Advancing Essential Fish Habitat Component 1 Descriptions and Maps for the 2023 5-year Review

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Abstract: Councils and NMFS are required to review the essential fish habitat (EFH) components of Fishery Management Plans (FMPs) and revise or amend these components based on available information at least every five years (50 CFR 600.815(a)(10)) in what is referred to as an EFH 5-year Review. The new EFH component 1 information available for the 2023 EFH 5-year Review demonstrates advances in EFH descriptions and identification (maps) based on modernizing the species distribution modeling (SDM) approach to mapping EFH that was established in the 2017 Review[9]. This document and supporting documents presents the complete 2023 SDM EFH mapping methods and results and reports the comprehensive and iterative review process that this work has undergone for the 2023 Review. All of the new SDM ensembles constructed for the summer distribution of FMP species in the eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) describe and map EFH Level 2 (habitat related abundance), meeting a key objective of the EFH Research Plan for Alaska. In addition and for the first time, SDMs describe and map EFH Level 1 (distribution) for settled early juvenile life stages in the GOA and SDMs and vital rates are combined for a subset of species in all regions to map EFH Level 3 information (habitat related vital rates), also meeting timely EFH research objectives for this 5-year Review. In the present work EFH is described and mapped for 31 North Pacific groundfish species in the EBS, 24 in the AI, 41 in the GOA across up to three life stages and additionally described and mapped for four crabs in the EBS, two crabs in the AI, and one octopus in all three regions. A total of 224 new or revised EFH Level 1, 2, and 3 maps for species' life stages are available for the 2023 Review. The 2023 SDM ensemble EFH mapping approach is a foundational improvement over the single SDM method of 2017. In particular, analysts identified that certain SDMs tend to under or over predict area occupied. The SDM ensemble helps mitigate that bias and provides a universal SDM application across multiple FMPs that can be easily expanded to consider additional constituent models in the future. Moving from using single SDMs to SDM ensembles (and other important methods advancements for the 2023 Review) should reduce the magnitude of the change in EFH area attributable to modeling methods in future EFH mapping, and improve our ability to identify events in shifting species distributions due to climate change or other impacts to habitat. The new descriptions and maps are an improved foundation to meet the EFH mandates. The underlying SDMs are an advancement of habitat science available to inform EBFM through several established and developing pathways. Future research is also recommended.

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Executive Summary

The objective of an essential fish habitat (EFH) 5-year Review is to review the ten EFH components of Fishery Management Plans (FMPs) and revise or amend EFH components as warranted based on available information (50 CFR 600.815(a)(10)). The EFH regulations outline ten components for the EFH contents of FMPs. For component 1, FMPs are required to describe and identify EFH in text that clearly states the habitats or habitat types determined to be EFH for each life stage of the managed species and to include maps that display the geographic locations of EFH or the geographic boundaries within which EFH for each species and life stage is found. Additionally, FMPs must demonstrate that the best scientific information available was used in the description and identification of EFH, consistent with national standard 2 (50 CFR 600.815(a)(1)(i)(B)).

This Discussion Paper and supporting documents presents the new information that NMFS developed under EFH component 1, the description and identification of EFH, for the 2023 5-year Review. **These documents describe research using species distribution models (SDMs) to describe and map EFH for life stages of the summer distribution of North Pacific groundfishes and crabs** and provide the details of the iterative review process for this body of work and future research recommendations.

The requirements for EFH component 1 are that some or all portions of the geographic range of the species are mapped (50 CFR 600.815(a)(1)(iii)(1)). These mapping requirements have been comprehensively met for the 2023 SDM ensemble EFH maps. The new EFH maps also support the EFH component 2 fishing effects evaluation.

Component 1 EFH Descriptions and Identification

Component 1 descriptions and identification of EFH (50 CFR 600.815(a)(1)) consist of written summaries, tables, and maps in the FMPs or their appendices. The EFH regulations provide an approach to organize the information necessary to describe and identify EFH (50 CFR 600.815(a)(1)(iii)). When designating EFH, the Council should strive to describe and identify EFH information in the FMPs at the highest level possible (50 CFR 600.815(a)(1)(iii)(B))—

Level 1: Distribution data are available for some or all portions of the geographic range of the species.

Level 2: Habitat-related densities or relative abundance of the species are available.

Level 3: Growth, reproduction, or survival rates within habitats are available.

Level 4: Production rates by habitat are available. [Not available at this time.]

Further, the EFH regulations state that Councils should strive to describe habitat based on the highest level of detail. **The study presented uses this approach to explain the SDM information and maps in terms of EFH Levels 1 and 2, and for the first time, Level 3.**

2017 EFH 5-year Review

The North Pacific Fishery Management (Council) completed the last EFH 5-year Review in 2017 (Simpson et al. 2017). For that 5-year Review, a new approach to EFH component 1 was developed that used SDMs to map distribution and relative abundance across different habitats for individual life stages of species in Alaska FMPs, including Groundfish of the Bering Sea and Aleutian Islands Management Area (BSAI FMP), Groundfish of the Gulf of Alaska (GOA FMP), and Bering Sea/Aleutian Islands King and Tanner Crabs (Crab FMP). New information was also reviewed for the FMP for Salmon Fisheries in the EEZ off Alaska that included quantitative model-based maps (Echave et al. 2012) and for the FMP for Fish Resources of the Arctic Management Area that included maps of species distribution from surveys.

Three types of SDMs were used to model the distribution and relative abundance of species' life stages in the BSAI, GOA, and Crab FMPs, including a generalized additive model (GAM), hurdle GAM, and maximum entropy model (MaxEnt), using 4th root transformed catch-per-unit-effort (CPUE) data from NMFS Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys. The type of SDM applied was determined *a priori* by the prevalence of a species' life stage in the survey catch.

The 2017 SDM approach to EFH was a significant advancement, providing new EFH Level 1 (distribution) and Level 2 (habitat-related density or abundance) information for groundfish and crabs and substantially improving the EFH maps. The new and revised EFH descriptions and maps were combined with advancements in understanding the impacts of fishing and non-fishing activities on EFH and other new information in the 2017 5-year Review (Simpson et al. 2017). Accordingly, the Council and NMFS revised the EFH sections of these FMPs to incorporate the results of 2017 5-year Review and the EFH Omnibus Amendment package was approved on May 31, 2018 (83 FR 31340, July 5, 2018).

2023 EFH 5-year Review

The 2023 EFH 5-year Review is an iterative review process. Review of current and new EFH information by experts and other stakeholders is an important part of an EFH 5-year Review for our region and serves to strengthen the contributing research and the EFH 5-year Review process overall.

Since the 2017 EFH 5-year Review, NMFS has worked to improve the EFH descriptions and maps and the results of this work are presented here. During the 2023 Review process, the studies contributing new information for EFH component 1 have been reviewed by the SSC, Ecosystem Committee, Plan Teams, stock assessment authors, species experts, and other stakeholders. EFH analysts have incorporated feedback from each of these reviews into revisions to the new SDM ensemble methods, EFH maps, and EFH component 1 reporting for the 2023 Review. As some recommended improvements are not possible at this time without additional extensive research, input will inform priorities for the next iteration of EFH mapping, where continued incremental improvements will add value to EFH component 1. Chapter 2 of this document is an overview of the stages of the iterative process by which NMFS and the Council are reviewing the EFH component 1 descriptions and maps for the 2023 EFH 5-year Review—

- NMFS and the Council launched the 2023 Review in April 2019 with a presentation by NMFS to the Ecosystem Committee of the preliminary plan for review of the ten EFH components in the Council's FMPs and proposed approach to advancing the SDM EFH mapping approach of the 2017 Review.
- The SSC in June 2020 and a joint meeting of the Groundfish Plan Teams (JGPT) in September 2020 provided input to NMFS on proposed methods and planned research to support the new EFH component 1 information for the 2023 Review[10].
- In January 2021, NMFS EFH component 1 analysts and senior stock assessment scientists convened a summit of stock assessment authors to co-develop the process for their review of EFH component 1, which was an innovation by NMFS of the 2023 Review process.
- NMFS presented the 2023 Review Plan to the SSC in April 2021, when EFH component 1 analysts responded to the SSC and Plan Team input received in 2020, by providing an update on methods and revised draft results examples. The 2023 Review Plan was also presented to the

[10] EFH Component 1 SDM EFH Discussion Paper and Presentation to SSC January 2020 https://www.npfmc.org/efh-distribution/

Crab Plan Team (CPT) in May 2021, including draft SDM ensemble results for crabs.

- The stock author review of the draft SDM ensemble methods, results, EFH maps, and current EFH component 1 information in the FMPs occurred from May–September 1 2021. EFH analysts presented a response plan to address all reviewing stock author concerns to the extent possible at this time to JGPT in September 2021.
- Between September 2021 and January 2022, EFH component 1 analysts worked with reviewing stock authors to address their concerns, revised the draft methods, updated the results, and submitted three regional NOAA Technical Memoranda to the NMFS publication process (Supporting Documents 5).
- Stock assessment author review of the draft SDM ensemble methods, results, and EFH maps is discussed in detail in Appendix F. EFH analysts presented a draft of this report and how we worked with stock assessment authors to address their review to the JGPT in November 2021.
- EFH analyst responses to extensive SSC and Plan Team input on EFH component 1 from June 2020 through November 2021 are in Appendix A.
- EFH analysts presented the complete package of draft SDM ensemble EFH maps available for the 2023 Review to the CPT and EC in January 2022 and to the SSC for review in February 2022. This review represents an important transition in the iterative review process.
- In February 2022, SSC reviewed the new draft EFH component 1 SDM ensemble results and draft EFH maps, incorporating revisions from the stock author 2021 review addressing concerns to the extent possible at this time. We provided the SSC with the EFH Component 1 SDM EFH Discussion Paper (January 2022 version of this document), a report of the stock assessment author review of EFH component 1 (Appendix F), and other supporting documents (Chapter 5). SSC noted that the new EFH maps reflect the best available science for characterizing EFH component 1 at this time and recommended clarification for some of the new information.
- In October 2022, by their request the SSC reviewed an update to the EFH component 1 SDM ensemble EFH maps and how remaining stock author concerns and recommendations had been addressed in a Supplemental Analysis prepared by NMFS (Appendix G). SSC recommended that the 2023 EFH SDM approach (component 1) and the Fishing Effects model (component 2) represent a reasonable scientific basis for evaluating whether the effects of fishing are more than minimal and not temporary. SSC also provided future research recommendations.
- EFH analysts prepared the draft 2023 EFH 5-year Review Summary Report[11] following the October 2022 meeting.

New SDM ensemble-based EFH maps for the 2023 EFH 5-year Review

The Alaska EFH Research Plan that guides research to meet EFH mandates in Alaska was revised following the completion of the 2017 5-year Review (Sigler et al. 2017). This revision incorporated additional research and information needs along with the five long-term EFH research goals that have guided EFH research in Alaska since 2005. The revised plan provided two-specific research objectives to advance EFH information for Alaska in the intervening 5 years leading up to the 2023 5-year Review:

1. Develop EFH Level 1 (distribution) or Level 2 (habitat-related densities or abundance) for life stages and areas where missing.
2. Raise EFH information from Level 1 or Level 2 to Level 3 (habitat-related growth, reproduction, or survival rates (i.e., vital rates)).

[11] 2023 EFH 5-year Review Summary Report; available on Council agenda for this meeting

NMFS Alaska Region (AKR) and AFSC funded several studies to accomplish Alaska EFH Research Plan research objectives. **This document presents new research from the following study available for the 2023 EFH 5-year Review—**

Advancing Model-Based Essential Fish Habitat Descriptions for North Pacific Species, Ned Laman[12], Jodi Pirtle[13], Jeremy Harris[14], Margaret Siple[10], Chris Rooper[15], Tom Hurst[16], and Christina Conrath[17], funded by the Alaska EFH Research Plan in FY19, FY20, and FY21 (hereafter referred to as Laman et al. study) (Chapter 3).

The purpose of this study is to describe and map EFH for federally managed North Pacific groundfish and crab species in the EBS, AI, and GOA using SDMs and to advance levels of EFH information for the life stages of those species. This study is guided by the Alaska EFH Research Plan (Sigler et al. 2017) research priority 1 to characterize habitat utilization and productivity using the best available scientific information to accomplish the two specific research objectives of the revised plan.

The Laman et al. study demonstrates an **SDM ensemble EFH mapping approach** for the 2023 EFH 5-year Review, where EFH is described and mapped for the summer distribution of 31 North Pacific groundfish species in the EBS, 24 in the AI, 41 in the GOA across up to three life stages. In addition, EFH is described and mapped for four crabs in the EBS, two crabs in the AI, and one octopus in all three regions. The ensembles describing and mapping EFH in this study advance EFH information levels and refine EFH area maps for North Pacific species' life stages from none to Level 1 and from none or Level 1 to Level 2. This study also applies habitat-related vital rates from other studies to the ensemble outcomes to describe and map EFH Level 3 for the first time. **This study comprises the bulk of new EFH component 1 information available for the 2023 EFH 5-year Review and also supports the EFH component 2 fishing effects analysis.**

Two other EFH component 1 studies are not contributing to the EFH component 2 fishing effects evaluation and are presented in the 2023 Review subsequent to the Laman et al. study and fishing effects evaluation. **These additional studies for the GOA and Arctic FMPs are introduced in Chapter 1 of this document and included in the draft 2023 EFH 5-year Review Summary Report[18].**

The Laman et al. study's approach to using SDM-based ensembles for mapping EFH is described and contrasted with the SDM EFH approach of the 2017 EFH 5-year Review in the Methods 3.2 and Table 1. Highlights from the Laman et al. study approach are developing several data updates and modeling refinements, introducing EFH Level 3, and advancing EFH information levels, including—

- Expanding the SDM approach from the 2017 5-year EFH Review to include up to five constituent SDMs in an ensemble that provides a robust modeling framework for future EFH Reviews (three SDMs were applied in 2017 and a single SDM was selected *a priori* for each species' life stage based on prevalence in the bottom trawl surveys);
- Refining our methodology by modeling numerical abundance instead of 4th root transformed CPUE facilitated skill testing (lowest cross-validated root mean square error; RMSE) to identify the best fitting models for inclusion and weighting in the ensemble and improved the interpretability of model results (i.e., predicting numbers of animals instead of a heavily derived abundance index);

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[17] GAP, AFSC, Kodiak, AK
[18] Chapter 2 in EFH 5-year Review Summary Report; available on the Council's agenda for this meeting.

- Demonstrating the incorporation of new sources of species response data for the settled early juvenile life stage of groundfishes in the GOA added nearshore areas not previously modeled and allowed us to evaluate EFH for this critical life stage for the first time;
- Updating habitat covariates applied as independent predictors in the ensembles provided the opportunity to expand our observed temperature data set with an additional five years of AFSC RACE-GAP summer trawl survey bottom temperature observations, include recently modeled bottom temperature data from the coastal GOA regional ocean modeling system 3 km grid (applied to early juvenile SDMs only), update the GOA bathymetry and seafloor slope covariates, include additional derived seafloor terrain metrics in all regions, develop and include a seafloor rockiness metric for the AI and GOA, and to incorporate the most recent substrate data in the Bering Sea;
- Enhancing existing data sets (both response and predictor variables) with the addition of five recent years of survey results from the AFSC RACE-GAP summer bottom trawl surveys (2015–2019) extended our temporal coverage in the EBS to 38 years (1982-2019), in the AI to 29 years (1991-2019), and to 27 years in the GOA (1993-2019);
- Updating length-based life stage definitions for North Pacific groundfish species in the SDM ensembles based on updated maturity schedules or life stages definitions documented in the recent scientific literature tailored our abundance predictions to the best available scientific information and increased the number of life stages we could model; and
- Extending EFH to include settled early juvenile life stages allowed us to model this critical ontogenetic phase for North Pacific groundfish species for the first time.

The results of applying the SDM ensemble approach for mapping EFH are presented in the document as **three regional results case studies demonstrating EFH Level 2 maps with bridging comparisons between the 2017 and 2023 EFH maps.** These case studies present the full set of results for one species' life stage in each region and have been selected as examples of EFH area decreasing (arrowtooth flounder adults in the eastern Bering Sea), increasing (golden king crab life stages in the Aleutian Islands), and remaining relatively even (Pacific cod adults in the Gulf of Alaska) between 2017 and 2023 Reviews. Pacific cod settled early juveniles in the Gulf of Alaska are presented demonstrating EFH Level 1 and Level 3 maps for this life stage in that region.

The complete set of results for all species' life stages modeled in the three regions are provided in the three regional NOAA Technical Memoranda (Supporting Documents 5) and summarized in Appendix C. Comparisons between the 2017 SDMs and 2023 SDM ensembles and EFH maps are in Appendix D and the full set of the 2017 and 2023 EFH map overlay figures (e.g., as presented in the regional case study bridging figures) are provided in the supporting documents (Chapter 5). Expanded reporting of additional performance metrics considered by the Laman et al. study and requested for consideration by the SSC are in Appendix E. A synthesis (section 3.3.3) concludes the Laman et al. results section and draws from the results summaries and comparisons in the Appendices.

One valuable feature of habitat-related SDMs is that they can provide insight into the environmental conditions that affect patterns of species distribution and abundance to inform the EFH text descriptions and understanding of ecological mechanisms affecting species-habitat associations. The three most influential (highest percent contribution to the deviance explained by the SDM or ensemble) covariates for each species' life stage in the 2023 EFH 5-year Review are reported in Table C1 and in the results synthesis (section 3.3.3). **Summarized across all species' life stages modeled, the most influential covariates were—**

- Geographic location and bottom depth. One or both of these were present in the top three contributing covariates for over 90% of the SDMs and ensembles.

- Bottom currents and bottom temperature were less influential, but each appeared in the top three for approximately 25% of the SDMs and ensembles.
- Tidal maximum, bathymetric position index (BPI), sediment grainsize (*phi*), rockiness, and sponge presence were occasionally top contributors, and appeared in the top three in approximately 5–15% of SDMs and ensembles.

The most influential covariates also varied by region. In the AI, bottom currents were relatively more influential and bottom temperature was relatively less influential. In the Bering Sea, temperature was more influential and tidal maximum was less influential. In the GOA, sponge presence and BPI were relatively more influential than in other regions.

Complementary and recently published studies developing temporally dynamic SDM methods for mapping EFH (e.g., Barnes et al. 2022) will help improve understanding of how species' habitat-related distribution, abundance, vital rates, and population productivity (EFH Levels 1-4) are influenced by the rapidly changing environment in our region, which has the potential to help NMFS become more climate responsive to the EFH regulations and EBFM.

In comparing the 2017 SDMs and 2023 SDM ensembles (e.g., Table D2), it is apparent that the type of model used in 2017 had a large effect on the performance metrics and calculated EFH areas. **In the majority of cases, the performance metrics from the 2023 SDM ensembles demonstrated clear improvements over the 2017 SDMs. The 2023 SDM ensembles showed improvement in—**

- Lowest cross-validated root mean square error (RMSE) in 88% of models,
- Spearman's correlation (ρ) in 69% of models,
- Area under the receiver operating characteristic curve (AUC) in 52% of models,
- Poisson deviance explained (PDE) in 99% of models.
- In other cases, where clear improvement was not observed, the difference between the models was usually small, and in no instance was a decline observed across all metrics.
- Approximately 25% of ensembles in the present work predicted EFH areas larger by 100% or more; in almost all of these cases the 2017 SDM was hGAM.
- Approximately 18% of ensembles resulted in EFH areas that were smaller by at least half; in each of these cases the 2017 SDM was a MaxEnt model.

The SDM ensemble EFH mapping approach for the 2023 EFH 5-year Review provides several advantages. Certain classes of SDMs have tendencies to over- or under-predict distribution and abundance (i.e., MaxEnt and hGAM) (e.g., Harris et al. In preparation). Ensemble modeling essentially averages the predictions from multiple, best-performing constituent SDMs, which can provide abundance predictions that are more representative of habitat-related distribution and abundance than those produced by single SDMs in isolation. Due to the effect of moving from mapping EFH using single SDMs in 2017 to SDM ensembles in 2023, and barring large methods changes in future EFH mapping efforts, **we expect that changes in future EFH maps should be less attributable to the underlying mapping methods so that changes in species distribution due to the environment or other impacts may be more easily detected.**

Updates to data and methods used during the 2023 EFH 5-year Review have resulted in advancements in EFH Level for many species' life stages (Table D1). EFH Level 1 is applied to species' life stages with a model that predicts distribution or presence/absence, EFH Level 2 with a model that can also predict abundance or density, and EFH Level 3 where a vital rate has been combined with a model to supplement either Level 1 or Level 2 predictions. **The following EFH Level advancements are available for the 2023 Review—**

- Across all regions, 61 new species' life stages were modelled for the first time, and their EFH level was advanced from none to Level 2.
- In the GOA, the settled early juvenile life stages for 11 species were modelled for the first time and their EFH level was advanced from none to Level 1.
- Eight species' life stages where the settled early juvenile life stage was modelled for the first time are presented with additional EFH Level 3 information, advancing their EFH level to Level 3. Two of these species were based on Level 2 ensembles for the AI and EBS, while six were based on Level 1 SDMs for the GOA that use combined survey data.
- Seven species' life stages were not updated, and the EFH Level 1 designation from 2017 has not changed. These cases refer to species/life stages where fewer than 50 positive survey catches were available in 2022 (e.g., hauls where the species was present).
- In total, 55 species' life stages were advanced from EFH Level 1 to 2.
- Across all regions, 84 species' life stages were modelled as EFH Level 2 in both 2017 and 2022, although the data and methods were updated and revised in the 2022 ensemble approach to mapping EFH.
- For the first time, EFH Level 2 models were combined for member species of each of 10 stock complexes in the BSAI (6) and GOA (4) groundfish FMPs to represent the EFH of member species where a model was not possible at this time (i.e., fewer than 50 positive survey catches were available) (50 CFR 600.815(a)(1)(iv)(E)).

A total of 224 new and revised EFH descriptions and maps for the BSAI, GOA, and Crab FMPs are available for the 2023 EFH 5-year Review—

- New EFH Level 1 descriptions and maps for settled early juvenile life stages in the GOA FMP (11).
- New and revised EFH Level 2 descriptions maps for the BSAI (114), GOA (75), and Crab (6) FMPs (195).
- New EFH Level 2 descriptions and maps for stock complexes as a proxy for member species where a model was not possible at this time for the BSAI (6) and GOA (4) FMPs (10).
- New EFH Level 3 descriptions maps for settled early juvenile life stages for the BSAI (2) and GOA (6) FMPs (8).

While completing the body of work presented here, and through the iterative review process of the 2023 EFH 5-year Review, EFH component 1 analysts identified refinements and recommendations that could be considered for future EFH 5-year Reviews. These recommendations are in three categories:

1. Prioritize and improve EFH for select species (data and modeling);
2. Increasing the scope and applicability of EFH research; and
3. Improving process and communication.

A Future Recommendations section is included in this document and in each regional NOAA Technical Memorandum, which provides more detailed descriptions of the research and collaborative pathways the EFH component 1 analysts are recommending (Supporting Documents 5).

Importance of the new EFH Component 1 Information

The study presented in this document and two additional studies advance the SDM EFH maps of the 2017 Review and offer new techniques, including SDM ensembles, Arctic species SDMs, and IBM-based mapping for pelagic early life stages. This work is available to update the EFH descriptions and maps for many groundfish and crab species in the BSAI, GOA, Crab, and Arctic FMPs, including new and revised EFH Level 1 and 2, and for the first time EFH Level 3.

This body of work represents a significant advancement over the SDM EFH mapping approach of the 2017 Review. The 2023 SDM ensembles, and other data and mapping refinements, provide a robust and flexible framework for future EFH 5-year Reviews. This valuable set of information developed in an EBFM approach to EFH can be extended to stock assessment and other information needs in the region, as other **habitat science to management on-ramps** are established.

Since June 2020, we have received input on progress in a comprehensive and iterative review process from the SSC, Ecosystem Committee, Plan Teams, stock assessment authors, species experts, and the public. We look forward to sharing the body of new EFH component 1 information in the 2023 EFH 5-year Review Summary Report with the Council in February 2023.

Highlights of the 2023 Review:

- This EFH review focused on improving the SDM methods for mapping EFH component 1 and has modernized the SDM EFH mapping approach of the 2017 Review to update the EFH text descriptions, maps, and information levels in the BSAI, GOA, Crab, and Arctic FMPs.
- The Arctic FMP currently does not have SDM EFH maps and the current qualitative distribution maps combine many life stages and include most of the management area. The new SDM EFH maps are a substantial update with refined the text descriptions and considerations of climate change effects on EFH for Arctic species (Marsh et al. In review).
- The 2023 SDM ensembles are a foundational improvement to the single SDMs of 2017 for the BSAI, GOA, and Crab FMPs. In particular, NMFS identified that certain SDMs tend to under or over predict the area of occupied habitat (Harris et al. In preparation). The SDM ensemble helps mitigate that bias and provides a universal SDM application across multiple FMPs that can be expanded to consider additional constituent models in future EFH Reviews.
- Some of the revised EFH maps have smaller or larger EFH areas than the 2017 EFH maps. Moving from using single SDMs to SDM ensembles should reduce the magnitude of the change in EFH area attributable to modeling methods in future EFH mapping so that changes in species distribution due to the environment or other impacts may be more easily detected.
- The 2023 SDM EFH mapping approach has the potential to improve our ability to identify events in shifting species distributions due to climate change or other impacts to habitat, in particular when EFH is mapped over smaller time series (e.g., 5 year hindcasts) and with improved SDM forecasting methods (e.g., Rooper et al. 2021, Barnes et al. 2022).
- Research supporting future EFH 5-year Reviews could develop methods if resources are available to add other data sources and constituents to the SDM ensembles for a subset of species life stages, where additional data would really add value to EFH maps.
- Habitat science is a critical element of EBFM. The new EFH maps are an improved foundation to meet the EFH mandates. The underlying SDMs are an advancement of habitat science available to inform EBFM through several pathways (e.g., Goldstein et al. 2020, Rooper et al. 2021, Barnes et al. 2022, Shotwell et al. 2022).

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1 Introduction

1.1 Essential Fish Habitat Overview

Essential fish habitat (EFH) is defined as those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity (50 CFR 600.10). The EFH Final Rule requires that the National Marine Fisheries Service (NMFS) and Fishery Management Councils (Councils) describe and identify EFH for managed species, minimize to the extent practicable the adverse effects of fishing and other anthropogenic activities on EFH, and identify actions to encourage the conservation and enhancement of EFH. Federal agencies that authorize, fund, or undertake actions that may adversely affect EFH must consult with NMFS, and NMFS must provide conservation recommendations to federal and state agencies regarding these actions. As part of this mandate, EFH text descriptions and maps are necessary for each life stage of species in a Fishery Management Plan (FMP) (EFH component 1, descriptions and identification) (50 CFR 600.815) with an overarching consideration that the science related to this effort meets the standards of best available scientific information (NMFS National Standard 2 – Scientific Information 50 CFR 600.315).

The North Pacific Fishery Management Council (Council) described EFH for its FMPs in 1999 with an environmental assessment that also outlined human-induced effects on EFH. In 2000, a legal challenge of the EFH provisions nation-wide resulted in a reevaluation of EFH information by all Councils. In 2005, the Alaska Region and Council completed a more comprehensive EFH description and effects analysis in an environmental impact statement (EIS)[19].

Councils and NMFS are required to review the EFH components of FMPs and revise or amend these components based on available information at least every five years (50 CFR 600.815(a)(10)). The six Council FMPs are:

- Groundfish of the Bering Sea and Aleutian Islands Management Area (BSAI FMP)
- Groundfish of the Gulf of Alaska (GOA FMP)
- Bering Sea/Aleutian Islands King and Tanner Crabs (Crab FMP)
- Fish Resources of the Arctic (Arctic FMP)
- Salmon Fisheries in the EEZ off Alaska (Salmon FMP)
- Scallop Fishery off Alaska (Scallop FMP).

The Council conducted its first EFH 5-year Review and updated the EFH information for all six FMPs in 2010 (77 FR 66564, 11/06/2012). The Council concluded its second EFH 5-year Review in 2017 and updated EFH information for five FMPs (83 FR 31340, 7/05/2018, Simpson et al. 2017) (see section 2017 EFH 5-year Review).

For the 2023 Review, NMFS and the Council are evaluating the EFH components in the Council's FMPs. NMFS has prioritized the seven EFH components in bold for a comprehensive review:

1. **EFH descriptions and identification**
2. **Fishing activities that may adversely affect EFH**
3. Non-MSA fishing activities that may adversely affect EFH
4. **Non-fishing activities that may adversely affect EFH**
5. Cumulative impacts analysis
6. **EFH conservation and enhancement recommendations**
7. **Prey species list and locations**
8. Habitat Areas of Particular Concern (HAPC) identification
9. **Research and information needs**

[19] https://www.fisheries.noaa.gov/resource/document/final-environmental-impact-statement-essential-fish-habitat-identification-and

10. Review EFH every 5 years.

A comprehensive review of each of the seven EFH components prioritized by NMFS and the Council will be presented to the Council in a Summary Report in February 2023. If the Council chooses to update its FMPs based on the report, FMP amendments will be prepared along with the appropriate analytical documents through the normal Council process.

