFM also relies on understanding of the critical mechanisms linking climate with ecological and biological processes that ultimately impacts population dynamics and stock assessment (e.g., EcoFoci, Food habits, and ecosystem modeling).

management. In addition, new advancements in climate and ecosystem forecasting[26], and rapid evaluation of the skill of tools built on these forecasting resources will help continue to support rapid decision making, especially through anticipating potential climate, ecosystem, market and other potential shocks to the system. In this, performance metrics (See Appendix 5.3) reflective of NPFMC goals and objectives, will be important for evaluating the potential added benefit of forecasting tools to existing management processes as well as modified HCRs.

4.2 Broad goals of modified HCRs

The intent of considering modifications to HCRs for some or all Tier levels as well as some or all stocks is to provide additional protection and increased resilience for the long-term sustainability of fish and crab stocks under changing environmental conditions. This is consistent with the Council's stated goal in adopting a Climate work plan of "enhanced climate resilient management in the GOA and the BSAI".

Multiple alternative HCRs have been considered throughout the evolving work in ACLIM and GOACLIM. To focus on showing contrast amongst HCRs, three major approaches were selected, which include: providing for declining fishing mortality at high stock sizes to increase buffering against environmental shocks (HCR 5 and HCR 10; Table 9), an HCR framework that varies according to estimated changes in stock productivity (potentially informed from a linkage to an environmental covariate; HCR 7), and contrasted with a static fishing mortality rate applied across high stock sizes which declines below a target stock size to provide for automatic rebuilding (HCR 1, status quo). The framework presented as HCR 7 is meant as an HCR-based method to bridge from qualitative risk tables to quantitative advice (Table 9; Appendix 2).

Table 9 Candidate HCRs and the goals each HCR is intended to achieve.

HCR	GOAL
Status Quo (HCR #1)	Automatic rebuilding below target stock size (Status Quo baseline sloping CR used for BSAI and GOA Groundfish)
Lower fishing mortality at high stock size (HCR #5)	Maximize ecosystem biomass and SSB (intent to increase reserves, buffer against environmental shocks, and enhance long-term sustainability with lower fishing mortality)
Lower fishing mortality at high stock size (HCR #10)	Similar objectives as with HCR 5 (intent to provide increased buffering against environmental shocks through proportional reductions in fishing mortality)
Dynamic HCRs that respond to time-varying stock productivity (HCR #7)	Transition from qualitative risk tables to an explicit analytical approach in which recommended harvest rates respond to estimated temporal changes in stock productivity (obtained from population models with time-varying parameters, linkages with environmental covariates or other methods)

The range of HCRs under consideration (Figure 11) vary in shape based upon the approach and what the HCR is designed to achieve. Some allow for higher fishing mortality at higher stock sizes and thus a higher ABC under specific environmental conditions than the status quo HCR currently provides.

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[26] Additionally, potential future development of a tier system for data and forecasting quality might help categorize confidence in forecasting and predictive tools and resources.

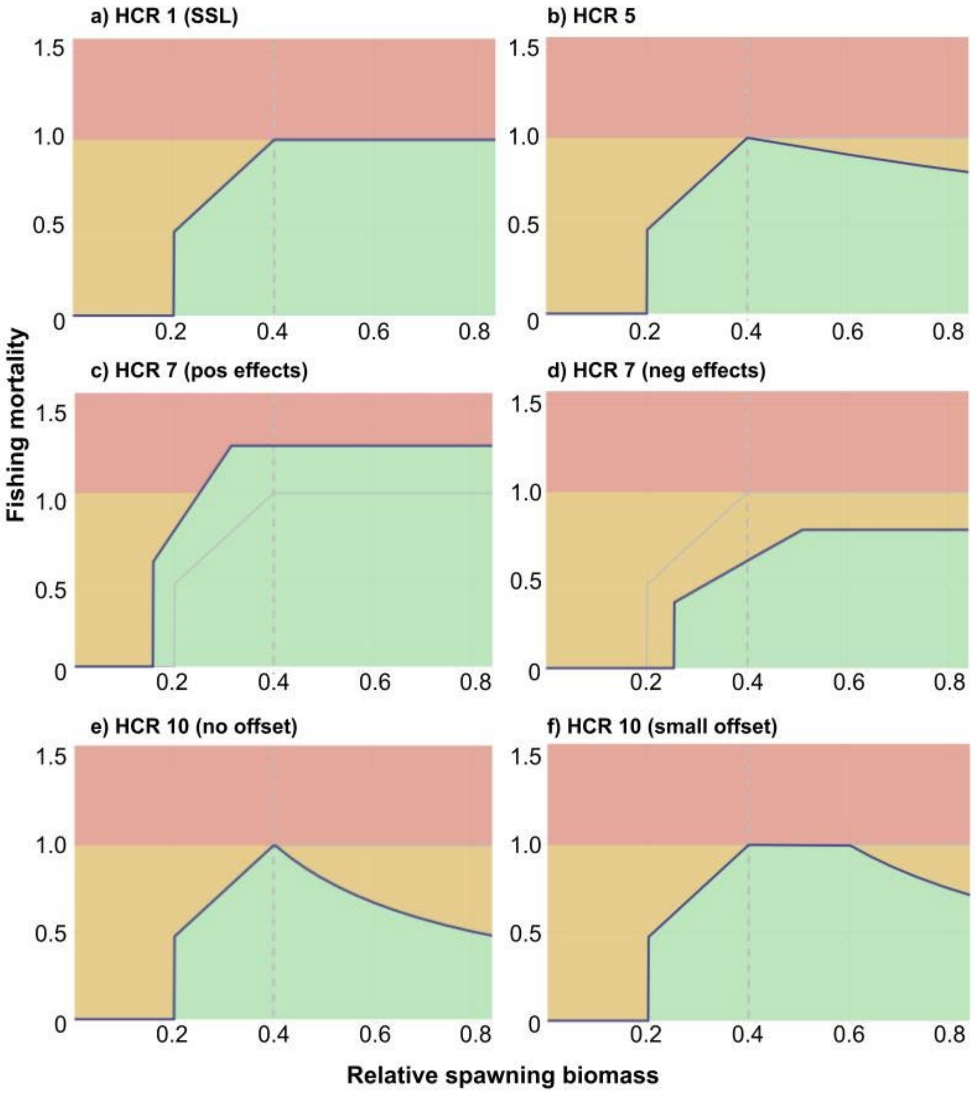

Figure 11 **Candidate HCRs illustrated with various HCR modifications. (a) Status quo (HCR1) with inflection at $B_{40\%}$ (dotted grey line) and directed fishery cutoff at $B_{20\%}$ (see Appendix 2 for additional details on formulations; b) HCR 5 with sloping adjusted F rate above $B_{40\%}$ to maximize spawning biomass age class diversity; c) HCR 7 dynamic response to time-varying stock productivity with positive environmental effects on productivity, and d) HCR 7 with negative environmental effects on productivity; e) HCR 10, as in 5 but with declines in F inversely proportional to SSB (cap catch), f) HCR 10, as in previous with an offset in the cap effect similar to effective F for pollock given 2mt cap effects. Green shading indicates biomass above target while yellow shading is biomass below target (or fishing rates above target) and red indicates fishing rates above the limit (indicated by F_{ABC}). Shading only applies to the candidate HCRs not the backdrop HCR1. Figures generated from the ACLIM HCR online tool (https://kholsman.shinyapps.io/HCRshiny. Note this tool is intended for research purposes only at this time).**

The top right penal and bottom two panels of Figure 11 (Figure 11b HCR5, Figure 11e-f HCR10) are examples of candidate HCRs which provide lower fishing mortality at higher stock sizes. Here below the target stock size for groundfish (at $B_{40\%}$) the HCR is identical to the status quo (with the figure showing a directed fishery closure for SSL prey species such as pollock and Pacific cod below $B_{20\%}$). These candidate HCRs are designed to maximize ecosystem and spawning biomass productivity by increasing biomass reserves thus creating a buffer against environmental shocks and enhancing long-term sustainability. These HCRs aim to enhance stock robustness to uncertainty in environmental conditions and provide increased potential for higher recruitment levels and growth of fish to larger sizes through preserving higher levels of SSB when the population is abundant. HCR10 builds on HCR5 by providing an option for an offset in SSB (e.g., Figure 11f) and a proportionally steeper F rate decline at $B_{60\%}$ (rather than a more shallow decline in HCR5 at SSB levels $>B_{40\%}$).

Initial simulation results provide some indication that for a subset of species these two HCRs result in an increase in SSB, lower catch at high biomass but overall reduced catch volatility and increased stability in annual catch, more diversity in the spawning biomass age structure and prevention or forestalling of stock declines/crashes under variable environmental conditions (Holsman et al. 2020, in prep. Whitehouse et al. 2020, Goethal et al. in review). Additional performance metrics will be evaluated during ongoing 2026 simulations.

The middle two panels of Figure 11c-d show examples of dynamic HCRs that respond to time-varying stock productivity. This example provides a transition from qualitative risk tables to a more explicit, analytical approach for species whose productivity is known to vary with environmental conditions. Here adjustments can be made to F_{target} and B_{target} with changes in population productivity. This example builds on work by Dr. Paul Spencer (Spencer et al., in prep) indicating that F_{target} varied with sea surface temperature (SST) in the EBS specifically for EBS pollock. This dynamic HCR extends the elements of the Status Quo HCR under Tier 1. While the current formulation of this HCR is parameterized such that productivity varies with an environmental covariate (e.g., currently SST) additional explorations are designed towards cases where productivity has varied over time but without a clear link to a particular environmental covariate. Notably as shown in Figure 11d where environmental effects reduce productivity, a more conservative SSB target is used (shown here at $B_{50\%}$) and a more conservative F rate and directed fishery closure than status quo. In contrast in Figure 11c the stock responds positively to environmental effects resulting in a less conservative SSB benchmark (shown here at $B_{30\%}$) and higher F rates than status quo. Under this HCR, higher harvests can be achieved than possible under the current HCRs in use in the NPFMC system. Although fishing at target rates higher than F_{abc} would not occur, the estimates of F_{abc} itself may be higher in years of high productivity.

4.3 Defining Objectives

The Council should articulate the objectives of this effort moving forward, understanding that not every HCR being considered will meet those objectives to the same degree, and there will likely be tradeoffs for any HCR approach in meeting the objectives. However, all the candidate HCRs are intended to provide increased resilience against continued environmental variability. Once the Council has articulated the goals and objectives for modified HCRs, the HCRs under development will be tested in simulation and management strategy evaluation (MSE) frameworks (see a range of proposed modeling frameworks in Appendix 3) to evaluate how they meet these objectives according to performance metrics (See example objectives and corresponding performance metrics in Appendix 4) and may also be modified further to better address stated objectives. To assist the Council with articulating the objectives (to align with overarching goals) for modified HCRs, the analysts have compiled some stated objectives of the HCRs under development as well as some that have been noted in Plan Team, SSC and stakeholder discussions. These include and are not limited to the following[27]:

- Sustainable biomass for groundfish and crab stocks (note this needs to be defined)
- Prevent overfishing

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[27] Note that some of these objectives also apply to current HCRs

- Transitioning from the use of risk tables under the status quo system to an explicit analytical approach for species whose productivity is known to vary with environmental conditions
- Increased buffering against environmental shocks
- Socio-economic stability
- Community level objectives (note these need to be defined)
- Transparency in the ABC setting process

If the Council wishes to move forward with this effort at this meeting, the Council should define explicit draft objectives and a draft purpose and need statement for the analysis.

4.4 Range of stock-specific issues

A range of issues have been raised in recent years in the assessment process for groundfish and crab stocks under observed environmental variability. This has led to increased focus in addressing these through the process of assessing risk and uncertainty in the harvest specifications process whether through the assessment, recommending ABCs below the maximum permissible, alternative HCRs, alternative biological reference points or during TAC setting as noted in Section 3. Some of these issues by stock are summarized in Table 10. Some stocks have been the focus of SSC discussions and are recommended as the initial focus of any alternative HCRs under consideration. Additional information by stock to detail specific issues that have been addressed in the assessment process are described in Appendix 5. Addressing the impact of environmental variables on population dynamics through alternative HCRs is an alternative to within-assessment linkages to population dynamics, or qualitative adjustments to ABC. In addition, HCRs could be combined with environmentally linked models or qualitative adjustments so long as environmental mechanisms are not being "double counted" by alternative methods (see Joint Groundfish Plan Team recommendations from Jan 2026).

Table 10 Stocks and key assessment/population related uncertainty issues and potential HCR approaches

Key Issues	Stocks	Potential HCR approaches
Recruitment variability, especially irregular large recruitment events	Sablefish, rockfish, pollock,	HCR5 or 10, sablefish HCRs under MSE
Increased natural mortality: elevated or event driven	GOA cod, AI cod, EBS snow crab	HCR with environmental covariates (HCR7), HCR5 or 10?
Prolonged recruitment failure	Greenland turbot	HCR7
Environmental sensitivity of year-class strength	BSAI/GOA Pollock, Bristol Bay red king crab	HCR with environmental covariates (HCR7), HCR5 or 10?
Long-lived, slow recovery, declining productivity despite large biomass levels	BSAI/GOA Pacific ocean perch	Dynamic HCRs that adjusts reference points to reflect trends in stock productivity (variant of HCR 7)

One issue raised in previous discussions of candidate stocks is the appropriate characterization of the application of the status quo maxABC HCR. This is of particular importance for crab stocks. As discussed in Section 3.2.2, ABCs for crab stocks have been recommended based on buffer values below maxABC to account for scientific uncertainty (Table 4). TAC levels for crab are set by the State of Alaska and account for additional stock and management uncertainty.

Moving forward, some specific considerations related to BSAI crab stocks include the following and would need to be clarified in framing both the scope (purpose and need) of HCR modifications to include crab as well as in framing the analysis and HCR development more tailored to crab stocks:

ABC Control rule for BSAI crab stocks: As noted previously, the current ABC HCR for crab stocks does not account for scientific uncertainty in the OFL and as such has never been used to set ABCs. An alternate HCR for crab stocks would require an amendment tto he FMP to replace the Status Quo ABC CR and as such would be intended to better reflect scientific uncertainty in the OFL and reduce the necessity of using qualitative buffer percentages to set ABC annually.

Considerations of status quo for BSAI crab stocks: Defining a status quo ABC HCR for crab stocks requires assumptions about the buffer values to be applied given that the maxABC HCR has never been utilized. Additional concerns have been raised about the coordination and reflection of the State HCR as the State determines actual catch levels (TAC) for these stocks and the ABCs are generally much larger than the TACs. The CPT noted that a status quo aligned HCR for crab stocks needs to be developed prior to layering in climate complexity and consider such factors as the State HCR and the lack of alignment between State and Federal HCRs.

Candidate HCRs for BSAI crab stocks: The CPT has previously commented[28] that the current suite of HCRs under consideration were not developed explicitly for crab stocks and additional consideration may be needed to evaluate alternative HCRs that are better suited to specifics of crab population dynamics and biology. There was strong emphasis on framing HCRs in a way that resonates with State perspectives on stock status and the TAC-setting process, developing simulations that capture crab-specific demographics (e.g., male/female dynamics, shell condition), and recognizing stock-specific differences among crab species. Additionally, volatile population declines and concerns regarding the concentration of fishing effort on the largest commercial size male crab as well as the current currency of management (MMB as a proxy for SSB) have led to reconsideration of appropriate biological reference points and recruitment time series for various stocks. Development of more crab-specific and potentially mortality event driven reference points for developing appropriate HCRs may need to be considered separately from the HCRs developed for groundfish population dynamics. Specific issues related to EBS snow crab and Bristol Bay red king crab are detailed further in Appendix 5.5.

4.5 Council decision points

The Council has already expressed their interest in considering alternative HCRs to enhance climate resilience under changing environmental conditions. If the Council chooses to move forward with this analysis, the Council should identify goals and objectives to be achieved through the action, develop a purpose and need statement to include these goals and objectives, and a draft suite of alternatives for analysis. These draft alternatives could be generally framed to accommodate different HCRs that are under development or may be developed in light of new evaluation results. Section 4.2 provides some draft high-level goals and tailored example objectives that may assist the Council in selecting these for the analysis. As noted previously some of these objectives may be in conflict with each other, but analysis of the HCRs will indicate to what extent each HCR achieves various objectives, and tradeoffs between objectives. Performance measures will be developed (see Appendix 4 for examples) in conjunction with public input on appropriate metrics to meet the Council's objectives.

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[28] See November 2025 CPT report

Some considerations for the Council in drafting alternatives for this include the following:

1. FMPs to be considered:
   a. Does the Council wish to consider alternative ABC HCRs for both Groundfish (BSAI and GOA) and BSAI Crab stocks at this time?
2. HCRs under consideration:
   a. Alternative 1: Status Quo. Maintain the current ABC HCRs specified by Tier system and stock status under the FMPs
   b. Alternative 2- X (e.g., potentially multiple alternatives): Alternative ABC HCRs. A range of different HCRs may be included here aligned with various goals and objectives specified by the Council. These HCR alternatives need not be mutually exclusive and may vary by species groups. Examples include:
      i. HCR which buffers against environmental shocks
      ii. HCR which explicitly address productivity shifts due to environmental conditions
3. Options to apply to alternatives:
   a. Trigger mechanism (including duration) to move from the Status Quo HCR to an alternative HCR. This concept needs further development before moving forward. Note there could be a range of different trigger mechanisms, and they may be stock specific. This would indicate that alternative HCRs would not replace current HCRs under status quo unless a specific environmental or other population-based trigger was reached and ABCs would continue to be specified under the alternative HCR until a conditional threshold was reached[29]. Trigger mechanisms were recommended by the Joint Groundfish Plan Teams to be stock-specific and on a case-by-case basis.

The Council may also provide direction to the analytical team on an appropriate communication and engagement strategy for this analysis outside of the normal Council analytical review process to best inform and involve all stakeholders throughout the project.

4.6 Ongoing engagement and communication

Given the complexity of this analysis, the SSC's February 2026 comments on the need for a targeted engagement and communication strategy combined with the need for effective stakeholder participation in identifying performance metrics against which to evaluate HCR performance, some additional ideas are put forward to enhance engagement efforts for Council consideration. These are organized into engagement and communication on the general nature of this analysis as well as specific feedback on the performance measures being developed.

General Communication and Engagement ideas: Building on the structure of this paper, provide a series of short information pieces (e.g., infographics, interviews with scientists or other concepts to be considered) on each section of the paper to enhance understanding of the status quo harvest specifications framework in general and building toward better understanding of the complexities of HCRs (current and proposed) and the MSE analyses investigating the performance of alternative climate resilient HCRs.

Appendix 3 provides example performance metrics (biological, economic, and social) to measure HCR performance against goals and objectives articulated by the Council. A plan for developing and synthesizing social indicators is also being proposed for this incorporation in performance metrics for this

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[29] Note that the Joint Groundfish Plan Teams commented: "Potential triggers (meaning when to apply an alternative HCR) might include (but are not limited to) stocks where multiple successive years of SSB are below B_{target} or those with 5+ years in Tier 3b status, multiple risk table reductions have been used in the past or where risk table adjustment discussions identified concerning patterns, realized catches are substantially below (above) expected catch, there appears persistent declines in recruitment, or other concerning trends identified through stock assessments, environmental monitoring, or evaluation of stock productivity."

effort. It is important to get stakeholder buy-in on the appropriate performance metrics to use and therefore an additional engagement process is sought for consideration of performance metrics once the objectives are fully defined. A plan should be developed for this additional engagement either through an existing Council committee review or other means to solicit public input on the draft performance metrics.

4.7 Timeline and milestones

Note: The timeline below is relative and intended for planning purposes only. All milestones and timeframes are preliminary and subject to revision.

- **Synthesis and initial review of performance metrics (now– Sep 2026; finalized Dec 2026):** Synthesize prior input on performance metrics and existing metrics. Share with Council and advisory bodies for feedback, including opportunities for public input.
- **Engagement and Communication Strategy (now - Dec 2026):** Finalize engagement and communication strategy and associated timing (Council-led).
- **Finalization of high-priority performance metrics (Feb 2027):** Finalize key (high-priority) performance metrics (Council-led; potentially with involvement from the Ecosystem Committee).
- **Scoping based on ongoing HCR and biological reference point (BRP) simulation work (now – Feb 2027):** Conduct and solicit input on the scope of ongoing simulation work (e.g., through ongoing R&D efforts).
- **Reporting on ongoing HCR and biological reference point (BRP) simulation outcomes (Feb 2027 – June 2027):** Report back on outcomes from simulation scoping activities.
- **Potential Management Strategy Evaluation (MSE) for high-priority cases (Jan 2028 – Dec 2029):** Conduct MSE analyses for prioritized cases from simulations, as appropriate.
- **Iterative Council review (Annually, Spring):** Conduct iterative review of simulation and MSE work within the Council process.
- **Plan Team and SSC check-ins (Annually, Fall):** Hold regular check-ins with Plan Teams to review progress and alignment.
- **Initial Review draft analysis (Tentatively Feb 2030):** Earliest anticipated timing for an initial draft review analysis for Council consideration.

5 Appendices

5.1 Appendix 1 Glossary

Table A1.1 Glossary of terms used in this discussion paper

Management reference point	Definition
HCR	harvest control rule
OFL	Overfishing limit
ABC	Acceptable biological catch
TAC	Total Allowable catch
SSB	Spawning stock biomass
SSB_{target}	Target spawning stock biomass
F	Fishing mortality rate
F_{limit}	Limit fishing mortality rate
F_{target}	Target fishing mortality rate
$B_{100\%}$	Unfished biomass
$B_{40\%}$	40% of unfished biomass (inflection point in NPFMC groundfish control rules)
$B_{35\%}$	35% of unfished biomass (proxy for BMSY in NPFMC groundfish control rules)
B_{MSY}	Biomass representing maximum sustainable yield
$B_{MSY\ proxy}$	A proxy value for biomass representing maximum sustainable yield (for groundfish this value is B35%)
$F_{40\%}$	Fishing rate that reduces biomass to 40% of unfished biomass
$F35\%$	Fishing rate that reduces biomass to 35% of unfished biomass
maxABC	The maximum permissible ABC resulting in the application of the FMP ABC HCR by Tier
F_{OFL}	OFL fishing mortality rate
F_{ABC}	ABC fishing mortality rate
α	Alpha, value at this the OFL and ABC HCRs are 0. For groundfish this value is 0.05, for crab this value is 0.10
β	Beta, value at which directed fishing for BSAI crab stocks is 0. This value is 0.25

5.2 Appendix 2 HCRs under development

The following section and tables and figures are excerpted, with slight modifications, from Holsman et al., 2025 An Overview of Stage 1 (2025-2026) Alternative HCR Evaluations Through ACLIM and GOACLIM provided to the Groundfish Plan Teams and Crab Plan Team in the fall of 2025 following a Council request in October 2025. This provides additional details on the HCRs being developed as well as a specific focus upon HCRs 1,5,7 and 10 per SSC and Council requests. Overview of the ten HCRs under development are shown in the Table A2.1 and Figure A2.1 below with a focus on the HCRs 1,5,7, and 10.

Table A2.1: Overview of ACLIM and GOACLIM 2025 HCR options. “Stage 2” denotes the HCRs that are not being evaluated as part of the Council’s request following the June SSC workshop, but have been or are being evaluated as part of the ACLIM and GOACLIM work.

HCR	Name	Detail	HCR Stage
HCR 1	Status quo	This HCR is the baseline sloping harvest control rule used for groundfish in Alaska	1
HCR 5	Maximize productivity/ increased reserve (buffer shocks)	HCR 5 is designed to maximize ecosystem and spawning biomass productivity by increasing reserves, creating a buffer against environmental shocks and enhancing long-term sustainability.	1
HCR 7	Risk Table Bridging, R/S variability, with potential linkage to an environmental covariate	This HCR provides a way to transition from qualitative risk tables to a more explicit, analytical approach for species whose productivity is known to vary over time, with potential linkage to an environmental covariate.	1
HCR 10	Maximize productivity/increased reserve, linear version (1/ B_target) with offset	This HCR builds on HCR 5 by applying a proportional reduction in fishing mortality based on biomass levels, further enhancing stock and environmental productivity through strengthening the buffer against environmental shocks.	1
	(Stage 2 HCRs Below)		
HCR 2	Lagged recovery to estimate emergency relief financing needs	Simulations with this HCR will mimic economic-driven fishery closures and delayed recovery in order to estimate emergency relief needs.	2
HCR 3	Long-term resilience (stronger reserve) B_target	This HCR aims to enhance long-term stock resilience by adjusting B_target (as a proportion of unfished biomass)	2
HCR 4	Environmental index informed sloping rate, e.g., MHW category alpha	Simulations with this HCR will assess whether adjusting harvest intensity based on poor forecasted conditions—such as marine heatwaves—can accelerate stock recovery following climate or environmental disturbances.	2
HCR 6	Combination of MHW (HCR4) + Maximize productivity (HCR5)	This HCR combines the approaches of HCR 4 and HCR 5 to address both immediate and long-term environmental impacts.	2
HCR 8	Adjust effective spawning biomass (simulate adjusted B_target)	This HCR adjusts the effective spawning biomass instead of the target biomass threshold, serving as a sensitivity approach to explore variability in spawning stock biomass (SSB) estimates within a given assessment year or to evaluate alternative B_target values.	2
HCR 9	Forecast informed version of HCR 5	This HCR builds on HCR 5 by using environmental forecasts to dynamically adjust reserves, enhancing ecosystem productivity and resilience to environmental shocks.	2

HCR Scenarios

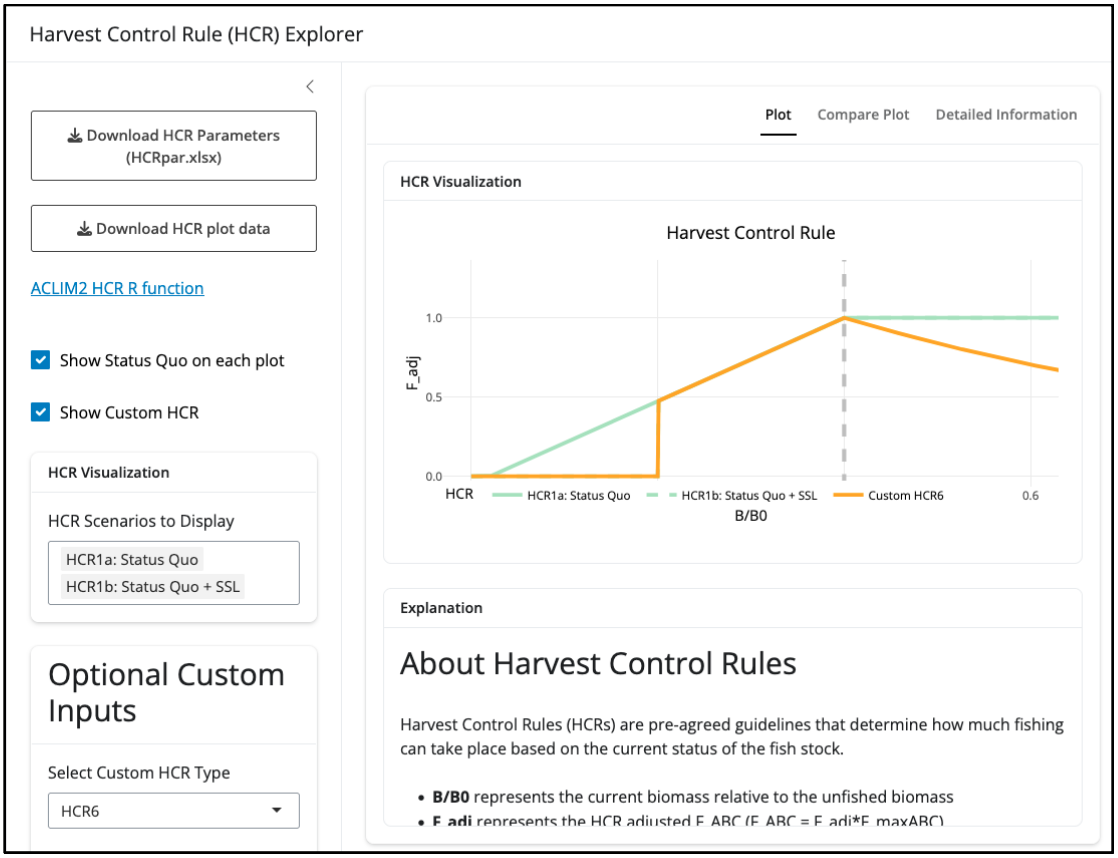
ACLIM2

HCR	Name
ABC+HCR 1	Status quo
ABC+HCR 2	Lagged recovery to estimate emergency relief financing needs
ABC+HCR 3	Long-term resilience (stronger reserve) B_target
ABC+HCR 4	Environmental index informed sloping rate, e.g., MHW category alpha
ABC+HCR 5	Maximize productivity/ increased reserve (buffer shocks)
ABC+HCR 6	Combination of MHW (HCR4) + Maximize productivity (HCR5)
ABC+HCR 7	Risk Table Bridging, R/S variability covariate adjusted HCR
ABC+HCR 8	Adjust effective spawning biomass (simulate adjusted B_target)
ABC+HCR 9	Forecast informed version of HCR 5
ABC+HCR 10	Maximize productivity/increased reserve (HCR5), linear version (1/ B_target) with offset

Figure A2.1. Subset of stage 1 HCRs for evaluation by ACLIM3 and GOACLIM2 during 2025-2026. Slide courtesy of K. Holsman.

5.2.1 Description of stage 1 HCRs (1, 5, 7 and 10)

Below we describe a general overview of the subset of environmentally linked HCRs that are identified for the first stage of ACLIM and GOACLIM coordinated evaluations in 2025/2026. A more detailed description (including the analytical formulation) of each HCR can be found on the HCR Shiny app (Figure A2.1) under the "detailed information" tab (see options on landing page in upper right corner).



☑ Show Status Quo on each plot

☑ Show Custom HCR

HCR Visualization

HCR Scenarios to Display: HCR1a: Status Quo, HCR1b: Status Quo + SSL

Optional Custom Inputs

Select Custom HCR Type: HCR6

About Harvest Control Rules

Harvest Control Rules (HCRs) are pre-agreed guidelines that determine how much fishing can take place based on the current status of the fish stock.

- **B/B0** represents the current biomass relative to the unfished biomass
- **F_adj** represents the HCR adjusted F_ABC (F_ABC = F_adj*F_maxABC)

Figure A2.2. Harvest Control Rule (HCR) Explorer available at https://kholsman.shinyapps.io/HCRshiny

5.2.1.1 HCR 1: Status Quo

HCR 1 (Figure A2.1 upper left; Figure A2.3) is the baseline sloping harvest control rule evaluated in ACLIM phases 1 and 2 (Holsman et al. 2020, Reum et al. 2020, Whitehouse et al. 2020, Punt et al. 2024) and continues to be evaluated during ACLIM3 and GOACLIM2 simulations. It is the Tier 3 HCR currently used by the NPFMC to manage Alaska groundfish stocks, where F_{ABC} is reduced when current biomass falls below target biomass ($B_{40\%}$). For Steller sea lion prey species, there is a cutoff at $B_{20\%}$ for Alaska pollock, Atka mackerel, and Pacific cod where fishing falls to zero to prevent overfishing of these important Steller sea lion prey species. Including the baseline HCR allows us to determine its performance under future EBM, environmental, and climate scenarios.

This is the basic sloping harvest control rule for groundfish in the EBS (Eq. A2.1). There is a $B_{20\%}$ cut-off for SSL prey species (Atka, pollock, P. cod). $F_{ABC_{mxc}}$ is the HCR adjusted F rate that corresponds to ABC. The Tier three approach is to set the slope of the sloping HCR to $\alpha = 0.05$ and $B_{lim} = 0$ and $B_{target} = B_{40\%}$ or $B_{target} = 0.4$ (i.e., 40% of unfished biomass B_0, as an MSY proxy) for most species except $B_{lim} = 0.2\ B_0$ ($B_{20\%}$) for pollock and Pacific cod.

Equation A2.1. HCR 1: Status quo

$$F_{ABC_{max}} = \left[\begin{array}{ll} F_{ABC} & \frac{B_y}{B_{target}} > 1 \\ F_{ABC}((\frac{B_y}{B_{target}} - \alpha)/(1-\alpha)) & \frac{B_{lim}}{B_{target}} \leq \frac{B_y}{B_{target}} < 1 \\ 0 & \frac{B_y}{B_{target}} < \frac{B_{lim}}{B_{target}} \end{array} \right.$$

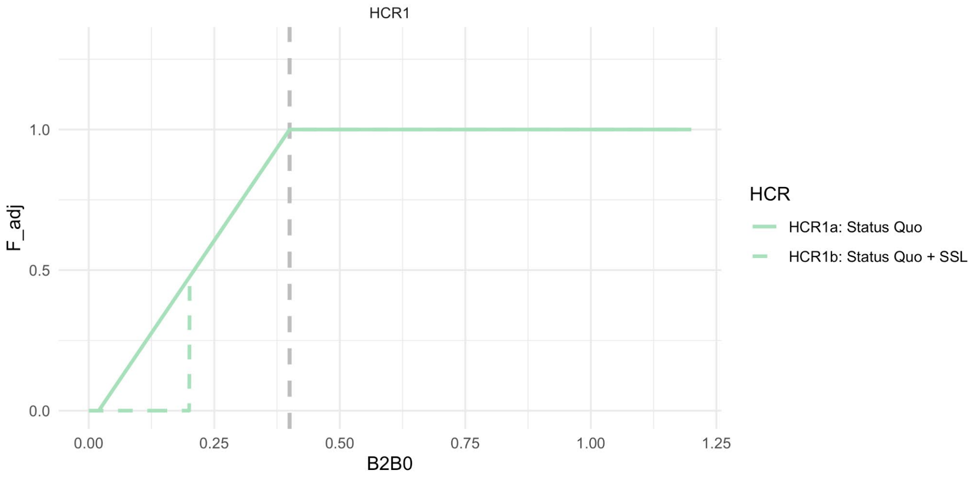


Figure A2.3. HCR 1: Status quo. This is the Tier 3 Harvest Control Rule, including the cutoff for certain species

5.2.2 HCR 5 & 10: Cap-like benefits / Maximize productivity / increased biomass reserve (buffer environmental shocks)

HCR 5 is designed to maximize ecosystem and spawning biomass productivity by increasing biomass reserves, creating a buffer against environmental shocks and enhancing long-term sustainability. These HCRs aim to enhance stock robustness to uncertainty in environmental conditions and provide increased potential for higher recruitment levels and growth of fish to larger sizes through preserving higher levels of SSB when the population is abundant.

HCR 10 builds on HCR 5 by applying a proportional reduction in fishing mortality based on biomass levels. It also includes an optional SSB offset, ie. $B_{target+offset}$ (e.g., start slope at $B_{50\%}$).

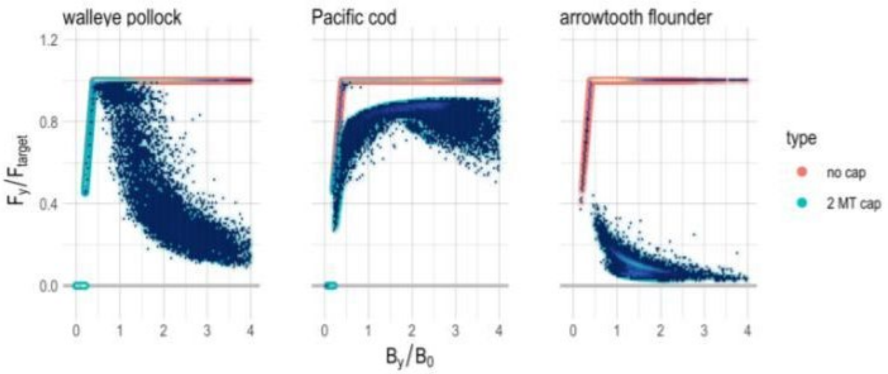
HCR 5 and HCR 10 (Figure A2.1 bottom left and bottom right) have the same shape as HCR 1 when SSB <= B_{target}, but allow for a reduction in F_{target} when biomass is above B_{target}. These HCRs are inspired by the effective shape of the realized BSAI pollock harvest rate (F) under current management with the 2 million Ton annual cap on Bering sea groundfish harvest (Holsman et al. 2020, Ianelli et al. 2011). Despite strong environmental effects on stock productivity, BSAI pollock catch was relatively stable through recent marine heatwaves, perhaps due to the combined effect of the HCR and cap on catch above $B_{40\%}$ (i.e., population age structure reserve that helps stabilize ecosystem and stock productivity during unfavorable climate conditions). To test this hypothesis, CLIM modelers aim to test whether using an HCR that follows the shape of the effective pollock F could help impart a similar benefit to other stocks. Again, modelers are testing the hypothesis that by stabilizing catch above some point like B_{target} (Figure A2.5 bottom, ski slope shape) or B_{target} with a biomass offset (Figure A2.5 top HCR 10; plateau + slope-like shape) the HCR might:

a) increase the age class diversity
b) promote a higher productivity state in the fished biomass
c) promote more larger fish
d) increase ecosystem productivity and therefore fishery productivity

Performance of these HCRs relative to HCR 1 will be evaluated on fishery and management performance metrics described below. Initial results are promising with some indication that HCR 5 and HCR 10 result in an increase of spawning biomass, increased stability in annual catch, more diversity in the spawning biomass age structure, and prevention or forestalling of stock declines/crashes under variable environmental conditions. These are preliminary findings that may change as we expand the suite of models and species being evaluated with HCR 5 and 10. The simulation goals for HCRs 5 and 10 are to better understand the combined influence of the sloping HCR and the ecosystem cap in total catches, as well as evaluating whether buffering fishing mortality by maintaining larger stock sizes has additional benefits to the population against environmental shocks.

Overview: HCR 5: Maximize productivity / increased biomass reserve (buffer environmental shocks)

HCR 5 recreates the realized pollock cap effect on F_{target} when a stock is over B_{target} , which may maximize long-term ecosystem and stock productivity. The steepness of the cap effect could be varied based on vulnerability analyses (e.g., Spencer (2019); Hare (2016)) (or approximated via MSE), with species that are known to be more sensitive to environmental variability, such as Pacific cod (Barbeaux et al. 2022), needing more reserve in the “bank”. Pollock is an example of HCR 5 in practice (via effects of the 2MT cap + sloping HCR; Holsman et al. 2020; Figure A2.4).



Supplementary Figure 3. Effective harvest rate F_y under the no cap and 2 MT cap scenarios. Ratio of effective F_y to F_{target} as a function of the ratio of biomass to unfished biomass reference points (B_y/B_0) for each pollock (left), Pacific cod (middle), and arrowtooth flounder (right). Scenarios without the cap (orange; follow the ABC harvest control rule exactly) and scenarios with the 2 MT cap (scatter, teal).

Figure A2.4. Effective F given cap effects on pollock, Pacific cod, and arrowtooth flounder in the EBS. Figure from Holsman et al. 2020.

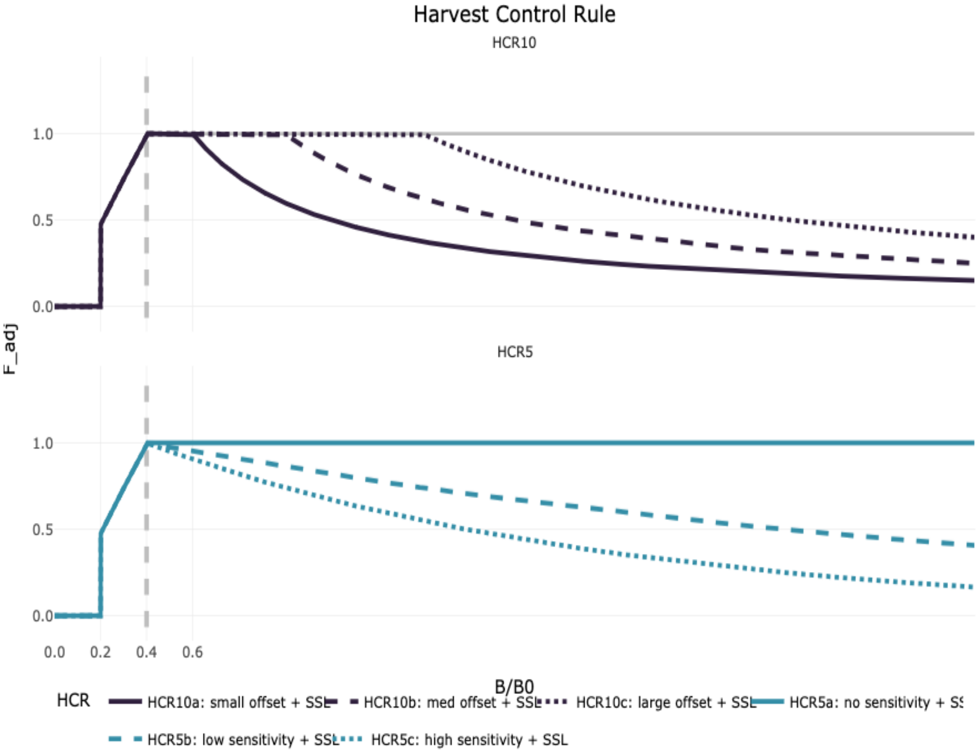


Figure A2.5. Cap-like HCRs 10 (top) and 5 (bottom). Below or at B_{target} this HCR is the same as the Status Quo (HCR1) Tier 3 Harvest Control Rule, including the cutoff for certain species at low SSB. Above B_{target} catch is stabilized (F is reduced) with (HCR10) or without (HCR5) biomass offsets.