1.2 Component 1 EFH Descriptions and Identification

Each North Pacific Fishery Management Council FMP contains EFH information—

- BSAI FMP; section 4.2, and Appendices D, E, and F
- GOA FMP; section 4.2, and Appendices D, E, and F
- Crab FMP; section 8.16, and Appendix D.3.

Component 1 descriptions and identification of EFH consists of text, tables, and maps. The BSAI, GOA, and Crab FMPs contain **The requirements for EFH component 1 are that some or all portions of the geographic range of the species are mapped (50 CFR 600.815(a)(1)(iii)(1)). These mapping requirements have been comprehensively met for the 2023 summer distribution SDM ensemble EFH maps.** NMFS recommends that the complete set of new summer distribution SDM ensemble EFH maps represents the best available science for mapping EFH for these species life stages at this time and provides a substantial improvement over the 2017 summer distribution SDM EFH maps. In addition to the summer distribution EFH component 1 maps from the 2017 EFH 5-year Review, each FMP contains EFH maps for fall, winter, and spring as available. EFH mapping efforts for the 2023 5-year Review did not revise those maps and they will remain in the FMPs

The EFH regulations provide an approach to organize the information necessary to describe and identify EFH (50 CFR 600.815(a)(1)(iii)). When designating EFH, the Council should strive to describe and identify EFH information in the FMPs at the highest level possible (50 CFR 600.815(a)(1)(iii)(B))—

Level 1: Distribution data are available for some or all portions of the geographic range of the species.

Level 2: Habitat-related densities or relative abundance of the species are available.

Level 3: Growth, reproduction, or survival rates within habitats are available.

Level 4: Production rates by habitat are available. [Not available at this time.]

1.2.1 2017 EFH 5-year Review

Prior to the 2017 EFH 5-year Review, EFH component 1 (descriptions and identification) in the six FMPs was the distribution of species' life stages and maps based on survey results and observed catch. A new approach to develop species-specific habitat information for EFH component 1 was developed for the 2017 EFH 5-year Review that used species distribution models (SDMs) to describe and map the habitat-related distribution and abundance for many species of groundfish in the BSAI and GOA FMPs and crabs in the Crab FMP, where data existed for egg, larval, juvenile, and adult life history stages in four seasons. SDM results were provided as text and maps that described and identified the attributes and location of EFH. The SDM EFH approach of the 2017 Review is discussed in detail in the 2017 EFH Summary Report (Simpson et al. 2017), three NOAA Technical Memoranda (Laman et al. 2017, Turner et al. 2017, Rooney et al. 2018), and a peer-reviewed publication (Laman et al. 2018). New information was also reviewed for the Salmon FMP that included quantitative model-based maps (Echave et al. 2012) and for the Arctic FMP that included maps of species distribution from surveys (Simpson et al. 2017).

As an outcome of the 2017 Review, the Council adopted SDMs to describe and identify EFH (Laman et al. 2018) and updated EFH information levels and maps for species life history stages (Simpson et al 2017). EFH maps are available on the Alaska[20] and National[21] EFH Mappers, the NMFS Alaska Region EFH webpage[22,] and in the six FMPs[23]. The SDMs developed during the 2017 Review resulted in more quantitative, precise descriptions and identification of EFH in the FMPs, and met the recommendations in the MSA to use the best available scientific information to define EFH (50 CFR 600.315).

1.2.2 2023 EFH 5-year Review

The Alaska EFH Research Plan has guided research to meet EFH mandates in Alaska since 2005 (AFSC 2006, Sigler et al. 2012). Revisions of this plan accompany the EFH 5-year reviews that summarize the status of EFH research (EFH component 9, research and information needs), which provides a basis to determine future research directions. Building on the progress of the 2017 EFH 5-year Review, the Alaska EFH Research Plan was revised (Sigler et al. 2017), incorporating additional research and information needs along with the five long-term EFH research goals (Sigler et al. 2017). The revised plan provided two-specific research objectives to advance EFH information for Alaska in the intervening 5 years leading up to the 2023 5-year Review:

1. Develop EFH Level 1 (distribution) or Level 2 (habitat-related densities or abundance) information for life stages and areas where missing; and
2. Raise EFH information from Level 1 or Level 2 to Level 3 (i.e., vital rates like habitat-related growth, reproduction, or survival).

NMFS Alaska Region (AKR) and AFSC funded several studies to accomplish Alaska EFH Research Plan research objectives. **This Discussion Paper presents new research from the following study available for the 2023 EFH 5-year Review—**

Advancing Model-Based Essential Fish Habitat Descriptions for North Pacific Species, Ned Laman[24], Jodi Pirtle[25], Jeremy Harris[26], Margaret Siple[10], Chris Rooper[27], Tom Hurst[28], and Christina Conrath[29], funded by the Alaska EFH Research Plan in FY19, FY20, and FY21 (hereafter referred to as **Laman et al. study**) (Chapter 3).

The Laman et al. study demonstrates the SDM ensemble EFH mapping approach for the 2023 EFH 5-year Review utilizing the best available scientific information. **The ensembles describing and mapping EFH in this study advance EFH information levels and refine EFH area maps for the summer distribution of North Pacific species' life stages** from none to Level 1 and from none or Level 1 to Level 2. This study also applies habitat-related vital rates from other studies to the ensemble outcomes to describe and map EFH Level 3 for the first time. The EFH descriptions and maps from this study comprise the bulk of new EFH component 1 information available for the 2023 EFH 5-year Review and also support the EFH component 2 fishing effects analysis.

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[20] https://www.fisheries.noaa.gov/resource/map/alaska-essential-fish-habitat-efh-mapper
[21] https://www.habitat.noaa.gov/protection/efh/efhmapper/index.html
[22] https://www.fisheries.noaa.gov/alaska/habitat-conservation/essential-fish-habitat-efh-alaska
[23] https://www.fisheries.noaa.gov/rules-and-announcements/plans-and-agreements?title=&management_area%5BAlaska%5D=Alaska&sort_by=title
[24] GAP, AFSC, Seattle, WA
[25] HCD, NMFS AKR, Juneau, AK
[26] GAP, AFSC, Lynker, Seattle, WA
[27] DFO, Nanaimo, BC, Canada
[28] FBEP, AFSC, Newport, OR
[29] GAP, AFSC, Kodiak, AK

This document presents the Laman et al. study complete methods and results, including case studies for species' life stages in the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA (Chapter 3). Regional methods details and the full set of species' life stage results are in three Technical Memoranda (Supporting Documents 5). The iterative review process that this and other EFH component 1 studies have undergone for the 2023 EFH 5-year Review is described (Chapter 2). EFH analyst responses to SSC and Plan Team input from the June 2020–November 2021 stages of the iterative review, regarding this study and the overall direction of new information developed for EFH componenet 1 in the 2023 Review are in Appendix A. The stock assessment author 2021 EFH component 1 review, included the study's draft methods and results as described in Appendix F with EFH analyst responses. A supplemental analysis for the SSC's October 2022 review, describing the main categories of reviewer concerns and recmmendations for a subset of species, is provided in Appendix G.

Two other studies that have developed new EFH component 1 information are not contributing to the EFH component 2 (fishing effects evaluation) are being presented at later stages of the 2023 EFH 5-year Review:

- **Model-Based Essential Fish Habitat Descriptions for Fish Resources of the Arctic Management Area** by Jennifer Marsh[30], Jodi Pirtle[31], Franz Mueter[32], and Jeremy Harris[33] funded by BOEM FY19/20.
    - Arctic EFH maps are not currently based on SDMs. This study has developed SDMs for life stages of Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*) and snow crab (*Chionoecetes opilio*), including EFH Level 1 and Level 3 descriptions and maps, concurrently with the Laman et al. study, to advance Arctic species EFH descriptions and maps current with the state of science for the region. In addition, this work compares the area of occupied habitat and habitat-related vital rates for species life stages in warm and cold years as a first step to consider climate change effects on EFH for Arctic species.
    - This study has a document prepared as a NOAA Technical Memorandum in review (Marsh et al. In review).
    - New SDM EFH maps for Arctic species are scheduled to be presented in February 2023 (2023 EFH 5-year Summary Report[34] and Marsh et al. In review[35]).
- **Developing a Novel Approach to Estimate Habitat-Related Survival Rates for Early Life History Stages using Individual-Based Models** by Kalei Shotwell[36], William Stockhausen[37], Georgina Gibson[34], Jodi Pirtle[29], Chris Rooper[38], and Alison Deary[32], funded by Alaska EFH Research Plan FY18/19.
    - This integrated modeling study applies biophysical individual-based models (IBMs), SDMs, spawning locations, spawning biomass, and vital rates to develop EFH Level 2 and 3 descriptions and maps for pelagic early life stages of Pacific cod (*Gadus macrocephalus*) and sablefish (*Anoplopoma fimbria*) in the GOA, providing a novel

[30] University of Alaska Fairbanks (UAF), HCD, NMFS AKR, Anchorage, AK
[31] HCD, NMFS AKR, Juneau, AK
[32] UAF, Juneau, AK
[33] GAP, AFSC, Lynker, Seattle, WA
[34] Chapter 2.7 (Arctic FMP) in 2023 EFH 5-year Review Summary Report (January 2023) available on Council agenda for this meeting
[35] Arctic SDM EFH Maps (Marsh et al. In review) available on Council agenda for this meeting
[36] REFM, AFSC, Juneau, AK
[37] REFM, AFSC, Seattle, WA
[38] DFO, Nanaimo, BC, Canada

alternative to develop EFH information for life history stages that are difficult to comprehensively sample by field surveys alone. In addition, this work informs spawning-to-nursery habitat connectivity and compares connectivity, and habiat-related distribution, density, and vital rates annually as a first step to consider climate change effects on EFH for groundfish early life stages (Shotwell et al. In preparation).

- This study has one peer reviewed manuscript in review **Can seamounts in the Gulf of Alaska be a spawning ground for sablefish settling in coastal nursery grounds?** (Gibson et al. In review) and one in progress (Shotwell et al. In preparation).
- New IBM-EFH maps for GOA species are scheduled to be presented in June 2023(T) (2023 EFH 5-year Summary Report[39] and Shotwell et al. In preparation).

This body of work for EFH component 1 available for the 2023 EFH 5-year Review is innovative and inclusive of many contributors that are developing new habitat related distribution, abundance, and vital rate information for North Pacific species.

In addition to supporting our EFH mandates, the new species and life stage specific habitat information presented for the 2023 EFH 5-year Review is extensible to stock assessment and other ecosystem-based fisheries management (EBFM) information needs for our region. The Ecosystem and Socioeconomic Profiles (ESP) in the Stock Assessment and Fishery Evaluation (SAFE) Reports include SDMs developed for EFH component 1 in the 2017 EFH 5-year Review (Rooney et al. 2018) and the GOA Integrated Ecosystem Research Program (Pirtle et al. 2019) (e.g., GOA walleye pollock; Shotwell et al. 2019). Recent studies have also applied these SDMs and contemporary extensions to demonstrate a synthesis of life history information for groundfish species (Doyle et al. 2018), develop example stock-specific indicators for the ESPs (Shotwell et al. 2022), develop high resolution SDMs as a case study for EFH species and their prey in the nearshore (Grüss et al. 2021), test hypotheses about groundfish recruitment processes in the GOA (Goldstein et al. 2020), and identify spatial-temporal stock structure in the EBS under future climate scenarios (Rooper et al. 2021) and most recently with new temporally dynamic SDMs (Barnes et al. 2022). Several milestones of the Alaska EBFM Roadmap Implementation Plan (NMFS 2018) reference actions related to habitat science and EFH. In these examples, information and SDMs developed for EFH, such as those presented in this Discussion Paper, are extended in a meaningful context to further support fishery and ecosystem management in our region.

2 Iterative Review

Since the 2017 Review, NMFS has worked to improve the EFH component 1 descriptions and maps in the BSAI, GOA, Crab, and Arctic FMPs. The advancements of this work and recommended updates to the EFH component 1 sections of the FMPs is presented in the 2023 EFH 5-year Review Summary Report[40]. Review of current and new EFH information by experts and other stakeholders is an important part of an EFH 5-year Review for our region and serves to strengthen the contributing research and the EFH 5-year Review process overall.

During the 2023 Review the studies contributing new information for EFH component 1 have been reviewed by the SSC, Ecosystem Committee, Plan Teams, stock assessment authors (SAs), species experts, and other stakeholders. As the Council process is public, materials provided for review to the

[39] Chapter 2.5 (GOA FMP) in 2023 EFH 5-year Review Summary Report (January 2023) available on Council agenda for this meeting

[40] 2023 EFH 5-year Review Summary Report (January 2023) available on Council agenda for this meeting

Council bodies have been available to the public and valuable stakeholder testimony was received at each meeting. EFH analysts have incorporated feedback from each of these sources into the work products for component 1.

Chapter 2 is an overview of the iterative process by which NMFS and the Council is reviewing the EFH component 1 descriptions and maps for the 2023 EFH 5-year Review, including a process timeline, description of the stock assessment author review, and SSC input from their February and October 2022 reviews with research recommendations.

In addition to Chapter 2, a detailed accounting of SSC and Plan Team input with EFH analyst responses during stages of review from June 2020–November 2021 is in Appendix A, Table A1. The report of the SA review of EFH component 1 from May–September 2021 is Appendix F. SSC review of the full set of new SDM ensemble EFH maps occurred in February 2022 and the EFH component 2 fishing effects evaluation was launched, incorporating the new SDM ensemble EFH maps. A detailed analysis of the main categories of concerns and recommendations for the SDM EFH maps from SA and SSC input leading up to the fishing effects evaluation is in Appendix G and the Fishing Effects Discussion Paper[41].

2.1 Iterative Review Process

This section provides a timeline describing the stages of the iterative review process for EFH component 1 in the 2023 EFH 5-year Review. Stages of the process involving key milestones are highlighted (bold text).

2.1.1 Timeline

2.1.1.1 April 2019–November 2021

April 2019: NMFS and the Council launched the 2023 EFH 5-year Review with a presentation by NMFS to the Ecosystem Committee of the preliminary plan for review of the EFH components of FMPs.

June 2020: SSC reviewed proposed methods and preliminary results examples and provided input regarding study methods, progress to date, and planned research products to support the new EFH component 1 information for the 2023 Review. Following this first SSC review, EFH analysts took steps to revise their approach in response to this input (Table A1 items 1a-l).

September 2020: JGPT reviewed proposed methods and preliminary results examples and provided input regarding study methods, progress to date, and planned research products to support the new EFH component 1 information for the 2023 Review. Following this first JGPT review, EFH analysts took steps to further revise their approach in response to this input and then proceeded to develop the draft results for further evaluation (Table A1 items 2a-c).

January 2021: NMFS EFH analysts and senior stock assessment scientists convened a summit of SAs to develop the process for their review of EFH components 1 and 7, which was a collaborative process innovation of the 2023 Review. At this meeting, SAs were informed of the EFH 5-year Review process, tools in development to provide new EFH component 1 (descriptions and identification) and component 7 (prey species) information, and their role. EFH analysts and SAs co-developed an approach and timeline for the SA review of these two EFH components for the 2023 Review. Agreement was reached on the timeline to coordinate the review (i.e., of current FMP EFH text and maps and new SDM ensemble EFH draft methods and results) with existing stock assessment timing and workload, agreeing on a review period from May 15 to September 1, 2021. Agreement was also reached on the content and nature of the review, which was to provide an extensive, expert peer review of the current information available for components 1 and 7 and, in particular, the new information for component 1. SAs reviewed

[41] EFH Fishing Effects Discussion Paper (January 2023) available on the Council agenda for this meeting

EFH component 1 and 7 EFH information on the same stocks for which they authored assessments. Finally, SAs led a discussion on connections between EFH components 1 and 7 research and stock assessment to identify opportunities to strengthen work products and support shared management needs for stock assessment, EFH, and EBFM.

April 2021: A paper describing the 2023 EFH 5-year Review Plan was presented to the SSC and Council. The paper described the ten EFH components, work related to the components and the FMPs, and what types of new information will be included in the EFH 5-year Review summary report. The SSC highlighted the importance of SA review in their minutes from April 2021: “The SSC considers consultation with assessment authors to be a critical link in evaluating model configuration and output, and was pleased to hear the EFH team was involving assessment authors early in the EFH review process.” SSC provided additional guidance (Table A1 items 3a-j).

May 2021: The 2023 EFH 5-year Review Plan was presented to the CPT in May 2021. The presentation included SDM ensemble methods and preliminary results for crabs. The presentation also provided the opportunity for the CPT members to participate in the review process as species experts along with the SAs. All species except for Tanner crab had at least two SA reviewers to offer edits, updates, and suggestions. The SA-species reviewer partnership for crabs was new for this review and offered more opportunities for expert feedback. The CPT requested that the crab SAs and experts receive the EFH components 1 and 7 review materials first to accommodate the timing of the crab stock assessments. The EFH analyst team agreed and provided crab reviewers with review materials in May 2021 (Table A1 items 4a-b). **The SA review process of EFH component 1 from May–September 2021 is described in section 2.2 and reported in Appendix F.**

May–September 2021: The agreed upon SA review period was from May–September 1. New EFH component 1 information was provided to the SAs for their review, revisions, and recommendations. During this time, EFH analysts conducted their own internal review of the draft methods and results. Following the SA review in September, EFH analysts began to review the SA review input and prepared for the September JGPT meeting to provide a first overview of the SA review results, and plan to address concerns and revise the draft results for subsequent SSC review in February 2022.

September 2021: The joint meeting of the Groundfish Plan Teams in September, 2021 was an opportunity for the EFH analysts to meet with the JGPT and groundfish SA community following their review that concluded on September 1, just prior to this meeting. At the meeting, the EFH analysts provided a preliminary summary the SA reviews received as well as the analysis team’s responses to the leading concerns and questions from the SAs. This included an explanation of replacing the single ensemble fit metric, Spearman’s rho-squared, with three conventional metrics to more comprehensively assess ensemble performance (section 3.2.7). Model performance was reevaluated for all SDM ensembles and revised in the species results chapters in the draft NOAA Technical Memoranda for the EBS, AI, and GOA (Supporting Documents 5).

EFH analysts clearly communicated at the meeting that they would follow up with all SAs who expressed concerns in their reviews to answer questions and communicate any necessary revisions, including updated model performance metrics and other results (Table A1 items 5a-g). Although EFH analysts had been following up with SAs as their reviews were returned over the summer, SAs with concerns that affected their confidence in the models and outcomes were prioritized for more in-depth follow-up. EFH analysts communicated at the JGPT September meeting that they would make revisions as needed and provide opportunity for the SAs to review the revised species chapters should they be interested prior to the SSC February Meeting when the full set of revised methods, results, and 2017/2022 EFH area comparisons would be shared with the SSC for review. See Appendix F for details on this communication process.

October 2021: The SSC reviewed the JGPT September meeting report, which included the Team’s report on the EFH presentation. Although SSC review of EFH component 1 was not planned for the October meeting, SSC provided additional and extensive requests for component 1 that the EFH analysts incorporated into this document and attachments for SSC review in February 2022 (Table A1 items 6a-n).

November 2021: The JGPT November meeting was an opportunity for EFH analysts to provide an overview of the iterative review process for EFH component 1 in the 2023 Review to date and to share the final stages of the SA review, including EFH analyst responses to all reviewing SAs. EFH analysts provided a draft of the Report of Stock Assessment Author Review of EFH Components 1 and 7 for the 2023 EFH 5-year Review as an attachment for this meeting that posted on November 9, 2021 to provide time to review the draft report prior to the presentation on November 15, 2021. From the meeting's minutes (Table A1 item 7a): "The Teams thanked the EFH analysts for the development and application of the EFH models, the responsiveness to stock assessment author reviews, and for the detailed report describing the review process." SSC and Plan Team input with EFH analyst responses during stages of review from June 2020–November 2021 is in Appendix A.

2.1.1.2 January 2022–February 2023

January–February 2022: Analysts presented the complete package of new SDM ensemble methods and EFH maps by the Laman et al. study to the CPT and Ecosystem Committee in January 2022 and to the SSC for review in February 2022. **The reviews from January 2022 to February 2023 represent an important transition in the 2023 Review process.**

February 2022: SSC reviewed the new draft EFH component 1 SDM ensemble results and draft EFH maps, incorporating revisions from the stock author 2021 review addressing concerns to the extent possible at this time. We provided the SSC with the EFH Component 1 SDM EFH Discussion Paper (January 2022 version of this document) summarizing the process and work to date, Stock Author Review of EFH Component 1 Report (Appendix F), and other materials supporting their review (Supporting Documents 5). SSC noted that the new EFH maps reflect the best available science for characterizing EFH component 1 at this time, recommended clarification for some of the new information leading up to the EFH component 2 fishing effects evaluation, and provided future research recommendations (Appendix G).

February–September 2022: Analysts revised the SDM ensemble EFH maps with a code correction (Appendix B), packaged and shared the revised maps and species results chapters for the EFH component 2 fishing effects evaluation (Appendix G and Fishing Effects Discussion Paper[42]), revised and resubmitted the three regional NOAA Technical Memoranda (Harris et al., Laman et al., Pirtle et al. In review) (Supporting Documents 5), and drafted a forthcoming manuscript, *Ensemble models mitigate bias in area occupied from commonly used species distribution models* (Harris et al. In preparation). It is a priority of NMFS to make available the SDM ensemble EFH code used to develop the new summer distribution EFH maps in the 2023 Review so that our methods are transparent, accessible, and repeatable. Analysts established the Alaska Groundfish Essential Fish Habitat repository that is available on GitHub: https://github.com/alaska-groundfish-efh. Updates will be forthcoming as we continue to finalize the R code (R Core Team 2020) and documentation.

October 2022: by their request the SSC reviewed an update to the EFH component 1 SDM ensemble EFH maps (Appendix B) and how remaining stock author concerns and recommendations had been addressed in a Supplemental Analysis prepared by NMFS (Appendix G and Fishing Effects Discussion Paper). SSC recommended that the 2023 EFH SDM approach (component 1) and the Fishing Effects model (component 2) represent a reasonable scientific basis for evaluating whether the effects of

[42] EFH Component 2 Fishing Effects Discussion Paper (January 2023) available on the Council agenda for this meeting

fishing are more than minimal and not temporary. SSC also provided future research recommendations for EFH component 1.

January–February 2023: Analysts prepared the draft 2023 EFH 5-year Review Summary Report[43] and updated documents from earlier stages of the 2023 Review following the October 2022 meeting. The Ecosystem Committee at their January meeting and the SSC and Advisory Panel will receive presentations on the new Arctic SDM EFH maps (Marsh et al. In Review) and the EFH 5-year Review Summary Report at their February meetings. The Summary Report describes the new EFH component 1 advancements and recommended changes to the EFH descriptions in the BSAI, GOA, Crab, and Arctic FMPs. Although EFH descriptions for salmon and scallops were not the focus of the current EFH Review, the report recommends how these could be updated following new research for the next EFH 5-year Review. The Council will receive a presentation of the EFH 5-year Review Summary Report at the February meeting. **If the Council recommends ammendments to the EFH sections of the FMPs, NMFS staff will draft the Environmental Assessment and Omnibus Amendment package for review at the October 2023(T) meeting.**

2.1.2 Stock Assessment Author Review of EFH Component 1

This section describes the SA review of EFH component 1 in the 2023 Review. The full process and results of the 2021 SA review is reported in Appendix F. In addition, a detailed analysis of the main categories of concerns and recommendations for the SDM EFH maps from SA and SSC input leading up to the fishing effects evaluation is in Appendix G and the Fishing Effects Discussion Paper[44].

Review by SAs and species experts is a critical element of the iterative EFH 5-year Review process and serves to strengthen the evaluation. Reviewers are provided guidance that their recommendations should be based on their review of the current and new EFH information and the guidance of National Standard 2 and the EFH Final Rule to describe EFH based on the best scientific information available at the highest level of detail possible (50 CFR 600.815(a)(1)(iii)(B)).

For the 2017 Review, each SA was asked to review current FMP EFH component 1 information for each species or species complex for which they have responsibility. SAs were asked to review and update, if appropriate, EFH text descriptions, EFH levels, habitat association tables, habitat-related life history information including prey of EFH species (component 7), and relevant literature. SAs were provided with the new SDM maps developed for the 2017 Review and compared the new maps to the old maps from the 2010 EFH Review. Following the SA and subsequent SSC review of EFH component 1, SAs were provided output from the Fishing Effects model and asked to evaluate the effects of fishing to EFH for their stocks, following a method developed during the 2017 Review for EFH component 2 fishing activities that may adversely affect EFH.

The 2023 EFH 5-year Review provided an opportunity to improve on the process of the 2017 Review of EFH components 1 and 7. NMFS started the SA review with a workshop in January 2021 and concluded the process by presenting the SA Review Report to the SSC in February 2022 (Appendix F). Improvements to the process in the 2023 Review, included reaching agreement with SAs regarding the timing and expectations of the document review period, achieved in the January 2021 workshop, and providing SAs with access to both the draft methods and preliminary results for the EFH component 1 SDMs in their review, which was not part of the the SA review in 2017.

The SA review of EFH component 1 is described and reported in Appendix F. The SA review report describes the SA EFH component 1 review process, timeline, methods, results, and communication

[43] 2023 EFH 5-year Review Summary Report; available on the Council agenda for this meeting
[44] EFH Component 2 Fishing Effects Discussion Paper (January 2023) available on the Council agenda for this meeting

between EFH analysts and SAs to understand and address their concerns and recommendations to the extent possible for the 2023 Review or as research developments for future EFH Reviews. The SA review of EFH component 1 assisted EFH analysts to identify and recommend changes to the EFH sections of BSAI, GOA, and Crab FMPs described in the 2023 EFH 5-year Review Summary Report[45].

2.1.3 February and October 2022 Review of the SDM Ensemble EFH Maps

2.1.3.1 SSC February 2022 review

In February 2022, the SSC reviewed the new set of summer distribution EFH component 1 SDM ensemble maps that NMFS developed and recommends for replacing the 2017 summer distribution EFH maps based on a single SDM. The SSC also reviewed the proposed approach to the EFH component 2 fishing effects evaluation that launched in April 2022 applied the new SDM ensemble EFH maps for the summer distribution of adults (or all combined life stages) of groundfishes and crabs to the fishing effects model output (Fishing Effects Discussion Paper[46]).

Following their February 2022 review, the SSC noted that the new EFH maps reflect the best available science for characterizing EFH component 1 at this time and requested more information on the reviewing stock assessment author concerns for a subset of the SDM ensemble EFH maps in their 2021 review. To address this SSC request, EFH analysts continued conversations with stock authors and developed a supplementary analysis to provide the SSC with a description of the main categories of concern (add species data, life history, and ongoing data issues), how we have addressed these concerns now, how these concerns may be addressed if possible for a future EFH Review, and recommendations for proceeding in the 2023 EFH 5-year Review for EFH component 1 (Appendix G).

2.1.3.2 SSC October 2022 review

The following input was received by the SSC on the revised set of EFH component 1 SDM ensemble EFH maps and actions that analysts took to further address concernes and recommendations following earlier stages of review (e.g., Appendix G):

- The SSC recommends the current EFH methodology and FE estimates as a reasonable basis for the determination of fishing impacts, and that no species needs to be elevated for mitigation due to fishing impacts. Based on the information provided, the SSC finds that the 2022 FE evaluation supports the continued conclusion that the adverse effects of fishing activity on EFH are minimal and temporary in nature.
- The SSC notes that both the current SDM approach to defining EFH and the FE model represent substantial methodological advances since the 2017 EFH review process. The SSC appreciates the substantial efforts by EFH component 1 and component 2 teams in advancing the EFH analysis in this cycle and incorporation of feedback from stock assessment authors and the SSC throughout the process.
- The SSC suggests consideration during the next 5-year EFH review cycle of whether subsequent evaluations should consider other life stages for which EFH has been defined.

2.1.4 SSC EFH Component 1 Research Recommendations

The SSC provided research recommendations for future EFH 5-year Reviews, during their review of EFH components 1 at their February and October 2022 meetings.