As in HCR 1 with the 20% cutoff for SSL prey species (Eq. A2.1), set the target to 40% of B_0 ($\alpha = 0.05$, $B_{lim} = B_{20\%}$, $B_{target} = B_{40\%}$). After $B_{40\%}$ have a slowly sloping F proportional to climate sensitivity to mimic realized F rates of pollock under the 2 MT cap. This approach is designed to maximize ecosystem productivity and build a reserve biomass for environmental or climate shocks (sensu Holsman et al. 2020). In this (Eq. A2.2) the climate sensitivity buffer γ is a value > 0 that controls the F decay rate (increase in reserve biomass) above B_{target}, i.e., $B_{40\%}$:

Equation A2.2: HCR 5

$$F_{ABC_{max}} = \left[\begin{array}{lr} F_{ABC}\ e^{(-\gamma(\frac{B_y}{B_{target}}-1))} & \frac{B_y}{B_{target}} > 1 \\ F_{ABC}((\frac{B_y}{B_{target}} - \alpha)/(1-\alpha)) & \frac{B_{lim}}{B_{target}} \leq \frac{B_y}{B_{target}} < 1 \\ 0 & \frac{B_y}{B_{target}} < \frac{B_{lim}}{B_{target}} \end{array} \right.$$

where, $0 \leq \gamma \leq 1$.

Example: Set the biological reference points as in HCR 1, i.e., 40% of B_0, ($\alpha = 0.05$, $B_{lim} = B_{20\%}$, $B_{target} = B_{40\%}$). Above B_{target} apply the gamma / 2MT cap effects. Shown in Fig. 6, for low sensitivity stocks set $\gamma = 0.1$, for highly sensitive stocks set $\gamma = 0.2$. We're testing whether this would result in more stable biomass levels and catches through environmental shocks.

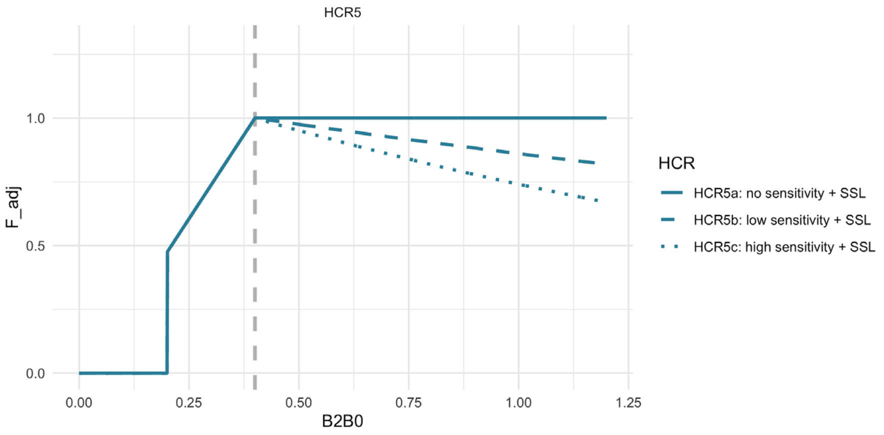


Figure A2.6: HCR 5: climate sensitivity reserve (buffer shocks). Below or at B_{target} this HCR is the same as the Status Quo (HCR1) Tier 3 Harvest Control Rule, including the cutoff for certain species at low SSB. Above B_{target} catch is stabilized (F is reduced).

As in HCR 5 (Eq. A2.2), HCR 10 aims to recreate the benefits of the cap effect on pollock via implementing and HCR that follows the effective F rates above B_{target}. The steepness of that cap effect here is inverse to SSB, with an optional B_{target} offset (γ, i.e. the point at which F reduction starts), more sensitive species might need a lower gamma (γ) to drive a larger age class reserve resulting in increased abundance of large spawners and benefits to recruitment and stock productivity sooner. BSAI Pollock are an example of the HCR 10 in practice (via effects of the 2MT cap + sloping HCR; Figure A2.6).

Equation A2.3: HCR 10

$$F_{ABC_{max}} = \left[\begin{array}{ll} F_{ABC}/(\frac{B_y}{B_{target}}\frac{1}{(1+\gamma)}) & \frac{B_y}{B_{target}} > (1+\gamma) \\ F_{ABC} & 1 < \frac{B_y}{B_{target}} < (1+\gamma) \\ F_{ABC}((\frac{B_y}{B_{target}} - \alpha)/(1-\alpha)) & \frac{B_{lim}}{B_{target}} \leq \frac{B_y}{B_{target}} < 1 \\ 0 & \frac{B_y}{B_{target}} < \frac{B_{lim}}{B_{target}} \end{array} \right.$$

where, $0 \leq \gamma \leq 1$.

Example: As in HCR1 (Eq. A2.1), set the target to 40% of B_0, ($\alpha = 0.05$, $B_{lim} = B_{20\%}$ for amendment 80 species, $B_{target} = B_{40\%}$). Shown in Fig. 7, “small offset” where γ = 0.5, “medium offset” γ = 1.5, and “large offset” where γ = 3. We’re testing whether this would result in more stable biomass levels and catches through upcoming environmental shocks.

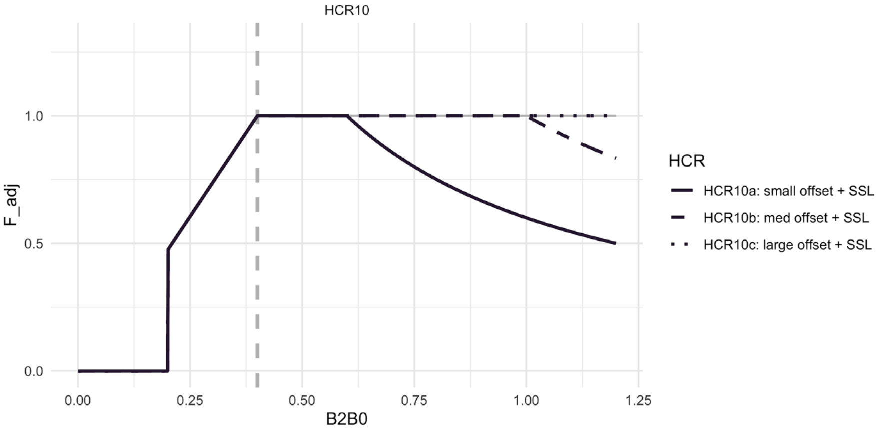


Figure A2.7: HCR 10: gamma offset on inverse SSB decay rate.

5.2.2.1 HCR 7: Risk Table Bridging: R/S variability covariate adjusted HCR

This HCR provides a way to transition from qualitative risk tables to a more explicit, analytical approach for species whose productivity is known to vary with environmental conditions. HCR 7 is a dynamic HCR that allows for adjustments in the F_{target} and B_{target} with changes in population productivity and is based on recent work of Dr. Paul Spencer on Tier 1 HCRs where he found that the estimated F_{target} varied with sea surface temperature (SST) in the EBS. We borrowed from that to adjust either F or B_{target} or a combination of both as a function of an index of annual bottom temperature. The goal of this HCR is to evaluate a HCR that allows for a transition from qualitative risk tables to a quantitative approach for species with known productivity variation due to environmental conditions. Currently, HCR 7 is parameterized such that productivity varies with an environmental covariate (Eq. 4). Future work will modify HCR 7 to address cases where productivity (i.e. expected recruits produced per spawner at low stock sizes where density-dependent mortality is negligible) has varied over time but without a clear link to a particular environmental covariate. Evaluation of time-varying stock productivity can be informed by retrospective analyses of stock-recruitment relationships.

HCR 7 is of particular interest to CLIM modelers. Preliminary evaluations reveal good performance; catch looks similar to Status quo (HCR 1) but SSB is higher with fewer catch or SSB crashes under high environmental variability (Holsman et al. in prep). The HCR reference points for HCR 7 are adjusted based on variability in spawner-recruitment relationships using a covariate X_y (e.g., SST) such that:

Equation A2.4: HCR 7

$$F_{ABC_{max}} = \left[\begin{array}{ll} F_{ABC}\ e^{(\omega_1 * \mathrm{x}_y)} & \frac{B_y}{\hat{B}_{target}} > 1 \\ F_{ABC}((\frac{B_y}{\hat{B}_{target}} - \alpha)/(1-\alpha))\ e^{(\omega_1 * \mathrm{x}_y)} & \frac{B_y}{\hat{B}_{lim}} \leq \frac{B_y}{\hat{B}_{target}} < 1 \\ 0 & \frac{B_y}{\hat{B}_{target}} < \frac{\hat{B}_{lim}}{\hat{B}_{target}} \end{array} \right.$$

such that F_{ABC} is adjusted by covariate x_y according the parameter ω_1 and B_{target} and B_{lim} are adjusted based on the parameters ω_2 and ω_3 such that:

$$\hat{B}_{target} = B_{target}e^{(-\omega_2 * x_y)}$$

and

$$\hat{B}_{lim} = B_{lim}e^{(-\omega_3 * x_y)}$$

and $\omega_1,\ \omega_2\ and\ \ \omega_3 \geq 0$.
For the ACLIM HCR 7 simulations ω_1 and ω_2 will eventually be fit using retrospective analyses of spawner-recruitment relationships across scaled (z-scored) SST (x_y) on EBS pollock by Spencer et al. in prep.

Example: Set the target to 40% of B_0 ($\alpha = 0.05$, $B_{lim} = B_{20\%}$, $B_{target} = B_{40\%}$). In the example below (x_y) = 2.4 and for case 7a all ω values were set to 0.0, in case 7b $\omega_1 = \omega_2 = \omega_3$ = 0.1, and in case 7c ω_1 = -0.1, ω_2 = -0.1, ω_3 = -0.1.

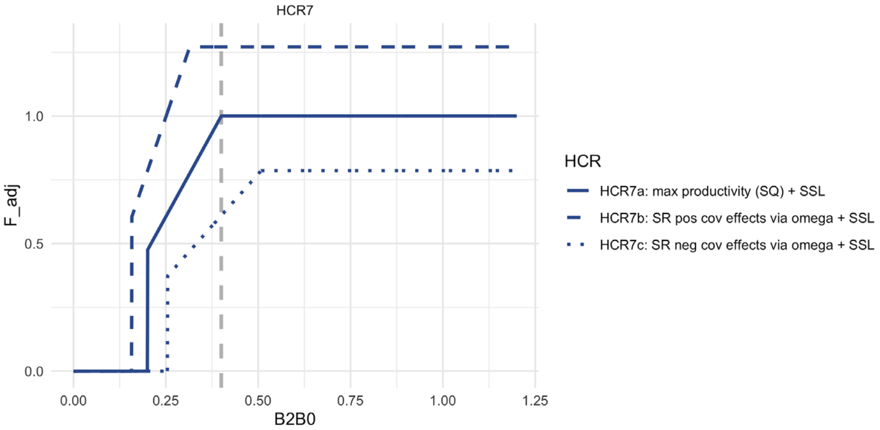


Figure A2.8. HCR 7:Recruit per spawner biomass variability adjusted HCR.

5.3 Appendix 3. Examples of performance metrics and evaluation options to enable tradeoff discussions around various alternative options

5.3.1 Overview

This section uses a subset of FMP and FEP goals and objectives as examples to highlight the considerations needed to inform the selection of key measures to evaluate performance of alternative management options. They are meant to be illustrative, rather than comprehensive, to help anchor discussions of performance criteria considerations. The aim of this section is to help support Council directions on which management objectives and performance criteria could be used to help frame tradeoff discussions of alternative options (and when to implement an alternative HCR, for example). We also provide examples of specified management objectives, quantities of interest, and performance measures that have been used in several case studies and are in line with our subset of high level FMP goals. We use these case studies to highlight the key decision points when developing performance metrics.

5.3.2 Background

Fisheries performance metrics are integral quantitative measures when evaluating harvest control rules. They are used to identify trade-offs between different management objectives and evaluate the success of a management strategy relative to specified management objectives. Therefore, a key starting point is for the Council, in partnership with user groups, to specify priority objectives from which measurable outcomes and performance metrics can be developed (Punt et al. 2016). The NPFMC Groundfish Fishery Management Plans (FMPs) for the Bering Sea and Aleutian Islands (NPFMCa, 2024) and the Gulf of Alaska (NPFMCb, 2024), as well as the Bering Sea Fishery Ecosystem Plan (FEP; NPFMC 2019) outline management goals and objectives that are used to guide potential management measures. The Groundfish FMPs define 45 objectives that are organized under 9 specific goals (https://www.npfmc.org/groundfish-management-policy-and-reviews/) and the Bering Sea FEP includes 6 goals with 17 objectives (https://www.npfmc.org/bering-sea-fishery-ecosystem-plan/). The high-level goals and objectives presented in the management plans can serve as a starting point for performance measure development discussions. We will focus on several illustrative FMP goals and objectives, given the overlap with the Bering Sea FEP:

Goal 1: Prevent overfishing

1. *Adopt conservative harvest levels for multi-species and single species fisheries and specify optimum yield.*

Goal 2: Promote sustainable fisheries and communities

7. *Promote management measures that, while meeting conservation objectives, are also designed to avoid significant disruption of existing social and economic structures.*

Goal 3: Preserve food web

10. *Develop indices of ecosystem health as targets for management.*

Goal 4: Manage incidental catch and reduce bycatch and waste
Goal 7: Promote equitable and efficient use of fishery resources

31. *Provide economic stability to harvesting and processing sectors through fair allocation of resources.*

Goals 1, 2, and 7 are derived from the Magnuson-Stevens Fishery Conservation and Management Act (MSA) National Standard (NS) guidelines making them relevant examples that are durable over time. Goal 3, although not part of the NS guidelines, is included in the Groundfish FMPs Management Approach Statement.

Performance metrics commonly fall into several general categories: status, safety, yield, and stability and are often used in a single-species context (Taylor *et al.* 2024, Valero *et al.* 2025). We have adopted this nomenclature with some modification. First, the status and safety categories include metrics that convey the risk of a negative event happening relative to specific target or limit reference points. As such, we collectively refer to them as ‘status’ throughout this document. Additionally, stability metrics in the literature are most often framed in terms of yield; thus, we include yield stability metrics in the yield category and use the term stability to refer to biological stability. Ecosystem metrics when using multispecies and ecosystem models and societal metrics are also of value and provide a broader view of potential trade-offs. Therefore, we classify performance metrics within status, yield, stability societal, and ecosystem categories (Table A3.1).

Case studies

Stock status is a primary concern of most fishery management bodies and performance metrics that address this concern are commonly used to evaluate harvest control rules and other management strategies (Johnson *et al.* 2025, Kapur *et al.* 2024, Hicks *et al.* 2024, Valero *et al.* 2025; Table A3.1). The case studies we reviewed specified status management objectives in several ways: 1) maintaining biomass above a biomass target or limit, 2) minimizing the chance of being in an overfished status, and 3) minimizing the chance of overfishing. The performance metrics to address these objectives were specified in a variety of ways. For example, to quantify the avoidance of an overfished stock, the British Columbia (BC) Sablefish management strategy evaluation required achieving stock biomass levels above 40% of stock B_{MSY} with a 95% probability, whereas the International Halibut Commission (IPHC) MSE required a less than 5% probability of relative spawning biomass falling below 20%. Another variant of this type of metric is the Inter-American Tropical Tuna Commission’s (IATTC) management objective to remain within the green area of the Kobe Plot (Figure A3.1). This objective was measured using a combination of biomass and fishing mortality measures and required a 60% probability of being in the green zone of the Kobe Plot. The crucial decision points for fishery managers shared in all examples were identifying the biomass metrics and reference points of interest, as well as probability thresholds to communicate risk tolerance. Status performance metrics are in line with the broad NPFMC FMP goals 1 (prevent overfishing) and 2 (promote sustainable fisheries).

Fishery output performance metrics fall under the yield category. Examples of management objectives aligned with yield have included maintaining average catch or maximizing catch for species of interest over a specified period, maximizing overall catch over a certain period, and minimizing the average annual variation in catch (Table A3.1). The Transboundary Sablefish MSE and the IPHC MSE have used average catch calculated over a variety of time frames as a performance measure to quantify the maintenance of yield (Kapur et al. 2024, IPHC). The BC Sablefish MSE approach to this differed in that they used the probability of catch being above a minimum catch level as a metric. Identifying the minimum catch level was a crucial aspect of this MSE and required extensive discussions with the fishing industry to come to an agreement. Stability of catch was a management objective specified by all case studies reviewed and measured as the average annual variation in catch (AAV). More specifically, the BC Sablefish MSE used the median average annual variation in catch (AAV) as the performance measure associated with this objective, whereas the Transboundary Sablefish MSE quantified the probability of AAV being less than 15%. Identifying an acceptable level of variation requires discussion between managers and the fishing community. Specifying variation in management changes as a management objective, as they provide a limit on yield, can also fall within the yield category. For example, the IPHC MSE has calculated the probability of the change in the Total Constant Exploitation Yield (TCEY), the mortality of Pacific halibut greater than 26 inches in length, being greater than 15% from one year to the next. This has been formulated in a number of ways and includes the probability of any one given year in a 10-year period that the change in TCEY is greater than 15% from one year to the next, as well as this probability for any two, three, four, and five given years in a 10-year period. Within the NPFMC context, it may be of interest to specify objectives relative to changes in allowable biological catch (ABC), given the HCR evaluation is focused on the ABC control rule. The example yield performance metrics reviewed are applicable to FMP goal 2 in measuring the impacts on fishing communities.

FMP goal 2 also specifies promoting sustainable fisheries. This can be quantified using biological metrics in addition to biomass relative to biological reference points. Example objectives are to maintain the age or length structure of a population that can be quantified as mean age or length. Quantifying mean age or length can be used as a measure of sustaining a reproductive stock into the future.

Societal performance metrics encompass economic and social priorities and also address broad management objectives under FMP goals 2 and 7. Economic performance measures can include total revenue, income stability, and profitability. These metrics are sometimes difficult to develop if the simulation approach does not include an economic model. Therefore, yield performance metrics are sometimes used as a proxy for economic metrics such as revenue and income stability, assuming market values remain relatively unchanged over time. Kapur *et al.* (2021) suggested mean fish length in the directed fishery as a performance metric as a metric for maximizing long term profitability. However, biological models coupled with economic models might be able to provide performance metrics such as mean revenue, mean percent change in revenue, or mean percent change in employment opportunities by fishery or community to evaluate the impact on communities. Social performance metrics such as food security and nutritional value are becoming increasingly important. Recent developments by Indivero *et al.* (pers. comm.), will allow us to develop a measure of nutritional value from size-based models. Discussions with fishing communities and industry are needed to develop and prioritize economic and social well-being performance measures. The ability to develop performance measures from societal priorities will depend on simulation model outputs and data availability. Barclay et al. (2023) have proposed measures such as employment, proportion of new entrants, distribution of catch value, and others. Additional analyses may model potential shifts in regional and local reliance and engagement, spatial distributions of landings and effort, and TAC utilization.

The case studies we reviewed were focused on single species management objectives; however, FMP goals 3 and 4 are focused on ecosystem objectives. The simulation models available for the HCR evaluation span single species to end-to-end ecosystem models; therefore, information about non-target species will also be available to develop performance metrics to address goals 3 and 4. Preserving the food web (goal 3 in the Groundfish FMPs) is more explicitly stated in the Bering Sea FEP as:

Ecosystem Goal 2: Protect, restore, and maintain the ecological processes, trophic levels, diversity, and overall productive capacity of the system

> *Objective 4. Maintain key predator/prey relationships.*
> *Objective 5. Conserve structure and function of ecosystem components.*

Given the FEP objectives, measures of interest could include abundance or biomass of predator and prey species and the abundance or biomass of species across trophic levels. Performance measures to address these objectives could include the average ratio of predators relative to prey, mean trophic level of system biomass and the change in species diversity score, and relative abundance of non-target species and species groups of interest.

5.3.3 Key decision points

As we move forward with developing performance measures for the HCR evaluations, there are several key decision points that we will have to address. First, priority management objectives will be identified as they are the mainstay of decision making. Objectives must be stated in a clear and specific manner. This will help us identify measurable quantities of interest. For example, identifying key summary statistics and determining whether risk metrics (e.g., the probability of an event happening) should be specified. We also must identify the time frame over which the performance metrics will be calculated.

Defining the performance metric time frame will partially be determined by whether the evaluation is tactical or strategic. Tactical decision making is often focused on more near-term decisions that result in providing specific catch or effort advice for stocks. Strategic decision making is for more long-term planning. The HCR evaluation that is being discussed will result in strategic decision making. In the case studies we reviewed, the period over which performance measures were calculated varied. The time frame used in BC Sablefish MSE varied among the performance metrics and were calculated over projected 10 years, 30 years, and two Sablefish generations (Johnson *et al.* 2025). The IPHC defines performance metrics over the short-term (4-13 years), mid-term (14-23 years), and long-term (greater than 23 years); whereas the IATTC used projected 3-year, 5-year, and 30-year periods.

Given the ensemble of models available for this work, model capabilities should also be considered when developing performance metrics. Not all models will be able to produce the same performance metrics; however, we should ensure that there is sufficient overlap for a core subset to make cross-model comparisons.

Table A3.1. Example objectives, quantities of interest, and performance metrics that can be used when evaluating harvest control rules, as well as case study performance metrics. This list is not a comprehensive list and should be expanded and refined as discussions continue.

Category	Objective	Quantity of interest	Case study metrics
Status	Maintain biomass above biomass limit/ Minimize the chance of being overfished	Biomass (B) and Blimit	$P(B> 0.4B_{MSY}) \geq 0.95$[a] $P(B > 0.25B_0)$[b] $P(RSB < 20\%) < 0.05$[c] $P(SSB < 7.7\%SSB_0) < 0.10$[d]
	Maintain spawning stock size above target reference points	Biomass and Btarget	$P(B_{2052} > B_{targ}) = 0.5$ [a] $P(B > 0.4B_0)$ [b] $P(RSB < 36\%) < 0.50$
	Maintain stock within the green zone of Kobe plot	Biomass and Blimit and Fishing mortality (F) and Flimit	$P(SSB \geq SSB_{MSY}\ \&\ F < F_{MSY}) \geq 0.6$[d]
Yield	Maintain average/ median/minimum catch	Catch	P(Catch > min(Catch) > 0.5 [b] Average catch last five projection years [b] Average catch by fishery for various time frames[d]
	Maximize catch	Catch	Total catch P(Catch > min viable catch)[a]
	Minimize catch variability over time	Variation in catch	Median across replicates of average absolute annual change in landed catch[a] $P(AAV \leq 0.15)$[b]
		Variation in output or input control (e.g., ABC or FABC)	P(Change in TCEY > 15%)
Stability	Maintain age structure or size structure	Age Size (length or weight)	Change in mean age or size
Societal	Maximize long term profitability	Size (length or weight) Revenue	Mean size of directed fishery[b] Mean revenue (by fishery or region)[e]
	Maintain employment	Regional employment (number of jobs)	Mean percent change in the number of jobs[e]
	Maintain or minimize change in nutritional value	Size at age and nutrition metrics	Change in nutritional value of overall fishery[e]
Ecosystem	Maintain key predator/prey relationships	Abundance or biomass	Average ratio of relative biomass of predator and prey[e]
	Conserve ecosystem structure	Trophic level and biomass or catch	Mean trophic level of system biomass or of catch[e]
		Number of species	Species diversity score for system[e]
		Abundance or biomass	Relative abundance of non-target species or relative abundance of species groups[e]

[a] Johnson et al. (2025), [b] Kapur et al. (2024), [c] Hicks et al. (2024), [d] Valero et al. (2025), and [e] not associated with a case study

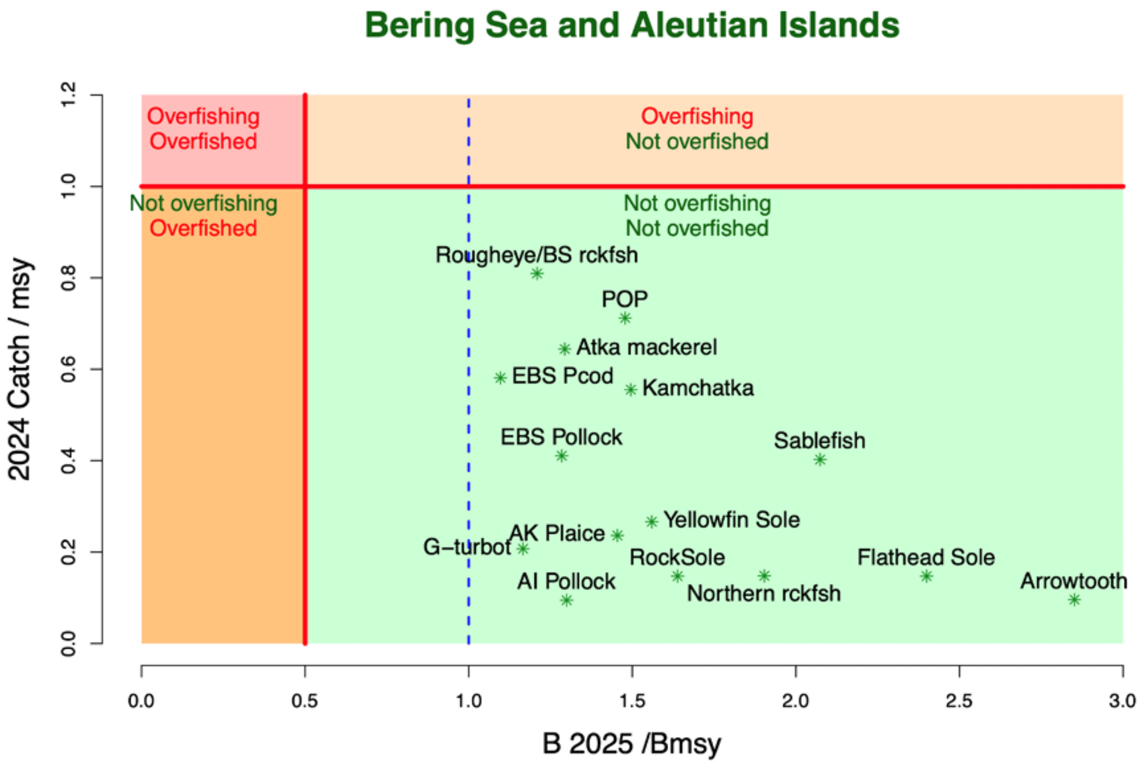


Figure A3.1. Example of a Kobe-like plot from the Bering Sea and Aleutian Islands Stock Assessment and Fishery Evaluation Report (NPFMC 2024c).

5.4 Appendix 4 Alternative options for scientific advice to help navigate climate shocks and changes

5.4.1 Overview for this Appendix:

This section summarizes how alternative approaches, both within and outside the current Alaska system, can inform management decisions, with particular emphasis on how analytical tools translate into decision points and the timing of application.

5.4.2 Background

In many fisheries management systems, harvest control rules (HCRs) are implemented as one component of a broader management procedure (MP). MPs encompass the full yearly (or periodic) decision-making cycle, including monitoring, estimation methods, and the agreed process for translating estimated quantities into management action (such as application of an HCR to calculate stock-specific catch limits). Framing HCRs within an MP highlights that management outcomes depend not only on the form of the HCR itself, but also on the surrounding processes that govern data collection, stock assessment, uncertainty characterization, and decision-making. Details are provided below.

The GOA and BSAI FMPs state *“The productivity of the North Pacific ecosystem is acknowledged to be among the highest in the world. For the past 25 years, the Council management approach has incorporated forward looking conservation measures that address differing levels of uncertainty. This management approach has in recent years been labeled the precautionary approach. Recognizing that potential changes in productivity may be caused by fluctuations in natural oceanographic conditions,* *fisheries, and other, non-fishing activities, the Council intends to continue to take appropriate measures to insure the continued sustainability of the managed species."*

Based on this goal, some alternative HCRs are based on evaluations of whether stock productivity has changed over time. This evaluation of stock productivity may include exploring linkages between population dynamics and environmental variables, or population models with time-varying stock-recruitment dynamics. Stock productivity refers to the maximum capacity of the stock to replace itself (i.e., the ratio of recruits produced per unit of spawner biomass, evaluated at low biomass to remove the effect of compensatory reductions in productivity at high biomass). Evaluation of stock productivity forms the basis of fishing rate reference points used within HCRs, either directly via stock-recruitment analysis or indirectly via spawner-per-recruit proxies (Clark 1991, Ianelli 2002).

Within this broader context, the following discussion focuses on how different components of the current system align with elements of an MP, and the timing associated with each pathway. A key consideration is that management responses to uncertainty and time-varying dynamics can occur through multiple pathways, each with different implications for timing, transparency, and consistency. Within the current FMPs, these pathways include: (1) changes and updates within stock assessments, (2) establishing ABC below maximum permissible, and (3) TAC-setting decisions. More broadly, additional pathways include modifications to ABC control rules and Optimum Yield ranges/caps, the latter which requires both amending to the current FMPs and for BSAI Groundfish, additional Congressional action.

5.4.3 Enhanced pop-dy/assessment modeling

Changes in assessment models reflect the normal process of evaluating and adopting alternative model configurations based on expert review. These include changes to model structure, parameterization, or projections (e.g., incorporating environmental covariates through initiatives such as CEFI or adjusting recruitment assumptions). These approaches can be implemented within the annual assessment cycle but may be less transparent and less consistent across stocks.

5.4.4 Alternative HCRs

Modifications to ABC control rules typically require multi-year analytical efforts, often supported by analyses to evaluate trade-offs among objectives. Examples include alternative HCR forms, climate-informed control rules, and adjustments to target reference points such as F reference points (e.g. is $F_{40\%}$ or $F_{30\%}$ or another appropriate proxy value). Ongoing efforts such as the sablefish management strategy evaluation and national-level initiatives (e.g., NS1 revisions, CAFA HCR research) illustrate this pathway. While slower to implement, HCR modifications may provide a more transparent and consistent mechanism for incorporating risk and environmental variability into management advice.

5.4.4.1 Examples of alternative HCRs

Within the ACLIM project, research on alternative HCRs for EBS walleye pollock has focused on a climate-enhanced Ricker spawner-recruit model, which incorporates a linkage between sea surface temperature and pollock recruitment (Mueter et al. 2011, Spencer et al. 2016). A climate-enhanced dynamic HCR would use current estimates of stock productivity to compute fishing and biomass reference points (with perhaps some smoothing). Evaluation of this alternative HCR for EBS walleye pollock under projected future conditions indicates higher stock biomass, lower fishing rates, and reduced frequency of years with overfished status (Spencer et al. in prep.).

In contrast, HCRs evaluated in a NOAA-CAFA project (Climate and Fisheries Adaptation) HCR project have focused on state-space recruitment models in which the productivity parameter is modeled as a state variable following a random walk, and the recruits per spawner are modeled as an observation variable. Analogous to the ACLIM simulations, dynamic HCRs would be updated based on current estimates of stock productivity and their effect on fishing and harvest rate reference points. Example HCR simulations have focused on 3 stocks: Gulf of Maine white hake (Urophysis tenuis), Georges Bank winter flounder (Pseudopleuronectes americanus), and BSAI Pacific ocean perch (*Sebastes alutus*). The HCR simulations for these stocks have focused on counterfactual simulations to estimate how alternative HCRs would have performed in previous years. Similar to the ACLIM simulations, time-varying HCRs maintain higher biomass (particularly in low productivity years) (Collie et al. in revision).

In each of these evaluations of dynamic HCRs, the structural form of the HCRs has not been redefined or modified, but what has been changed is the basis for updating the fishing and biomass reference points that underlie the HCR. Additionally, for NPFMC stocks in Tiers 1-3, our existing HCRs are time-varying to some degree because fishing and biomass reference points are re-estimated with each full or update assessment. In stock assessments with largely time-invariant parameters, the reference points may change slightly between assessments. However, for stock assessments with time-varying processes, particularly fishing selectivity and size-at-age, the reference points and control rules may change more substantially. The alternative HCRs considered here reflect that stock productivity is another important process that is potentially time-varying, and may be most relevant when it shows long-term trends. Finally, both the ACLIM and CAFA research utilize stock-recruitment analysis to evaluate stock productivity. Development of dynamic HCRs for stocks without well-estimated stock-recruitment curves is a current research priority.

5.4.4.2 Elements of a full closed-loop, simulation-tested management procedure

In a full closed-loop simulation analysis , the harvest control rule is evaluated not as an isolated formula, but as one component of a broader management procedure (MP) that links monitoring, assessment, decision-making, implementation, and feedback over time. The defining feature of a closed-loop simulation analysis is that the full sequence of management actions is simulated repeatedly under uncertainty, so that performance reflects not only the nominal control rule, but also the quality of data, estimation error, implementation error, and the way exceptional situations are handled. A closed-loop simulation analysis typically includes the following components:

5.4.4.2.1 Operating model (the “true” system).

The operating model represents the underlying population and fishery dynamics that are assumed. This includes population processes such as recruitment, growth, maturity, and natural mortality, as well as fishery processes such as selectivity and catchability. The operating model may also specify spatial distribution of stocks, movement, and fleet behavior, as well as ecosystem or environmental effects, non-stationary productivity, and alternative hypotheses about future conditions. Because the true system is never known with certainty, closed-loop simulation analysis generally examines multiple operating model configurations and/or environmental and fishing scenarios to test robustness.

5.4.4.2.2 Monitoring and data collection.

The monitoring component specifies what information is collected from the fishery and the ecosystem, how often it is collected, and with what uncertainty. This may include fishery-independent surveys, retained catch, discard estimates, fishery-dependent indices, age and length compositions, biological samples, environmental indicators, and other supporting information. In the simulation framework, these observations are generated from the operating model with realistic observation error, sampling variation, missing data, and possible biases. This component is critical because the performance of an MP depends strongly on whether the data available are sufficient to detect changes in stock status or productivity in time for management to respond.

5.4.4.2.3 Estimation model or assessment procedure.

The estimation model is the method used to convert available data into quantities needed for management advice. Depending on the system, this may be a full stock assessment, an empirical index-based procedure, a state-space estimator, or a simpler model. The estimation model need not match the operating model exactly, as closed-loop simulation is often most informative when testing MPs under structural mismatch between the "true" system and the estimation procedure. Outputs from the estimation model may include stock biomass, recruitment, exploitation rate, productivity metrics, or derived reference points used by the control rule.

5.4.4.2.4 Harvest control rule or decision rule.

The HCR is the pre-agreed rule that translates estimated stock status or indicators into a recommended management action. In many settings this is expressed as a target fishing mortality, exploitation rate, or catch limit recommendation conditional on biomass, stock status or another indicator. In a broader MP framework, the HCR may also include constraints such as biomass thresholds, caps on annual change, minimum stock protection rules, or provisions for smoothing changes in catch limit recommendations. Closed-loop simulation allows evaluation not only of alternative HCR shapes, but also of the indicators and reference points on which they depend.

5.4.4.2.5 Application of the MP

The MP must specify how the output of the HCR becomes management advice and, ultimately, a TAC or other implementable catch limit. This step is especially important in the NPFMC system (and other systems) where the fishing level generated by the HCR is not automatically identical to the realized TAC. For example, the process may include translation from estimated stock status to ABC, then from ABC to TAC through additional policy decisions, risk adjustments, ecosystem caps, allocation rules, or socioeconomic considerations. A fully specified MP should therefore make explicit whether the management output in the simulation is an OFL, ABC, TAC, or fleet-specific quota, and how each transition occurs. Where the actual management process includes routine reductions from ABC to TAC, or application of multi-species OY caps, those pathways should be represented in the simulation if the purpose is to evaluate management performance realistically.

5.4.4.2.6 Implementation and fishery response.

Realized removals may differ from the TAC or other intended management action because of implementation error, fleet behavior, allocation constraints, underages, overages, or changing availability of fish. Closed-loop simulation analysis can include these effects explicitly by simulating how the fishery responds to the management output. This is particularly relevant where realized catches are persistently below TAC for some stocks (such as where multi-species constraints and/or markets alter the practical effect of a stock-specific HCR), or where catch is redistributed across fleets.

5.4.4.2.7 Feedback through time.

The phrase "closed-loop" means that the consequences of each year's management actions are implemented in the simulation (e.g. the realized catch calculated within the simulation for a particular year are applied to the population in that year within the operating model) and thus affect the stock and fishery in subsequent years, which then affect future observations, assessments, and decisions. This iterative feedback is what allows evaluation of long-term properties such as stock status, yield, stability, resilience to regime shifts, and the ability to recover from poor recruitment periods or implementation error.

5.4.4.2.8 Performance metrics and trade-off evaluation.

Closed-loop simulation requires clear performance metrics that are developed to evaluate how well alternative MPs meet the management objectives (See Appendix 4 for example management objectives and corresponding performance metrics). Performance metrics may include biological metrics (e.g., metrics related to the probability of overfishing, stock status, and rebuilding time), fishery metrics (e.g., metrics related to average catch, stability in catch, frequency of fishery closure), economic or social metrics (e.g., metrics related to changes in job availability and which communities may be most affected), and ecosystem metrics (e.g. impacts on protected and prohibited species and other predators and prey) where relevant. Because no single MP performs best on all objectives, closed-loop simulation is used to evaluate trade-offs among alternatives..

5.4.4.2.9 Refine and revise

Potentially re-visiting/adding missing objectives and performance metrics (based on feedback from decision-makers and user groups), and/or tweaking alternative MPs based on new information from the first iteration of the analysis

5.4.5 Exceptional circumstances within an MP

A complete MP may also include exceptional circumstances provisions, which specify what happens when conditions arise that were not intended to be handled by the ordinary HCR alone. These provisions are important because even well-tested HCRs may perform poorly if observations, ecosystem conditions, or fishery conditions fall outside the range anticipated during development.

Exceptional circumstances can include, for example:

- major survey failure or loss of a key data source,
- abrupt changes in stock productivity or distribution,
- marine heatwaves or other extreme environmental conditions,
- evidence that assessment assumptions are no longer adequate,
- fishery disruptions that cause realized catch to differ strongly from intended catch,
- unanticipated ecosystem or protected-species concerns, or
- new information indicating that the MP is operating outside its tested domain.

Within a closed-loop simulation analysis, these circumstances can be addressed in at least two ways. First, they can be represented directly as scenarios in the operating model and monitoring system, allowing evaluation of how candidate MPs perform when such events occur. Second, the MP itself can include pre-agreed contingency actions, such as fallback HCRs, more precautionary default TAC reductions, temporary caps on exploitation rate, triggers for management review, or requirements for additional diagnostic analysis before standard advice is applied.

Including exceptional circumstances explicitly is valuable because it helps distinguish between:
(a) uncertainty that the HCR is expected to handle routinely, and
(b) unusual conditions that justify stepping outside the standard decision rule.

This distinction improves transparency and reduces the need for ad hoc departures from the management framework.

5.4.6 OY ranges and caps: an additional element of Alaskan MPs

Exploration of alternative HCRs in the Alaska system would involve considering the combined impacts of HCRs with the current groundfish OY ranges and in particular the caps, or maximum values (see Example 2 below for additional information). For the GOA where the groundfish OY cap has not been constraining, analyses need to consider assumptions about how to rescale ABCs to realistic catches for underutilized stocks. For the BSAI, it is necessary to consider model runs that combine alternative HCRs with a sub-model calculating stock-specific TACs and catches based on historical relationships (this history does not exist for the GOA). It may be of interest to include a baseline set of simulations with alternative HCRs assuming no groundfish OY caps (ABC = TAC for all species).

5.4.7 Implications for Alaska pathways

Relative to the current Alaska system, a full closed-loop-simulation-tested MP would make more explicit the full chain from data collection → assessment/estimation → HCR application → ABC/TAC translation → realized catch → feedback to the population. It would also clarify which parts of the process are pre-agreed and simulation-tested, and which parts remain discretionary. This is especially relevant where risk management is currently distributed across assessment choices, ABC reductions, TAC-setting processes, and OY caps. A closed-loop simulation analysis can therefore be used not only to evaluate alternative HCRs, but also to examine broader questions about how data limitations, assessment approaches, TAC-setting rules, and exceptional-circumstances provisions interact to determine management performance over time.