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[45] Chapter 2 in 2023 EFH 5-year Review Summary Report; available on the Council agenda for this meeting
[46] EFH Component 2 Fishing Effects Discussion Paper (January 2023) available on the Council agenda for this meeting

2.1.4.1 SSC February 2022 research recommendations

- SDM modeling is a rapidly evolving field, including the development of joint species distribution models. Although the analysts applied state-of-the-art approaches, the SSC suggests that the EFH Research Plan should consider an in-depth review of available approaches, including considerations of joint SDMs.
- The SSC encourages further efforts to identify ways in which the EFH information can contribute to the stock assessment process through ESPs and other 'on-ramps'.
- The current EFH definitions focus on summer survey data only and provide a much-improved snapshot of summer distributions. The SSC supports recommendations to extend the analyses in the future to use fishery-dependent data, longline surveys, acoustic surveys, etc., to both enhance maps of summer distributions and to define EFH at other times of the year where possible, building on the approach developed during the 2017 Review. However, the SSC notes that this type of intercalibration exercise will require careful consideration of the relative catchability among different gear types, the spatial distribution of effort, and targeting behavior in the case of fishery-dependent data.
- The SSC previously encouraged, and the discussion paper recommends, the move toward a more dynamic definition of EFH, for example in time blocks, which would require careful consideration of the time frames used for defining EFH. The SSC recommends that both longer-term average EFH and EFH under contrasting conditions for those species whose distribution is known to be linked to changing ocean conditions be considered in the next 5-year Review.
- The SSC appreciates the move to life stage specific models for almost all groundfish stocks and encourages the team to prioritize life stage specific models for crab species based on available maturity data.
- The SSC supports a recommendation brought forward by the CPT and in public testimony to consider mapping EFH by management area for separate stocks within an FMP area. One example is red king crab in the Bering Sea, which consists of three distinct stocks.
- The SSC encourages the analysts to consider objective approaches to eliminate isolated areas where the model suggests elevated abundances that are not supported by any occurrences in the data and are spatially separated from the main distributional areas.
- The SSC appreciates the inclusion of the PR-AUC as an additional criterion for evaluating the SDM models as it provides useful information on model performance with respect to the presence of a species, particularly for relatively uncommon species. The SSC suggests including the PR-AUC and species prevalence as routine criteria in future model updates.
- The SSC encourages the analysts to explore options that account for both abundance and uncertainty in the definition of EFH.
- The SSC encourages the analysts to provide general comparisons of the abundances estimated in the EFH SDMs and those estimated in the stock assessments.
- The SSC supports the additional recommendations in "Table 18 of the discussion paper" (section 3.5 Table 18) and highlights the following priorities:
    - Further development of methods to combine multiple surveys to make full use of available data and to expand coverage beyond any one survey region.
    - Development of process studies to advance EFH descriptions to Level 3 and possibly (Level) 4, if appropriate. The SSC suggests that the EFH research plan consider a case study for the development of Level 4 EFH description for at least one species / life stage to better understand the information and methods needed to advance to Level 4.

  - The SSC suggests adding (additional oceanographic covariates to the SDMs) variables that are indicative of frontal structures, which often aggregate prey and their predators. The SSC further suggests exploring the use of variables that reflect the vertical structure of the water column.
  - Inclusion of alternative data sources such as longline survey data, fishery-dependent data, acoustic data and other sources.

2.1.4.2 SSC October 2022 research recommendations

- EFH SDM intercalibration of bottom trawl survey data with data from fixed gear surveys (e.g., as applicable to a subset of species where inclusion of additional species data has high potential to improve EFH information).
- Exploration of the extent to which fishery-dependent data can help inform future EFH SDM analyses, while highlighting the inherent problem of preferential sampling associated with fishery-dependent information.
- Expansion of EFH definitions to other life stages and seasons where appropriate, based on available data to inform occurrence, abundance, and habitat associations.
- Reporting of species-specific habitat disturbance from the FE model by major gear classes would be beneficial in considering habitat impacts in a strategic manner.
- *The SSC referred EFH authors to its comments from February 2022 for further recommendations regarding future EFH evaluation.*

3 Advancing Model-Based EFH Descriptions for North Pacific Species

The purpose of this study (hereafter referred to as Laman et al. study) is to describe and map EFH for federally managed North Pacific groundfish and crab species in the EBS, AI, and GOA using SDMs and to advance levels of EFH information for the life stages of those species. This study is guided by the Alaska EFH Research Plan (Sigler et al. 2017) research priority 1 to characterize habitat utilization and productivity using the best available scientific information to accomplish the two specific research objectives of the revised plan—

Objective 1 – Develop EFH Level 1 information (distribution) for life stages and areas where missing, and

Objective 2 – Raise EFH level from 1 or 2 (habitat related densities or abundance) to Level 3 (habitat related growth, reproduction, or survival rates).

To meet the research priority and objectives described above and we demonstrated a modernized **SDM ensemble EFH mapping approach** for the 2023 EFH 5-year Review, for where EFH is described and mapped for 31 North Pacific groundfish species in the EBS, 24 in the AI, 41 in the GOA across up to three life stages. In addition, EFH is described and mapped for four crabs in the EBS, two crabs in the AI, and octopus in all three regions. All of the ensembles constructed for FMP species in the EBS, AI, and GOA in this present work describe and map EFH Level 2 (habitat related abundance). For early juvenile life stages in the GOA, SDMs describe and map EFH Level 1 for the first time. EFH Level 3 (habitat related vital rates) is described and mapped for a subset of species in each region for the first time.

The Final Environmental Impact Statement for EFH Identification and Conservation in Alaska defines EFH as the area inhabited by 95% of a species' population (NMFS 2005)[47]. Our habitat-based modeling approach characterizes EFH for species' life stages as **the spatial domain containing 95% of occupied habitat (where occupied habitat is defined as locations where model estimated species encounter probability is greater than 5%).** As in the 2017 EFH 5-year Review, we provide maps of SDM predictions and EFH area percentiles, where subarea percentiles are the upper 75% ("principal EFH area"), upper 50% (core EFH area; the subarea used in the EFH component 2 fishing effects analysis of the 2017 EFH 5-year Review), and upper 25% ("EFH hot spots"). Presenting this set of maps demonstrates that the SDMs can identify more nuanced habitat-related spatial patterns of species distribution and abundance than is communicated by the EFH area (upper 95%) alone, which expands the utility of these SDMs and provides a basis for discussions on how EFH is mapped for the North Pacific region.

We have refined and advanced the science of using SDMs to describe and map EFH while measurably improving model performance compared to the SDMs developed for the 2017 EFH 5-year Review. The combination of refinements to modeling techniques, advances in life history studies, and addition of new data and data sources resulted in differences in the areal extent of EFH compared with 2017. We provide regional case studies for species' life stages that illustrate in a stepwise fashion how each modeling refinement or data addition applied by our present work affected EFH areal extent. We summarize and compare the results of this study and the 2017 SDMs and EFH maps in the Results section and Appendices of this document and in the supporting documents, including 2017 and 2023 EFH area overlay maps and three regional NOAA Technical Memoranda with detailed results for each species' life stage modeled (Supporting Documents 5).

3.1 What's New?

3.1.1 Overview of Data Updates and Model Refinements

Since the 2017 EFH 5-year Review, we have updated our SDM inputs (dependent and independent variables) and refined our modeling methods (Table 5). In this section of this document we provide highlights as an overview of what is different about the updated data and modeling approaches. The complete methods for our SDM ensemble approach to describe and map EFH is included below in the Methods section. The three regional NOAA Technical Memoranda provide region-specific methods details where applicable (Supporting Documents 5; Harris et al., Laman et al., and Pirtle et al. In review).

3.1.2 Response Variables

The dependent response variables used in our SDM are species occurrence (i.e., encounter/non-encounter) and numerical abundance. Fundamental differences between the response variables presented in the 2017 EFH 5-year Review SDM are that we now use the complementary log-log (cloglog) link to approximate abundance (Fithian et al. 2015) from presence-only and presence-absence models (formerly reported as probability of suitable habitat or probability of presence, respectively) and we use count data with a log-linked Poisson distribution and log-area swept (fishing effort) as an offset instead of 4^{th}-root transformed catch-per-unit-effort (CPUE) and a Gaussian distribution. In the present models, we have incorporated an additional five years of NMFS Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) summer bottom trawl survey data (Table 2), extending the terminal year of the dataset from 2014 to 2019. We have also included new sources of data to assess the settled early juvenile life stages that extend our EFH mapping to this critical ontogenetic phase (Table 3).

[47] https://repository.library.noaa.gov/view/noaa/17391

3.1.3 Life History Information

Demography and length-based life stage definitions have been updated since the 2017 EFH 5-year Review (Table 4). Updated maturity schedules can be used to re-define subadult and adult life stage breaks for several species. Additionally, we include for the first time the ecologically important settled early juvenile life stage and describe their EFH for a subset of groundfish species in all regions. Inshore survey data from the recent update to the AFSC Nearshore Fish Atlas (NFA) of Alaska (Johnson et al. 2012, Grüss et al. 2021), Alaska Department of Fish and Game (ADFG) small-mesh bottom trawl survey (Jackson and Ruccio 2003, Spalinger 2020), and the AFSC Marine Ecology and Stock Assessment Program (MESA) juvenile sablefish tagging program (Echave et al. 2013), are combined with AFSC RACE-GAP large-mesh bottom trawl survey data to support modeling the settled early juvenile life stages of groundfishes in GOA (Table 3). Case studies of GOA Pacific cod present the SDM ensemble approach for adults and the SDM with combined survey data approach using presence-only MaxEnt models for the settled early juvenile life stages (GOA only) (Results 3.3).

3.1.4 Independent Variables

Several independent variables have been updated or added to the suite of habitat covariates for the SDMs (Table 5). The bathymetry compilation for the GOA has been extended west and updated (Zimmermann and Prescott 2015, Zimmermann et al 2019). Consequently, we revised the bathymetry-derived seafloor slope covariate for the GOA. We also added a measure of bathymetric position, and terrain curvature and aspect as new covariates for all regions. We developed a new metric of seafloor rockiness for the AI and GOA (e.g., Pirtle et al. 2015, 2019), and incorporated the most recent substrate data in the Bering Sea (Richwine et al. 2018). Five additional years of environmental data collection during the RACE-GAP summer bottom trawl surveys (2015-2019) and the addition of bottom temperature data from the coastal GOA regional ocean modeling system 3 km grid (Coyle et al. 2019) (1999-2019; applied to models of settled early juveniles only) have resulted in updates to the regional bottom temperature dynamic covariates.

3.1.5 Modeling Refinements

In the 2017 5-year Review, SDM methods were assigned to a species and life stage *a priori* based on their prevalence in trawl survey catch (Laman et al. 2018). In the case studies presented here, we use a new approach that fits multiple SDMs and then assembles them into a weighted ensemble. The five SDMs (MaxEnt = maximum entropy model, GAM_P = Poisson generalized additive model, GAM_{nb} = negative-binomial GAM, paGAM = presence-absence GAM, and hGAM = hurdle GAM) are weighted by their inverse squared root mean-square error (RMSE). The final prediction is the weighted average of the SDM predictions, and the standard error for predictions is calculated from the standard error for each constituent model as well as variance among ensemble members (Table 1). SDMs may be removed from the ensemble if they fail to converge, produce implausible results (predictions are greater than 10 times highest observed abundance), or if the RMSE for that SDM is high relative to the others (measured as receiving less than 10% weight in the ensemble). Additionally, the GAMP and GAMnb are never included in the same ensemble because they are structurally very similar. Figure 8 shows a flowchart illustrating the different steps used to fit the SDMs and construct the ensemble. Analyses are conducted in R (R Core Development Team 2020) using the maxnet and mgcv packages (Phillips 2017, Wood 2011).

3.1.6 Introducing EFH Level 3

We describe and map EFH Level 3 (habitat related vital rates) for a set of groundfish species' settled early juvenile life stages for the 2023 EFH 5-year Review. This was done by integrating temperature-dependent vital rates developed from field and laboratory studies with habitat-related SDMs. Temperature-dependent vital rates have been published or are in development for groundfish species in the BSAI, GOA, and Arctic FMPs (Table 6). Laurel et al. (2016) described the temperature-dependent growth rate of early juvenile Pacific cod (and other gadids), which we use as a representative example to demonstrate our EFH Level 3 approach in this Discussion Paper.

3.1.7 Advancing EFH Information Levels

The many updates and additions to survey data described above, along with advances in demographic information and refinements to modeling techniques, help us to meet the EFH Research Plan objectives addressing EFH mandates for Alaska while achieving application of the best scientific information. The EFH Final Rule[48] requires that the periodic reviews of EFH take into account available information such as published scientific literature, unpublished scientific reports, and previously inaccessible or unavailable data sources, as we have done here. Modeling refinements to our SDM approach have improved our methodology and will advance EFH information levels for many FMP species in Alaska (Table 4, Appendix D). Integrating new data with the modeling refinements has improved the quality of our SDM EFH approach and helped us to meet the two specific research objectives in the revised EFH Research Plan for Alaska (Sigler et al. 2017), to develop Level 1 (distribution) or Level 2 (habitat-related densities or abundance) EFH information where missing, and raise EFH information to Level 3.

3.2 Methods

3.2.1 Study areas

In the present work, three marine regions of Alaska were the focus of species distribution modeling efforts focused on mapping and describing EFH for North Pacific groundfish and crabs species. These regions extend from Dixon Entrance in southeast Alaska, through the Gulf of Alaska and along the Aleutian Islands archipelago to Stalemate Bank, and north across the eastern Bering Sea shelf and slope into the Northern Bering Sea.

3.2.1.1 Bering Sea

The Bering Sea study area includes the eastern Bering Sea (EBS) continental shelf (0 to 180 m), EBS upper continental slope (~200 m to 1000 m), and the northern Bering Sea (NBS) (Figure 2). Throughout this document, we refer to the shelf, slope, and NBS collectively as the EBS, which represents a total area of approximately 2,350,000 km^2. The EBS encompasses a diverse mosaic of benthic habitats. Much of the continental shelf, which extends more than 200 km from shore, is shallow, flat, and composed of soft unconsolidated sediments (Smith and McConnaughey 1999, Rooper et al. 2016). The shelf region is commonly divided into three domains: the inner shelf (0 to 50 m), middle shelf (50 to 100 m), and outer shelf (100 to 180 m; Coachman 1986). The shelf-slope break is located between 180 and 200 m depth, except at the northern edge of Bering Canyon, where the shelf-slope break is around 200 m (Sigler et al. 2015). The EBS upper continental slope (~200 m to 1000 m) is steep and includes five major canyon systems along its north-south axis. The seafloor of the upper continental slope is interspersed with areas of rocky substrata, especially in Pribilof Canyon, but is mainly dominated by soft unconsolidated sediments (Rooper et al. 2016). The northern Bering Sea is considered a distinct region and is not as well described as the more frequently sampled eastern Bering Sea shelf and slope. Grebmeier et al. (1988) indicated that the seafloor in the northern Bering Sea near Norton Sound is shallow, with average water depths < 50 m, and is composed of unconsolidated sediments similar to those found on the EBS continental shelf, although there is substantial variation in grain size that affects infaunal prey composition.

[48] 50 CFR 600.815

3.2.1.2 Aleutian Islands

The Aleutian Islands are a chain of volcanic islands stretching from southwest Alaska across the North Pacific, separating the western Gulf of Alaska (GOA) from the Bering Sea (Figure 3). The continental shelf and upper continental slope represent a diverse mosaic of benthic habitats from Unimak Pass (165°W) in the eastern Aleutian Islands to Stalemate Bank in the western Aleutians (170.5°E). The Alaska Coastal Stream flows westward on the Pacific side of the Aleutians, while on the Bering Sea side, the Aleutian North Slope Current flows eastward (Stabeno et al. 1999, Stabeno et al. 2002, Ladd et al. 2005). There is extensive transport to the north through passes in the island chain from the Pacific side to the Bering Sea. In the Aleutians, there is a very narrow continental shelf that ranges in width from 20 km to greater than 200 km. The continental slope is steep and features multiple passes incising the continental shelf. The seafloor of the Aleutian Islands is diverse, with extensive rocky substrate resulting from volcanic activity dominating the continental shelf (Zimmermann et al. 2013).

3.2.1.3 Gulf of Alaska

The GOA study area for these modeling studies extends from Dixon Entrance (131°W longitude) in southeastern Alaska to Unimak Pass (165°W° longitude) at the western edge of the Alaska Peninsula (Figure 4). The GOA coastline in this region forms an intricate complex of many bays and islands with diverse terrestrial and marine habitats (Johnson et al. 2012, Zimmermann 2019). The GOA continental shelf and upper continental slope encompass a mosaic of benthic habitats with extensive rocky substrate that has been uplifted due to tectonic activity and deposited by glacial retreat (Carlson et al. 1982, Zimmermann et al. 2019). Much of the continental shelf is dominated by soft unconsolidated sediments (Golden et al. 2016) and is narrow in southeastern Alaska and in the western GOA, but is relatively broad in the central GOA with numerous glacial troughs (Carlson et al. 1982, Goldstein et al. 2020) and islands throughout. The shelf break occurs at about 200 m throughout the GOA and the shelf itself is deeply incised by numerous gullies and troughs. Oceanic currents in the GOA ecosystem are the Alaska Coastal Stream and Alaska Coastal Current which both flow westward (counter-clockwise) around the GOA from Dixon Entrance to the Aleutian Island chain (Stabeno et al. 2004). These currents result in downwelling of surface water at the coast while seasonal freshwater discharge results in a highly stratified system in the summer (Stabeno et al. 2004, 2016).

3.2.2 Species Data

3.2.2.1 Large-mesh Bottom Trawl Surveys

Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering-Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys document the distribution and abundance of federally managed fish and invertebrate species in the eastern Bering Sea (EBS), Aleutian Islands (AI), and the Gulf of Alaska (GOA). The EBS bottom trawl survey has been conducted annually since 1982 and the present studies for this region use RACE-GAP survey data through 2019. The Aleutian Islands data set combines the AI and GOA surveys west of the faunal barrier represented by Unimak Pass (Stabeno et al. 2002). The AI and GOA surveys have been conducted at regular intervals since 1991 and are collectively referred to in this document as the AI survey. In the AI, triennial surveys were conducted between 1991 and 2000 and biennial surveys were conducted from 2002 to 2018 (von Szalay and Raring 2020). The western portion of the GOA survey characterizes the eastern portion of the Aleutian chain south of the archipelago and was conducted triennially from 1993 to 1999 and then biennially from 2001 to 2019 (von Szalay and Raring 2018). Both of these fishery-independent AFSC RACE-GAP surveys used a stratified random sampling design. RACE-GAP summer bottom trawl surveys and the data years included in the SDMs for the 2017 EFH 5-year Review and in the present study for the 2023 EFH 5-year Review are provided in Table 2. We refer the reader to the three regional

NOAA Technical Memoranda from this study for more detailed descriptions of the sampling strata for each region (Supporting Documents 5).

We used species-specific, length-based life stage definitions of settled early juveniles, subadults, and adults supported in the literature, from web resources, or from the smallest, species-specific mean length from beach seines recorded in the AFSC Nearshore Fish Atlas (Table 4) to apportion trawl catches into life stages by computing the proportional contribution of each stage in the random subsample for fish lengths in that trawl to each species' total catch. Not all species catches could be apportioned into life stages so that proportional contribution to catch length composition could not be determined and SDMs were calculated for all individuals of that species using a single combined life stage.

3.2.2.2 Bering Sea Large-mesh Bottom Trawl Surveys

The primary source for fish and crab distribution and abundance data from the EBS is the 1982–2019 annual fishery-independent AFSC RACE-GAP summer bottom trawl survey of the EBS continental shelf. Additional data included in our analyses were obtained from the AFSC RACE-GAP EBS upper continental slope survey (Hoff 2016) occurring in years 2002, 2004, 2008, 2010, 2012, and 2016 and AFSC RACE-GAP NBS surveys (Lauth 2011) in 2010, 2017, and 2019. Scientific bottom trawl survey samples have been collected in the EBS since the 1940s, but the first systematic survey of the EBS shelf was conducted in 1975 by the U.S. Bureau of Land Management. In 1982, EBS shelf bottom trawl surveys were standardized and have since been conducted annually during the summer under a repeatable systematic sampling design (Lauth and Conner 2014). For this reason, we include trawl survey data from 1982–2019 in our analyses. During this time frame, changes in taxonomic classifications have resulted in different time series for analyses of different species (Laman et al. In review; Table 1).

Three standardized AFSC RACE-GAP summer bottom trawl surveys are conducted in U.S. waters of the Bering Sea. The Bering Sea continental shelf summer bottom trawl survey is conducted annually on a regular 25 nautical mile (nm) grid using an 83-112 Eastern trawl (112' footrope and 83" headrope). To better assess local blue king crab concentrations, "corner stations" are added to the regular Bering Sea shelf survey grid in the water surrounding St. Matthew Island and the Pribilof Islands (Lauth et al. 2019). In recent years, the survey grid and sampling methodology have been extended to include the NBS and Norton Sound (Lauth 2011). The bottom trawl survey of the Bering Sea upper continental shelf and slope has been conducted quasi-biennially since 2002 at depths from 200 to 1200 m using a Poly Nor'Eastern high opening trawl net with bobbins and roller gear on the footrope and a stratified sampling design (Hoff and Britt 2011). We combined successful standard summer bottom trawl survey catches from the Bering Sea continental shelf and NBS (N = 14,514) with the successful Bering Sea upper continental slope trawls (N = 1,136) to estimate numeric abundance, length composition, and area swept (Alverson and Pereyra 1969) as inputs for the SDMs. Trawl catches included in modeling efforts had satisfactory trawl performance and the geographic location, distance fished, and water temperature at trawl depth were recorded for each trawl haul. Trawl hauls were satisfactory if the net was open within a predetermined "normal" range, the footrope maintained contact with the seafloor, and the net suffered little or no damage during towing. A total of 15,650 bottom trawl survey hauls from the EBS study area (1982–2019) met these criteria.

3.2.2.3 Gulf of Alaska and Aleutian Islands Large-mesh Bottom Trawl Survey

Assignment of sampling effort within strata for GOA and AI surveys was determined using a Neyman optimal allocation sampling strategy (Cochran 1977) which considers relative abundance and variance of commercially important groundfish species from previous surveys of the area as well as the previous year's ex-vessel price for select species. During the time period of these data collections, changes in taxonomic classifications have resulted in different effective time series for different species and these are reflected in the analyses presented here (Harris et al., Pirtle et al. In review; Table 1). For example, dusky and dark rockfishes were considered a single species prior to the 1996 survey so that only data since that survey were used to separately model these two species. All fishes and invertebrates captured by the trawl net were identified to species, or into higher level taxonomic groups, and weighed. Non-colonial taxa were also counted or estimates of total count were made. For species where length-based definitions of life stages were available, length ranges for settled early juveniles, subadults, and adults were used to partition the catch based on proportionality estimated from the random length subsample taken from each catch. These length-based definitions of ontogenetic life stages came from the extant scientific literature, web resources (e.g., the Ichthyoplankton Information System, AFSC RACE: https://access.afsc.noaa.gov/ichthyo/speciesdict.php), or length data collected in beach seines, purse seines, and small-mesh bottom-trawls and recorded in the updated Nearshore Fish Atlas (as described in Grüss et al. 2021) (Table 4).

The fishing gear used on the RACE-GAP AI and GOA bottom trawl surveys consists of a Poly Nor'Eastern high-opening bottom trawl with a 27.2 m headrope, a 36.3 m footrope, and 24.2 m roller gear constructed with 36 cm rubber bobbins separated by 10 cm rubber disks (Stauffer 2004). Under fishing conditions, the average net width is 16.0 m and average height is 6.7 m based on acoustic net mensuration equipment mounted on the wing-tips and headrope of the trawl. Each trawl was certified as conforming to measurements and dimension standards prior to its use in the survey as stipulated in the National Trawling Standards (Stauffer 2004).

3.2.2.4 Other Surveys

Three other surveys are included in the present study as additional data sources to parameterize SDMs for the groundfish settled early juvenile life stages in the GOA (Table 3). These surveys used a variety of gear types and were conducted inshore of the RACE-GAP summer bottom trawl surveys and in nearshore areas where the settled early juvenile life stages of groundfish also occur (Laurel et al. 2009, Pirtle et al. 2019, Grüss et al. 2021).

3.2.2.5 Gulf of Alaska Small-mesh Bottom trawl Survey

The Alaska Department of Fish and Game (ADFG) has conducted a series of fishery-independent small-mesh bottom trawl surveys (Jackson and Ruccio 2003, Spalinger 2020), which provided a new source of groundfish distribution and abundance data for the GOA. This summer survey targets shrimp, forage fishes, and commercially important groundfish species on the central and western GOA continental shelf, including areas inshore of the GOA RACE-GAP survey grid. The small-mesh survey uses a fixed-grid station design where stations are pre-selected randomly and deploys a high-opening box trawl constructed with 3.2 cm mesh throughout and designed to sweep a 9.8 m path at a height of 4 m which is the ADFG, NMFS, and Department of Fisheries and Oceans of Canada standard for shrimp trawl research. Since 1973, either ADFG or NMFS have conducted this small-mesh bottom trawl survey annually in the GOA (Jackson and Ruccio 2003, Spalinger 2020). In 2015, funding was reduced and a fishery-independent small-mesh survey was no longer possible. However, the survey was maintained at a minimal level in bays around Kodiak Island to provide a baseline to monitor the shrimp population from 2016 to 2019. Additional funding has recently been made available to continue the survey more broadly in 2020 and 2021.

In the present study, we used ADFG small-mesh bottom trawl survey data to parameterize SDMs of settled early juvenile life stages of groundfishes from survey years in the GOA spanning 1989–2019 (Table 3). Groundfishes collected on the survey were identified to species or genus level and fish lengths were measured to the nearest millimeter. This small-mesh survey catches all demersal life stages of our target groundfish species, providing the opportunity to use length data from the small-mesh survey to contribute to defining limits for length-based life stage definitions. In addition, these data hold the potential for future SDM EFH mapping that accounts for habitat use of other groundfish life history stages in areas inshore of the GOA RACE-GAP survey grid.

3.2.2.6 Nearshore Mixed Gear Surveys

AFSC Auke Bay Laboratories (ABL) has historically curated their nearshore fish surveys in a centralized, relational database called the Nearshore Fish Atlas (NFAA; Johnson et al. 2012). The NFAA database was developed in 2003 to consolidate the ABL's southeastern Alaska beach seine data dating back to 1998 when NOAA's EFH funds first became available. By 2012, the NFAA database was made available online and contained 19 years of fish catch data from more than 1,300 beach seine hauls made in shallow, nearshore waters (within 20 m of shore and shallower than 5 m) of southeastern Alaska, the Aleutian Islands, Prince William Sound (PWS), Cook Inlet, Bristol Bay, and the Arctic region, making it the largest online repository of Alaska nearshore fish data (Johnson et al. 2012).

In 2019, the offline NFAA database was updated for the primary purpose of modeling and mapping EFH (Grüss et al. 2021). Although the NFA started as a beach seine database, catch data from other gear types have been archived in the offline version for years. The 2019 expansion of the NFAA with contemporary survey data from multiple gear types, including beach seines, purse seines, bottom and midwater trawls, gillnets, jigs, fyke nets, and minnow traps, quintupled the number of data entries (to 85,827), with the majority of these entries in the GOA. The online NFAA database was updated in June 2022.

In the present studies, we used survey data from the updated NFAA (1995-2019) to parameterize SDMs of settled early juvenile life stages of groundfishes in the GOA (Table 3). We restricted data extracts to survey gear types of beach seine (3.2 cm mesh), purse seine (3.2 cm mesh), bottom trawl (various mesh sizes), and jigs. This wide variety of gear types represent several sampling designs in a variety of habitats inshore of the GOA RACE-GAP survey grid. The NFAA provides the opportunity to use length data collected by the inshore surveys to define lower limits for length-based life stage definitions of the settled early juvenile stage. The lower length limits of settled early juvenile stages from inshore surveys were compared to the maximum transformation lengths of the pelagic early juvenile stages that were sampled in the field prior to settlement (e.g., Doyle et al. 2019). Additional details about the NFAA are available in Johnson et al. (2012), Grüss et al. (2021), and on the database landing page[49].

3.2.2.7 Juvenile Sablefish Tagging Program

Beginning in 1985, juvenile sablefish have been sampled by jig, tagged, and released in a number of bays and inlets in southeast Alaska by the AFSC ABL Marine Ecology and Stock Assessment Program (MESA) (Echave et al. 2013). Annual sampling in St. John Baptist Bay near Sitka on Baranof Island is used as an indicator of the potential strength of an upcoming cohort. Tagging efforts have expanded to several areas of the central GOA, following reports of high catch rates in recent years (Goethel et al. 2020). The juvenile sablefish tagging program is included in the present study as an additional data source to parameterize SDMs for the sablefish settled early juvenile life stage, using capture locations throughout the GOA for years 1985–2020 (Table 3).

3.2.3 Habitat Covariates

The independent covariates used to parameterize SDMs (Table 5) for EBS species (Figure 5), AI (Figure 6), and GOA (Figure 7) were chosen on the basis of their potential to influence the distribution and abundance of North Pacific groundfish and crab life stages in the three regions. Some of these independent covariates (or predictor variables) were dynamic or static habitat attributes typically collected on the bottom trawl survey. Others were derived and modeled variables describing the marine environment in the study area (e.g., NEP5 ROMS; Danielson et al. 2011). They were combined into a suite of independent covariates used to parameterize the SDMs. We used variance inflation factors (VIF; e.g., Laman et al. In review; Table 3) calculated using the methods in Zuur et al. (2009) to eliminate

[49] NOAA Fisheries Nearshore Fish Atlas of Alaska database (updated June 2022) alaskafisheries.noaa.gov/mapping/sz/index.html?tab=fa.

strongly collinear terms (VIF ≥ 5.0; Sigler et al. 2015). Independent habitat covariates from each regional survey data time series (e.g., AI 1991–2018) were interpolated on regular spatial grids ranging from 0.1–1 km2 using natural neighbor interpolation (Sibson 1981), inverse distance weighting (Watson and Philip 1985), ordinary kriging (Venables and Ripley 2002) with an exponential semi-variogram, or empirical Bayesian kriging with a semi-variogram estimated using restricted maximum likelihood (REML; Diggle and Ribeiro 2002). Interpolation by inverse distance weighting and ordinary kriging were calculated on the R computing platform (R Core Development Team 2020) and Bayesian kriging was generated in ESRI ArcGIS mapping software. Rasters for our analyses were gridded at a resolution of 1 km^2. Rasters were gridded at a resolution of 100 m^2 for our analysis of the settled early juvenile life stages in the GOA only. All rasters were projected in the Alaska Albers Equal Area Conic (EAC) projection (standard parallels = 55° and 65°N and center longitude = 154°W).

For bottom temperature and bottom depth, year- and trawl-location-specific values were used for model fitting while long-term averages of those values were used to model abundance and to map EFH. All other habitat covariates were extracted from rasters of long-term average values at the bottom trawl stations by averaging the raster values along the towpath of each haul. Rasterized multi-year averages of all habitat covariates in each raster cell (including bottom depth and bottom temperature) were then used to represent average conditions in the study area over time, and were used in the ensemble models to predict species distributions and abundances and generate EFH maps. For species data sources supporting the GOA settled early juvenile stage models only, covariate raster values were extracted at point locations representing the geographic location of each sampling site. In both cases, these extracted predictors were used to train and identify the best fitting SDMs. When predicting species distribution and abundance, the complete raster of each retained covariate was used as input into the final models for a species and life stage. In the case of observed, dynamic predictor variables such as bottom temperature from the RACE-GAP survey, the observed values were kriged and rasterized over the study duration (e.g., AI 1991–2019) to represent average conditions in the study area over time (Table 2).

3.2.3.1 Bottom Depth and Temperature

We used two kinds of bathymetry data when formulating the SDMs used to model groundfish and crab distributions and abundances in the EBS, AI, and GOA. When fitting constituent SDMs, the bottom depth measured at each trawl station was used as a covariate predictor variable to train and test those SDMs. When predicting groundfish distribution and abundance for all life stages modeled, we used a bathymetry raster. For the EBS, this raster was built from several sources (Zimmermann and Prescott, 2018, Mark Zimmermann (AFSC) unpublished data, Steve Lewis (AKRO) unpublished data). For the AI, this raster was built from two sources that included data from the AI and the western GOA (Zimmermann et al. 2013, 2019). For the GOA, this raster was built from several sources (Zimmermann and Prescott 2014, 2015, Zimmermann et al. 2019, Coyle 2019). The primary sources for the bathymetry rasters were depth soundings from digitized NOAA National Ocean Service (NOS) smooth sheets from early hydrographic (Hawley 1931) and other surveys (hydrographic and non-hydrographic) that used manual soundings (e.g., lead lines), single-beam, or multi-beam acoustic echosounders. Details on the preparation and processing of the bathymetry datasets are documented in Zimmermann and Benson (2013) and Zimmermann et al. (2019). Point data from these compiled bathymetry datasets were gridded to the recommended resolution of 100 m^2, and also to create a raster surface using natural neighbor interpolation (Sibson 1981) in ArcMap. To achieve the 1 km^2 resolution used in our analyses, we averaged the 100 m^2 point data over 1 km^2 grid cells.

Similar to how we used depth data, we used temperatures measured at each trawl station to train and fit SDMs, then used a raster surface of those temperatures averaged across years to predict groundfish and crab distributions and abundances using the best-fitting SDMs in an ensemble. The bottom temperature raster was created by interpolating the observed temperatures at each trawl station over the entire study area and time series using empirical Bayesian kriging in ArcGIS (Diggle and Ribeiro 2002) with a semi-variogram estimated using restricted maximum likelihood (REML). The raster was interpolated over a 1-km^2 grid of the study area.

The GOA ROMS with integrated nutrient-phytoplankton-zooplankton (NPZ) is a high-resolution hydrodynamic model that is run using two domains, including a 3 km^2 resolution grid of the CGOA (coastal Gulf of Alaska) and an 11 km^2 grid of the Northeast Pacific with 42 vertical layers, as described in Coyle et al. (2019). The CGOA ROMS 3 km grid extends from Haida Gwaii in British Columbia to the Shumagin Islands and from the coastline to 1,200 km offshore. Bottom temperature values (°C) from May-September 1999–2019, were extracted from the deepest (closest to the seafloor) vertical layer at each point of the CGOA ROMS 3 km grid and averaged to produce a gridded 100 m^2 (natural neighbor interpolation) climatology surface of mean modeled bottom temperature (Pirtle et al. In review; Figure 3). This surface was used in the analysis of the settled early juvenile life stage SDMs and provided bottom temperature estimates for areas inshore of the GOA RACE-GAP survey grid.

3.2.3.2 Water Movement

Three attributes of water movement were used as habitat covariates in modeling and prediction: maximum tidal speed, bottom current speed and direction, and variability in bottom current. We estimated maximum tidal speed at each survey station over a lunar year (369 consecutive days between January 1, 2009 and January 4, 2010) using a tidal inversion program parameterized for each study region on a 1-km^2 grid (Egbert and Erofeeva 2002). This tidal prediction model was used to produce a series of tidal currents for spring and neap cycles at every bottom trawl survey station. The maximum of the lunar annual series of predicted tidal current was then extracted at each bottom trawl survey haul location. A 1-km^2 raster surface of maximum tidal current speed was kriged over the study region using an exponential semi-variogram and values were extracted and averaged along individual trawl haul towpaths to use as input to the best fitting SDMs when predicting distribution and abundance.

The second water movement variable was the predicted bottom water layer current speed and direction from ROMS models for that region (NEP5 for GOA and the AI, and Bering10K for the EBS) (Danielson et al. 2011; Kearney et al. 2020). These long-term current projections are available as points on a 10 km^2 grid. The ROMS model was based on a three-dimensional grid with 30 (EBS) and 60 (GOA/AI) depth tiers for each grid cell. The bottom current speed and direction for the deepest depth bin at each point (closest to the seafloor) was used in our analyses. These regularly spaced projections were interpolated to a 100 m^2 raster grid covering the study area using inverse distance weighting and then averaged over a 1 km^2 and across survey years (1991–2019) for our analyses. To characterize current at each bottom trawl station, ROMS current velocity components were extracted along each trawl towpath and the mean northing and easting values were computed for each trawl haul. The interpolated bottom current raster served as covariate input to the best fitting SDMs when making EFH maps.

Bottom current variability across summer months (May to September for GOA and AI, June to September for the EBS) was included as a third bottom current-related predictor in the SDMs. It was computed separately as the pooled standard deviation (Pooled SD_j) of the northing and easting components of bottom current at each NEP5 ROMS prediction locus through time such that:

$$Pooled\ SD_j = \sqrt{\frac{\sum_{i=1}^{k}\left[(n_i - 1) * s_{ij}^2\right]}{\sum_{i=1}^{k}[n_i - 1]}}$$

where j is the location of a prediction on the ROMS grid, n_i is the number of months projected in year i, s_{ij}^2 is the variance in bottom current speed at location j in across the months in year i, and k is the total number of survey years. The pooled standard deviation of bottom current speed represents the variability in currents from month to month while accounting for differences in the yearly mean. It can be considered a proxy for current stability near the bottom.

3.2.3.3 Geographic Location

Spatial modeling, such as the SDMs presented here, often include a location variable to represent geographic location and account for spatial autocorrelation (Ciannelli et al. 2008, Politou et al. 2008, Boldt et al. 2012). To reduce the effects of spatial autocorrelation on the results, we chose to combine latitude and longitude into a smoothed bivariate geographic location term included as an independent predictor in SDM formulations. Rooper et al. (2021) demonstrated that this approach can reduce spatial autocorrelation in the model residuals. Geographic location was collected during each haul using a variety of positioning systems through time (e.g., manual charting, long range navigation (LORAN-C), and digital global positioning system [dGPS]). Since 2005 (EBS) and 2006 (GOA and AI), start and end positions for the vessel during the on-bottom portion of the trawl haul were collected from a dGPS receiver mounted on the vessel. We corrected vessel position to represent the position of the bottom trawl by triangulating how far the trawl net was behind the vessel (based on the seafloor depth and the length of wire out) and subtracting this distance from the vessel position. We assumed that the bottom trawl was directly behind the vessel during the tow and that all bottom trawl hauls were conducted in a straight line from the beginning to the end point. The mid-point of the net's trawl path between the start and end positions was used as the location variable in the SDMs. The EAC projected longitude and latitude data for each haul (and all other geographical data for this study) were projected to eastings and northings prior to modeling. A geographic location covariate was not used in the SDMs (MaxEnt) for the settled early juvenile life stages in the GOA).

3.2.3.4 Seafloor Terrain

Several seafloor terrain metrics were derived from the bathymetry surfaces and describe attributes of seafloor morphology. The attributes included in the present study were slope, aspect, curvature, and bathymetric position index (BPI). Seafloor terrain metrics were derived at the original scale of the compiled bathymetry surface (100 m^2) using neighborhood-based analytical methods in ArcGIS 10.7 (ESRI) with the Benthic Terrain Modeler (Wright et al. 2012, Walbridge et al. 2018). All seafloor terrain metrics were derived using a 3 x 3 neighborhood of grid cells, with the exception of BPI. Computation algorithms are provided by Walbridge et al. (2018).

Seafloor slope is the rate of change in bathymetry over a defined area. Slope is the first derivative of the bathymetry surface and was reported in degrees of incline (Dolan and Lucieer 2014, Horn 1981). Terrain slope may be a determinant of colonization since flatter areas support different substrata and communities than those found on steeper slopes (e.g., Pirtle et al. 2019).

Aspect measures the direction of the maximum gradient of slope and is expressed as angular compass direction, which is a circular variable (Horn 1981). Aspect was decomposed into sine (west-east or "eastness") and cosine (south-north or "northness") components to be used in the SDMs as continuous surfaces ranging from -1.0 to 1.0, where negative values indicate westness or southness and positive values indicate eastness or northness (e.g., Walbridge et al. 2018). Aspect eastness and northness were derived from the aspect surface. Terrain aspect is considered an indirect indicator of current velocity over and around seafloor terrain features (Mienis et al. 2007, Dolan et al. 2008).

Terrain curvature is the second derivative of the bathymetry surface and the first derivative of the slope (Schmidt et al. 2003, Zevenbergen and Thorne 1987). Curvature defines convex, concave, and linear slopes and can be used to identify seafloor features such as mounds and depressions that may be ecologically meaningful (Wilson et al. 2007). Curvature is also an indicator of how currents interact with the seafloor, either accelerating or decelerating parallel to the direction of slope and converging or diverging perpendicular to the direction of slope. We derived standard curvature as a single terrain surface, incorporating curvature in directions parallel and perpendicular to the slope (Zevenbergen and Thorne 1987, Schmidt et al. 2003). With this surface, positive values are convex slopes where currents may decelerate or diverge, negative values are concave slopes where currents may accelerate or converge, and values near zero are linear slopes where the rate and direction of flow is not expected to change.

Bathymetric position index (BPI) describes the elevation of one location relative to the mean of neighboring locations in an annulus-shaped neighborhood around a central cell or cells (Guisan et al. 1999, Weiss 2001). BPI emphasizes features shallower or deeper than the surrounding landscape area, such as ridges and valleys and places with abrupt changes in slope such as the continental shelf break and the base of the continental slope. Broad-scale measures of BPI (> 1 km) have been useful in distinguishing between areas of trawlable and untrawlable seafloor encountered by the RACE-GAP bottom-trawl survey (Pirtle et al. 2015). BPI has been used as an SDM covariate describing groundfish habitat in the GOA (Pirtle et al. 2019) and in other habitat analyses (Wilson et al. 2007, Howell et al. 2011). We derived BPI from EBS bathymetry rasters using a 64-cell radius neighborhood and from AI and GOA bathymetry rasters using a 65-cell radius neighborhood, both with an inner radius of 3-cells. This is equivalent to a horizontal scale of 6.4 km (6.5 km for GOA and AI), representing relatively broad-scale terrain features in our study area. In the resulting surface, positive values are shallower than the surrounding area (e.g., ridges and crests) and negative values are deeper (e.g., channels and valleys). In the visualization of this covariate, we artificially stretched the scale to highlight the heterogeneity that exists in the study area.

3.2.3.5 Seafloor Rockiness

A seafloor rockiness surface was developed for the AI and GOA based on a compilation of rock features and sediment attributes to represent a continuous gradient from areas with high occurrence of rocky substrate to areas with low occurrence of rocky substrate, using methods similar to Pirtle et al. (2019). The following datasets were included for the AI region: 1) sediment and substrate features from digitized smooth sheets (Zimmermann et al. 2013); 2) EBSSED-2 regional selection of samples collected from grabs and cores (Richwine et al. 2018); 3) modeled untrawlable and trawlable seafloor based on a generalized linear model of multibeam acoustic backscatter and terrain available as a 6 m^2 raster dataset (Pirtle et al. 2015) that was regridded to 1 km^2 (and 100m^2 for the GOA) and exported as point locations, where model predictions of untrawlable and trawlable locations are proxies for high and low occurrence of rocky substrate; and 4) RACE-GAP bottom-trawl survey historic haul locations, including hauls that incurred gear damage from seafloor contact to represent locations where untrawlable rocky features were likely encountered and hauls with good performance to represent locations where untrawlable rocky seafloor was likely not encountered, using the corrected start positions of the on-bottom portion of tows. Compiled point location data from the four datasets were gridded using natural neighbor interpolation to produce a raster surface of 1 km^2 resolution (ArcGIS 10.7, ESRI).

The following additional datasets were also applied for the GOA region: 1) sediment and substrate features from digitized smooth sheets (Zimmermann and Prescott 2014, 2015); 2) dbSEABED format sediment and substrate features (Golden et al. 2016); and 3) RACE-GAP bottom-trawl survey grid, using centroid locations for grid cells with codes indicating presence of rocky substrate features (rocky, pinnacles, snags, ledges, bottom too hard) and non-rocky substrate features (sand waves). Compiled point location data from the six datasets were gridded using natural neighbor interpolation to produce raster surfaces of 100 m^2 and 1 km^2 resolution (ArcGIS 10.7, ESRI).

For all of the seafloor terrain and substrate variables, values were extracted from their raster surfaces along the towpath at each trawl station and were used when training the models and identifying the best-fit SDM. The complete terrain raster was used to predict species distributions and abundances when a terrain covariate was retained in the best-fitting model.

3.2.3.6 Biogenic Structure

Previous studies have indicated that structure forming invertebrates (SFI) such as sponges, corals, and pennatulaceans (sea pens and sea whips) can form important structural habitat for temperate marine fishes (e.g., Rooper et al. 2010, Stone et al. 2011, Laman et al. 2015). The occurrence of SFIs can also be indicative of substratum type (Du Preez and Tunnicliffe 2011) because these sponges and corals attach to rocks and hard substrata, whereas sea pens and sea whips anchor into soft substrata. Therefore, we included the presence and absence of a) sponges, b) corals, and c) pennatulaceans as three binomial factors in the suite of habitat covariates. Presence-absence of these SFIs in trawl catches was used to train and identify the best-fitting SDMs. Rasters of modeled presence-absence for these SFIs (Rooper et al. 2014, 2016, 2017, Sigler et al. 2015) were used as covariate inputs into the final ensembles for predicting groundfish distribution and abundance.

3.2.4 Statistical modeling

Our modeling strategy for this 5-year EFH Review has been to fit multiple habitat-based SDMs to fish and crab abundances, skill test among SDMs using the root-mean-square-error to indicate model performance (RMSE; Hastie et al. 2009), and incorporate the best performing models into an ensemble in R (R Core Team 2020). Ensemble models essentially average predictions across constituent models, making them more robust to overfitting and less sensitive to differences in predictive performance among constituents. Rooper et al. (2017b) found that ensembles performed better than the generalized linear or generalized additive models alone when predicting distributions of structure-forming invertebrates. Overall, the ensemble modeling approach provides a universal SDM application across multiple FMPs and can be easily expanded to consider additional constituent models in the future.

Previous EFH descriptions in Alaska (e.g., Turner et al. 2017), were based on habitat-related SDMs modeling species abundances from 4^{th}-root transformed catch-per-unit-effort (CPUE; $kg \cdot ha^{-1}$) using the area swept method (Wakabayashi et al. 1985) and assuming a Gaussian distribution. Modeling 4^{th}-root transformed CPUE has several shortcomings with respect to our study objectives, including: (1) residuals were not informative due to the zero-inflation and overdispersion that cannot be properly addressed by a Gaussian distribution; (2) the a priori and ad hoc nature of deciding to use a 4^{th}-root transformation relative to other equally defensible transformations; (3) the inability to interpret the scale of the output, which is in units of 4^{th}-root CPUE and hence must be back-transformed to calculate a total predicted CPUE in any subarea; and (4) the scale-dependence of results, where the 4^{th}-root transformation implies that density would change if the area swept in the survey changed (i.e., if sampling had occurred at a different scale). To improve on the challenges associated with using the 4^{th}-root transformed CPUE, we directly modeled numerical abundance with an area-swept offset to generate EFH descriptions that were fitted directly to raw data without prior transformation; this more precisely represents fishing effort.

We modeled numerical abundance using five different SDMs (Table 4): a maximum entropy model (MaxEnt), a presence-absence GAM (paGAM), a hurdle GAM (hGAM), and two forms of standard GAM using the Poisson distribution (GAM_P) and the negative binomial distribution (GAM_{nb}). The MaxEnt and paGAM use presence or presence-absence data to estimate probabilities of occurrence (Phillips et al. 2006, Wood 2017). Using these models in conjunction with the complementary log-log (cloglog) link function allowed us to approximate abundance from the estimated probabilities (Scharf et al. 2019). Transforming these native model outputs (probability) into approximate numerical abundance yields predictions in the same units as the response variables from the other 3 SDMs which enabled skill testing and model comparison while meeting the requirements to qualify predictions as EFH Level 2, habitat-related density or abundance. Because some models, (notably MaxEnt) produce results on different scales, predictions were rescaled by dividing by the mean of predictions at tow locations and multiplying by the mean of observations. This ensured that predictions from all models were directly comparable and could be used to construct a weighted ensemble (Figure 8).

3.2.4.1 Maximum Entropy Models (MaxEnt)

Maximum entropy modeling was developed to model probability of suitable habitat or species occurrence with presence-only data (Phillips et al. 2006) in cases of rare species and when presence-only or presence-absence data were available from multiple surveys with varied sampling designs (Elith et al. 2011; Guisan et al. 2007). This newer version of the MaxEnt model, implemented with the *maxnet* package in R (Phillips et al. 2017; R Core Development Team 2020), reformulates the model as an inhomogeneous Poisson process, which constructs the predicted probabilities as a proportion of the product of underlying relative abundance and sampling probabilities. Because of this, it was possible to estimate the species abundance by treating the cloglog link output of the MaxEnt model as if it were the linear predictor in a Poisson model. The relative abundance estimate was then calculated by adding an additional parameter, the entropy, to the cloglog linear predictor and exponentiating the sum.

The MaxEnt model utilized the same suite of covariates as the GAMs, but omitted geographic location (lat/lon) from the suite of predictor variables because MaxEnt does not separately distinguish spatial variation in sampling probability from spatial variation in resource density (Elith et al. 2011). The MaxEnt algorithm automatically constructed and selected terms based on several feature classes determining relationships between the species response data and covariates. The default feature set was used in this study, which includes linear, quadratic, and product interaction terms. By default, hinge features were included in models with more than 80 presence records and threshold features were not used. As part of the fitting process, a variety of these different features were tested in different combinations. MaxEnt uses a regularization multiplier to determine the penalty applied to larger models and to help regulate overall model complexity. Here, we evaluated regularization multiplier values between 0.5 and 3.0 in intervals of 0.5 with the best value determined by the lowest RMSE after 10-fold cross-validation as described below (see Cross-Validation and Skill Testing 3.2.5).

3.2.4.2 MaxEnt for Settled Early Juvenile Life Stages in the GOA

We modeled the early juvenile life stage for several species in the GOA (first column in Table 4). Modeling the settled early juvenile life stage presented different challenges than those encountered when modeling later life stages. These smaller animals are not as readily retained in the standard RACE-GAP large mesh bottom trawl survey as larger animals, and they typically reside in inshore areas not sampled by the GOA RACE-GAP survey. To address these data gaps and so that we could model distribution of this critical life stage, we incorporated fishery-independent surveys with a variety of sampling designs and gear types into our analyses, including the GOA RACE-GAP survey and surveys from areas inshore of the GOA RACE-GAP survey grid (e.g., Pirtle et al. 2019). These additional sources consisted of the ADFG small-mesh bottom trawl survey (Jackson and Ruccio 2003, Spalinger 2020), data from multiple surveys stored in an update to the NFA database (2019) (e.g., Grüss et al. 2021), and the AFSC MESA juvenile sablefish tagging program (Echave et al. 2013) (Table 3). However, integrating data from multiple disparate surveys makes it difficult to separate catchability and fishing gear effects from actual differences in population abundance. To address these concerns we modeled settled early juvenile life stages from presence-only data rather than use the ensemble approach used for subadults and adults modeled solely from the RACE-GAP summer bottom trawl surveys.

As a method for combining multiple surveys with different designs and gear types (i.e., various bottom trawls, beach and purse seines, and jigs), we reduced all settled early juvenile stage observations to presence-absence only for inclusion in the MaxEnt model. MaxEnt treats data within a presence-only framework (Phillips et al. 2006), which has been useful to combine data obtained from multiple sampling designs and for data-limited species (Guisan et al. 2007, Elith et al. 2011). MaxEnt models have been previously applied to the settled early juvenile life stages of groundfish species in the GOA (Pirtle et al. 2019, Shotwell et al. *in pres*) and to juvenile and adult groundfish life stages in the GOA, EBS, and AI for the 2017 EFH 5-year Review (GOA-Rooney et al. 2018, EBS-Laman et al. 2017, AI-Turner et al. 2017).

Here, we modeled the probability of suitable habitat with the *maxnet* package, which incorporates a newer MaxEnt algorithm and the cloglog link (Phillips et al. 2017). The GOA settled early juvenile MaxEnt models utilized the suite of covariates developed as 100 m^2 raster grids and omitted geographic location (lat/lon) since MaxEnt cannot distinguish spatial variation in sampling probability from spatial variation in resource density (Elith et al. 2011) (Table 5). For GOA settled early juvenile EFH, we produce Level 1 (habitat-related distribution) maps as a first approximation of the distribution of these groundfish early life stages based on the predicted probability of suitable habitat. This approach advanced the level of settled early juvenile life stage EFH information from none to EFH Level 1 for 11 groundfish species in this EFH 5-year Review (Objective 1; Sigler et al. 2017).

MaxEnt automatically constructs and selects terms based on several feature classes that determine relationships between the species response data and covariates. The default feature set was used in this study, which includes linear, quadratic, and product interaction terms. By default, hinge features are included in models with more than 80 presence records and threshold features are not used. As part of the fitting process, a variety of these different features were tested in different combinations. MaxEnt uses a regularization multiplier to determine the penalty applied to larger models and to help regulate overall model complexity. For settled early juvenile stage MaxEnt models, we evaluated regularization multiplier values between 0.5 and 3.0 in intervals of 0.5. All evaluations were carried out using the 10-fold cross-validation methods described below (see Cross-Validation and Skill Testing 3.2.5), with the exception that instead of using RMSE, we used AIC_c (Akaike 1974) to identify the best fit model:

$$AICc = \sum_{k=1}^{10} 2q_k - 2\ ln\ \widehat{L_k} + \frac{q_k^2+2q_k}{n_k-q_k-1}$$

where q_k is the number of non-zero coefficients in the model for cross-validation fold k, n_k is the number of data points where the species is present for cross validation fold k, and $\widehat{L_k}$ is the likelihood for the model in fold k. Since MaxEnt does not utilize a standard error distribution and thus does not provide a likelihood, the *aic.maxent* function from the *ENMeval* package (Muscarella et al. 2014) was used to provide an approximation of AIC_c.

To assess model fit for settled early juvenile MaxEnt models, we calculated the area under the receiver operating characteristic curve (AUC) as a measure of overall prediction skill. The AUC measures the ability of model predictions to accurately discriminate between two options, such as a species being present or pseudoabsences that are generated during model fitting. An AUC of near 0.50 indicates poor performance, whereas a score of 1.0 indicates perfect discrimination (Hosmer and Lemeshow 2005). We also presented the spatial variation in model predictions as the standard deviation among the 10 replicates. Because the MaxEnt predictions were in units of probability bounded between zero and one, the standard deviation is easily interpretable without any further modification (Pirtle et al. 2019).

3.2.4.3 MaxEnt for All Life Stages in the EBS and AI and Subadult and Adult Life Stages in the GOA

MaxEnt models of the subadult and adult life stages only use distribution and abundance data from the RACE-GAP summer bottom trawl surveys. The MaxEnt model implemented with *maxnet* (Phillips et al. 2017; R Core Team 2020), reformulates the model as an inhomogeneous Poisson process, which constructs the predicted probabilities as a proportion of the product of underlying relative abundance and sampling probabilities. Because of this, it was possible to estimate species abundance by treating the cloglog link output of the MaxEnt model as if it were the linear predictor in a Poisson model. The relative abundance estimate was then calculated by adding an additional parameter, the entropy, to the cloglog linear predictor and exponentiating the sum. In this case, we comprehensively produced Level 2 (habitat-related abundance) maps and advanced the level of EFH information available for several species in this EFH 5-year Review.

This set of MaxEnt models utilized the same suite of covariates as the GAMs described below, but omitted geographic location (lat/lon) from the suite of predictor variables since MaxEnt cannot distinguish spatial variation in sampling probability from spatial variation in resource density (Elith et al. 2011). The MaxEnt algorithm automatically selected various feature classes and we tested a range (0.5-3.0) of regularization multipliers with the best value determined by the lowest RMSE after 10-fold cross-validation as described below in the subsection *Cross-Validation and Skill Testing*.

3.2.4.4 Generalized Additive Models (GAM)

We used three classes of GAMs in this study: the paGAM (Wood 2017), the hGAM (Cragg 1971, Barry and Welsh 2002, Potts and Elith 2006), and the standard GAM with a Poisson distribution (GAM_P; Hastie and Tibshirani 1990); and a negative-binomial GAM (GAM_{nb}; Zuur et al. 2009). All GAMs were fit using the *mgcv* package (Wood 2011) in R. The paGAM uses the binomial distribution and the cloglog link function, which made it possible to approximate numerical abundance from model predicted encounter probabilities (Fithian et al. 2015). The hGAM models presence-absence and abundance in two stages and accounts for zero-inflation commonly seen in field collected data (McCullagh and Nelder 1989). In the first stage of the hGAM, the probability of occurrence was predicted from presence-absence data using a paGAM and binomial distribution. In the second stage of the hGAM, a standard GAM was constructed for the positive catches using a "zero-adjusted" (Zuur et al. 2009) Poisson distribution. Finally, an abundance estimate was obtained by multiplying the predicted probability of presence from step one with the abundance estimate from step two (Manel et al. 2001, Barry and Welsh 2002, Wilson et al. 2005). The GAM_P estimates abundance directly using the Poisson distribution and a log link. The GAM_{nb} was structurally similar to the GAM_P but used a negative binomial distribution with a log link, allowing the GAM_{nb} to account for overdispersion in the data (McCullagh and Nelder 1989).

For all GAMs, we used iterative backward stepwise term elimination to remove covariate terms based on minimizing the model-dependent generalized cross-validation (GCV) or unbiased risk estimator (UBRE) scores thereby identifying the best fitting model formulations (Weinberg and Kotwicki 2008, Zuur et al. 2009). Since the Poisson and negative-binomial GAMs were structurally very similar models, we used RMSE-based skill testing to identify and keep the best performing model (lowest RMSE) of this pair in the ensemble.

All GAMs in this study used a variety of two dimensional smoothing terms, one dimensional smoothing terms, and categorical variables fitted to the abundance data. To avoid overfitting in the GAMs, the basis degrees of freedom used in the smoothing function for each habitat covariate were constrained following the methods of Weinberg and Kotwicki (2008). However, attempting to extrapolate model predictions into areas with few data points requires additional consideration. In particular, the default smoother when fitting GAMs, a "thin-plate spline," sometimes produces exaggerated predictions in areas of sparse data (Wood 2003). To counter this behavior in one dimensional smooth terms, we used a smoothing penalty based on the first derivative (as opposed to the default second derivative), which tended to push the effect curve towards zero where data were unavailable. For two dimensional smooth terms, the same method was applied, but "Duchon" splines were used instead of thin-plate or cubic splines (Duchon 1977) which did a better job of penalizing the smooth function in areas with sparse data. Finally, if a GAM based on thin-plate splines failed, a second version using cubic splines in the one dimensional smooth terms was attempted. If both versions failed to converge or produced unreasonable results, that particular GAM was excluded from the final ensemble.