5.4.7.1 Example 1: Analysis of alternative HCRs for sablefish

Within the Sablefish MSE Project, a closed-loop simulation tool was developed to evaluate possible alternative HCRs for the management of sablefish. The project aimed to address biological and fishery concerns related to cyclical and spasmodic recruitment dynamics, including multiple successive large recruitment events in recent years. These extreme recruitment events precipitated rapid increases in ABC recommendations and TACs, as well as declines in prices as existing markets became saturated. This resulted in substantial concerns amongst user groups regarding whether the current management approach was capable of providing positive outcomes under highly variable recruitment conditions, or whether alternative approaches may perform better. The closed-loop simulation analysis evaluated the performance of various management approaches across three possible future recruitment scenarios. The operating model dynamics were based on the sablefish stock assessment estimates from 1960 to 2014. Simulations were conducted over a 75-year projection period, beginning in 2014 (i.e., when the sablefish spawning biomass was below the proxy for B_{MSY} ($B_{35\%}$) and just prior to the onset of multiple large recruitment events). Performance of various management options was evaluated across a suite of fishery and conservation metrics. Future recruitment scenarios included (1) a Beverton-Holt stock recruit relationship with random variability, (2) a regime-like scenario, in which recruitment oscillated between periods of high and low average recruitment, and (3) a crash scenario, in which a recruitment failure induced a population decline in the middle of the simulation period (Figure 4A.1).

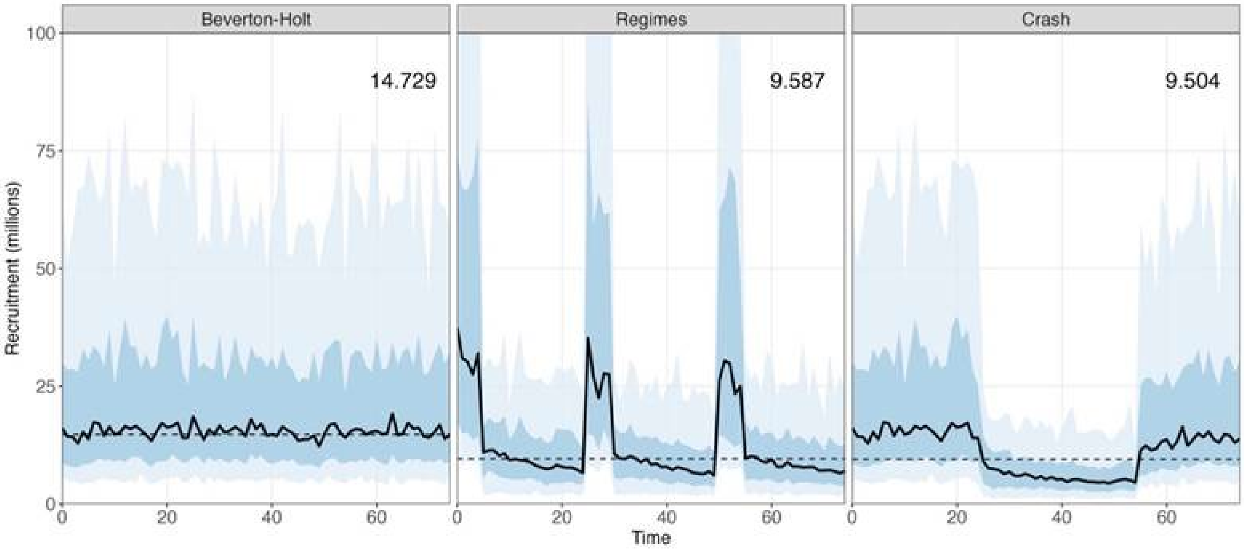


Figure A4.1: Time series of median recruitment (millions of recruits) across the 75-year projection period for the three recruitment scenarios. Shaded regions indicate the inner 50th and 80th percentiles of recruitment across 200 simulations. Numbers and horizontal dashed lines indicate average recruitment across the entire projection period.

These scenarios cover a range of possible climate-induced changes to sablefish recruitment, with the "Regime" scenario emulating previously observed periodicity in the occurrence of large recruitment events (Goethel and Cheng, 2024), and the "Crash" scenario covering a possible "worst-case" recruitment scenario. A range of alternative management approaches (Figure A4.2) were considered, all assuming that the maximum ABC, ABC, and TAC were the same value (the catch limit). The management alternatives included the use of lower fishing mortality levels as reference points (e.g., $F_{50\%}$ instead of $F_{40\%}$), addition of stability constraints to restrict changes (up or down) in catch limits from the previous year to a maximum percentage , application of harvest caps (maximum annual catch limits which superseded the fishing mortality reference point of the HCR, when the resulting max ABC would have been above the cap), and a hybrid approach that combined the threshold form (i.e., the ramping down of fishing mortality when stock size is below the biomass reference point) of the current F40 approach, with a 20k mt harvest cap, and a 10% "slow-up, fast-down" stability constraint.

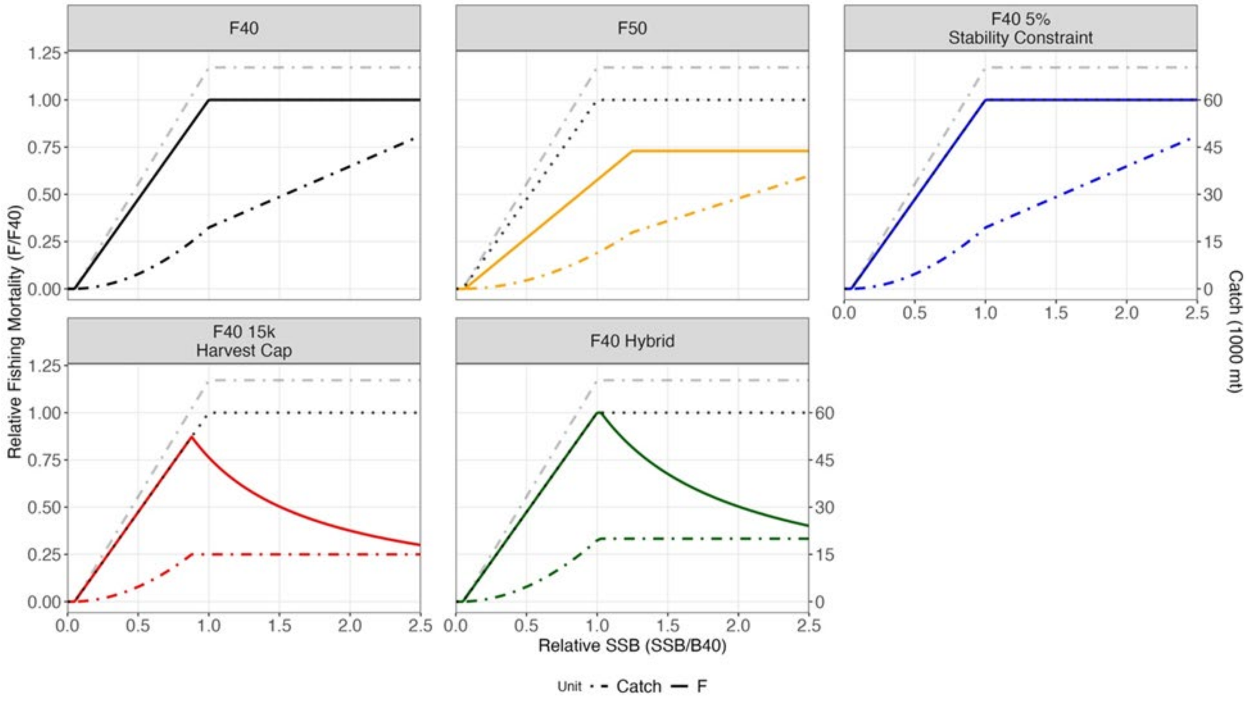


Figure A4.2: Relationship between relative spawning stock biomass (*SSB/B*$_{40}$) and relative fishing mortality (*F/F*$_{40}$; solid lines) or catch (dot-dash lines) under five of the alternative management approaches. Note that the annual stability constraints that differentiate the *F*$_{40}$ and *F*$_{40}$ +/- 5% approaches are not shown. The dotted gray line on each plot is the current *F*$_{40}$ HCR corresponding to max ABC, while the grey dot-dash line indicates the OFL HCR. Note that, in all cases, HCR alternatives are assumed to represent max ABC, and that max ABC = ABC = TAC.

The existing management approach for sablefish (labeled “F40” in the figures) was found to be widely robust to extended periods of reduced recruitment, but was prone to rapid catch limit swings with biomass increases induced by recruitment spikes (Figure A4.3). The existing F40 HCR (i.e., a threshold HCR that reduces the fishing mortality as spawning biomass declines below the biomass reference point) is based on total aggregate spawning biomass, and only considers the age structure of the population indirectly by way of the age-structure as estimated in the stock assessment that determines current spawning biomass levels(which are a function of the estimated numbers-at-age, weight-at-age, and maturity-at-age). Following large recruitment events, threshold HCRs may become increasingly reliant on a limited number of strong cohorts, and may result in declining age diversity and population resilience if large cohorts do not survive to mature age classes in sufficient numbers.

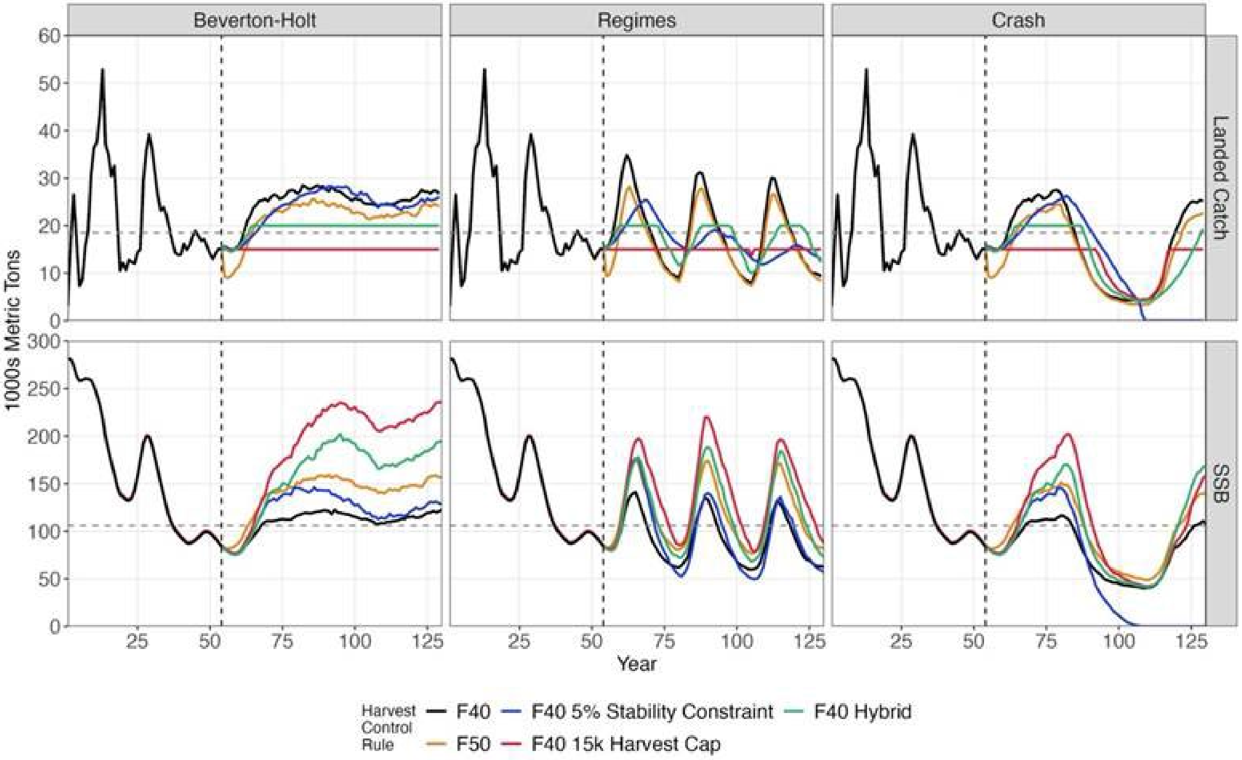
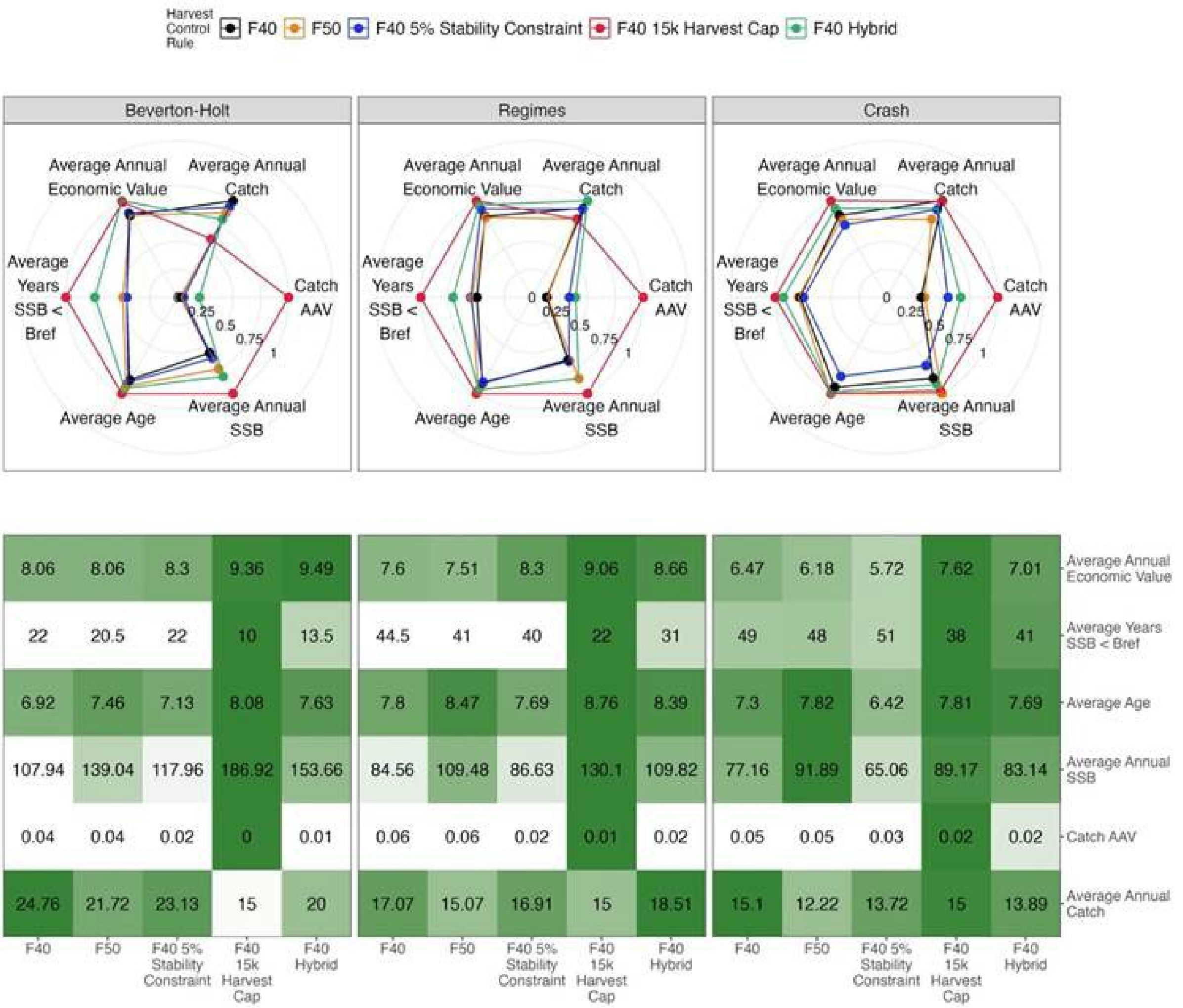


Figure A4.3: **Landed catch (top) and spawning stock biomass (SSB; bottom) trajectories across management strategy (color) and OM scenario (columns). Lines represent the median annual catch and SSB in each simulation year across 200 replicate simulations. Dashed vertical line indicates the start of the simulation period when alternative management strategies are applied. Horizontal dashed reference lines indicate (1) the median ABC from 2014-2023 (18,358 mt; top row) and (2) the most recent operational assessment estimate of B35 (105,935 m; bottom row; Goethel and Cheng 2024).**

The recent large recruitment events for Alaska sablefish have led to concomitant increases in both spawning biomass (as these large age classes mature) and catch levels. As of 2024, >80% of the population spawning biomass was <12 years old, with four year-classes (2014, 2016, 2017, and 2019) comprising nearly 60% of the total spawning biomass (Goethel and Cheng, 2024). If the ABC from the existing MP were to be fully utilized (recent utilization rates have been ~50% of the ABC), many fish from these year-classes may be caught prior to reproducing. This could have downstream impacts on future population size and stability. Preservation of age diversity in fish populations is widely acknowledged as an important factor for ensuring population stability through periods of reduced productivity or poor environmental conditions (McGilliard et al. 2017; Berkeley et al. 2004; Hixon et al. 2014), although maintenance of age diversity is rarely considered explicitly when setting management policies. However, future changes to the marine environment because of continued climate change makes age diversity preservation an important consideration for climate-ready fisheries management. The recent large recruitment classes have also inundated the sablefish market with a large quantity of relatively small, low-value fish under the existing MP (Goethel and Cheng 2024; Goethel et al. 2025). This has resulted in large declines in the ex-vessel value of the sablefish harvest, due to the combined effects of market saturation and the prevalence of smaller and therefore lower value fish within the harvest.

HCRs that apply stability constraints have the benefit of slowly increasing the ABC, giving markets time to prepare for higher, or lower, catch levels. They also ensure that biomass increases (and corresponding increases in catch) resulting from a single, or small number, of year-classes are slowly incorporated into the ABC, giving more time for those year classes to reproduce and grow to economically valuable sizes before a substantial proportion of them are caught. Stability constraints, unfortunately, are often not able to substantially improve population age diversity. While they allow for slow incorporation of biomass and year-class contributions during periods of productivity increases, they also allow for elevated catch levels during periods of productivity declines (i.e., if bi-directional constraints are implemented), effectively cancelling out any previous improvements in age diversity. These stability-constrained rules need to be considered carefully, as adoption of a symmetric bi-directional stability constraint (e.g., maximum 5% increase or decrease), as was explored in this study, carries potentially costly consequences if recruitment substantially declines for an extended period (Figure A4.3, Figure A4.4). A simple potential alternative to mitigate this concern is a uni-directional stability constraint, whereby ABC increases are constrained (a "slow-up, fast-down" constraint). Unidirectional constraints combine the inherent ability of the threshold HCR to reduce catch limits as productivity declines, while slowly incorporating increases in biomass (i.e., due to the 'slow up' constraint) to improve market stability.



	Beverton-Holt					Regimes					Crash				
	F40	F50	F40 5% Stability Constraint	F40 15k Harvest Cap	F40 Hybrid	F40	F50	F40 5% Stability Constraint	F40 15k Harvest Cap	F40 Hybrid	F40	F50	F40 5% Stability Constraint	F40 15k Harvest Cap	F40 Hybrid
Average Annual Economic Value	8.06	8.06	8.3	9.36	9.49	7.6	7.51	8.3	9.06	8.66	6.47	6.18	5.72	7.62	7.01
Average Years SSB < Bref	22	20.5	22	10	13.5	44.5	41	40	22	31	49	48	51	38	41
Average Age	6.92	7.46	7.13	8.08	7.63	7.8	8.47	7.69	8.76	8.39	7.3	7.82	6.42	7.81	7.69
Average Annual SSB	107.94	139.04	117.96	186.92	153.66	84.56	109.48	86.63	130.1	109.82	77.16	91.89	65.06	89.17	83.14
Catch AAV	0.04	0.04	0.02	0	0.01	0.06	0.06	0.02	0.01	0.02	0.05	0.05	0.03	0.02	0.02
Average Annual Catch	24.76	21.72	23.13	15	20	17.07	15.07	16.91	15	18.51	15.1	12.22	13.72	15	13.89

Figure A4.4: Performance of HCRs across six performance metrics and recruitment scenarios (columns). For radar plots (top row), values are standardized relative to the highest achieved performance value within each metric and recruitment scenario. Values closer to 1.0 (farther from the center) indicate a better performing HCR with respect to that performance metric. The Catch AAV and Average Years SSB < B_{ref} metrics are inverted to maintain the interpretation that a higher value represents a desirable outcome. The table presents median, un-standardized, performance values across 200 simulations. Cell shading reflects standardized performance (0.0-1.0), such that darker colors represent more desirable outcomes.

The level of stability constraint (e.g., 5% vs 15%) could also be explored, as constraints that are too restrictive may unnecessarily restrict harvest opportunity, and constraints that are too wide may have limited ability to positively impact economic conditions. Under future climate change scenarios, bi-directional stability constraints may fail to meet performance criteria, due to their inability to react quickly to sudden declines in relative spawning biomass. This can be seen in the "Crash" scenario explored here, where the addition of a 5% bi-directional stability constraint to the existing management approach resulted in relative spawning biomass declining more rapidly and to lower levels (extinction levels, in this case) than if an unconstrained rule had been used (Figure A4.3).

The harvest-capped HCR generally improved population status and reduced population age-truncation, thereby, increasing the proportion of the harvest that would be composed of large, high-value fish. Under the "Crash" scenario explored here, a 15k mt harvest cap led to improvements in nearly every performance metric (except catch) over the uncapped F40 management approach (Figure A4.4). While the harvest capped HCR was more effective at reducing age truncation than the HCR with stability constraints, it led to substantial reductions in average catch and fishing mortality during periods of high biomass. This highlights the overarching challenge of expanding age diversity without substantially reducing fishing opportunities and economic outcomes. A harvest cap that is too low may overly restrict catches and economic outcomes, while a cap that's too high may be unconstraining (see Example 2 below).

The hybrid HCR was found to substantially improve catch stability, population size, and economic value over other HCRs, consistent with the behavior of other harvest capped rules (Figure A4.4). The amount of time the population remained at low biomass levels following a recruitment crash was also reduced due to a slowed increase in catch following the end of the recruitment crash, courtesy of the stability constraint (Figure A4.5). The hybrid HCR has the distinct benefit of integrating the positive qualities of each type of management approach (e.g., reductions in fishing mortality at low stock size from F40, reduced rebuilding times from stability constraints, and highly stable intermediate catch levels from harvest caps), making it well suited for use through periods of high uncertainty in productivity.

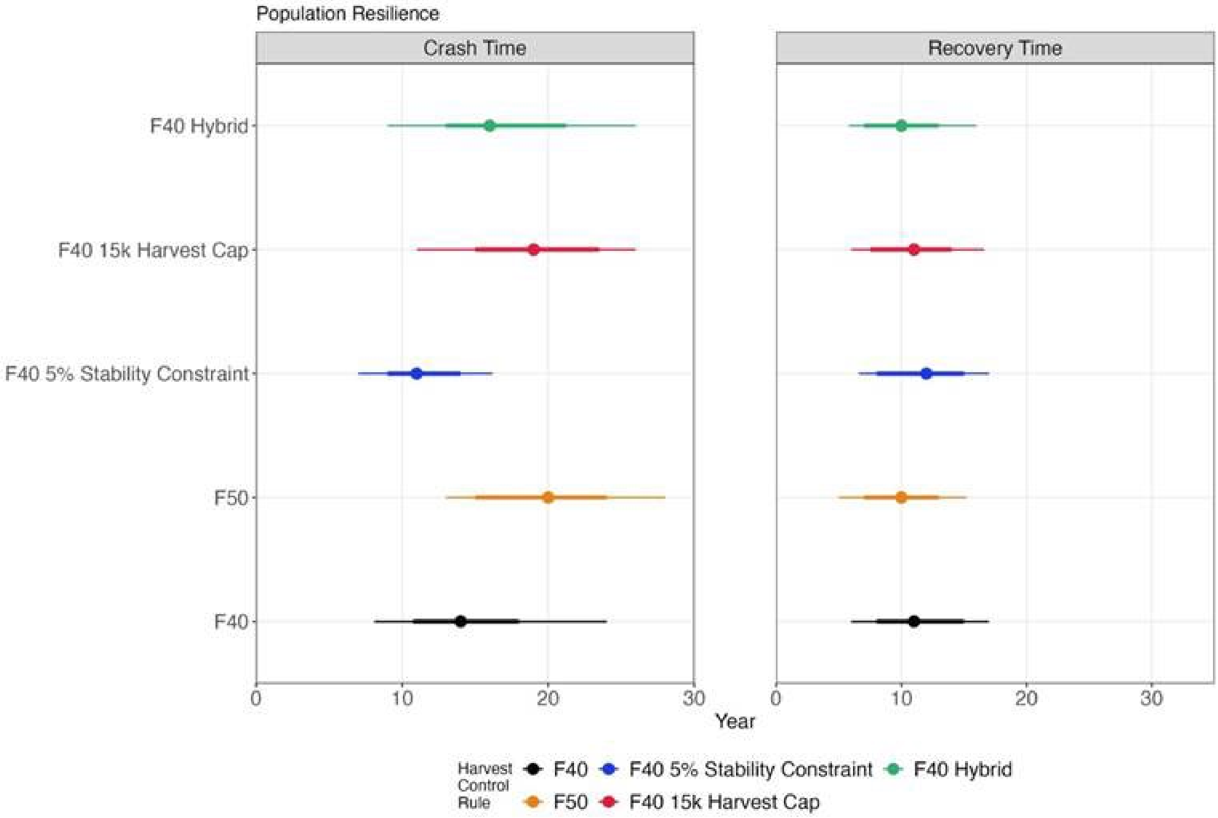


Figure A4.5: Distribution of years required for the population to crash ($SSB < 0.50 * B_{35}$; left) and subsequently recover ($SSB > B_{35}$; right) under the "Crash" recruitment scenario by management approach. Points are the median, thick bars the inner-50th percentile, and thin bars the inner-80th percentile across 200 simulations.

This project sought to identify HCRs that were robust to regime-like recruitment scenarios and thus not require modifications during periods of changing productivity. It is notable that regime-specific HCRs (that is, an HCR that switches between two options based on the detection of a regime change), are generally not recommended, due to concerns regarding the detectability of regimes (Szuwalski and Punt 2013). For the Alaska sablefish stock, which has undergone market saturation recently and for which

ABCs and TACs are expected to remain high in coming years, the adoption of a hybrid HCR (i.e., using an economically-informed harvest cap and “slow-up, fast-down” stability constraint) may be the most prudent mechanism by which to improve economic, fishing, and population conditions for the stock. From a management implementation standpoint and considering that the hybrid HCR and the harvest cap HCR performed similarly, the most efficient approach for sablefish might be to consider applying a harvest cap at the TAC level (so that no FMP amendment is required). Moreover, given the recency of this market concern, and a lack of thorough analyses regarding the economics of the sablefish fishery and markets, applying a harvest cap at the TAC level would also provide additional flexibility in the event markets expand in the future and managers determined that cap adjustments were warranted.

This work was performed specifically in the context of Alaska sablefish, particularly with respect to the recruitment scenarios that were analyzed, though results may be extended to other species. Notably, harvest caps can smooth catches through periods of high variability and extend the period over which biomass from isolated recruitment events can be caught without overwhelming economic markets (Licandeo et al. 2020). This likely has the most direct implications for a wide range of species in the context of possible future climate change. Climate change is expected to increase population variability as demographic rates, species distributions, and recruitment patterns change (Hollowed et al. 2013). Harvest caps are the simplest and most effective way to reduce variability in catches in the wake of the rapid increase in the population (Zahner et al. 2025). This may be relevant for species experiencing rapid changes in distribution or that are extremely sensitive to annual changes in environmental conditions (e.g., crabs). By not chasing periods of high catch, harvest caps may be a reasonable approach to buffer populations through periods of both good and poor conditions, which may become more frequent under future climate change. Further work on identifying management approaches that are resilient to wide swings in catch levels, are not over-reliant on a limited number of year-classes and promote expanded age diversity will be critical to ensuring that fisheries management remains robust to future climate change.

The Sablefish MSE project has, to this point, focused on evaluating alternative management approaches under a single-area model of Alaska. At the request of stakeholders, a spatially-explicit version of the simulation framework has been developed, allowing us to account for spatial variation in sablefish demographics, fishing dynamics, and management. This spatially-explicit framework separates Alaska into five regions – akin to the management regions defined for sablefish in the FMP – and assumes an age-varying movement matrix (from the spatial stock assessment model for sablefish; Cheng et al., 2025). Ongoing simulations are exploring how possible climate-induced changes in movement and residency patterns interact with alternative management approaches to affect different regions of Alaska. HCRs that attempt to more directly address the problems of age truncation and age diversity by only considering fully-mature age classes or assuming an alternative fecundity relationship, are also being explored. Such approaches may be valuable in helping to buffer populations through extended periods of adverse environmental conditions. Next steps in the project include finalizing the results from the spatially-explicit MSE framework as well as presentations to stakeholders, the Groundfish Plan Team, and any other interested bodies to discuss final results from both the single-area and spatial MSE analyses. The project is expected to conclude in 2026 and no additional future analyses are currently planned. The tool is open source and available for use by any interested party from the project GitHub repository[30].

The Sablefish MSE project has been developed and used as a research tool to explore the possible consequences of modifying the existing HCR for sablefish to better achieve desired management outcomes when confronting recent recruitment variability. There are currently no plans to integrate these results directly into the assessment process (e.g., recommending an ABC < maxABC). Adoption of any of the alternative HCRs discussed here by the NPFMC is beyond the specific scope of this project.

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[30] Single Area MSE Framework: https://github.com/ovec8hkin/SablefishMSE

Spatially Explicit MSE Framework: https://github.com/ovec8hkin/SpatialSablefishMSE

OM Simulation Framework: https://github.com/BenWilliams-NOAA/afscOM

5.4.7.2 Example 2: Groundfish Optimum Yield in the BSAI and GOA in the context of alternative HCRs

The current BSAI and GOA groundfish FMPs each define a multi-species optimum yield (OY) range for the sum of annual TACs across all federally-managed groundfish species in each FMP. The maximum value of the groundfish OY (the OY cap) is 2 million mt for the BSAI and 800,000 mt for the GOA; the minimum value of the groundfish OY is 1.4 million mt for the BSAI and 116,000 mt for the GOA (NPFMC 2024c). Historically, aggregate annual groundfish catches have been well above the minima in each region. The caps are listed in the FMPs as mechanisms contributing to the objective of preventing overfishing (NPFMC 2024a, 2024b). OY caps were initially established with implementation of the Magnuson-Stevens Act in 1976 prior to the implementation of harvest control rules and were defined as the sum of stock-specific MSY values in each year (Goodman et al. 2002). The logistics of having changing OYs each year was arduous within the federal system, and therefore OY caps were re-defined as as ranges of values that are static over time. The current Optimum Yield (OY) ranges for groundfish were established in 1984 under BSAI Amendment 1 for the Bering Sea/Aleutian Islands and in 1987 under GOA Amendment 15 for the Gulf of Alaska. Goodman et al. (2002) suggest that the current BSAI 2 million ton cap value was calculated as 85% of the sum of single-species groundfish MSY values (1968-1977) at the time. Early food web models developed by Taivo Laevastu (e.g. Low 1983) contributed to the development of the current OY cap ranges by showing that the OY should be less than the sum of single-stock MSY values due to biological interactions such as predation and competition. The OY cap for the GOA was set lower than the average sum of MSYs over individual groundfish stocks for 1983-1987 and roughly equal to the lowest sum of groundfish MSYs over the period 1982-1986 (Goodman et al. 2002, pers. comm. G. Thompson). While the 2 million mt groundfish OY cap in the BSAI has constrained the TACs of major commercial groundfish stocks annually (Figure A4.7), the sum of ABCs across all groundfish species in the GOA has been less than the 800,000 t groundfish OY cap in the GOA consistently in recent decades (Figure A4.8).

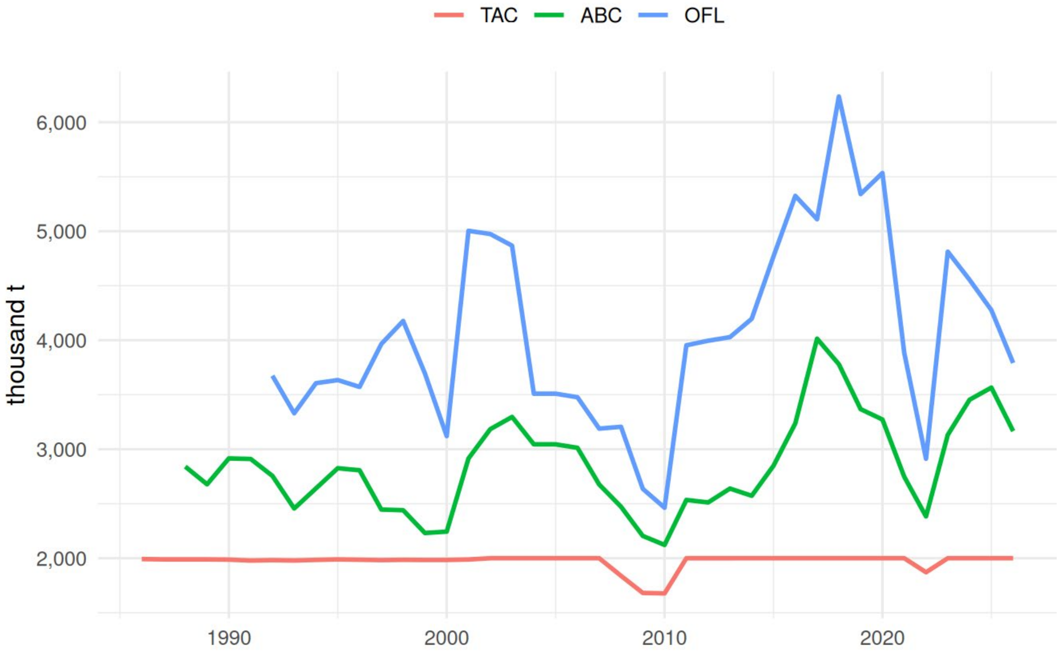

Figure A4.7. Sum of groundfish ABC, OFL, and TAC in the BSAI by year.

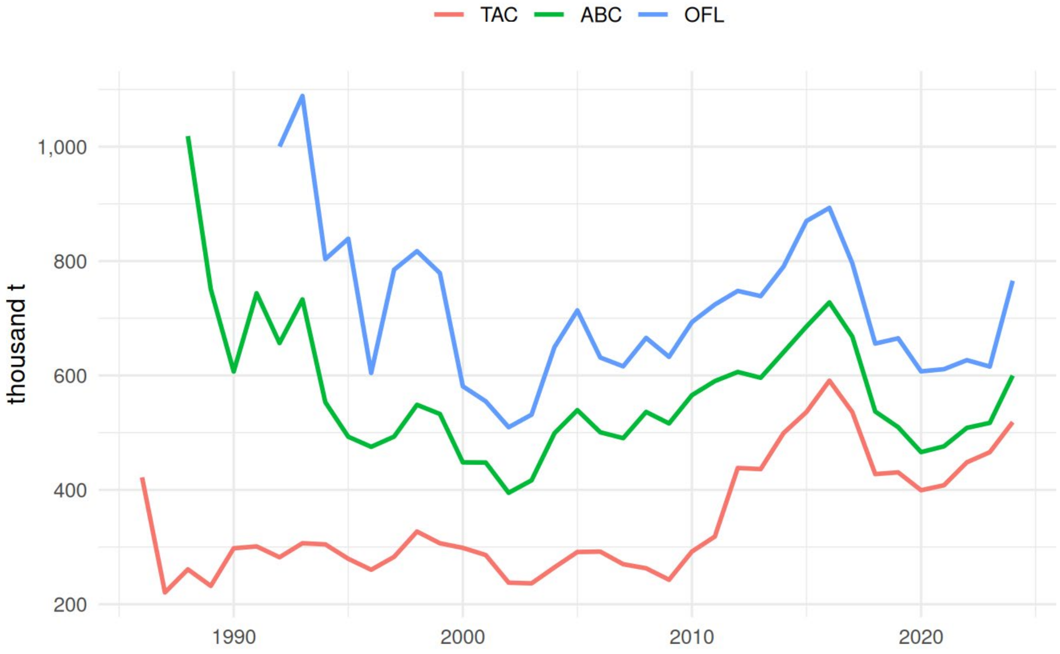

Figure A4.8. Sum of groundfish ABC, OFL, and TAC in the GOA by year.

Since the development of the current groundfish OY caps, conditions in the GOA and the BSAI have changed substantially, as has computing power and modeling methodology. One application of the GOACLIM suite of ecosystem models is to conduct updated explorations of groundfish OY for a variety of scenarios and assumptions. To that end, as part of a NOAA CAFA project, Rovellini et al. (2025) used an Atlantis end-to-end ecosystem model of the GOA to model 78 species groups, including the FMP groundfish species, to calculate aggregate groundfish MSY and compare it to the GOA OY cap. This Atlantis model accounts for species interactions (such as predation and competition), spatial distributions, and the influence of potential future environmental conditions on the system. The current groundfish OY cap in the GOA was above the value for multi-species MSY calculated by Atlantis GOA, and was not constraining in projections under various assumptions about future environmental conditions. The model also indicated that the utilization of arrowtooth flounder may influence MSY values for other species, such as pollock. We plan to repeat this exercise using other ecosystem modeling frameworks as described in the June 2025 discussion paper for the SSC, and for available BSAI ecosystem modeling frameworks. Using this suite of models, we hope to provide information about the interaction of the OY caps with potential future environmental conditions and fishing pathways, along with a characterization of scientific uncertainty about OY values.

A continuation of the Atlantis GOA research is using simulation analysis to explore alternative groundfish OY cap values in the context of potential future environmental conditions. To complete this work, the research team developed two methods for modeling the rescaling of catches from ABCs to implement constraining groundfish OY caps: (1) proportional rescaling for all stocks and (2) prioritization of TACs close to the ABC for a set of desirable commercial stocks. The ABCs were calculated using the current harvest control rules in the GOA FMP, or close proxies for the current HCRs. Preliminary results indicate that increasingly constraining groundfish OY caps may lead to maintenance of higher groundfish biomass than for non-constraining OY caps at the expense of foregone catch. In addition, groundfish OY cap values that constrain total catches under current conditions may not be constraining in the future as environmental conditions shift.

Rovellini et al. (2025) discusses applications of multi-species OY caps outside of the BSAI and GOA and recent analyses of multi-species MSY in the scientific literature. Though research and perspective papers often discuss multi-species catch caps as a potential tool (e.g. Patrick and Link 2015, Morrison et al. 2024), Alaska is one of the few systems in the world where they are in use. Other applications are in Thailand, where there is a multi-species fishery managed using a catch limit based on an estimate of total MSY across stocks (Fulton et al.), and at the Northwest Atlantic Fisheries Organization, where a multi-species MSY estimate is presented as part of the management process (Koen-Alonso et al.)

5.4.7.3 Example 3: Re-evaluating US west coast groundfish HCRs

The Pacific Fishery Management Council uses reference points based on spawning potential ratio within an HCR to calculate maxABC values for flatfish stocks. Before the late 1990s, the PFMC used a proxy for Fmsy (the fishing mortality rate that results in the Maximum Sustainable Yield) for most groundfish of $F_{35\%}$ (the rate that reduces the spawning potential per recruit to 35% of unfished levels). As for the GOA and BSAI FMPs, historically these SPR-based reference points were based on Clark (1991) that established $F_{35\%}$ as likely close to F_{MSY} for groundfish-like stocks. The Clark (1991) analysis evaluated (somewhat subjectively) the relationship between trade-offs of different plausible stock-recruitment relationships and given that uncertainty, derived the spawning-biomass per recruit component as a proposed proxy for F_{MSY}.

The Pacific Fishery Management Council (PFMC) began shifting from this uniform approach to fishing mortality rate to species-specific rates in the late 1990s, with a system of different fishing mortality rates for different species groups fully established by 2001. This transition was driven by the realization that certain species, particularly rockfish, were far less productive and more vulnerable to overfishing than previously believed. Following the PFMC’s 2000 Groundfish Harvest Rate Policy Workshop, the PFMC's Scientific and Statistical Committee (SSC) recommended that fishing mortality rates be tailored to the specific life histories of different species groups. Specifically, $F_{50\%}$ for rockfish, $F_{45\%}$ for round fish (such as sablefish and lingcod), and $F_{40\%}$ for flatfish and other groundfish species. These were implemented for the 2001–2002 management cycle. At this time all groundfish stocks were managed under the “40-10” HCR.

The Pacific Fishery Management Council (PFMC) updated its flatfish HCR and fishing mortality rate in 2009 to better align with estimates of flatfish productivity from flatfish stock assessments (Haltuch and Hicks 2009). Flatfish stocks on the U.S. West Coast were deemed more productive and able to withstand higher fishing mortality compared to other species groups such as rockfish, prompting the change to a rule that allowed for higher harvest closer to managing toward maximum sustainable yield. The rule changed from the "40-10" rule to a "25-5" HCR, which adjusted the target and limit reference points lower, and to a harvest rate of $F_{30\%}$ to allow for higher harvest. While the rule was adopted by the PFMC in 2009 for the 2009–2010 management cycle and beyond, it was not formalized until the Amendment 23 process during 2010, with further refinements continuing through subsequent amendments, such as Amendment 24 (2015), which finalized default harvest control rules.