3.2.5 Cross-Validation and Skill Testing

Species distribution models were subjected to k-fold cross-validation to estimate RMSE and to assess accuracy and uncertainty. We computed the error at each cross-validation fold (k) by fitting an SDM to a randomly selected "in-bag" partition containing 90% of the observed abundance at trawl stations (i), predicting abundance at the remaining "out-of-bag" partition containing the other 10% of trawl stations, and comparing the predicted (y) and observed (x) values for the testing subset. The k-fold cross-validation was repeated 10 times until every point in the data set had been tested and the RMSE from the accumulated out-of-bag sample was calculated as:

$$RMSE = \sqrt{\frac{\sum_{k=1}^{10}\sum_{i=1}^{n_k}(y_{ki} - x_{ki})^2}{\sum_{k=1}^{10} n_k}}$$

where y_{ki} is the predicted numerical abundance in cross-validation fold k, x_{ki} is the observed numerical abundance at trawl station i in cross-validation fold k, and n_k is the number of stations sampled in the kth fold. This process provides a test of prediction skill at unsampled locations within the cross-validation, and provides a measure of performance that can be used to compare models. The RMSE provides a metric of the ability of a model to accurately predict the abundance at a series of locations. The model with the lowest RMSE value was considered the best performer (Hastie et al. 2009). The cross-validation also allows for a consistent method of calculating the variance in model predictions by computing it at each location across folds.

Skill testing was used to eliminate constituent SDMs from the ensemble by identifying and dropping low-performing models with high RMSEs. Constituent SDMs retained in the ensemble were weighted by the inverse squared RMSE following the formula,

$$w_i = \frac{RMSE_i^{-2}}{\sum_{i=1}^{m} RMSE_i^{-2}}$$

where w_i is the weight for model i, $RMSE_i$ is the cross-validated RMSE for model i, and m is the number of constituent models. The inverse of RMSE-squared is sometimes called “precision”, and precision-weighting (as we use here) is often the optimal weighting method e.g., as used in shrinkage estimators and hierarchical models. The inclusion of poor performing models may degrade ensemble performance so if any constituent SDM received less than a 10% relative weight, it was eliminated from the ensemble and the weights of the remaining SDMs in the ensemble were recalculated.

The ensemble model extrapolated abundance into areas along the edges of the survey grid that were rarely sampled as well as across regions in the Bering Sea like the EBS Slope and NBS which have been sampled at much lower frequency than the EBS shelf. Under these conditions, SDMs that fit the majority of the data quite well can still produce unacceptable predictions around the edges and in these unfrequented regions. The unacceptable predictions usually take the form of unrealistically high abundance. To address this challenge, a criterion was implemented so that any SDM generating abundance predictions > 10 times the highest observed survey abundance was excluded from the ensemble. The resulting cumulative ensemble-predicted numerical abundance, based on the combined effects of all retained constituent SDMs, was translated into a map of the complete EFH area for each species.

3.2.6 Ensemble Models and Uncertainty

Ensemble modeling is a robust method to predict species distributions and abundances (Aruajo and New 2007). Potential advantages include better estimates of uncertainty, reduced bias, and results that are less sensitive to minor changes in the underlying data (e.g., accumulating data through annual surveys; Stewart and Hicks 2018). In the present study, we combined the best-fit constituent SDMs into single species life stage-specific ensemble predictions of habitat-related abundance to inform descriptions of EFH. In practice, this means we first identified the best performing MaxEnt, paGAM, hGAM, and GAM SDMs. In the MaxEnt models, this entailed testing a range of regularization multipliers, while in the GAMs this involved backwards stepwise term elimination. For the standard GAM, the Poisson and negative binomial error distributions were modeled separately and skill testing using the RMSE was employed to select the distribution that best characterized the data. The set of best SDMs from each category was then precision-weighted (i.e., weighted by the inverse of its cross-validated RMSE) and constituent SDM weights were normalized to sum to one. Predictions from the ensemble were made by multiplying each constituent prediction by its weight and summing the weighted predictions across SDMs. The result of this exercise was a final ensemble for each species' subadult and adult life stage that predicts habitat-related abundance.

The variance of the ensemble prediction was obtained based on a weighted combination of the variance in the predictions of each constituent model. For each constituent, 10 abundance prediction rasters were made using the 10 models fit during cross-validation. The variance across these 10 folds at each location was then calculated to provide a variance estimate for that constituent model. After repeating this process for all constituent models in the ensemble, we adapted the following equation from Burnham and Anderson (2002), substituting our RMSE derived weights for their AIC weights:

$$SD_j(ensemble) = \sum_{i=1}^{m} w_i \times \sqrt{var_{ij} + \left(y_j^* - y_{ij}\right)^2}$$

where SD_j is the standard deviation of the ensemble at location j, w_i is the weight for model i, m is the number of constituent models, var_{ij} is the variance for model i at location j, is the ensemble abundance prediction at location j, and y_{ij} is the abundance prediction for model i at location j. Then we computed the coefficient of variation (CV) from the SD (ensemble) as:

$$CV_j = \frac{SD_j}{y_j^* + c}$$

where CV_j is the coefficient of variation at location *j*, SD_j is the ensemble standard deviation at location *j*, and y^*_j is the ensemble prediction at location j. Because the term y^*_j in the denominator can sometimes be close to zero, a small constant *c*, which was set at 1% of the max predicted abundance for that species and life stage, must be added to all abundance estimates when calculating the CV.

3.2.7 Species Distribution Model Performance Metrics

In addition to the RMSE described above for skill testing among SDMs and constituent model weighting in the ensemble, we computed three commonly used metrics of SDM performance for constituent models and the ensembles. The three metrics we reported were the Spearman's rank correlation coefficient (ρ), the area under the receiver-operator-characteristics curve (AUC; Hosmer and Lemeshow 2005), and the deviance explained based on the Poisson distribution (PDE). Each metric measures a different aspect of model performance and has distinct strengths and weaknesses. All models should be assessed with reference to the underlying biology of the species being studied.

The ρ score compares predicted densities with observations for each sample, computing their rank correlation, and measuring how well a model accurately distinguished between high and low density areas (Best and Roberts 1975, Zar 1984). We employ the ρ instead of the more familiar Pearson correlation because the ρ is more appropriate for count data that do not follow a normal distribution (Legendre and Legendre 2012). Additionally, the EFH maps produced in this project are based on ranked percentiles of area occupancy, and ρ may provide some insight into the accuracy of the EFH maps. While there is no objective standard for what constitutes a "good enough" correlation, for this project, we adopt the framework that less than 0.2 represents "poor" predictive performance, between 0.2 and 0.4 is "fair", between 0.4 and 0.6 is "good," and greater than 0.6 is "excellent." Our framework is based on our knowledge of the ecology of the species being modeled and the available data. Because ρ is the rank correlation, a high value is easiest to obtain when there is a large difference between the lowest and highest abundances, such that small prediction errors do not affect the rankings. Conversely, a low value can result if the observed densities occupy a narrow range and a small prediction error will change the rankings.

The AUC is a measure of the ability of a model to discriminate between binary outcomes, such as presence and absence. The value of the curve at any point represents the ratio of true positives to false positives at that point, and the total area under the curve is a representation of the overall performance across the entire range of values. The AUC has a minimum value of 0.5 (i.e., random 50/50 chance) and a maximum of 1, and values under 0.7 are generally considered poor, values between 0.7 and 0.9 are good, and values greater than 0.9 suggest excellent discrimination ability (Hosmer and Lemeshow 2005). The AUC provides a measure of discrimination ability that is standardized across the range of probability predictions, which makes it useful as a summary of discrimination ability. In this case, discriminating where the RACE-GAP bottom trawl survey catches individuals and where it does not. However, it can sometimes be misleading in situations where an overwhelming majority of observations are either present or absent and only a small portion of the probability space has been adequately sampled.

The PDE provides a generalization of "variance explained" for the constituent SDMs as well as the ensemble. We assume the Poisson distribution when computing the deviance explained for these models because count data are not normally distributed and traditional estimates of the variance explained tend to be misleading. Additionally, with the Poisson distribution, the size of errors is expected to change with the mean of the predictions. Therefore, it is common to compute the deviance explained by a model. This value is a measure of the percent reduction in the residual deviance of a model compared to a naïve null model, which contains only an intercept and no predictor terms. Because we employ a variety of models that utilize different distributions (binomial, Poisson, negative binomial), and different underlying data types (presence-absence, count), we estimate the deviance explained in comparison to a fixed null Poisson model. Therefore, the PDE represents the percent deviance explained in relation to a null Poisson model, which allows for a fairer comparison of the different models. We specifically extracted predicted numerical density as common currency from all models, and compared this prediction with the observed count at each station using the formula for deviance-explained for a Poisson distribution. In this case, we adopt a similar metric to the correlation, where less than 0.2 indicates "poor" performance, between 0.2 and 0.4 "fair" performance, between 0.4 and 0.6 "good" performance, and greater than 0.6 is "excellent" performance. A high PDE can result when model predictions are accurate, or when the observed data are highly variable and the model represents a significant improvement over a simple null model. Similarly, a low value can sometimes occur even when predictions are accurate if there is no improvement over the null model, indicating that a simpler method would probably be acceptable. Deviance is calculated as,

$$D = 2\sum_{i=1}^{n}\left[x_i ln\left(\frac{x_i}{exp(y_i)}\right) - \left(x_i - exp(y_i)\right)\right],$$

$$D_0 = 2\sum_{i=1}^{n}\left[x_i ln\left(\frac{x_i}{exp(\bar{x})}\right) - \left(x_i - exp(\bar{x})\right)\right], \text{ and}$$

$$PDE = \frac{D}{D_0},$$

where D represents the deviance of a given model, D_0 is the deviance of the null model, x_i represents the observed abundance for data point i, represents the mean of observed abundance, and y_i represents the predicted numerical abundance for data point i as calculated from the log- or cloglog-linked linear predictor used in each constituent model.

Species Distribution Model Performance Metric Rubric:

ρ: < 0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (good), 0.61–0.99 (excellent)

AUC: < 0.70 (poor), 0.71–0.90 (good), 0.90–0.99 (excellent)

PDE: < 0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (good), 0.61–0.99 (excellent)

3.2.8 Essential Fish Habitat (EFH) Maps

3.2.8.1 Encounter Probability

Encounter rates were derived from model predictions and used to remove locations that had low encounter probabilities from inclusion in the EFH area. For settled early juvenile MaxEnt SDMs in the GOA, the cloglog probability of suitable habitat was used in place of encounter probability. In settled early juvenile ensembles in other regions, as well as all ensembles for subadult and adult life stages, we assumed that the abundance predictions approximately followed a Poisson distribution. Under this assumption, the probability of encounter was equal to one minus the likelihood of zero abundance, given the predicted abundance at that location.

3.2.8.2 Mapping EFH from SDMs

New Level 1 EFH maps, based on habitat-related species distribution for the settled early juvenile life stage in the GOA, met an Alaska EFH Research Plan objective for this EFH 5-year Review (i.e., Objective 1: Develop EFH Level 1 information (distribution) for life stages and areas where missing; Sigler et al. 2017). For all settled early juveniles in other regions, subadults, and adults, maps of species' habitat-related abundance predicted from the ensembles were used to describe and map new EFH Level 2 information for this EFH 5-year Review.

Occupied habitat was defined as all locations where a species' life stage had probability of suitable habitat (GOA settled early juveniles) or encounter probability (all others) greater than 5%. Four areas were identified containing 95%, 75%, 50%, and 25% of the occupied habitat, where habitat is defined as areas exceeding a threshold of 5% predicted species encounter probability. The definition of EFH area in Alaska is the area containing 95% of the occupied habitat (NMFS 2005). Each of the lower quantiles (hereafter referred to as subareas) describes a more focused partition of the total EFH area. The area containing 75% of the occupied habitat based on SDM predictions is referred to as the "principal EFH area." For the fishing effects analysis of the 2017 EFH 5-year Review (EFH component 2; Simpson et al. 2017), the area containing 50% of the occupied habitat is termed the "core EFH area" and we have applied this terminology to our results. The areas containing the top 25% of the occupied area are referred to as "EFH hot spots". Mapping habitat percentiles for EFH subareas like these helps demonstrate the heterogeneity of fish and crab distributions over available habitat within the larger area identified as EFH and aligns our results with those of other EFH-related projects.

3.2.8.3 Species Complexes

Some groundfishes in Alaska are managed as members of stock complexes (e.g., the Other Rockfish Stock Complex in the Gulf of Alaska). While EFH must be designated for each managed species, EFH may be designated for assemblages of species with justification or scientific rationale provided (50 CFR 600.815(a)(1)(iv)(E)). In the present study, and for the first time in an EFH 5-year Review, we presented EFH descriptions of multi-species stock complexes using aggregated single species SDMs to produce descriptions of EFH to serve as proxies for individual species in the stock complex where an SDM EFH map was not possible due to data limitations (i.e., < 50 catches over the study period). To achieve this, we first generated multi-species abundance maps by summing the predicted abundances at each raster cell for each species in the complex that supported an ensemble. Then, using the same method described above for single species maps, we constructed an EFH map for the stock complex. In complexes where there was a mixture of available life history information (e.g., some species with known length-based life stage definitions and some without), life stages were combined for the species mapped together from the complex. See the introductory section of each species complex chapter (see section *Results*) for details about the species and life stages that were included.

3.2.8.4 EFH Comparisons between 2017 and 2022

The 2017 EFH 5-year Review used GAM and hGAM SDMs to predict species distributions in units of 4^{th} root-transformed CPUE. For comparison with the 2023 ensembles, the 2017 predictions were converted into numerical abundance by raising them to the 4^{th} power and dividing by the original fishing effort recorded during the RACE-GAP bottom trawl survey. This allowed the 2023 fit metrics (ρ, AUC, PDE) to be calculated for the 2017 SDMs (e.g., Table 9 and Table D2). In 2017, some species distributions were modelled using a type of MaxEnt SDM that is restricted to predicting probability and only AUC was calculated in these cases.

3.2.8.5 Bridging Figures

The changes from the maps produced for the 2017 EFH 5-year Review and those produced during the 2023 EFH 5-year Review were summarized in two ways. First, the 2017 EFH map was compared to the 2022 EFH map, and the percentage change in EFH areal extent was calculated (e.g., Figure 13). Second, the transition from the 2017 EFH map to the 2022 EFH map was broken into five steps to demonstrate the impact of specific advancements to the SDM methods (e.g., Figure 14).

Step one incorporated new life history information such as updated lengths at 50% maturity (L_{50}) into the data used to fit the SDM. This step was omitted if no new life history information was available. Step two incorporated any new data acquired during the RACE-GAP bottom trawl surveys from 2015–2019.

Step three incorporated all the advancements to the SDMs employed in the 2023 EFH 5-year Review. These include the following:

- The response variable changed from 4^{th} root transformed CPUE (2017 EFH 5-year Review) to numerical abundance (2023 EFH 5-year Review).
- If the 2017 SDM was a GAM:
  - Step three changed from a Gaussian error distribution (2017) to either a Poisson or negative binomial distribution (2023).
  - The definition of occupied habitat was changed from all locations with positive CPUE (2017) to all locations with greater than 5% encounter probability (2023).
- If the 2017 SDM was a hGAM
  - The error distribution for the probability model was changed from a binomial distribution with a logit link (2017) to a binomial distribution with a cloglog link (2023).
  - The error distribution for the density model was changed from a Gaussian distribution (2017) to a zero-adjusted Poisson distribution (2023).
  - The definition for occupied habitat was changed from all locations with positive CPUE and with predicted encounter probability above an estimated threshold (2017), to all locations with greater than 5% encounter probability (2023).
  - The estimated threshold in 2017 was the probability that maximized sensitivity + specificity in a classification task, whereas 2023 used a consistent probability of 5%.
- If the 2017 SDM was a MaxEnt
  - The model changed from using the dismo package to fit a traditional maximum entropy model (2017) to using the maxnet package to fit it as an inhomogenous Poisson point process (2023).

- The 2017 MaxEnt SDMs could not approximate numerical abundance, while this is possible in 2023.
- The definition of occupied habitat changed from all locations with greater than 5% probability of suitable habitat (2017) to all locations with greater than 5% encounter probability (2023).

Step four added additional habitat covariates to the SDM. Lastly, step five used skill testing to make a weighted ensemble of multiple SDMs. At each step, the change in EFH area relative to the previous step was calculated.

3.2.8.6 EFH Level 3 Habitat Related Vital Rates

We advanced EFH information to Level 3 (habitat related vital rates) in the GOA for a set of groundfish species' settled early juvenile life stages to achieve a key Alaska EFH Research Plan objective for this EFH 5-year Review (Objective 2; Raise EFH level from 1 (distribution) or 2 (habitat-related densities or abundance) to Level 3 (habitat-related growth, reproduction, or survival rates); Sigler et al. 2017). This was done by integrating temperature-dependent vital rates developed from field and laboratory studies with SDM predictions of probability of suitable habitat. Temperature-dependent vital rates have been published or are in development for groundfish species in Alaska (Table 6). A representative example that can be applied in this context is from Laurel et al. (2016), who described the temperature-dependent growth rate of early juvenile Pacific cod as:

$$GR = y_0 + a * T + b * T^2 - c * T^3,$$

$$GR = 0.2494 + 0.3216 * T - 0.0069 * T^2 - 0.0004 * T^3$$

where *GR* is the growth rate expressed as the % change in body weight per day (% body weight per day), *T* is temperature in degrees-Celsius, and y_0, *a*, *b*, and *c* are estimated parameters. Species-specific vital rate formulations are detailed in each Results chapter where EFH Level 3 information was generated.

We constructed the EFH Level 3 maps by first mapping the temperature-dependent vital rates across the survey study area, using the CGOA ROMS 3 km bottom temperature covariate raster as the temperature value in the rate equations. Next, we computed the product of the rate map and the SDM-predicted probability of habitat map by multiplying the two rasters together. The product map was then transformed onto a relative scale ranging from zero to one, where zero indicates areas of low probability of suitable habitat and low habitat-related temperature-dependent growth potential and one indicates areas of high probability of suitable habitat and high habitat-related temperature-dependent growth potential. The Level 3 maps provide additional context when interpreting EFH Level 1 or Level 2 maps developed from the same SDMs.

3.2.9 Tables

Table 1. Comparison of species distribution model (SDM) data and methods in the present work with that of the 2017 EFH 5-year Review (e.g., Laman et al. 2017): RACE-GAP = NMFS Resource Assessment and Conservation Engineering Groundfish Assessment Program summer bottom trawl surveys; ADFG = Alaska Department of Fish and Game; MaxEnt = maximum entropy model, GAM = generalized additive model, hGAM = hurdle GAM, paGAM = presence-absence GAM.

SDM data and methods for the 2017 EFH Review	SDM data and methods for the 2023 EFH Review
Dependent variables	
RACE-GAP bottom trawl surveys through 2014	RACE-GAP bottom trawl surveys; 2015-2019 added
-	(GOA settled early juvenile life stage only) AFSC updated Nearshore Fish Atlas beach and purse seines, and small-mesh bottom trawls (1998-2019), and hook (1989-2019), juvenile sablefish hook-and-line survey (1985-2019)
-	(GOA settled early juvenile life stage only) ADFG small-mesh bottom trawl surveys (1989-2019)
-	(GOA settled early juvenile life stage only) AFSC juvenile sablefish tagging program hook-and-line (1985-2019)
-	Settled early juvenile life stage
Length-based life stages	Updated length-based life stages
Lengths at maturity through 2014	Updated lengths at maturity
Independent variables	
Bathymetry data through 2014	GOA bathymetry data updated through 2019
Slope (derived from bathymetry data through 2014)	GOA slope derived from bathymetry data through 2019
-	Bathymetric position index (BPI) derived from bathymetry data through 2014 (EBS and AI) and 2019 (GOA)
-	Seafloor aspect northness and eastness derived from bathymetry data through 2014 (EBS and AI) and 2019 (GOA)
-	Seafloor curvature derived from bathymetry data through 2014 (EBS and AI) and 2019 (GOA)
-	Rockiness (GOA and AI)
Sediment grain size (*phi*) data through 2014	Updated sediment grainsize (*phi)* data through 2019
Bottom temperature data through 2014	Updated bottom temperature through 2019

SDM data and methods for the 2017 EFH Review	**SDM data and methods for the 2023 EFH Review**
Bottom current data through 2014	Updated bottom currents
Bottom current variation through 2014	Updated bottom current variation
SDM methods	
Three possible SDMs selected *a priori* (either MaxEnt, hGAM, or GAM)	Five possible SDMs as constituents in an ensemble (MaxEnt, paGAM, hGAM, GAM_P, and GAM_{nb})
Use dismo package (Hijmans et al. 2017) to implement MaxEnt models	Use maxnet package (Phillips 2017) to implement MaxEnt models†
-	New paGAM using binomial distribution and cloglog link†
hGAM using binomial logit and Gaussian steps	hGAM using binomial cloglog and zero-adjusted Poisson steps
GAM using Gaussian distribution	Use Poisson and negative binomial distributions in GAM (GAM_P and GAM_{nb})
GAMs use 4th root transformed CPUE	GAMs use count data with effort offset
-	Settled early juveniles modeled (GOA only) using MaxEnt and species presence-only data from summer surveys of various gear-types (*see new dependent variables, above*)
Fit Metrics	
80% of data used to train model, 20% used to evaluate performance	Used 10-fold cross-validation to estimate ensemble weights
Best model chosen based on prevalence	SDMs skill tested and weighted based on inverse squared RMSE
AUC used to evaluate MaxEnt; Pearson r^2 used to evaluate GAMs	All SDMs evaluated with three metrics: Spearman's ρ, AUC, and PDE
EFH	
EFH area mapping method changed depending on model	EFH area mapping method is the same for all SDM ensembles
MaxEnt models EFH Level 1, GAMs model EFH Level 2	Almost all models can estimate approximate abundance and are EFH Level 2*
†- Uses a complementary log-log (cloglog) link function and can be used to approximate numeric abundance * GOA settled early juveniles do not estimate abundance and should be considered EFH level 1	

Table 2. National Marine Fisheries Service (NMFS) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys, large marine ecosystems (LME) represented by each, and the data years included in the species distribution models for the 2017 EFH 5-year Review (*italics*) and added in the present study for the 2023 EFH 5-year Review (bold).

Survey Name	Large Marine Ecosystem	Data Years Included	Periodicity
Aleutian Islands *	Aleutian Island LME	*1991-2014* **2015-2019**	Triennial (1991-2000), Biennial (2000-present)
Eastern Bering Sea Shelf	Eastern Bering Sea LME	*1982-2014* **2015-2019**	Annual
Eastern Bering Sea Slope	Eastern Bering Sea LME	*2002,‘04,‘08,‘10,‘12* **2016**	Periodic
Gulf of Alaska	Gulf of Alaska LME	*1993-2013* **2015, 2017, 2019**	Triennial (1993-2001), Biennial (2001-present)
Northern Bering Sea	Arctic LME	*2010* **2017 and 2019**	Periodic
* For our analyses, we appended the western Gulf of Alaska portions of RACE-GAP summer bottom trawl surveys to the Aleutian Islands data set in interposing survey years to support the geographic split between the two LMEs at Unimak Pass.			

Table 3. Catch data sources used to develop SDM of groundfish early juvenile life stages in the Gulf of Alaska (GOA), including location with GOA subregion indicated (western = w, central = c, eastern = e, and all = a), gear type, and years included; ADFG = Alaska Department of Fish and Game, AFSC = NMFS Alaska Fisheries Science Center, RACE-GAP = AFSC Resource Assessment and Conservation Engineering Division's Groundfish Assessment Program.

Survey/ Source	Location	Gear Type	Years
RACE-GAP Summer Bottom Trawl Survey (von Szalay and Raring 2019)	GOAa, continental shelf	RACE Poly Nor'Eastern Bottom Trawl	1993-2019
ADFG Small-mesh Bottom Trawl Survey (Jackson and Ruccio 2003, Spalinger 2020)	GOAce, nearshore, continental shelf	Small-mesh bottom trawl (3.2 cm mesh)	1989-2019
AFSC updated Nearshore Fish Atlas of Alaska (Johnson et al. 2012; Grüss et al. 2021)	GOAa, coastal, nearshore	Beach seine, purse seine, small-mesh bottom trawl (3.2-32 mm mesh), hook-and-line	1998-2019
AFSC Sablefish Tagging Program (Echave et al. 2013)	GOAa, nearshore	Hook-and-line	1985-2020

Table 4. North Pacific groundfish species modeled to describe and map essential fish habitat (EFH) for the 2023 EFH 5-year Review with length-based life stage breaks (length units = mm) and survey region indicated where differences in life history information is documented. Life stage breaks updated since the 2017 EFH 5-year Review are indicated with bold text. (*rougheye and blackspotted rockfishes are modeled as a complex and apportioned separately).

Species Common Name	Early Juvenile	Subadult	Adult
Alaska plaice	**35**–140	**140–319** (≤ 280)	> 319 (> 280)
arrowtooth flounder	**35**–160	161–**480**	> **480**
flathead sole	**20**–140	AI: 141–**342**; EBS: 141–342 (≤ 250); GOA: 141–**333**	AI: > **343**; EBS: > 342 (> 250); GOA: > **333**
Greenland turbot	–	≤ **580** (≤ 650)	> **580** (> 650)
northern rock sole	**20**–140	AI: 141–**309**; EBS: 141–**309**; GOA: 141–**328**	AI: > **310**; EBS: > **310**; GOA: > **329**
yellowfin sole	**30**–140	141–296 (≤ 250)	> 296 (> 250)
Kamchatka flounder	–	**≤ 550**	**> 550**
Greenland turbot	–	**≤ 580**	**> 580**
Bering flounder	–	**≤ 238**	**> 238**
Petrale sole	–	**≤ 331**	**> 331**
English sole	**20 - 140**	**141 - 230**	**> 230**
Dover sole	**30 - 140**	**141 - 439**	**> 440**
rex sole	**70 - 140**	**141 - 352**	**> 352**
Sakhalin sole	--	**50 - 196**	**> 196**
starry flounder	GOA: **20 - 150**	BSAI: **≤ 350**; GOA: **151 - 350**	**> 351**
sand sole	**20 - 140**	**141 - 170**	**> 171**
southern rock sole	--	**≤ 347**	**> 348**
butter sole	--	**≤ 140**	**> 141**
Atka mackerel	--	**≤ 340**	**> 341**
sablefish	150–399	400–585 (≤ 400)	> 585 (> 400)
Pacific cod	40–150	BSAI: 151–**580**; GOA: 151–**503**	BSAI: > **580**; GOA: > **503**
walleye pollock	**40**–140	AI: 141–**381**; EBS: 141–**381**; GOA: 141–**410**	AI: > **381**; EBS: > **381**; GOA: > **410**

Species Common Name	Early Juvenile	Subadult	Adult
blackspotted rockfish	–	≤ 453 (≤ 430)	> 453 (> 430)
harlequin rockfish	–	≤ 188 (≤ 230)	> 188 (> 230)
northern rockfish	–	BSAI: ≤ 277 (≤ 250) GOA: ≤ **310**	BSAI: > 277 (> 250) GOA: > **310**
Pacific ocean perch	**25**–200	201–250 (≤ 250)	> 250
rougheye rockfish	–	≤ **430** (≤ 430)	> **430** (> 430)
shortspine thornyhead	--	**≤ 215**	**> 216**
longspine thornyhead	--	**≤ 178**	**> 179**
greenstriped rockfish	--	**≤ 220**	**> 221**
rosethorn rockfish	--	**≤ 215**	**> 216**
quillback rockfish	--	**≤ 290**	**> 291**
redstripe rockfish	--	**≤ 290**	**> 291**
yelloweye rockfish	--	**≤ 450**	**> 451**
redbanded rockfish	--	**≤ 420**	**> 421**
sharpchin rockfish	--	**≤ 250**	**> 251**
shortraker rockfish	--	**≤ 499**	**> 500**
spiny dogfish	–	**≤ 973**	**> 973**
big skate	–	**≤ 1486**	**> 1486**
Bering skate	–	**≤ 690**	**> 690**
longnose skate	–	**≤ 1131**	**> 1131**
mud skate	–	**≤ 595**	**> 595**
Alaska skate	–	**≤ 930**	**> 930**
Aleutian skate	–	**≤ 1320**	**> 1320**
whiteblotched skate	–	**≤ 964**	**> 964**

Table 5. Covariates used in habitat-based species distribution models (SDM) to fit (identify best fitting formulation) and then predict distributions and abundances from the final ensembles or final model of North Pacific groundfish and crab species to describe essential fish habitat (EFH) in Aleutian Islands (AI), Gulf of Alaska (GOA), and eastern Bering Sea (EBS). Covariates applied to SDMs are indicated by region (columns) and life stage (in parentheses under regions; settled early juvenile = EJ; subadult = SA; and adult = A). X's in the region columns indicate that covariates were used for every life stage.

Variable	Unit	Description of Prediction Raster	Interpolation method	Data Source and Usage	AI	GOA	EBS
Bottom temperature	°C	Mean bottom temperatures measured on bottom trawls during AFSC RACE-GAP summer trawl surveys (1982–2019)	Empirical Bayesian kriging	Temperature data collected at bottom trawl hauls	x	SA, A	x
Bottom temperature (modeled)	°C	Bottom temperature (deepest depth bin) predicted from the CGOA ROMS 3 km grid (Coyle et al. 2019) from May-September and averaged (1999–2019).	Natural neighbor	Modeled temperature data from CGOA ROMS 3 km	--	EJ	--
Bottom current Northing and Easting	m·sec-1	Seafloor ocean current components predicted from the NEP5 ROMS (Danielson et al. 2011) averaged for the bottom layer across summer years (1991–2018)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom current	x	SA, A	--
Bottom current Northing and Easting	m·sec-1	Seafloor ocean current components predicted from the Bering10K ROMS (Kearney et al. 2020) averaged for the bottom 5m across summer years (1982–2019)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom 5m current	--	--	x
Bottom current Northing and Easting variability	m·sec-1	Pooled standard deviation of seafloor ocean current components predicted from the NEP5 ROMS (Danielson et al. 2011) averaged for the bottom layer across summer years (1991–2018)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom current pooled standard deviation	x	SA, A	--
Bottom current Northing and Easting variability	m·sec-1	Pooled standard deviation of seafloor ocean current components predicted from the Bering10K ROMS (Kearney et al. 2020) from the bottom 5m across summer years (1982–2019)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom 5m current pooled standard deviation	--	--	x
Maximum tidal current	cm·sec-1	Predicted tidal current maximum at each bottom trawl location over a lunar year cycle (Egbert and Erofeeva 2002)	Ordinary kriging	Training: mean towpath value Prediction: kriged surface of tidal maxima	x	x	x
Geographic Location	Latitude, Longitude	Midpoint of bottom trawl hauls corrected for position of the trawl net relative to the vessel in Alaska Albers Equal Area conic projection	--	Training: position collected during bottom trawl hauls. Prediction: raster of positions	x	SA, A	x
Bottom Depth	meters (m)	Bathymetry of the seafloor based on acoustic seafloor mapping data and digitized, position corrected NOS charts	Natural neighbor	Training: mean bottom depth of trawl Prediction: raster of bathymetry soundings data	x	x	x

Variable	Unit	Description of Prediction Raster	Interpolation method	Data Source and Usage	AI	GOA	EBS
Slope	degrees	Maximum gradient in depth between adjacent cells, derived from bathymetry (Horn 1981) applied with Benthic Terrain Modeler in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of slopes derived from bathymetry	x	x	x
Bathymetric Position Index	--	Relative difference of elevation between neighboring locations, illustrates bathymetric highs and lows across the landscape, derived from bathymetry (Guisan et al. 1999) applied in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of bathymetric position index derived from bathymetry	x	x	x
Aspect Eastness and Northness	--	Describes concavity/convexity as well as sloping nature, derived from bathymetry (Horn 1981) applied in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of aspect derived from bathymetry	x	x	x
Curvature	--	Combined plan and profile curvature to return “standard” curvature; derived from bathymetry (Schmidt et al. 2003) applied in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of curvature derived from bathymetry	x	x	x
Rockiness	--	Continuous surface of compiled datasets representing locations of rocky and not rocky substrate (updated from Pirtle et al. 2019)	Natural neighbor	Training: mean towpath value Prediction: raster of seafloor rockiness.	x	x	--
Sediment grain size	*phi*	Sediment grain size derived from sampling in the eastern Bering Sea and curated in the EBSSED2 database (Richwine et al. 2018)	Ordinary kriging	Training: mean towpath value Prediction: kriged surface of sediment grain size	--	--	x
Coral presence or absence	probability	Coral presence-absence in bottom trawl catches / model-predicted coral presence-absence (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	--	Training: presence-absence of corals in trawl catches Prediction: Raster of model-predicted binary presence-absence of coral (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	x	x	x
Sponge presence or absence	probability	Sponge presence-absence in bottom trawl catches / model-predicted sponge presence-absence (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	--	Training: presence-absence of sponge in trawl catches Prediction: Raster of model-predicted binary presence-absence of sponge (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	x	x	x

Variable	Unit	Description of Prediction Raster	Interpolation method	Data Source and Usage	AI	GOA	EBS
Pennatulacean presence-absence	probability	Pennatulacean presence-absence in bottom trawl catches / model-predicted penn. presence-absence (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	--	Training: presence-absence of pennatulaceans in trawl catches Prediction: Raster of model-predicted binary presence-absence of pennatulaceans (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	x	x	x

Table 6. Groundfish species in the Gulf of Alaska and life stages for which vital rates are available from the literature or ongoing studies; combining these vital rates with EFH will advance EFH information to Level 3. Settled early juvenile = EJ.

Species	Life Stage	Region	Vital Rate
walleye pollock	age-0, EJ	AI [a, b], GOA [a, b, c]	growth [a], lipid accumulation (condition) [b], winter energy loss (condition) † [c]
Pacific cod	age-0, EJ	EBS [a, b], GOA [a, b]	growth [a], lipid accumulation (condition) [b]
sablefish	EJ	GOA	growth [d]
yellowfin sole	EJ	GOA	growth [e]
northern rock sole	EJ	GOA	growth [e]
Pacific ocean perch	EJ	GOA	growth [f]

[a] Laurel et al. 2016, [b] Copeman et al. 2017, [c] Laurel et al. *in prep*, [d] Krieger et al. 2019, [e] Hurst *in prep*, [f] Rooper et al. 2012. † Addressed by Laurel et al. *in prep* for the 2022 EFH Review.

3.2.10 Figures

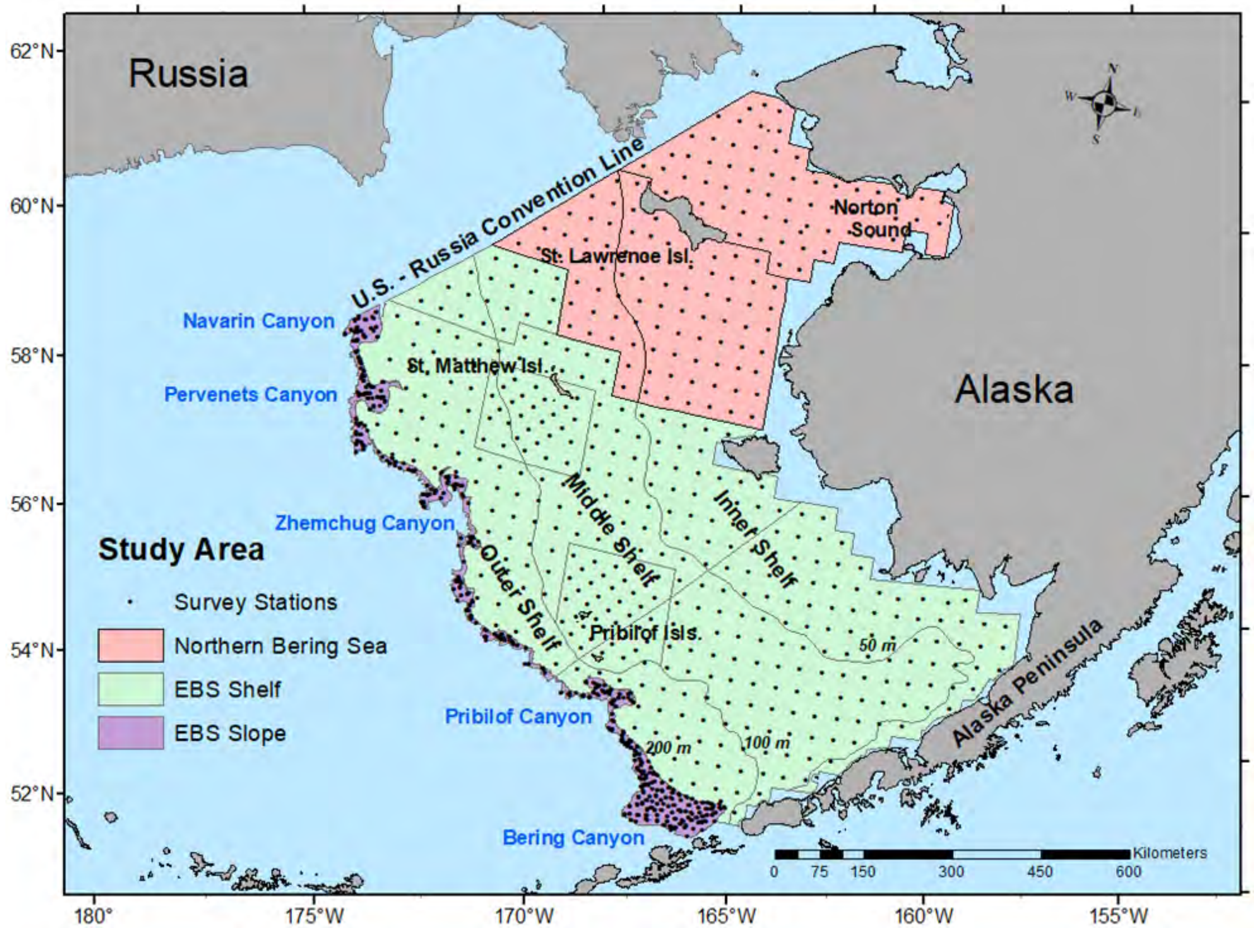

Figure 1. Eastern Bering Sea (EBS) from the Alaska Peninsula to the northern Bering Sea where this modeling study was conducted. Dots indicate the locations of bottom trawl stations from the eastern Bering Sea shelf annual bottom trawl survey (1982–2019), the eastern Bering Sea slope biennial bottom trawl survey (2002-2016), and the northern Bering Sea survey (2010, 2017, 2019) showing the 50 m, 100 m, and 200 m isobaths.

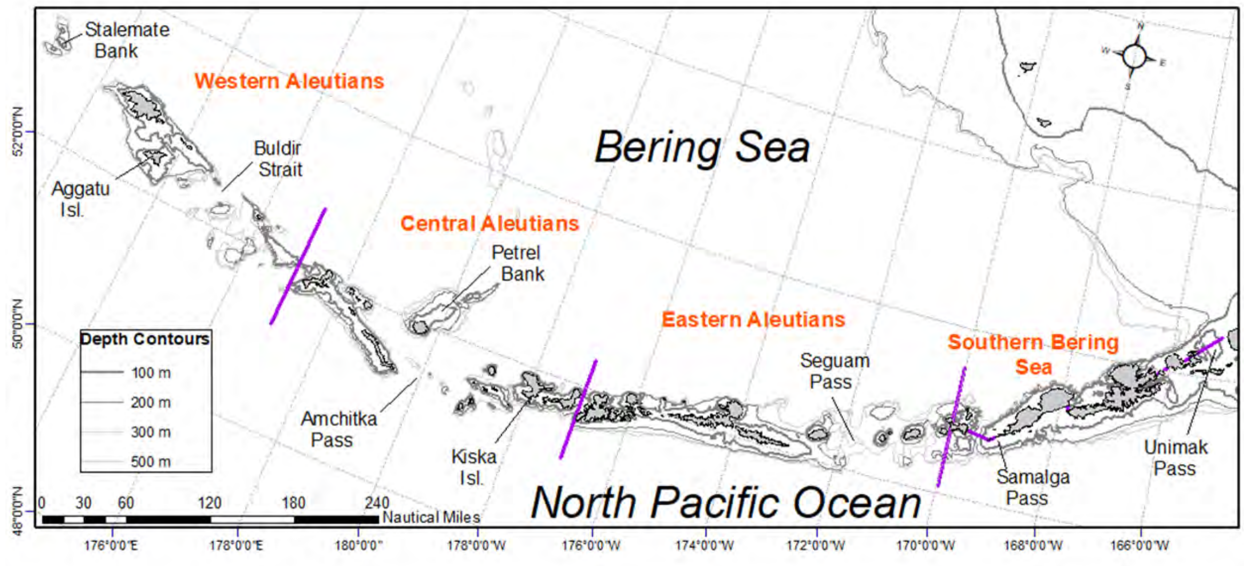

Figure 2. Aleutian Islands (AI) from Unimak Pass to Stalemate Bank where data for this modeling study were collected on Alaska Fisheries Science Center (AFSC), Resource Assessment and Conservation Engineering-Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys (1991-2019).

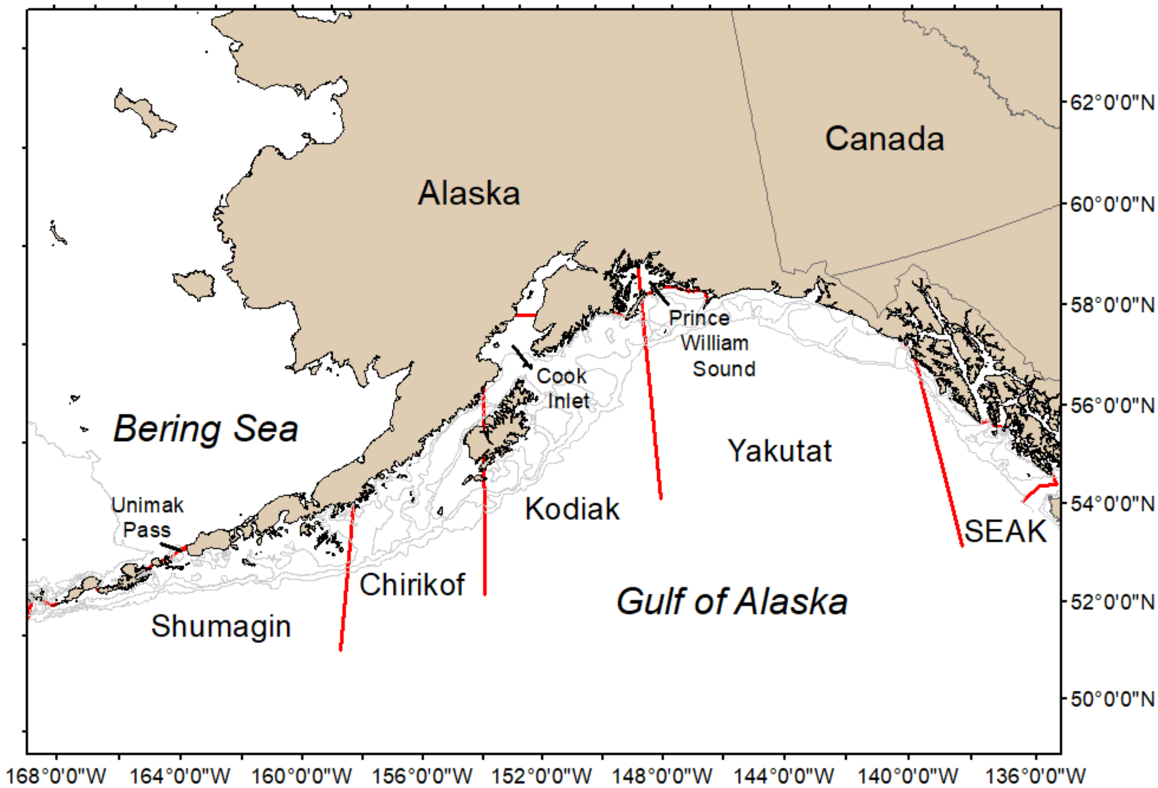

Figure 3. Gulf of Alaska (GOA) from Unimak Pass to Dixon Entrance where data for this modeling study were collected on Alaska Fisheries Science Center (AFSC), Resource Assessment and Conservation Engineering-Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys (1993-2019).

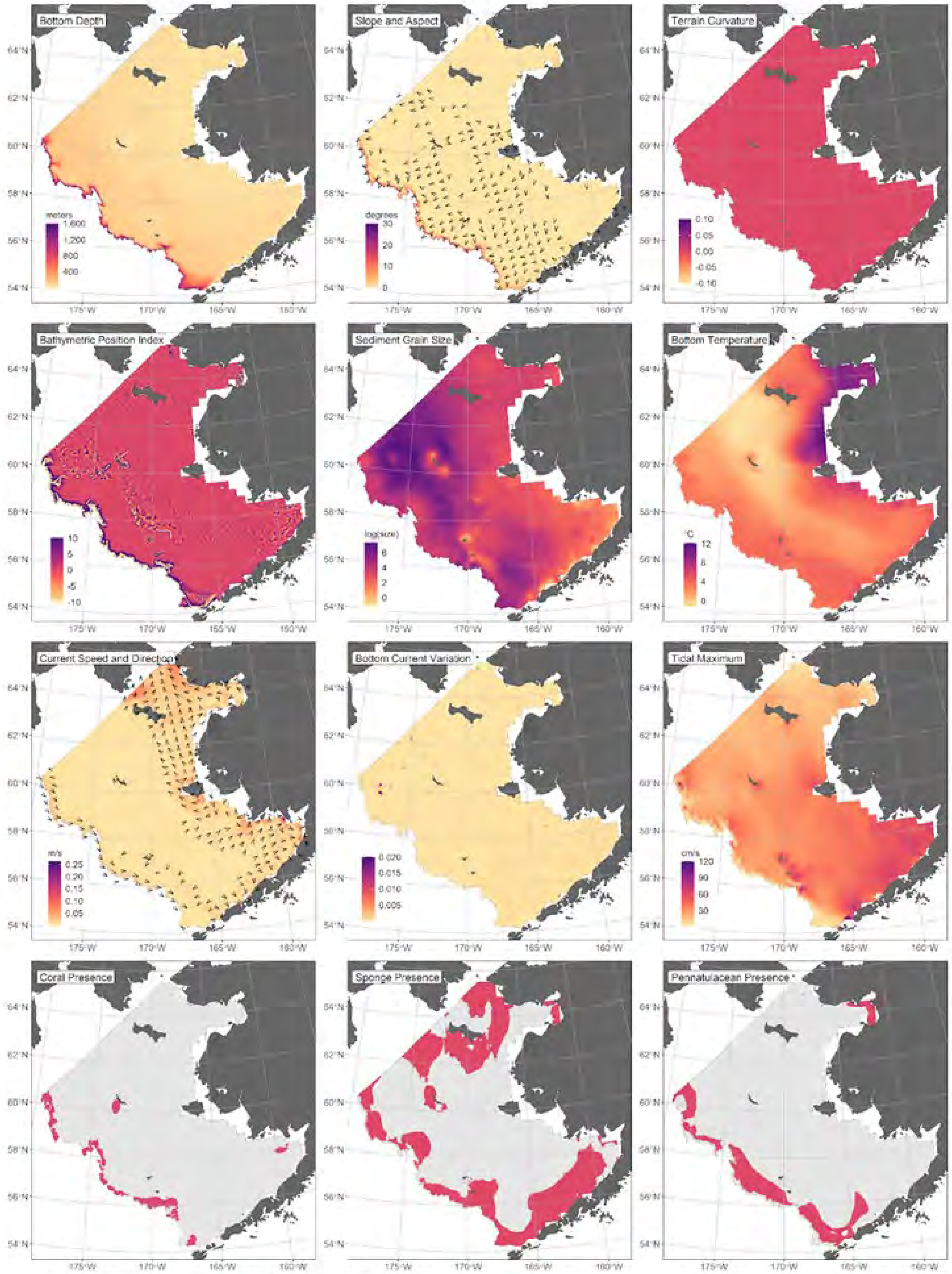

Figure 4. Maps showing the covariates used in the 2023 EFH 5-year Review of the EBS. “Slope and Aspect" and “Current Speed and Direction” are vectors composed of multiple components and the color indicates the magnitude of the vector and the arrows show the direction. Locations with values of zero are not marked with an arrow. Structure forming invertebrates (coral, sponge, and pennatulaceans) are shown in the bottom row and the colored areas indicate where they are present.

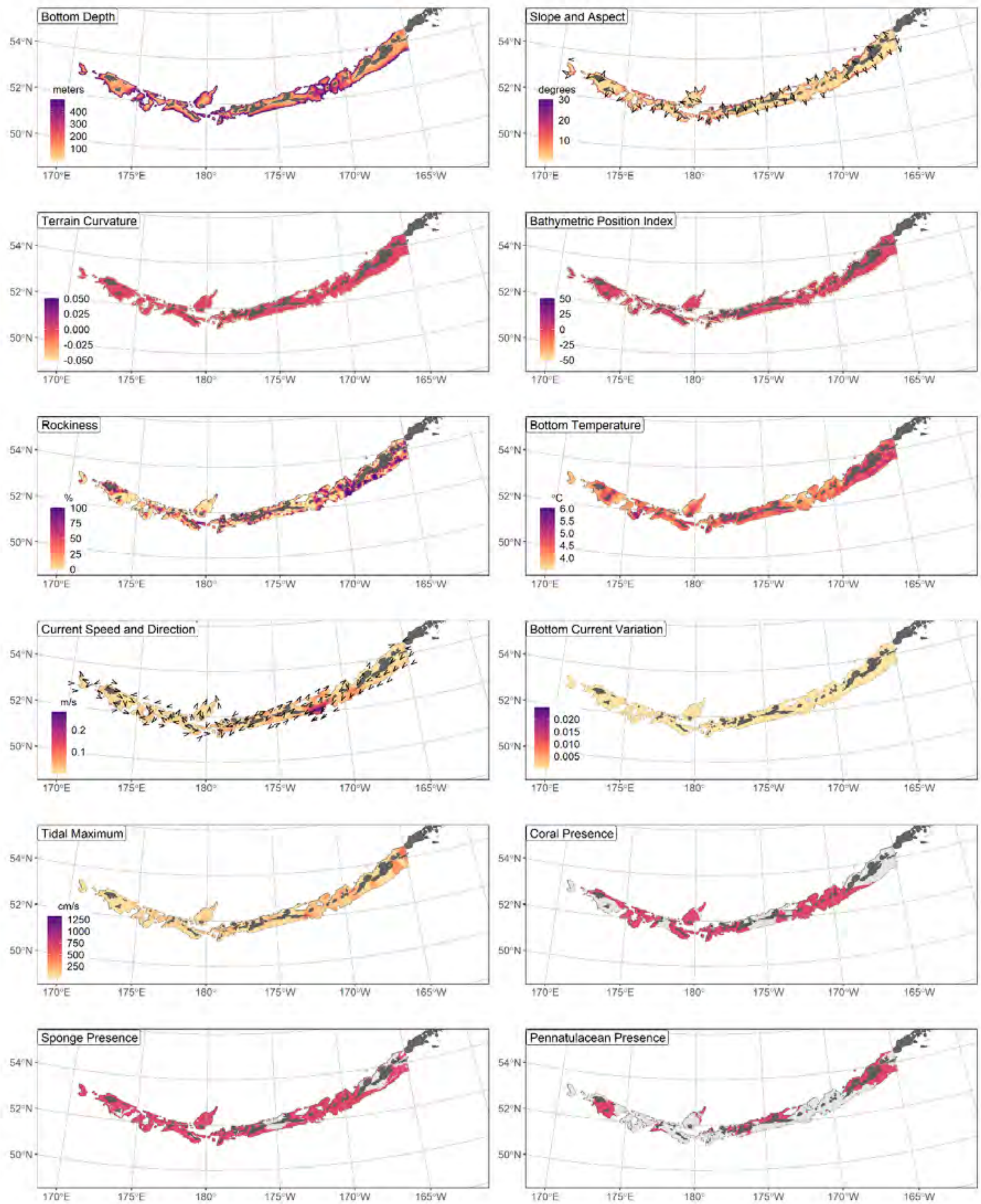

Figure 5. Maps showing the covariates used in the 2023 EFH 5-year Review of the AI. The AI maps include data from the GOA survey west of Unimak Pass. “Slope and Aspect” and “Current Speed and Direction” are vectors composed of multiple components and the color indicates the magnitude of the vector and the arrows show the direction. Locations with values of zero are not marked with an arrow. Structure forming invertebrates (coral, sponge, and pennatulaceans) are shown in the bottom row and the colored areas indicate where they are present.

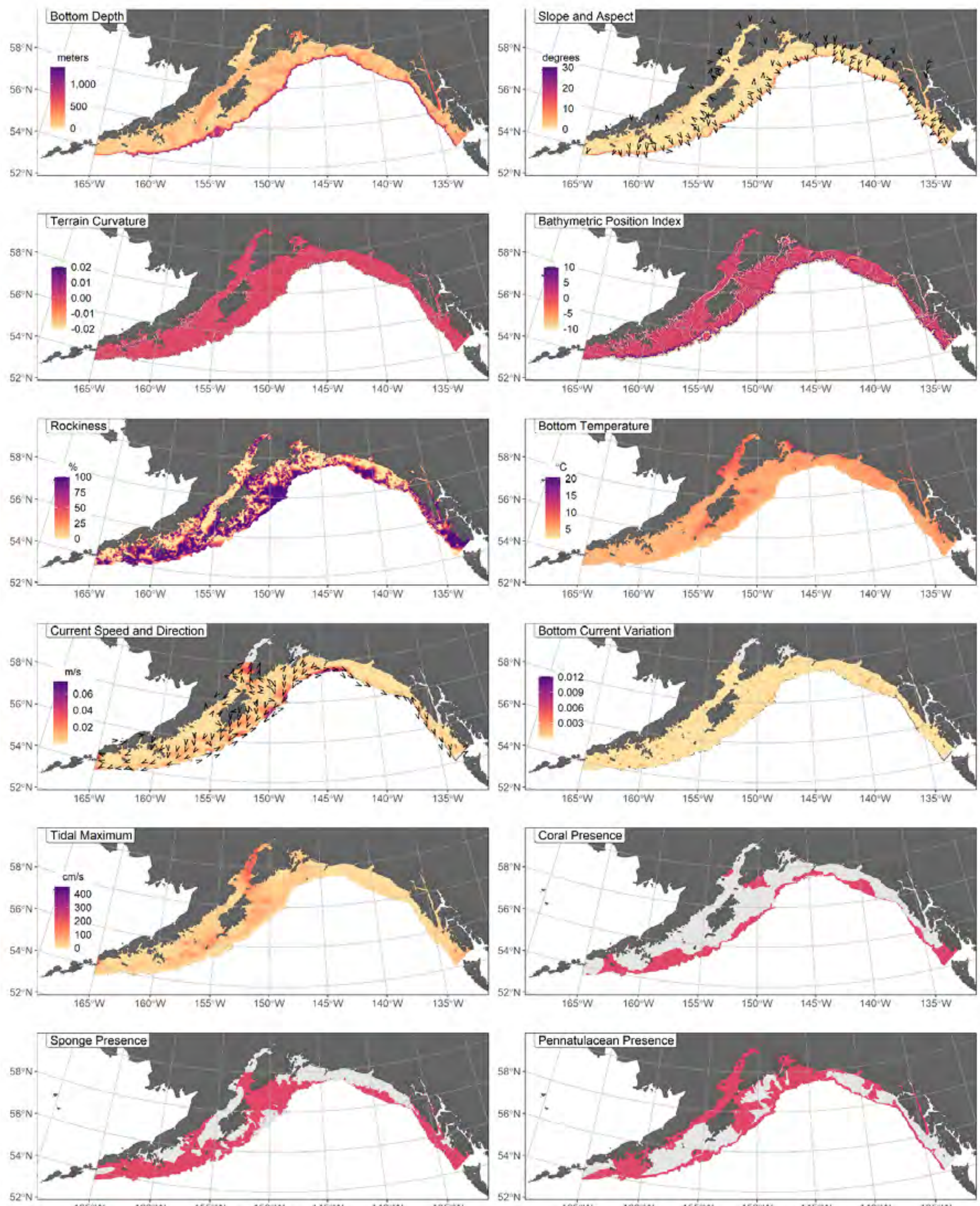

Figure 6. Maps showing the covariates used in the 2023 EFH 5-year Review of the GOA. Data from the GOA survey area west of Unimak Pass has been removed and is included in the AI. "Slope and Aspect" and "Current Speed and Direction" are vectors composed of multiple components and the color indicates the magnitude of the vector and the arrows show the direction. Locations with values of zero are not marked with an arrow. Structure forming invertebrates (coral, sponge, and pennatulaceans) are shown in the bottom row and the colored areas indicate where they are present.