Wetzel et al. (2017) implemented an evaluation of the performance of the “25-5 HCR and $F_{30\%}$ harvest rate for Pacific coast flatfish species using closed-loop simulation model with petrale sole as the focal species for the analysis because the 2009 stock assessment provided the impetus for the implementation for the flatfish “25-5” HCR and $F_{30\%}$ harvest rate. Petrale sole had also been fished to low stock sizes for an extended period of time, spending over 20 years around or below 10% of the estimated unfished biomass, which made it ideal with respect to the information available on which to base the estimation of a stock-recruitment curve. The authors ran the closed-loop simulation incorporating uncertainty in recruitment, observation error, and estimation error (using a full age-structured stock assessment model for the estimation modeling step of the analysis). Furthermore, the authors conducted sensitivity analyses by configuring the operating model with alternative assumptions about stock productivity.The study concluded that the PFMC 25-5 HCR with $F_{30\%}$ maintained stocks at or near the B_{MSY} proxy of 25% of unfished biomass when stock-recruit steepness (a measure of productivity) was 0.85 or greater, with very low probabilities of reducing relative biomass below a Minimum Stock Size Threshold (set at 0.50 of the B_{MSY} proxy for the “25-5” HCR). This work supported the 2009 change of the HCR used for all federally-managed flatfish species.

5.4.8 Summary

These analyses, whether focusing on regional reference points (as demonstrated by the PFMC flatfish work) or utilizing closed-loop MSE (as shown with Sablefish), collectively define the ABC / HCR modifications pathway discussed in the ensuing framework. This section therefore provides a decision-oriented framework—assessment, HCR, and TAC pathways and their timing—while Section 3 provides the catalog of alternative approaches that inform those pathways. In contrast to fully specified MPs evaluated through MSE, the current system distributes risk management and decision-making across these pathways, resulting in a combination of high flexibility at the cost of varying transparency and analytical standardization. The table below synthesizes the four key decision pathways.

Pathway	Timing	What gets adjusted	Role within MP	Example applications	Strengths	Limitations
Assessment-level change	Annual (within assessment cycle)	Model structure, parameters, projections (e.g., recruitment, M, environmental covariates)	Estimation model (data → stock status)	CEFI-informed models; time-varying projections; environmental linkages	Rapid, flexible, responsive to new information	Less transparent; may vary across stocks; not always consistent
ABC / HCR modifications	Multi-year (requires analysis, often MSE)	Control rule form, reference points (e.g., FSPR), climate-informed rules	Decision rule (stock status → harvest advice)	Sablefish MSE; alternative HCR shapes; CAFA HCR work	Transparent, consistent, explicitly linked to objectives	Time-intensive; requires simulation and clear objectives; May require FMP amendment
TAC decisions	Annual (Council process)	Catch limits below ABC; ecosystem caps; socio-economic adjustments	Implementation layer (ABC → TAC → realized catch)	Risk table and OY cap-related reductions; Council discretion	Immediate implementation; incorporates broader considerations	Not analytically standardized; may be inconsistent
Integrated MPs (MSE-tested)	Multi-year (design + evaluation)	Full system: monitoring → estimation → HCR → implementation	Fully specified management procedure	Pacific sardine HCR; survey-based HCRs; international MSE systems; Sablefish MSE	Coherent, explicitly tested, evaluates trade-offs end-to-end	Requires upfront investment; less flexible once adopted

5.5 Appendix 5 Case study examples of climate informed advice (history and future needs) in various assessments

5.5.1 Overview for this Appendix:

Assessments of the following stocks have developed various approaches to navigate climate-induced challenges to advice (see Table 10 in document). Additional details of the specific and varied issues by stock are provided below and illustrate the ways in which assessment advice and Council processes have navigated past challenges, highlight new methods to connect mechanistic understanding of climate drivers of population processes to EBFM advice, and identify outstanding needs and opportunities to meet future climate shocks and long-term change with next generation forecasting tools.

5.5.2 Sablefish

Recent high recruitment events for Alaska sablefish have resulted in rapid population growth and resulting catch of small, lower value fish. For the past two years HCR modifications have been explored to better address socioeconomic conditions caused by cyclical and spasmodic recruitment dynamics through development of a closed loop simulation analysis for sablefish. Additional information on the project is found in Appendix 3.

Over the past two decades, the sablefish stock assessment has evolved significantly to address several persistent biological, ecological, and methodological challenges. The main issues that have dominated the Scientific and Statistical Committee (SSC) and Plan Team discussions include:

5.5.2.1 Extreme Recruitment Volatility and Truncated Age Structure

Historically, sablefish have demonstrated spasmodic recruitment dynamics characterized by short periods of high magnitude cohorts followed by prolonged periods of low recruitment. Since 2014, the sablefish stock has been in an extended period of above average recruitment, which includes the highest magnitude (2016) and 3rd highest (2014) year classes on record.

- The long-term cyclical recruitment dynamic has caused severe truncation in the population's age structure, leading to a heavy reliance on a few young cohorts to support the future spawning biomass while older fish have rapidly declined.
- Estimates of these massive recruitments have been highly volatile (e.g., the estimated strength of the 2014 year-class dropped by 56% between the 2017 and 2019 assessments). Because the stock's future reproductive potential hinges on these young fish maturing, the SSC has recommended precautionary reductions from the maximum Acceptable Biological Catch (ABC) to account for this uncertainty.

5.5.2.2 Whale Depredation

Depredation by sperm and killer whales on longline survey gear and commercial catches has been a chronic issue.

- Whales stripping sablefish from hooks artificially suppresses catch rates and survey abundance indices (though the impact on the survey is limited).
- Over the years, the assessment integrated formal mathematical corrections to account for this unobserved mortality, which involved adjusting survey catch-per-unit-effort (CPUE) upward where sperm whale depredation occurred and deducting projected whale depredation directly from the ABC limits.

5.5.2.3 Assessment Model Fits and Retrospective Biases

Assessment authors have continually struggled to reconcile conflicting data indices.

- The commercial longline fishery CPUE has frequently shown different trends (often declining or remaining stable) compared to the fishery-independent trawl and longline surveys, raising concerns about hyperstability where fleets target high-density areas.
- The current model has limited retrospective bias in SSB, but exhibits moderate retrospective bias in recruitment, especially recently when the very large recruitment year classes initially enter the fishery.
- Additionally, the model has historically struggled to fit age and length composition data, frequently underestimating the abundance of younger fish and overestimating the abundance of older fish. Model structures have been routinely updated to address this, such as transitioning to a split-sex model to account for differences in male and female growth and mortality.

5.5.2.4 Spatial Apportionment

Determining how to allocate the ABC across different Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) management areas has been a highly debated issue due to the highly mobile nature of sablefish and the differences in fleet structure and gear usage across Alaska.

- The methodology has shifted repeatedly, moving from weighted averages of survey and fishery CPUE, to fixed static allocations, and more recently to a 5-year moving average of survey biomass.
- Because sablefish tend to move from western areas to the east as they mature, shifting area apportionments often creates tension between tracking the biological distribution of the stock and providing economic stability for regional fisheries.

5.5.2.5 Rapid Gear Transitions and Fishery Performance

In recent years, the commercial fleet has undergone a **rapid transition from traditional longline gear to longline pot gear**, primarily to mitigate whale depredation.

- This shift has complicated the assessment because the two gear types may have different size and age selectivities, prompting requests from the SSC to explore modeling them as separate fleets.
- Furthermore, the fishery has recently faced severe performance issues, including declining TAC utilization (catching less than 50% of the quota in 2024) and substantial reductions in market value, largely driven by the high proportion of small, low-value fish in the population.

5.5.2.6 Environmental and Biological Shifts

The assessment has increasingly had to account for dynamic biological parameters and ecosystem conditions.

- Recent assessments have grappled with the impact of GOA marine heatwaves, which may have benefited early recruitment but may also have led to poor fish condition and potential density-dependent reductions in growth rates due to the high abundance of young fish.

5.5.2.7 Data loss

- In 2024, the assessment faced a unique challenge when it was elevated to a Level 2 concern (requiring a 5% ABC reduction) because key data sources—the longline survey, the bottom trawl survey, and fishery logbooks—were all simultaneously unavailable or cancelled, creating data gaps for monitoring the stock.

5.5.3 EBS pollock

5.5.4 EBS Pollock Management Challenges (1998–2024)

Management of EBS pollock has been characterized by a long-standing tension between the formal Tier 1 classification and persistent uncertainty in stock productivity, leading to reliance on precautionary buffers and ad hoc adjustments. All of the individual assessments from 1998 through 2024 were examined for characteristics related to how the SSC was provided information on applying FMP guidelines for the annual specifications process (see: NPFMC SAFE catalog/audit). Similarly, we created a single file of all the past SSC reports to the Council. This was used to investigate how their final ABC and OFL recommendations were developed.

The time-series of Tier 1 and Tier 3 estimates showed that realized catch generally stayed below the corresponding Tier 1 ABC series, while often tracking much closer to Tier 3 ABC (Figure A5.1). In several periods, especially the lower-ABC years after 2008 and again in the early 2020s, the realized catch sits between the two control-rule outcomes (Figure A5.1).

We note that EBS pollock was historically treated as a Tier 1 stock, but the SSC often relied on Tier 3 calculations to impose a buffer below the maximum permissible Tier 1 ABC. That pattern reflected long-standing concerns about the stock-recruitment relationship, selectivity, and broader ecosystem risk, even while the formal stock classification remained in Tier 1.

On closer examination, a useful example of how these ABC values were interpreted in practice comes from the 2008 assessment cycle, when the SSC recommended managing EBS pollock under Tier 1b and setting the 2009 ABC at the maximum permissible level of 815,000 t, with an OFL of 977,000 t. In the previous year, the SSC had applied an additional precautionary buffer below the maximum Tier 1 value, but it concluded that such an *ad hoc* reduction was unnecessary for the 2009 specifications. The rationale was that uncertainty was already being handled within the assessment and the harvest control rule itself, and that the stock outlook had improved materially relative to the immediately preceding period.

The SSC's confidence rested on several lines of evidence. First, the assessment was supported by an unusually strong set of surveys with consecutive years of both bottom-trawl and hydroacoustic coverage. Second, both survey types indicated that the 2006 year class was strong, and by the following cycle that conclusion had been reinforced by repeated observations across multiple surveys. Third, exploitation on spawning pollock had been reduced. Together, those points gave the SSC confidence that the assessment and control rule were capturing uncertainty adequately without layering on a separate discretionary buffer.

The Tier 1b designation itself was also an important context for interpreting the time series. This designation occurred because the biomass was estimated to have fallen to roughly 75% of the B_{msy} estimate. This was due to a period of below-average recruitment. Under Tier 1b, fishing mortality is reduced automatically as biomass declines below target, so the conservation response is built into the control rule rather than imposed as a separate post hoc adjustment. The stronger 2006 year class estimate was central to that outlook: survey data showed above-average abundance at ages 1 and 2, and BASIS ecosystem results suggested that although age-0 abundance in 2006 was initially not especially high, juvenile energy density was unusually high, implying good late-summer feeding and strong over-winter survival. That combination supported projections that the stock could rebuild toward the MSY target by 2010 and helped explain why catch limits around 2009 were set where they were. *This provides an example of holistic reasoning in setting ABC based on a broad array of information.*

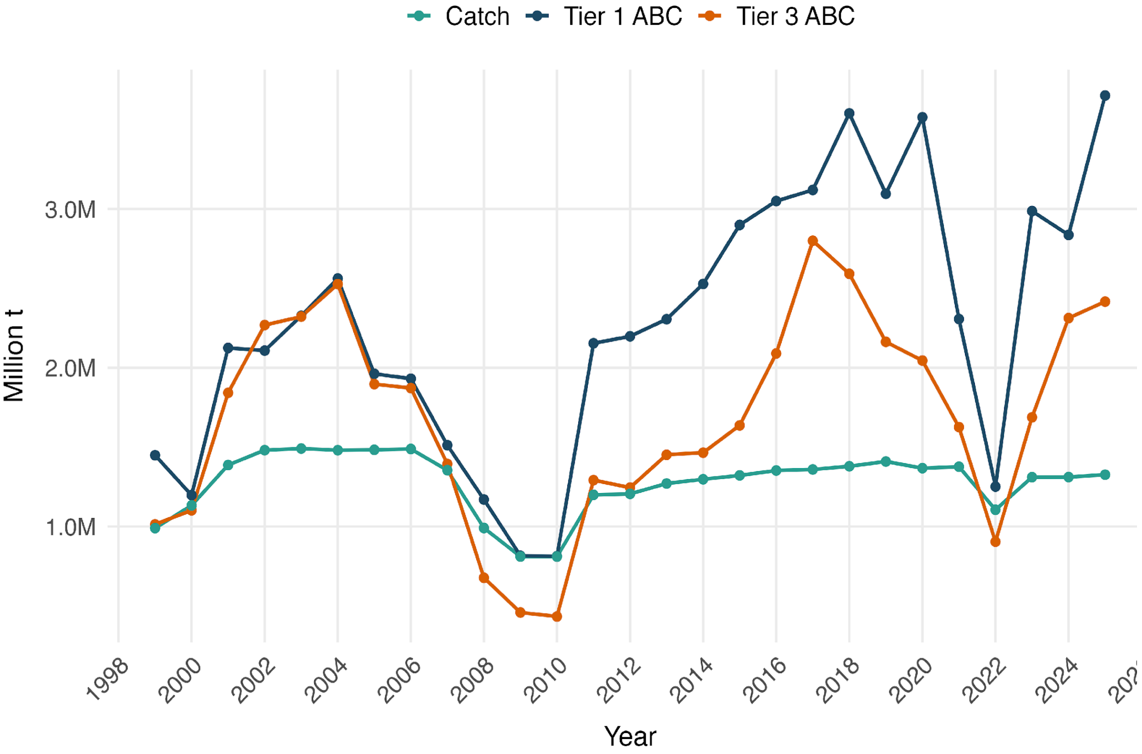

Figure A5.1: Realized catch compared with 1-year-ahead Tier 1 and Tier 3 ABC projections.

5.5.4.1 The Stock-Recruitment Relationship (SRR): Core Uncertainties

To provide further background on the assessment history and the SSC's decision process, we present further details on the stock-recruitment relationship (SRR). Within the Tier 1 framework, the SRR is central to the pollock assessment because it drives estimates of stock productivity, reference points such as F_{msy} and B_{msy}, and formally risk-averse ABC specifications (based on the harmonic mean of the F_{msy} distribution). Over the years, several recurring SRR themes appear across the assessment history:

- Assessments evaluated both Beverton-Holt and Ricker forms, but generally favored a parameterization based on unfished recruitment R_0 and steepness h, with the Ricker-style treatment often carrying the main management interpretation.
- Steepness has been constrained with an informative prior because the pollock data alone do not reliably identify the SRR at low stock size. When more diffuse priors were tested, they produced implausible productivity patterns and unrealistic estimates of low-biomass recruitment.
- The 1978 year class was identified as an influential outlier because it was extremely strong despite low parental biomass. Sensitivity analyses repeatedly showed that removing it lowers estimated steepness, but retaining it was considered important because it strongly informed the slope near the origin (of the SRR).

- Estimation of recruitment variability (σ_R) was explored formally, but keeping it fixed at 0.9 was judged more precautionary because lower estimated variability made the SRR steeper and inflated F_{msy} and implied productivity.
- The most recent one to two year classes are routinely excluded from the SRR fit because retrospective checks show those cohorts are too unstable early in life to anchor long-run productivity estimates.
- Recent assessments increasingly stressed that SRR *stationarity* is doubtful. Temperature, stratification, predation, and other ecosystem drivers affect recruitment success, and newer work has moved toward explicitly evaluating environmental covariates (see pollock example in appendix on HCR alternatives).

This background matters directly for management. Tier 1 requires a reliable estimate of F_{msy} and its uncertainty, which depends on the SRR. Tier 3 avoids that dependence by using proxy reference points such as $F_{35\%}$. The 2024 assessment reflects this tension most clearly, recommending use of Tier 3 management until the stock-productivity and SRR issues are revisited more fully.

5.5.4.2 Ecosystem Non-Stationarity and Recruitment Drivers

The SRR discussion in the pollock assessments is tightly linked to a broader ecosystem narrative about why recruitment can vary so strongly from one period to another. Several mechanisms recur throughout the assessment history:

- Temperature and stratification affect age-0 energy allocation. In warm, stratified summers, young pollock tend to spend more energy on growth and less on lipid storage, leaving them with poorer condition entering winter and raising over-winter mortality.
- Winter sea ice governs the extent of the summer cold pool, which structures habitat use across the EBS. In cold years, the cold pool acts as a barrier that helps separate age groups spatially, while in warm years its contraction or disappearance increases overlap between adults and juveniles (and potential for cannibalism).
- Bottom-up prey conditions matter directly. Small copepods support larvae and early juveniles, while larger, lipid-rich copepods and euphausiids help age-0 fish build the reserves needed for winter survival. Poor late-summer prey fields are repeatedly associated with weak recruitment.
- Top-down controls are also important. As noted above, adult pollock are major predators of juvenile pollock, so reduced cold-pool separation can increase cannibalism. The assessments also note predator interactions with arrowtooth flounder, including a cultivation or depensation dynamic in which large adult pollock suppress a predator of juvenile pollock.
- Oceanographic transport and broader ecosystem competition influence survival pathways as well. Years with more favorable larval transport can improve nursery retention, while post-2010 divergence between pollock (increased) and Pacific cod (reduced) recruitment has been interpreted as evidence of broader ecosystem change.

Recent warm years, especially the 2014–2021 warm period and the extreme 2018–2019 conditions, are often treated as evidence that the SRR is unlikely to be stationary. The loss of the cold pool, degraded prey resources, poor fish condition, and broad zoogeographic shifts all reinforce the argument that environmental forcing can change realized productivity even when the fitted time-invariant SRR itself is largely unchanged. Research suggests that SR models with time-varying parameters might be more effective in detecting temporal changes in stock productivity (e.g., Peterman et al. 2000, Spencer et al. 2016, Marshall et al. 2024, Spencer et al. in prep, Collie et al. in revision).

The assessments also place the SRR in a broader multi-species and management setting:

- Multi-species statistical models suggest that pollock natural mortality can be materially higher than the fixed rates assumed in simpler single-species models once predation by pollock, Pacific cod, marine mammals, and other consumers is represented explicitly.
- Those same efforts reinforce how large cannibalism can be in absolute terms and why trophic feedbacks complicate interpretation of the single-species SRR and the reference points derived from it.
- Fishery-management responses, especially those associated with Steller sea lion conservation, changed the spatial and temporal distribution of harvest through exclusion zones, habitat-specific TAC limits, and greater seasonal dispersion. Those measures do not alter the SRR directly, but they are part of the management backdrop against which pollock productivity, prey availability, and localized depletion concerns have been interpreted.

Together, these points help explain why recent assessments have become more cautious about leaning too heavily on a single stationary SRR for management. The stock-recruitment model remains essential, but the assessments increasingly frame it as one component of a system that is also shaped by climate, prey fields, predation, movement, and management structure.

The archived assessments also report B_{msy} and $B_{35\%}$ reference points. Their year-to-year movement provides context for how the underlying SRR and productivity assumptions changed through time. The inferred reference points are not fixed constants across the archive. Instead, they move as assessment authors refine model specifications including spawning-biomass weight-at-age, the SRR treatment (e.g., prior assumptions, the stock-recruit conditioning periods, σ_R, etc.). The dashed lines show the 2002-2024 averages: mean B_{msy} = 2.164 million t and mean $B_{35\%}$ = 2.212 million t. The missing $B_{35\%}$ point in 1998 is because it predates the later reporting convention used in the Amendment 56-era documents (Figure A5.2).

5.5.4.3 2024: Reclassification to Tier 3a and Implications

In 2024 the SSC changed the framework after a period of large differences between Tier 1 and Tier 3 (Figure A5.1). Rather than continuing to apply large ad hoc downward adjustments under a Tier 1 label, the SSC supported reclassifying EBS pollock to Tier 3a. The rationale, as described in the SSC minutes, centered on three points:

- Much of the information driving F_{msy}, B_{msy}, and the probability distribution for F_{msy} came from the conservative priors used in the assessment model rather than from contrast in observations near the SRR origin.
- Despite the pollock assessment being one of the most “data-rich” in Alaska, there are relatively few recent observations at low stock size, so productivity at low spawning biomass remains difficult to estimate with confidence.
- The Tier 3a classification was considered a clearer acknowledgment of the uncertainty and subjective nature about stock productivity.