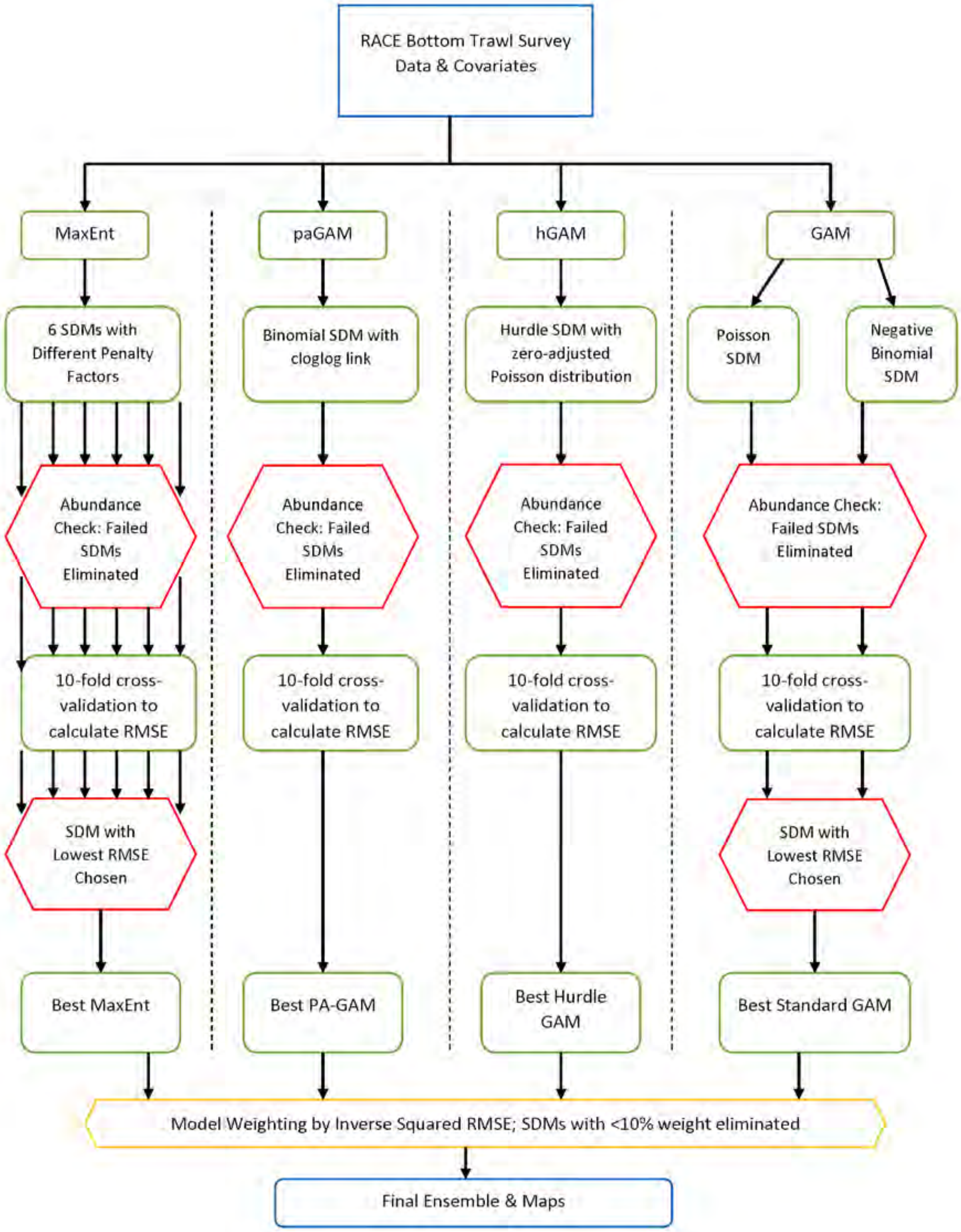

Figure 7. Pathways to formulation and assessment of five species distribution models (MaxEnt = maximum entropy, paGAM = presence-absence generalized additive model, hGAM = hurdle GAM, GAM_{P} = standard Poisson GAM, GAM_{nb} = standard negative-binomial GAM) for inclusion in or elimination from a final ensemble predicting habitat-related distribution and abundance used to describe and map essential fish habitat (EFH) in Alaska: RMSE = root mean square error.

3.3 Results

The Laman et al. study has demonstrated a revised SDM ensemble EFH approach for the 2023 EFH 5-year Review, where EFH is described and mapped for 32 North Pacific groundfish species in the EBS, 25 in the AI, 42 in the GOA across up to three life stages. In addition, EFH is described for five crabs in the EBS, two crabs in the AI, and octopus in all three regions.

This results section presents case studies for a selection of species' life stages modeled by this study in the EBS, AI, and GOA with new or revised EFH maps and bridging comparisons between the 2017 and 2022 EFH maps. The complete set of results for each species' life stage modeled by this study for the 2023 EFH 5-year Review are provided in the NOAA Technical Memoranda (Supporting Documents 5) and summarized in Appendix C). Comparisons between the 2017 and 2023 EFH maps are summarized in Appendix D). The full set of the 2017 and 2023 EFH map overlay figures are provided (Supporting Documents 5) and examples are presented in the three case studies in this section. Appendix E is expanded reporting of additional performance metrics considered in the present work and requested for consideration by the SSC (Table A1 items 6j and k). A Synthesis subsection concludes the Laman et al. study results section and draws from the results summaries and comparisons in the Appendices.

3.3.1 EFH Levels Advancements

Updates to data and methods used during the 2023 EFH 5-year Review have resulted in advancements in the EFH Level for many species' life stages (section D.1). This information is provided as an outcome of an EFH 5-year Review (e.g., Simpson et al. 2017) and SSC requested a summary of EFH Level advancements in the 2023 EFH 5-year Review for the February 2022 SSC review of EFH component 1 (Table A1 item 6e). EFH Level 1 is applied to species' life stages with a model that predicts distribution or presence/absence, EFH Level 2 with a model that can also predict abundance or density, and EFH Level 3 where a vital rate has been combined with a model to supplement either Level 1 or Level 2 predictions. **The following EFH Level advancements are available for the 2023 5-year Review—**

- Across all regions, 61 new species' life stages were modelled for the first time, and their EFH level was advanced from none to Level 2.
- In the GOA, the settled early juvenile life stages for 11 species were modelled for the first time and their EFH level was advanced from none to Level 1.
- Eight species' life stages where the settled early juvenile life stage was modelled for the first time are presented with additional EFH Level 3 information, advancing their EFH level to Level 3. Two of these species were based on Level 2 ensembles for the AI and EBS, while six were based on Level 1 SDMs for the GOA that use combined survey data.
- Seven species' life stages were not updated, and the EFH Level 1 designation from 2017 has not changed. These cases refer to species/life stages where fewer than 50 positive survey catches were available in 2023 (e.g., hauls where the species was present).
- In total, 55 species' life stages were advanced from EFH Level 1 to 2.
- Across all regions, 84 species' life stages were modelled as EFH Level 2 in both 2017 and 2022, although the data and methods were updated and revised in the 2022 ensemble approach to mapping EFH.
- For the first time, EFH Level 2 models were combined for member species of each of 10 stock complexes in the BSAI (6) and GOA (4) groundfish FMPs to represent the EFH of

member species where a model was not possible at this time (i.e., fewer than 50 positive survey catches were available)[50].

A total of 224 new and revised EFH descriptions and maps for the BSAI, GOA, and Crab FMPs are available for the 2023 EFH 5-year Review—

- New EFH Level 1 descriptions and maps for settled early juvenile life stages in the GOA FMP (11).
- New and revised EFH Level 2 descriptions maps for the BSAI (114), GOA (75), and Crab (6) FMPs (195).
- New EFH Level 2 descriptions and maps for stock complexes as a proxy for member species where a model was not possible at this time for the BSAI (6) and GOA (4) FMPs (10).
- New EFH Level 3 descriptions maps for settled early juvenile life stages for the BSAI (2) and GOA (6) FMPs (8).

3.3.2 Regional Case Studies

Case studies are presented demonstrating the revised SDM EFH approach by the Laman et al. study for the 2023 EFH 5-year Review. Three case studies are new and revised EFH Level 2 maps with bridging comparisons between 2017 and 2023. These case studies include the full set of results for one species' life stage in each region and were selected as examples of EFH area decreasing between 2017 and 2022 (arrowtooth flounder adults in the eastern Bering Sea), increasing (golden king crab life stages in the Aleutian Islands), and remaining relatively even (Pacific cod adults in the Gulf of Alaska). A final case study presents Pacific cod settled early juveniles in the GOA to demonstrate new EFH Level 1 and Level 3 maps for this life stage in that region.

3.3.2.1 Arrowtooth flounder adults in the Bering Sea

Arrowtooth flounder (*Atheresthes stomias*, ATF) is a large-bodied flatfish that can be found from the Kuril Islands in the western Pacific Ocean to California in the east (Orlov 2004). In the Bering Sea, ATF occur over the continental shelf (Shotwell et al. 2020) and along the edge of the continental slope, particularly in the south and southeast, possibly reflecting spawning along the shelf break (Doyle et al. 2018) and their tendency to avoid colder temperatures (Spencer 2008). The majority of female ATF become sexually mature around 480 mm F.L. in the EBS (L_{50}; Stark 2012), though age at maturity can vary considerably across regions (Spies et al. 2018). This species is highly predatory and is thought to be an important part of the marine food web. In particular, it is a major predator of juvenile walleye pollock (*Gadus chalcogrammus*; Yang and Livingston 1986).

Adult ATF were widely distributed across the middle and outer shelf domains in EBS RACE-GAP summer bottom trawl survey catches (1992–2019; Figure 9). We considered five constituent SDMs to include in the ensemble predicting numerical abundance of adult ATF in the EBS (Table 7), but the GAM_{nb} was eliminated in favor of the GAM_P. Four models were included in the final ensemble. The MaxEnt and hGAM were given less weight than the paGAM or GAM_P. Overall, the ensemble fit to observed adult ATF distribution and abundance was excellent. The ensemble was excellent at predicting catches of high and low adult ATF abundance (ρ = 0.81), presence-absence (AUC = 0.96), and at explaining deviance (PDE = 0.64). Geographic location, bottom temperature, and bottom depth accounted for 84% of the deviance explained by the ensemble predicting adult ATF numerical abundance (Table 8). Adult abundance was highest in the southern EBS over the middle shelf and shelf break as well as along the shelf break in the north near the heads of Navarin and Pervenets Canyons at depths between 300 and 400 m at bottom water temperatures greater than 5°C (Figure 10). The CVs of predicted abundance were

[50] 50 CFR 600.815(a)(1)(iv)(E)

high over the middle shelf domain of the EBS. Encounter probabilities for adult ATF were high in Bristol Bay, along the southern middle shelf domain, and northward along the outer shelf domain to the northwestern extent of the survey area (Figure 11).

Habitat-related ensemble-predicted numerical abundance of ATF life stages collected in RACE-GAP summer bottom trawl surveys of the EBS (1992–2019) was translated into EFH areas and additional habitat-related subareas (Figure 12). The EFH area for adult ATF was focused over the middle and outer shelf domains with core EFH area and EFH hot spots in deeper waters.

Table 7. Constituent species distribution models (SDMs) used to construct the ensemble predicting Essential Fish Habitat (EFH) for adult arrowtooth flounder: MaxEnt = Maximum entropy; paGAM = presence-absence generalized additive model; hGAM = zero-adjusted Poisson hurdle GAM; GAM_P = standard Poisson GAM; and GAM_{nb} = standard negative-binomial GAM. Ensemble performance (ρ = Spearman's rank correlation coefficient), root-mean-square-error (RMSE), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE) were generated from 10-fold cross-validation. The presence of "--" in a field indicates that this value was not calculated because the corresponding model was eliminated from the final ensemble.

Models	RMSE	Relative Weight	ρ	AUC	PDE	EFH area (km^2)
MaxEnt	36.1	0.16	0.81	0.96	0.37	333,000
paGAM	28.1	0.26	0.81	0.96	0.58	456,900
hGAM	27.0	0.29	0.81	0.96	0.63	389,800
GAM_P	26.9	0.29	0.80	0.95	0.63	403,800
GAM_{nb}	27.4	0	--	--	--	--
ensemble	26.6	1	0.81	0.96	0.62	426,400
* Refer to the Species Distribution Model Performance Metrics subsection within the Statistical Modeling section of the Methods for detailed descriptions of individual model performance metrics.						

Table 8. Covariates retained in the adult arrowtooth flounder species distribution model (SDM) final ensemble, the percent contribution to the ensemble deviance explained by each, and the cumulative deviance explained: *phi* = sediment grain size, SD = standard deviation, and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
geographic location	30.4	30.4
bottom temperature	28.7	59.2
bottom depth	24.9	84.0
current	6.5	90.5
slope	3.1	93.6
phi	2.5	96.1
current SD	1.0	97.1
BPI	0.7	97.8
aspect northness	0.4	98.2
tidal maximum	0.4	98.6
pennatulacean presence	0.4	99.0
curvature	0.4	99.4
sponge presence	0.3	99.7
aspect eastness	0.2	99.9
coral presence	0.1	100.0

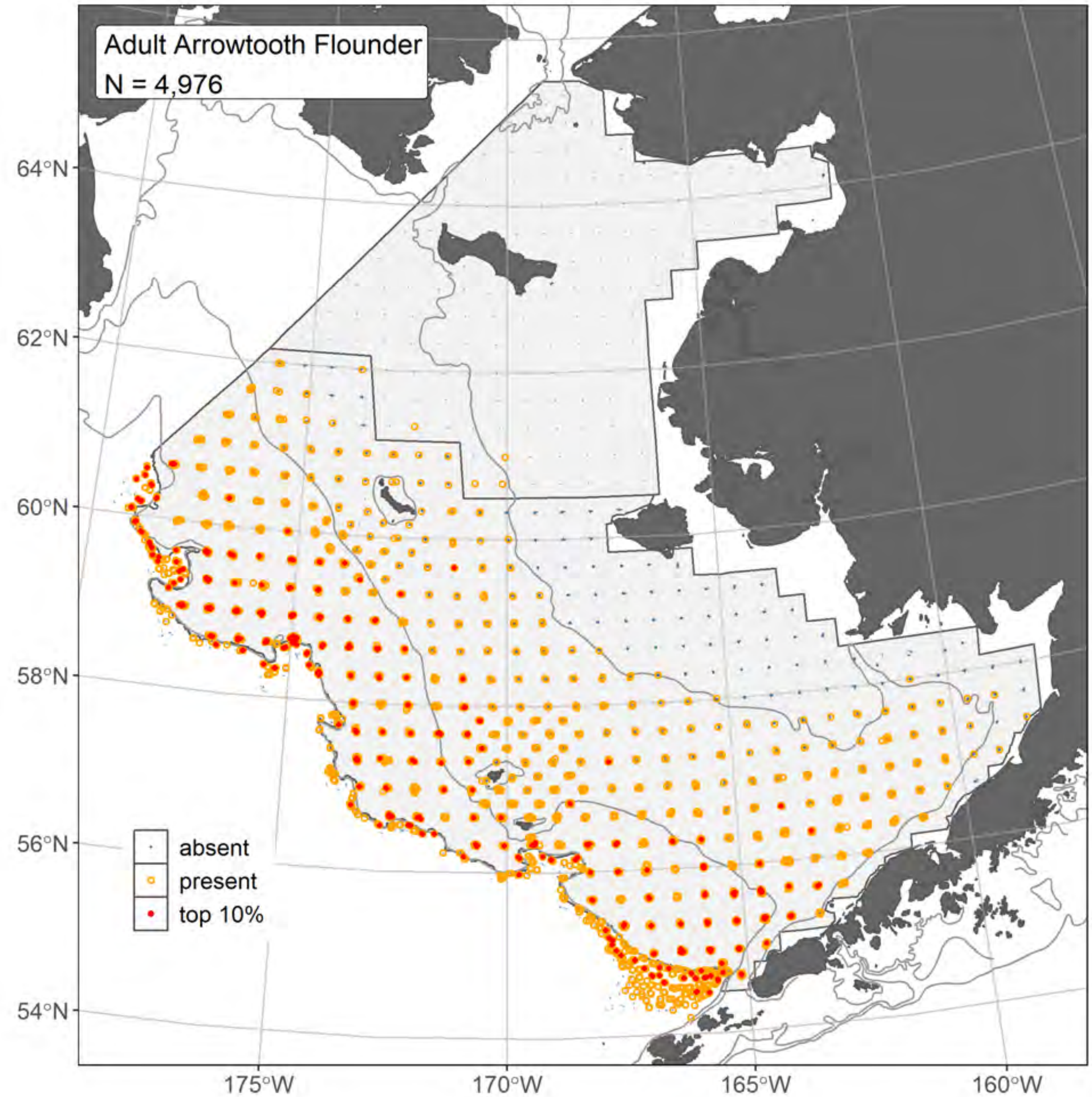

Figure 8. Distribution of adult arrowtooth flounder catches (N = 4,976) in 1992–2019 AFSC RACE-GAP summer bottom trawl surveys of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present.

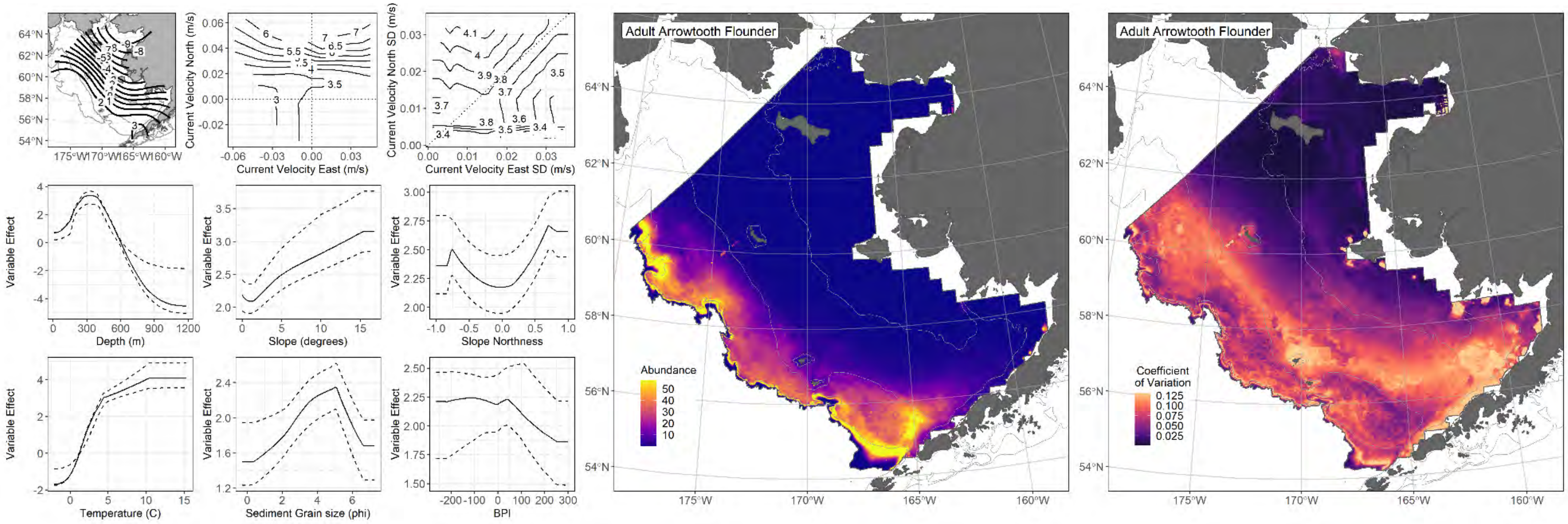

Figure 9. The top nine covariate effects (left panel) on ensemble-predicted adult arrowtooth flounder numerical abundance across the eastern Bering Sea Shelf, Slope, and Northern Bering Sea (center panel) alongside the coefficient of variation (CV) of the ensemble predictions (right panel).

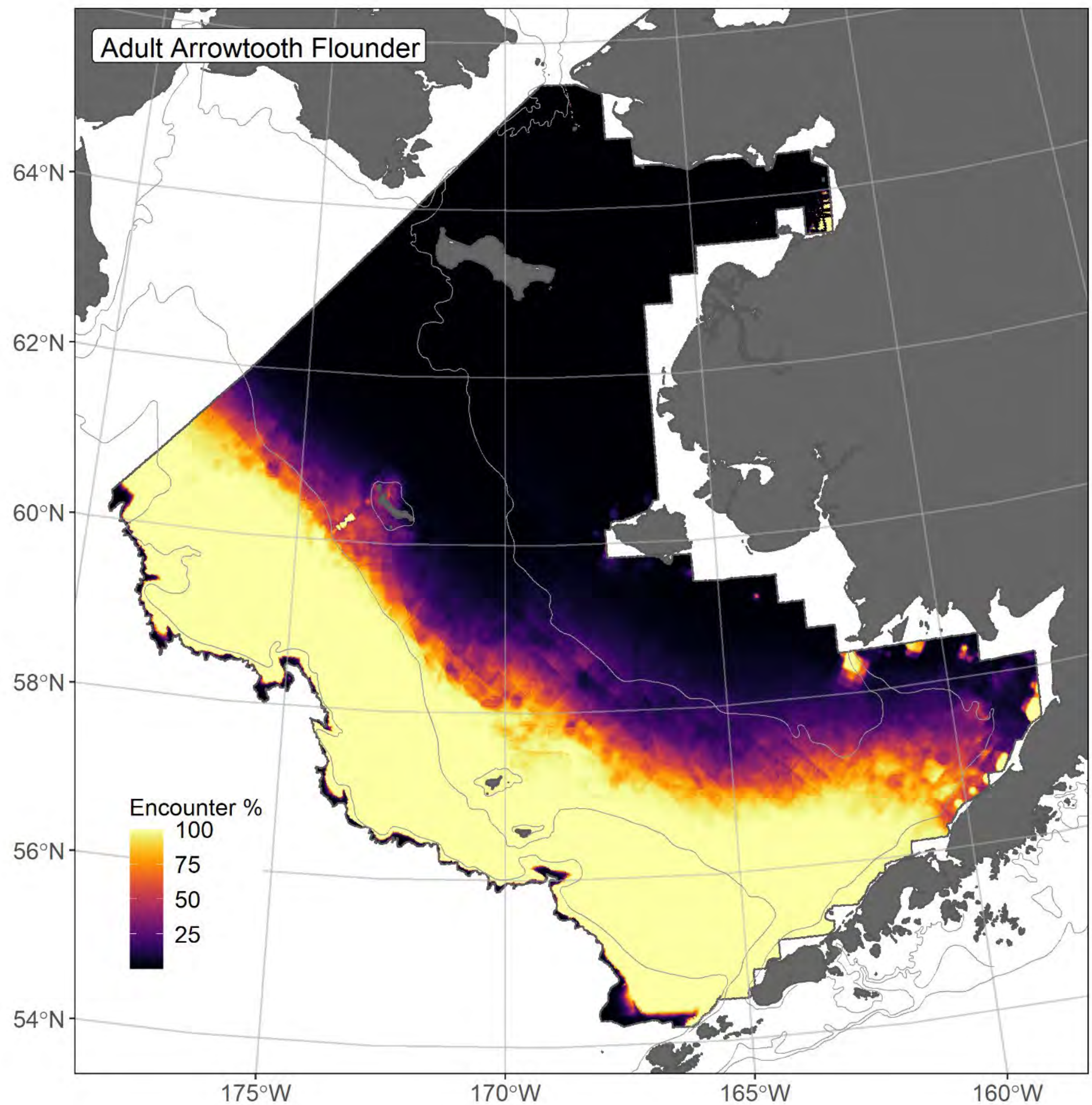

Figure 10. Encounter probability of adult arrowtooth flounder from AFSC RACE-GAP summer bottom trawl surveys (1992–2019) of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated.

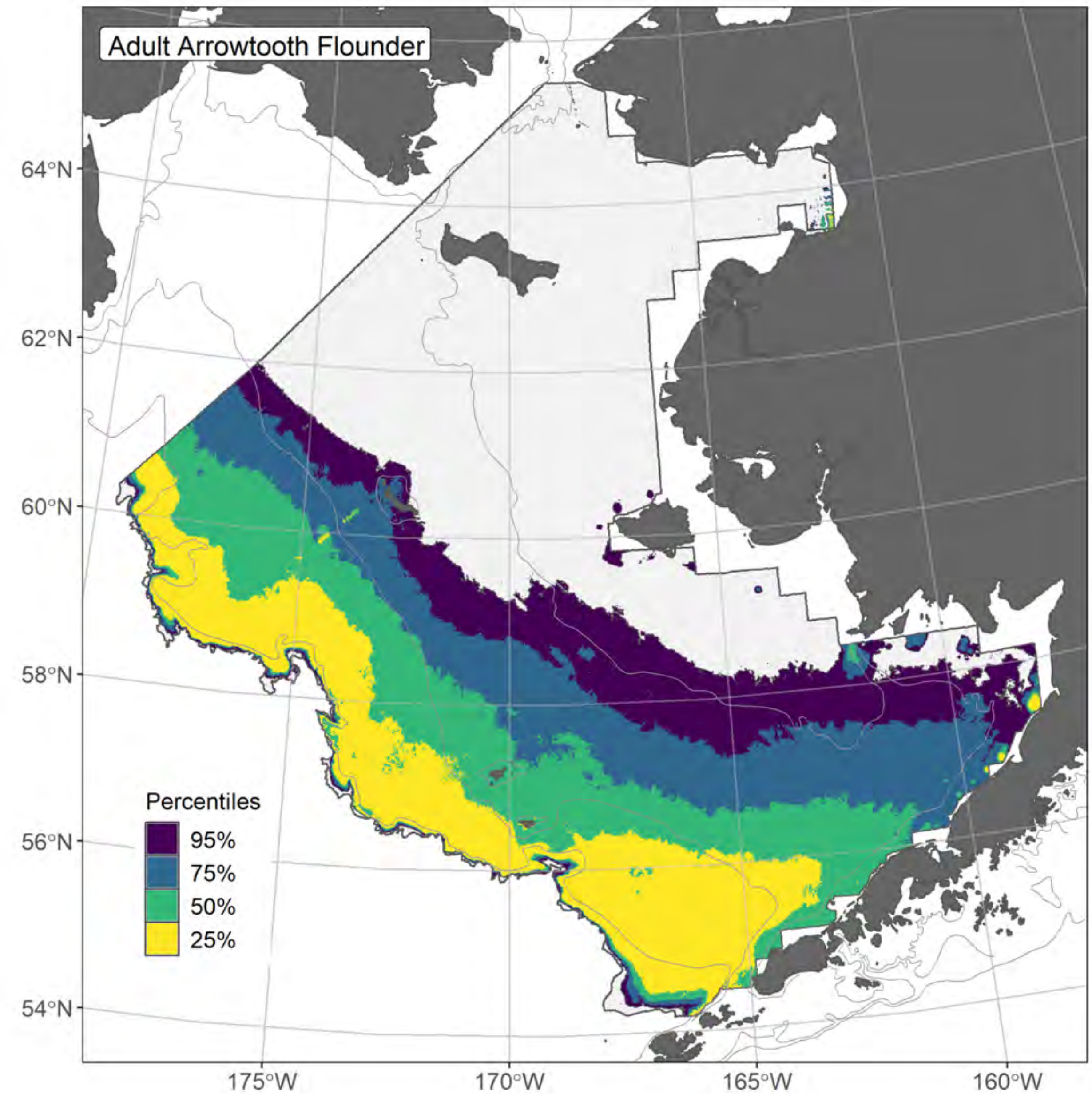

Figure 11. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult arrowtooth flounder distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1992–2019) with 50 m, 100 m, and 200 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of habitat-related, ensemble-predicted numerical abundance.

3.3.2.2 Bridging the 2017 and 2022 EFH designations for adult arrowtooth flounder in the Bering Sea

The new ensemble produced for the 2023 5-year Review for adult arrowtooth flounder in the Bering Sea showed improved performance relative to the 2017 model (Table 9). The RMSE of the 2023 ensemble was much lower, suggesting more precision in abundance predictions. While the scores for ρ and AUC were nearly identical, the 2022 ensemble showed improvement in terms of deviance explained (PDE). Taken together, these metrics suggest that the new 2022 SDM ensemble is an improvement over the SDM from the 2017 EFH 5-year Review.

The changes implemented during the 2022 EFH review resulted in 15.5% reduction in adult arrowtooth flounder EFH area from 504,500 km^2 in 2017 to 426,400 km^2 in 2023 (Table 9, Figure 13). Most of the reduction was attributable to the elimination of almost all of the northern Bering Sea from the arrowtooth flounder EFH, though this was partially offset by the addition of some areas in Bristol Bay and the inner continental shelf. The 2023 EFH map better corresponded to the observed spatial distribution of trawl catches for this species than the 2017 map (Figure 9), and the reduction in EFH area reflected improvements to the SDM process.

Refinements to our modeling approach altered EBS adult ATF EFH relative to the 2017 areal extent (Figure 14). Panel A shows the original EFH designation for adult arrowtooth flounder produced during the 2017 cycle. In panel B, updating the length-based life stage definition separating subadults from adults from 350 mm (Zimmermann 1997) to 480 mm (Stark 2012) resulted in minor changes to the EFH areal extent. In panel C, the addition of 5 more years of bottom trawl survey data, including 874 new catches of ATF, had little effect on the EFH description. In panel D, shifting to the prediction of numerical abundance as the response variable and updating the EFH definition resulted in a 25.1% reduction in total area extent and the removal of all locations in the northern Bering Sea from the EFH description. In panel E, the addition of new terrain and bottom current covariates caused a small shift in overall area with the inclusion of the middle shelf Bristol Bay. Finally, in panel F, the creation of the ensemble from four SDMs described a small further extension of EFH into Bristol Bay.