With this move, Tier 1 considerations will be omitted from the recommendations for ABC and instead will rely on the Tier 3 control rule. Additional considerations on ecosystem status and ancillary information as considered during the 2008-2010 period will continue to play a role.

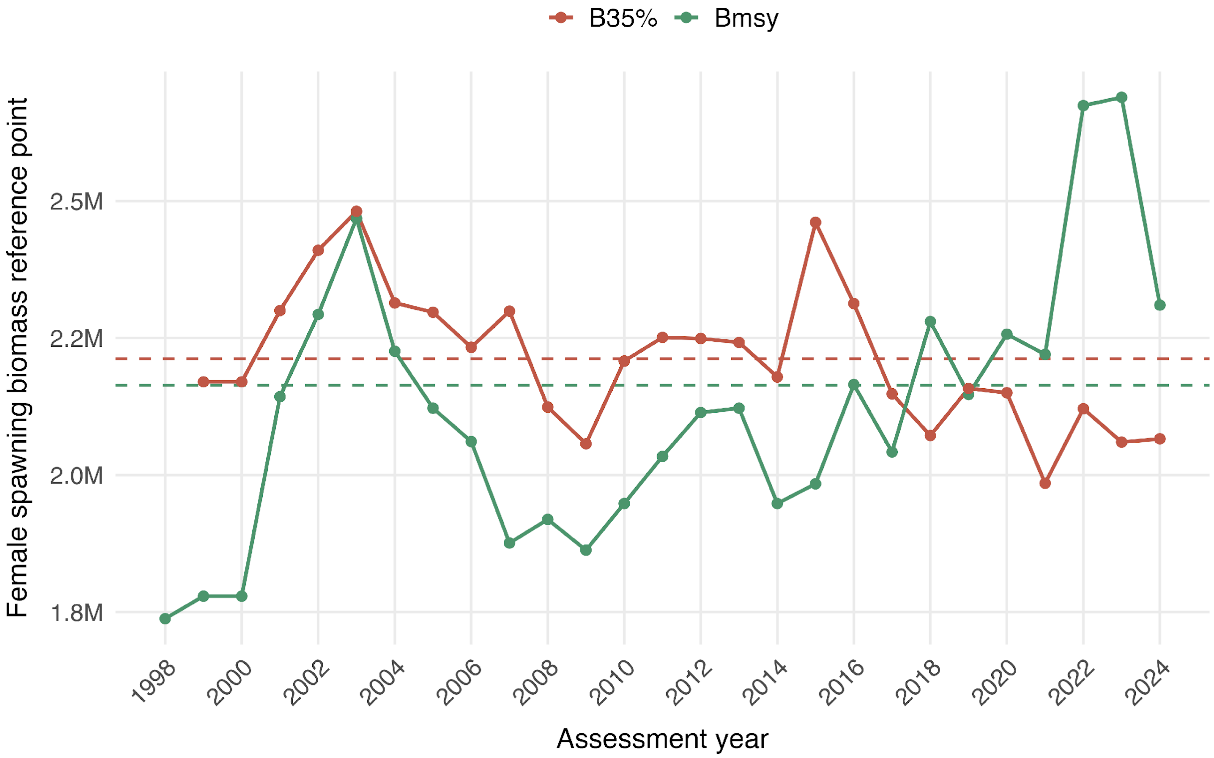

Figure A5.2: Assessment-year history of Bmsy and B35% reference points extracted from the archived pollock assessments. Dashed lines mark the 2002-2024 means.

5.5.4.4 BSAI/GOA Rockfish

Rockfish in the BSAI and GOA show variability in stock productivity and recruitment that suggest alternatives to the status quo HCR may be beneficial. A recent analysis of U.S. fish stocks by Marshall et al. (2024) found time-varying stock productivity in 50 of 84 fish stocks, including both BSAI and GOA POP. Stock productivity refers to the maximum capacity of the stock to replace itself (i.e., the ratio of recruits produced per unit of spawner biomass, evaluated at low biomass to remove the effect of compensatory reductions in productivity at high biomass). Stock productivity was estimated with state-space recruitment models in which the productivity parameter (i.e., the density-independent parameter of the Ricker recruitment model) was modeled with temporal variation. BSAI and GOA POP showed similar patterns in stock productivity, with low productivity during the 1960s, and increasing productivity from the 1970s to maximum productivity in the early 1980s. Since the early 1980s, productivity has shown a decades-long decline and now is estimated as below the long-term mean for each stock. GOA and BSAI POP represent interesting cases in which stock biomass is relatively large (i.e., Tier 3a with SSB > $B_{40\%}$) despite potential temporal declines in productivity. Because stock-recruitment analyses are typically not conducted for these Tier 3 stocks, these changes in productivity are not considered in the computation of the reference points and control rules. Research on alternative HCRs indicate that dynamic HCRs which are updated in response to temporal patterns in productivity would allow higher yields during high-productivity periods, and maintain the stocks at higher biomass levels (Collie et al. in review, Spencer et al. in prep; see section 3 below).

BSAI blackspotted/rougheye rockfish indicate how uncertain estimates of recent recruitment can affect Tier 3 biomass reference points, and produce non-intuitive harvest recommendations under the current HCR. In the 2024 BSAI blackspotted/rougheye stock assessment, the 2011 year class was estimated as more than 8 times larger than the next largest year class, with a large coefficient of variation of 0.42.

Despite this year class being 13 years old at the time of the 2024 assessment, the late age of survey selectivity and maturity has limited the contributions of this year class to survey biomass estimates and SSB, respectively. However, under current methods this estimate of recruitment would be incorporated into the estimate of $B_{40\%}$ (i.e., $B_{40\%}$ = mean recruitment * $SPR_{F40\%}$). Without any adjustments to the 2011 year class estimate, the change in mean recruitment and $B_{40\%}$ would lower the relative stock size (i.e., $B/B_{40\%}$) from 1.04 in the 2023 harvest projection to 0.73 for the 2024 stock assessment, and the ABC would be reduced by approximately 20% (despite the survey abundance increasing in the 2022 and 2024 surveys). Following methods applied for other Alaska stocks with similar issues, the approach adopted in the 2024 BSAI blackspotted/rougheye assessment was to replace the 2011 year class estimate with a value considered more likely (i.e., the 2022 year class estimate, the next largest value) for the purpose of computing average recruitment and $B_{40\%}$.

The central issue in the BSAI blackspotted/rougheye example is that there is currently no standardized procedure for addressing uncertain recent year classes that disproportionately affect biomass reference points (i.e., $B_{40\%}$) and relative stock size (i.e., $B/B_{40\%}$) more than estimated stock size. A potential approach is to base biomass reference points on changes in stock productivity rather than simply changes in recruitment (see section 3 below in dynamic HCRs). Short of this, a standardized protocol to address the impact of recent, uncertain year class estimates on Tier 3 biomass reference points would be useful.

5.5.4.5 Greenland turbot

A primary issue for BSAI Greenland turbot is that it is a stock characterized by infrequent recruitment events. Between 2012 and 2023, recruitment was below average with several years (2019-2022) completely lacking age-1 through age-3 observations of Greenland turbot in the Bering Sea Shelf Bottom Trawl Survey. This period of below average recruitment was preceded by relatively strong recruitment events between 2007 and 2010 and was associated with a larger cold pool extent and a cool stanza in the Bering Sea. Recruitment is expected to remain low under warming conditions.

Other issues stemming from the assessment are:

- Poor fits to several data sources
- A strong retrospective pattern
- Uncertainty about initial population size and its impact on the estimate of population scale.

5.5.4.6 Snow crab

Multiple issues have arisen in the EBS snow crab assessment and associated management in recent years including the total collapse of snow crab stock prompting a directed fishery closure and rebuilding plan when the stock was declared overfished (Szuwalski et al., 2023). In 2023 the stock was at a historic low, with the last 9 years being the lowest on record.

Volatile abundance changes have occurred as a result of:

- recruitment variability
- fishing mortality (although this is likely less of an impact given that only a small fraction of the stock is actually vulnerable to the fishery (<5% of the modeled crab in the assessment). However, it's possible that the fishery has had a large impact on the crab that are vulnerable to the fishery and if there are feedbacks with maturity, that could have big impacts on how many crab grow to commercial size.
- marine heatwave induced mortality events[Szuwalski et al., 2023].

Additional assessment-related issues include:

- Convergence
- Updated maturity data
- Uncertainty around the reproductively important fraction of stock
- Density dependence in maturity and cessation of growth

Currently, commercial sized male snow crab are at a historic low and assessment authors for several years have noted that the current management currency of mature male biomass (MMB) in the OFL setting (HCR context) could allow for all large males to be theoretically harvested should the TAC be set close to the OFL (Szulwalski et al., 2025). Alternative biomass currencies (such as an alternative functional maturity definition set at 95 mm) have been proposed in the assessment process but as yet no changes to reference points or the biomass currency upon which OFL (and ABC) specifications are made for management purposes. The SSC has recommended that a stock-specific ABC control rule could be developed for snow crab which would limit the exploitation rate for larger-sized crab.[31].

5.5.4.7 Bristol Bay red king crab

Substantial stock status issues have arisen for BBRKC in recent years including closures of the directed fishery from 2021/22-2022/23. A 20-25% buffer on OFL for ABC has been employed with notable stock concerns including the following:

- Continued lack of recent recruitment likely due to early life history bottlenecks
- Model's poor fit to the female survey biomass in the last few years
- Concerns over model retrospective patterns

Poor environmental conditions have also been noted for this stock including:

- Poor feeding conditions for larval red king crab in 2025 which is likely to result in a prolonged period of continued decline in recruitment due to poor larval survival (ref to ESP).
- Recruitment declines may be attributed to susceptibility of the stock to bottom water pH declines (ocean acidification) which result in negative impacts on growth, shell hardening and survival.
- Potential reduction in the reproductive potential of the stock as evidenced by an observed increase in the proportion of mature females with empty clutches in 2025.
- Distributional shifts attributed to cold pool

Bristol Bay red king crab was recommended for inclusion in any alternative HCR evaluations by the CPT (in addition to snow crab) to capture stock specific biological differences and in particular distinct biological differences for crab stocks from groundfish stocks.

5.5.4.8 Gulf of Alaska Pacific Cod

The text for this section is contributed from a manuscript that is currently in peer review entitled "Integrating environmental considerations in the U.S. stock assessment process: Lessons learned and future directions"

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[31] See SSC minutes June 2025 "Given that the OFL is specified in the FMP, the SSC recommends that the author and CPT consider whether concerns about the currency of management could be satisfactorily addressed with a simplified ABC control rule that limits the exploitation rate for larger-sized crabs. The SSC notes that stock-specific ABC control rules have been applied occasionally for groundfish, such as for GOA pollock, and exploitation rates have been used to justify lower ABCs in BS pollock."

Pacific cod (Gadus macrocephalus) is a fast growing and short-lived species that is important commercially and for subsistence in the Gulf of Alaska (GOA) (Maschner et al. 2008). Analyses have shown that Pacific cod move to deeper water in warmer years increasing their availability to the Alaska Fisheries Science Center's (AFSC) longline survey (a key data input in the assessment) (Barbeaux et al. 2017; Yang et al. 2019; Fig 8). An unusually severe and protracted marine heatwave in 2014-2016 resulted in stark declines in Pacific cod biomass (Barbeaux et al. 2017). Two causal mechanisms were hypothesized to explain the rapid and extreme response of cod to the anomalously warm conditions: (1) reduction in suitable thermal habitat for hatching GOA Pacific cod led to reduced hatching success (Walsh et al. 2018; Laurel and Rogers, 2020), and (2) increased metabolic demand combined with reduced prey supply led to lower growth potential of maturing cod (Barbeaux et al. 2020).

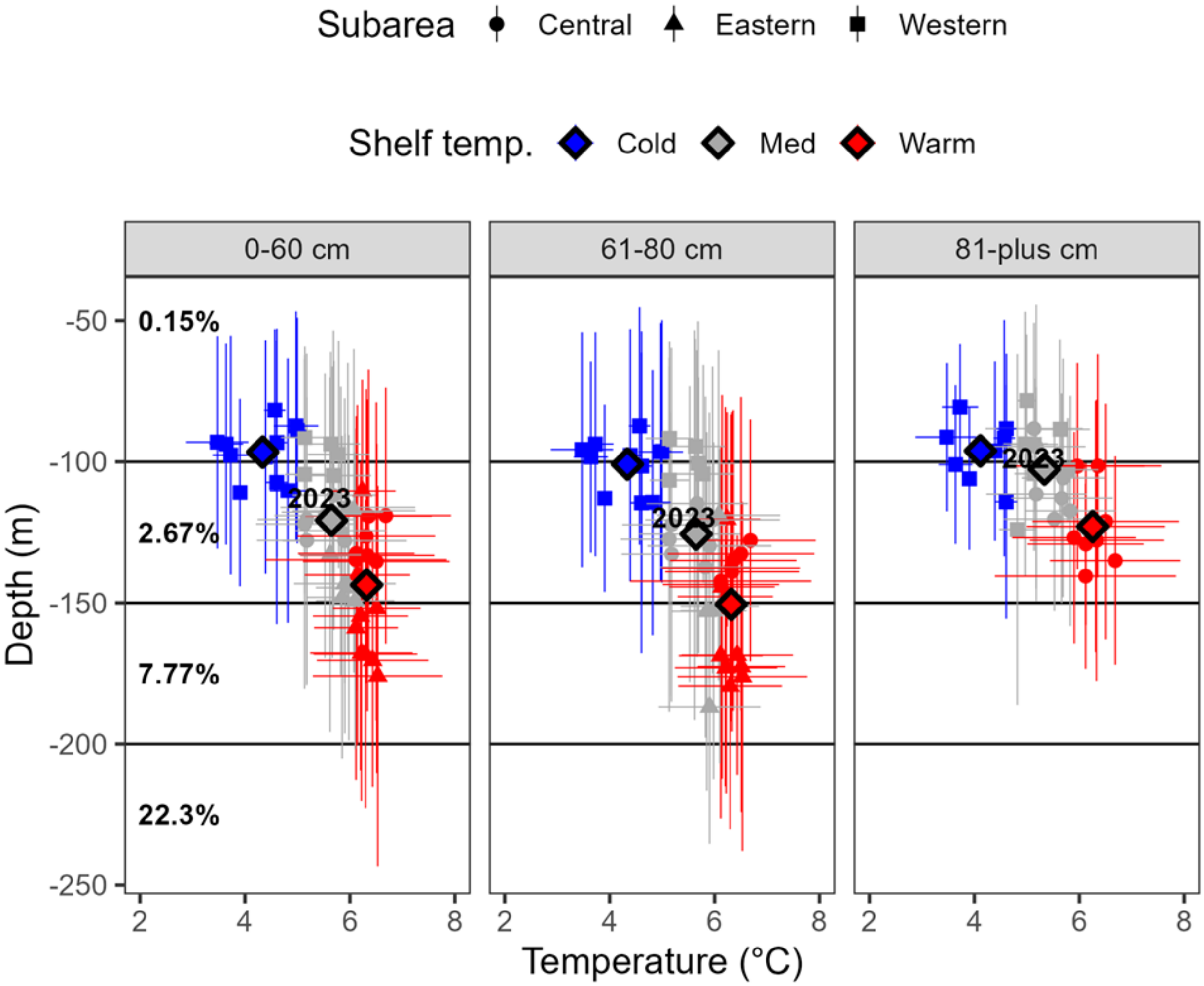

Figure A5.3. Area-weighted observed bottom temperature compared to CPUE-weighted depth of Gulf of Alaska (GOA) Pacific cod from the AFSC's GOA bottom trawl survey for different size classes. 'Cold', 'Med', and 'Warm' temperatures are defined as 33% percentiles of observed area-weighted bottom depths. The year of the most recent survey is shown in text, as the average temperature and depth across the Subareas. Horizontal black lines indicate the depth strata for the AFSC longline survey that overlap with GOA Pacific cod depth distribution, and bold black text is the proportion of hatchis deployed by the AFSC longline survey in these depth strata. ***Figure originally from the 2023 GOA Pacific cod stock assessment (Hulson et al. 2023))***

The impacts of temperature anomalies on the availability of Pacific cod to the longline survey was first incorporated into the stock assessment as a research model in 2016 (Barbeaux et al. 2016) and in the operational model in 2017 (Barbeaux et al. 2017). The assessments showed that the center of abundance of Pacific cod in the GOA moved deeper and better-overlapped the depth surveyed by the AFSC longline survey in warm years, a finding later confirmed by Yang et al. (2019). In the 2017 assessment, the catchability of the AFSC longline Relative Population Numbers index included a parameter to modify annual values based on a bottom temperature index (the June Climate Forecast System Reanalysis 10cm index bottom temperature anomaly for shallow depths in the central GOA; "CFSR index"). The relationship between the CFSR index and catchability was represented by a log-linear relationship: log(Qy) = log(Q + TyB) where Qy is catchability for a given year, Q was the time-invariant mean catchability, Ty was the annual CFSR index and B is the scaling parameter. The model also introduced internal estimation of natural mortality specifically for marine heatwave years (2015-2016) to account for the suspected increase in mortality during the 2014-2016 marine heatwave with a separate natural mortality parameter for all other years in the model. Both natural mortality parameters were estimated with lognormal priors (Barbeaux et al. 2017).

Two analyses have been conducted that test the preference of the model's inclusion of the environmental link to ensure that this relationship holds over time (e.g., Hulson et al. 2023). The first test includes a retrospective analysis in which a model without the environmental link is compared to the current operational assessment that includes the environmental link through AIC comparison. The second test compares the operational assessment model to a model that includes a 'white noise' environmental link. Both of these tests continue to prefer the CFSR bottom temperature index over a model without an environmental link and one that merely includes 'white noise'. Thus the 2018-2024 stock assessments have maintained both the linkage between the CFSR index and longline survey catchability and the 2-parameter configuration for natural mortality, with a slight modification to expand the years corresponding to the marine heatwave natural mortality parameter to be 2014-2016.

Several research models have been developed to explore environmental linkages to various aspects of Pacific cod population dynamics. The most recent research model was presented alongside the operational assessment model in 2020 and built on the operational assessment model by including relationships between the marine heatwave index and recruitment variability and age-specific natural mortality (which were explored in previous research models); this research model also included the effects of the CFSR index on several growth parameters (Barbeaux et al. 2020). Specifically, L∞ and k from a von Bertalanffy growth function were both modeled with linear relationships to the CFSR index. Recruitment was modeled assuming a Beverton-Holt stock-recruit curve with unfished recruitment (R0) scaled to the winter marine heatwave index and both steepness and R0 estimated with broad uniform priors. Relationships between the winter marine heatwave index and natural mortality were modeled separately for ages 1, 3, and 5. A single age- and time-invariant natural mortality parameter was estimated for ages 7-10. Natural mortality estimates for ages 2, 4, and 6 were linearly interpolated from the estimates for ages 1, 3, 5, and 7-10. In 2020 the authors concluded that the environmental linkages to recruitment and growth parameters required further study prior to use in an operational stock assessment model. The authors presented an updated version of the 2020 research model again in 2021, but this time conducted a more thorough evaluation of the strength of the environmental linkages per request from the SSC.

To evaluate the strength of the environmental linkages in the 2020 research model, the authors conducted three analyses: (1) an examination of the MLE variance estimates obtained through the square root of the inverse Hessian for the ecosystem-linked parameters; (2) diagnostics from MCMC runs; and (3) placing normal priors ($\mu = 0$) with various levels of variance to test the strength of the relationships. All three tests confirmed strong relationships between environmental indices and natural mortality estimates and length at the youngest age in the model. Environmental linkages to recruitment parameters and other growth parameters were weak (Barbeaux et al. 2021). The 2020 research model was the author's preferred model in 2021 due to its overall performance and the strength of the relationships found for the environmental linkages. However, the SSC concluded that the additional complexity included in the model was premature without further explanation and exploration of the individual changes, and advised that each change should be supported with a sufficient rationale and an assessment of model improvement (Dec 2021 SSC meeting minutes). The SSC was particularly concerned with the lack of significant relationship for the environmental linkage to the von-Bertalanffy k parameter. Since the 2021 assessment, investigations into environment-linked models have continued through funding provided by the Pacific Cod Disaster Relief, however, the authors have yet to recommend operational models with additional environment-links.

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