Table 9. Comparison of performance metrics and area for SDM predictions and EFH areal extent from the 2017 and 2023 5-year Reviews of EBS adult arrowtooth flounder. The metrics presented are number of positive catch hauls (N), root-mean-square-error (RMSE), Spearman’s rank correlation coefficient (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). The 2017 SDM predictions were converted from 4th root CPUE to count abundance prior to calculating the performance metrics assessed in 2023. The percent change in area (km^2) is constant for the EFH area and core EFH area.

EFH Review	SDM Method	N	RMSE	ρ	AUC	PDE	EFH Area	Core EFH Area	% Change in Area
2017	GAM_{CPUE}	4,102	83.9	0.82	0.95	0.45	504,500	265,500	--
2022	Ensemble	4,976	26.6	0.81	0.96	0.64	426,400	224,400	-15.5 %

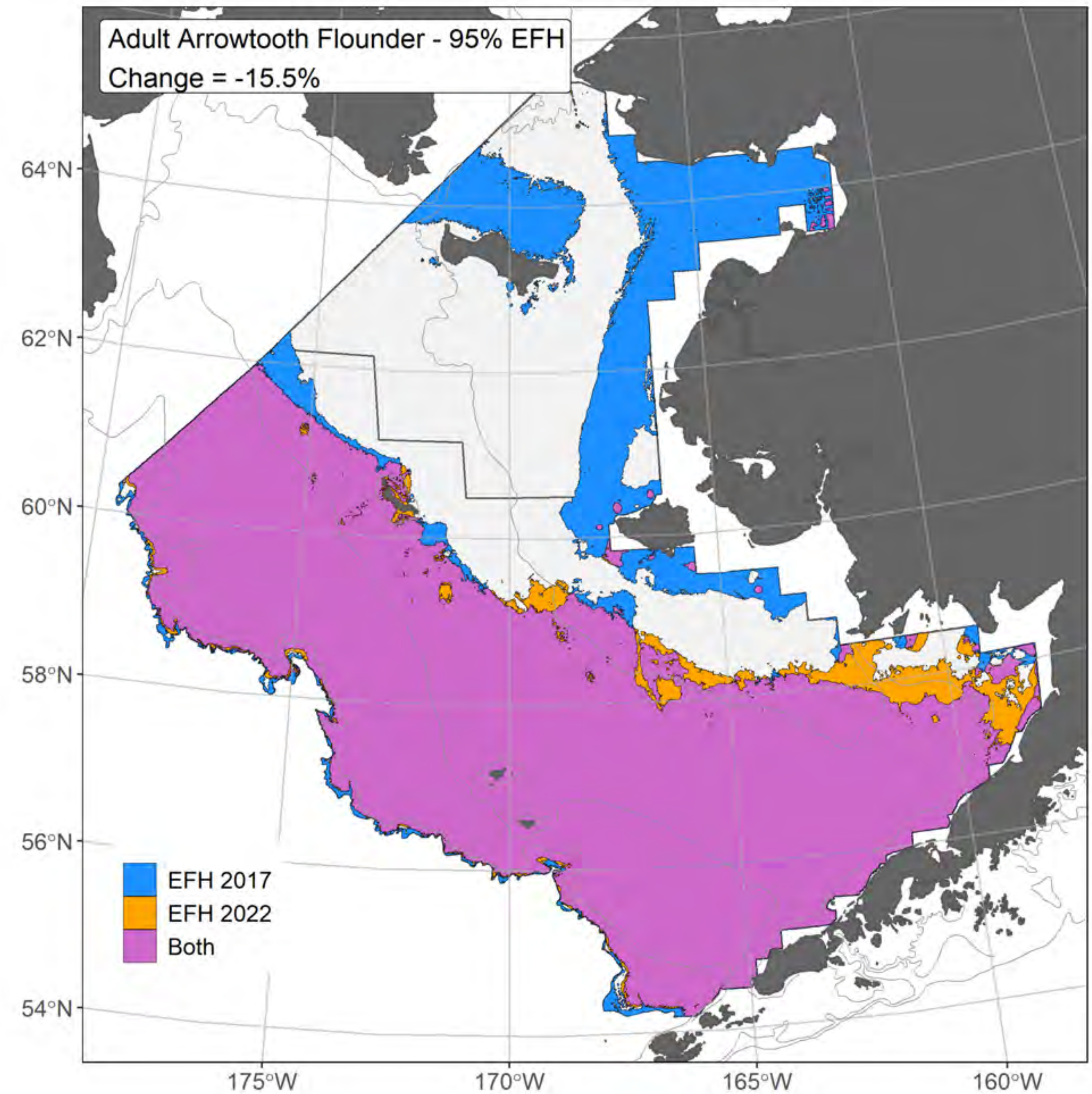

Figure 12. Change from 2017 to 2022 (2023) in essential fish habitat (EFH), which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from adult arrowtooth flounder catches in AFSC RACE-GAP summer bottom trawl surveys (1992–2019) with 50 m, 100 m, and 200 m isobaths indicated. Colored areas represent EFH in 2017, 2022 (2023), or both.

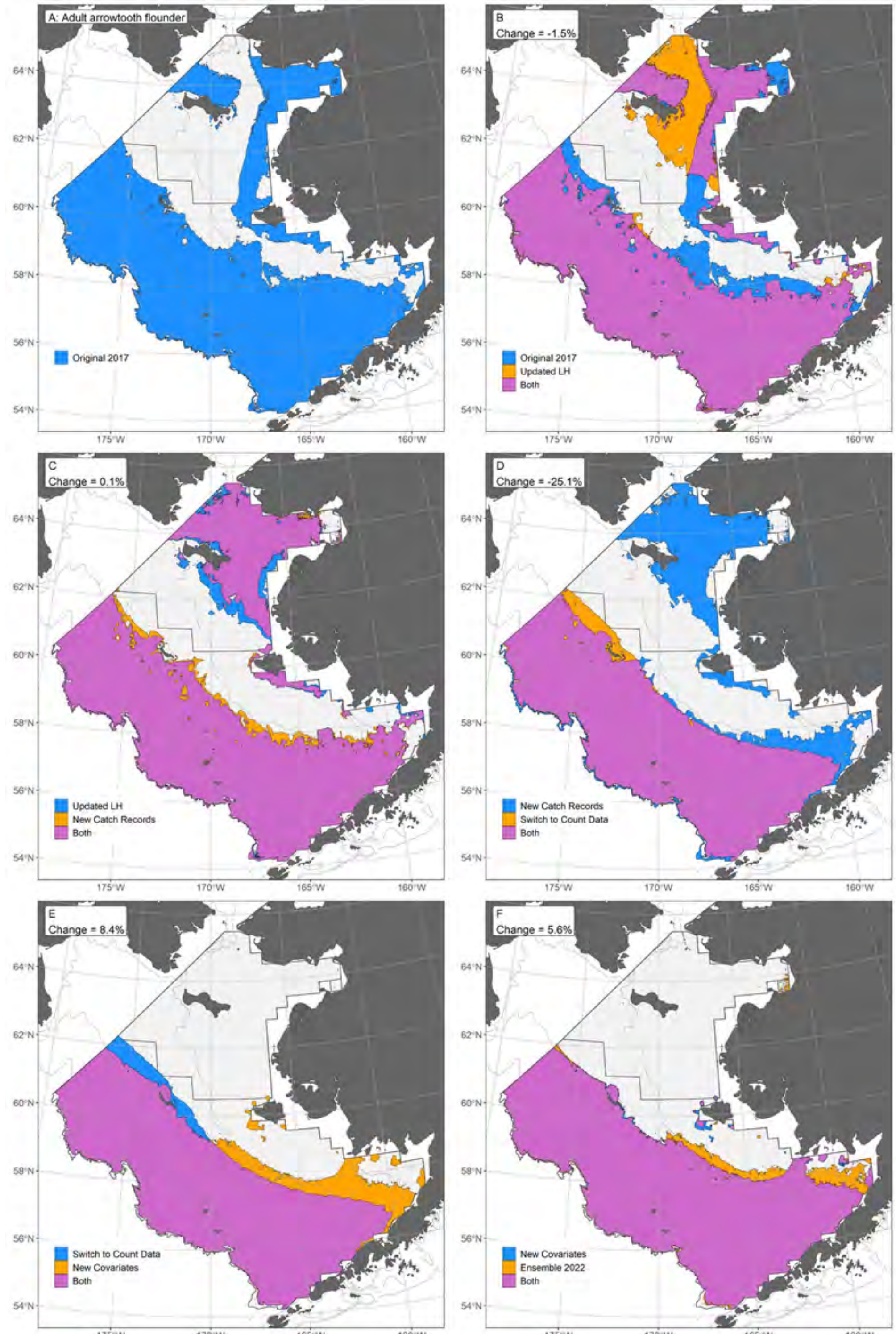

Figure 13. Change in EFH area for adult arrowtooth flounder as a result of successive changes to the SDM EFH mapping approach for the 2023 Review. Panel A shows the 2017 EFH map. Panel B shows the change resulting from the addition of new life history information. Panel C shows the addition of new catch records between 2015 and 2019. Panel D shows the results of changes to the modelling process, including using a count data model. Panel E shows the addition of new habitat covariates. Panel F shows the 2022 (2023) EFH map, derived from the combined predictions of four constituent SDMs in an ensemble. The 50 m, 100 m, and 200 m isobaths are indicated. The % change in area is calculated relative to the previous step, and is different from the overall change shown in Figure 13.

3.3.2.3 Golden king crab in the Aleutian Islands

Golden king crab (*Lithodes aequispinus*, GKC) are found from the coast of British Columbia across the North Pacific to Japan. GKC are typically found in deep water (> 300 m; Somerton and Otto 1981) and often prefer high-relief rocky or coral habitats. These characteristics make it more difficult to harvest with trawl gear, and prior to the mid-1980s, the fishery for GKC was limited. However, declines in other king crab species have resulted in increased interest in this species and prompted advances in its management (Olson et al. 2018). The reproductive cycle is thought to last approximately 24 months and at any time of year, ovigerous females can be found carrying egg clutches in highly disparate developmental states (Otto and Cummiskey 1985). Eggs are large compared to other king crab species and are carried by the females for an extended period before hatching. Larvae do not appear to remain at depth and owing to the large yolk reserves, can develop into juveniles without additional feeding (Shirley and Zhou 1997). Long molting cycles also contribute to difficulty in assigning ages to this species. These life history complexities and the lack of a fishery independent crab survey have made GKC populations difficult to assess using standard age-based stock assessment tools (Siddeek et al. 2019). GKC life stages caught in RACE-GAP summer bottom trawl surveys are combined in an SDM ensemble for mapping EFH in the Aleutian Islands.

GKC from the RACE-GAP summer survey were distributed in the Aleutian Islands from 169° W across the archipelago (Figure 15). Catches occurred primarily along the continental slope and were most common around Seguam Pass. Five models were initially fitted to observed abundance. The GAM_P was selected over the GAM_{nb} by skill testing with RMSE, so only the GAM_P was included in the ensemble (Table 10). The final ensemble contained four models with approximately equal weights and achieved a good fit to the data (Table 10). The ensemble was good at predicting relatively high or low density areas (ρ = 0.56), discriminating locations where this species was likely to be present (AUC = 0.89), and was able to account for a good portion of the ensemble deviance (PDE = 0.48). Bottom depth, bottom current, and geographic location were the most important covariates and accounted for 55.9 % of the deviance explained by the ensemble, but other covariates such as maximum tidal current, bottom temperature, and slope aspect were also important (Table 11). In general, high GKC abundance was predicted at deeper depths, in northeasterly bottom current, with strong tidal movement, lower temperatures, and rocky terrain (Figure 16). Predicted abundance was highest in the area between Atka and Unalaska Islands, with pockets of high density predicted further to the west. The CV of abundance predictions was higher in areas where predicted abundance was also higher, which reflects uncertainty in the numbers caught in higher abundance areas (Figure 15). Encounter probability was higher in most of the passes throughout the island chain, which is consistent with the modelled preference for deep water and stronger currents (Figure 17).

Based on RACE-GAP summer bottom trawl data (1991–2019), the habitat-related predicted abundance was translated into EFH area and additional subareas (Figure 18). The EFH area of GKC in the AI encompassed most of the survey area along the continental slope at depths greater than 300 m. EFH hot spots occurred in Seguam Pass, Amchitka Pass, and Buldir Strait. The ensemble predicting GKC abundance and forming the basis for describing its EFH had good performance across multiple metrics.

Table 10. Constituent species distribution models (SDMs) used to construct the ensemble predicting Essential Fish Habitat (EFH) for GKC: MaxEnt = Maximum entropy; paGAM = presence-absence generalized additive model; hGAM = zero-adjusted Poisson hurdle GAM; GAM_P = standard Poisson GAM; and GAM_{nb} = standard negative-binomial GAM. Ensemble performance (ρ = Spearman's rank correlation coefficient), root-mean-square-error (RMSE), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE) were generated from 10-fold cross-validation. The presence of "--" in a field indicates that this value was not calculated because the corresponding model was eliminated from the final ensemble.

Models	RMSE	Relative Weight	ρ	AUC	PDE	EFH area (km^2)
MaxEnt	6.95	0.23	0.55	0.89	0.17	40,900
paGAM	6.60	0.26	0.56	0.89	0.25	47,400
hGAM	6.64	0.26	0.53	0.89	0.26	49,500
GAM_P	6.69	0.25	0.51	0.85	0.23	53,100
GAM_{nb}	6.75	0	--	--	--	--
ensemble	6.13	1	0.56	0.88	0.48	51,400

* Refer to the Species Distribution Model Performance Metrics subsection within the Statistical Modeling section of the Methods for detailed descriptions of individual model performance metrics.

Table 11. Covariates retained in the GKC species distribution model (SDM) final ensemble, the percent contribution to the total deviance explained by each, and the cumulative percent deviance: SD = standard deviation, and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
bottom depth	29.5	29.5
current	14.8	44.3
geographic location	11.5	55.9
tidal maximum	7.2	63.1
bottom temperature	6.2	69.3
aspect northness	5.0	74.3
current SD	4.6	78.9
rockiness	4.6	83.5
aspect eastness	4.1	87.6
coral presence	3.3	90.9
sponge presence	3.1	94.0
slope	2.3	96.3
curvature	2.2	98.5
BPI	1.5	100.0
pennatulacean presence	0.0	100.0

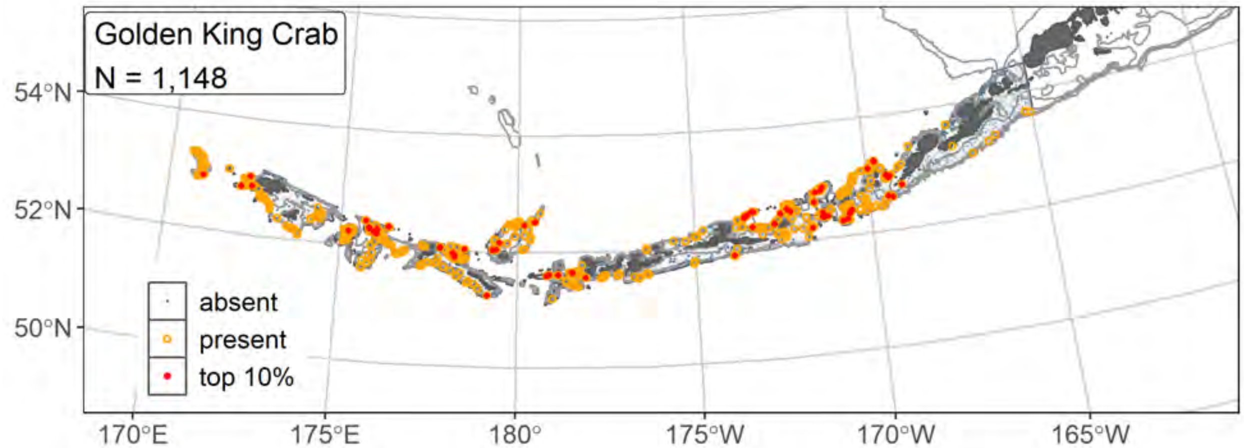

Figure 14. Distribution of GKC catches (N = 1,148) in 1991–2019 AFSC RACE-GAP summer bottom trawl surveys of the Aleutian Islands with the 100 m, 300 m, and 500 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and small blue dots indicate absence.

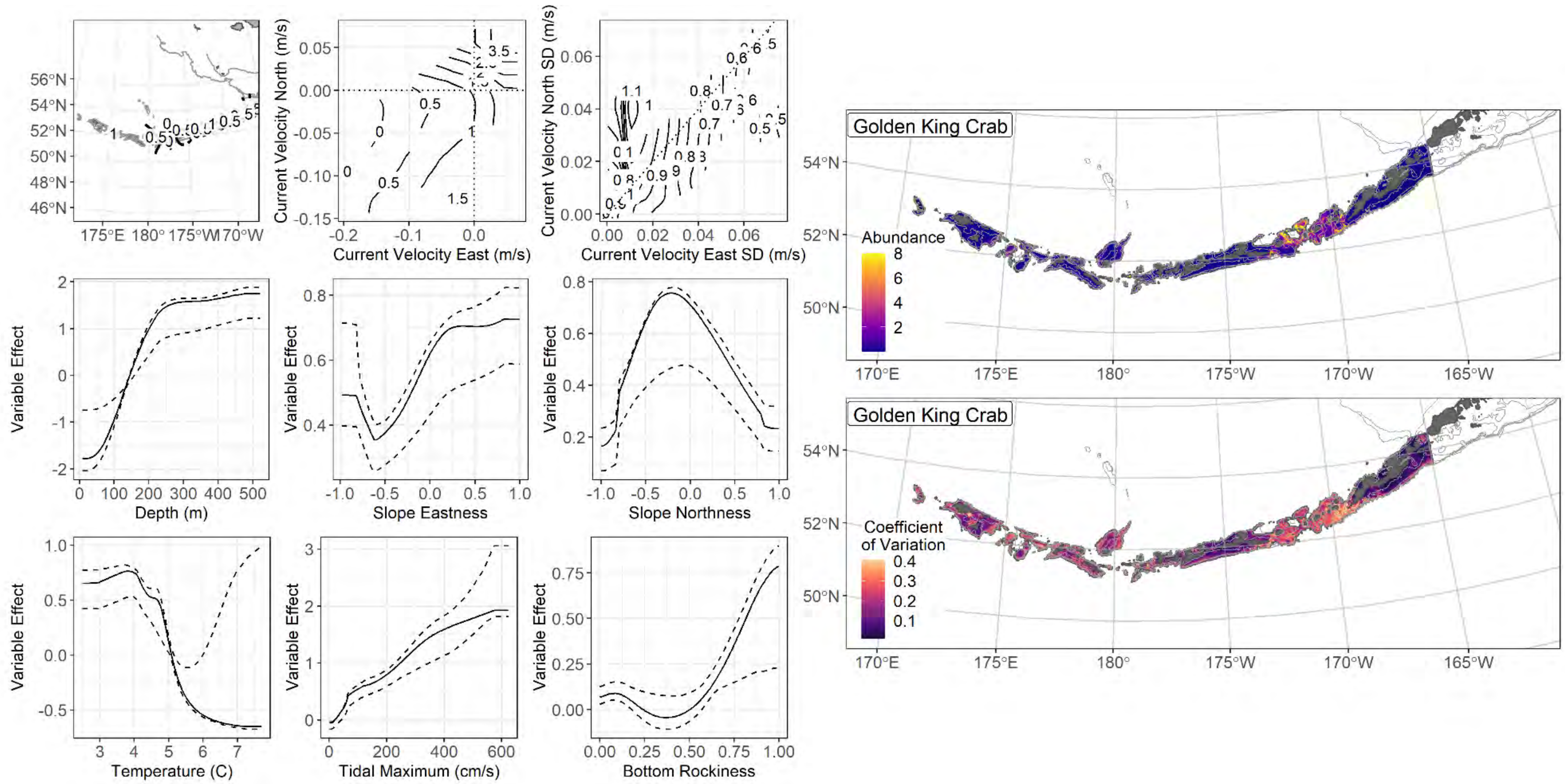

Figure 15. The top nine covariate effects (left panel) on ensemble-predicted GKC numerical abundance across the Aleutian Islands (upper right panel) alongside the coefficient of variation (CV) of the ensemble predictions (lower right panel).

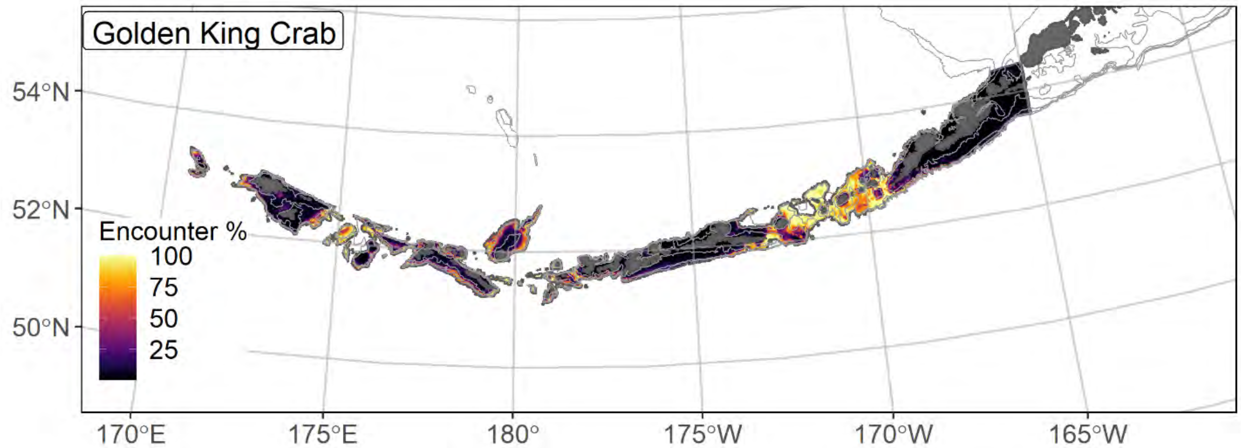

Figure 16. Encounter probability of GKC from AFSC RACE-GAP summer bottom trawl surveys (1991–2019) of the Aleutian Islands with the 100 m, 300 m, and 500 m isobaths indicated.

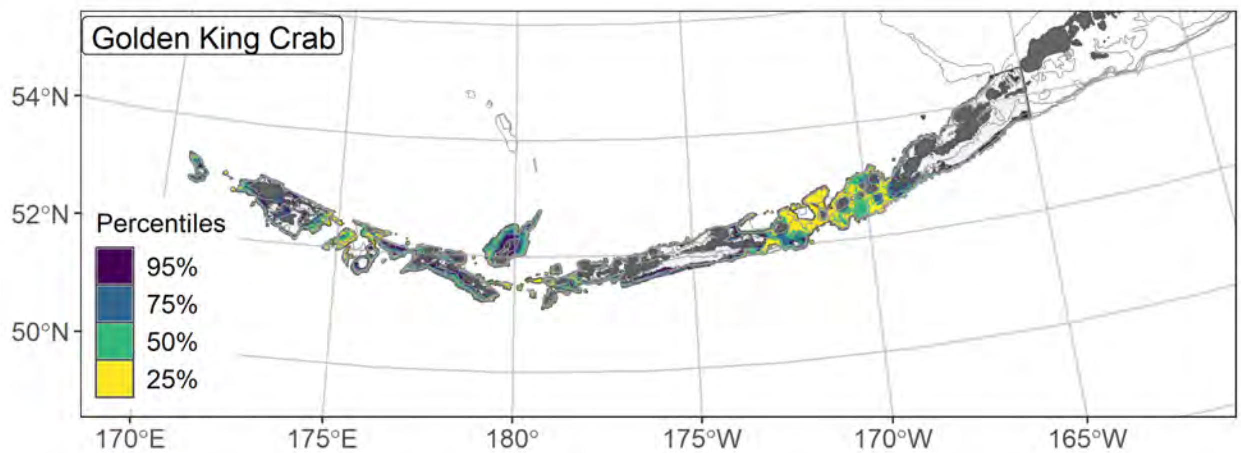

Figure 17. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to GKC distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1991–2019) with 100 m, 300 m, and 500 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of habitat-related, ensemble-predicted numerical abundance.

3.3.2.4 Bridging the 2017 and 2023 EFH designations for golden king crab in the Aleutian Islands

The new ensemble produced for the 2023 5-year Review showed improved performance relative to the 2017 SDM (Table 12). The scores for RMSE, ρ, and AUC were nearly identical, but the 2023 ensemble showed improvement in terms of deviance explained (PDE). These metrics suggest that the new 2023 ensemble is a marginal improvement over the 2017 SDM.

The changes implemented during the 2023 EFH 5-year Review resulted in an increase of 94.8% in GKC EFH area from 26,400 km^2 modeled from an hGAM in 2017 (i.e, an SDM known to produce highly constrained area predictions) to 51,400 km^2 modeled with an ensemble in 2023 (Figure 19). The increase in area was attributable to an extension of EFH into shallower areas (50–200 m). GKC have been found in shallower water on RACE-GAP bottom trawl survey catches (Figure 15), and the 2023 EFH map corresponded well to the observed spatial distribution of trawl catches for this species. By comparison, the 2017 EFH map emphasized deeper areas (>200 m).

Refinements to our modeling approach altered GKC EFH relative to the 2017 areal extent (Figure 20). Panel A shows the original EFH map for GKC produced during the 2017 EFH 5-year Review. This species was modeled with an hGAM as a single life stage that combined all specimens and there were no changes to the life history information in 2023. In panel B, the addition of 5 more years of bottom trawl survey data, including 192 new catches of GKC, had little effect on the EFH area. In panel C, shifting to the prediction of numerical abundance as the response variable and updating the EFH mapping approach based on the 2023 ensemble methods resulted in a 90% increase in EFH areal extent. This step added many shallower places to the EFH area including locations near Samalga Pass, Petrel Bank, the Rat Islands, and Attu Island. The change in EFH mapping approach from 2017 to 2023 was a factor in the large increase in the predicted EFH area. Specifically, 2017 methods mapped EFH as 95% of all locations with positive CPUE and above 28% encounter probability, whereas EFH mapped based on the 2023 ensemble methods is 95% of all locations with greater than 5% encounter probability. In panel D, the addition of new terrain and bottom current covariates caused minimal changes. Similarly, in panel E, the creation of the ensemble from four SDMs produced minor changes in the EFH area.

Table 12. Comparison of performance metrics and area for SDM predictions and EFH areal extent from the 2017 and 2023 5-year Reviews of AI GKC. The metrics presented are Spearman’s rank correlation coefficient (ρ), root-mean-square-error (RMSE), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). The 2017 SDM predictions were converted from 4th root CPUE to count abundance prior to calculating the performance metrics assessed in 2023. The percent change in area (km^2) is constant for the EFH area and core EFH area.

EFH Review	SDM Method	N	RMSE	ρ	AUC	PDE	EFH Area	Core EFH Area	% Change in Area
2017	$hGAM_{CPUE}$	908	6.50	0.57	0.88	-0.29	26,400	13,900	
2023	Ensemble	1148	6.13	0.56	0.89	0.48	51,400	27,100	94.8%

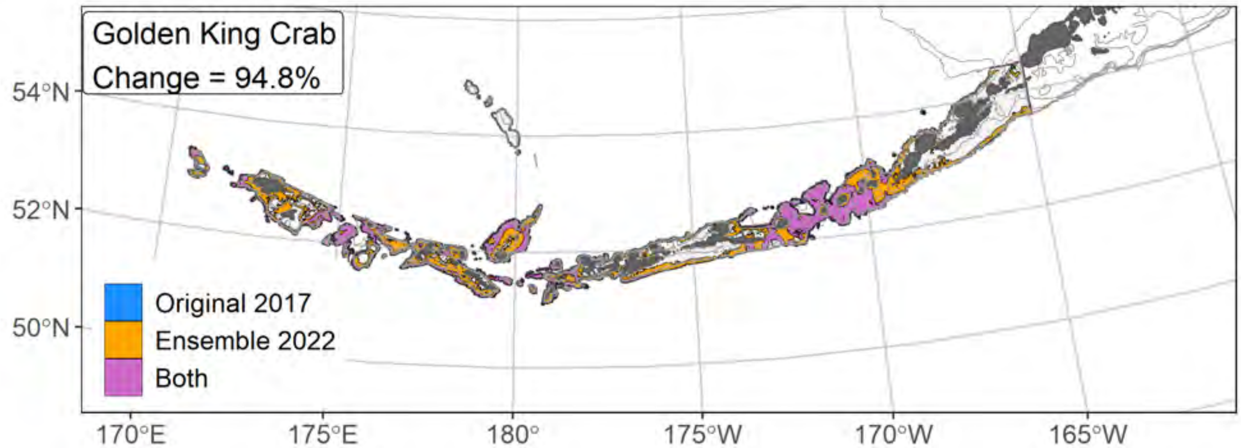

Figure 18. Change from 2017 to 2022 (2023) in essential fish habitat (EFH), which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from GKC catches in AFSC RACE-GAP summer bottom trawl surveys (1991–2019) with 50 m, 100 m, and 200 m isobaths indicated. Colored areas represent EFH in 2017, 2022 (2023), or both.

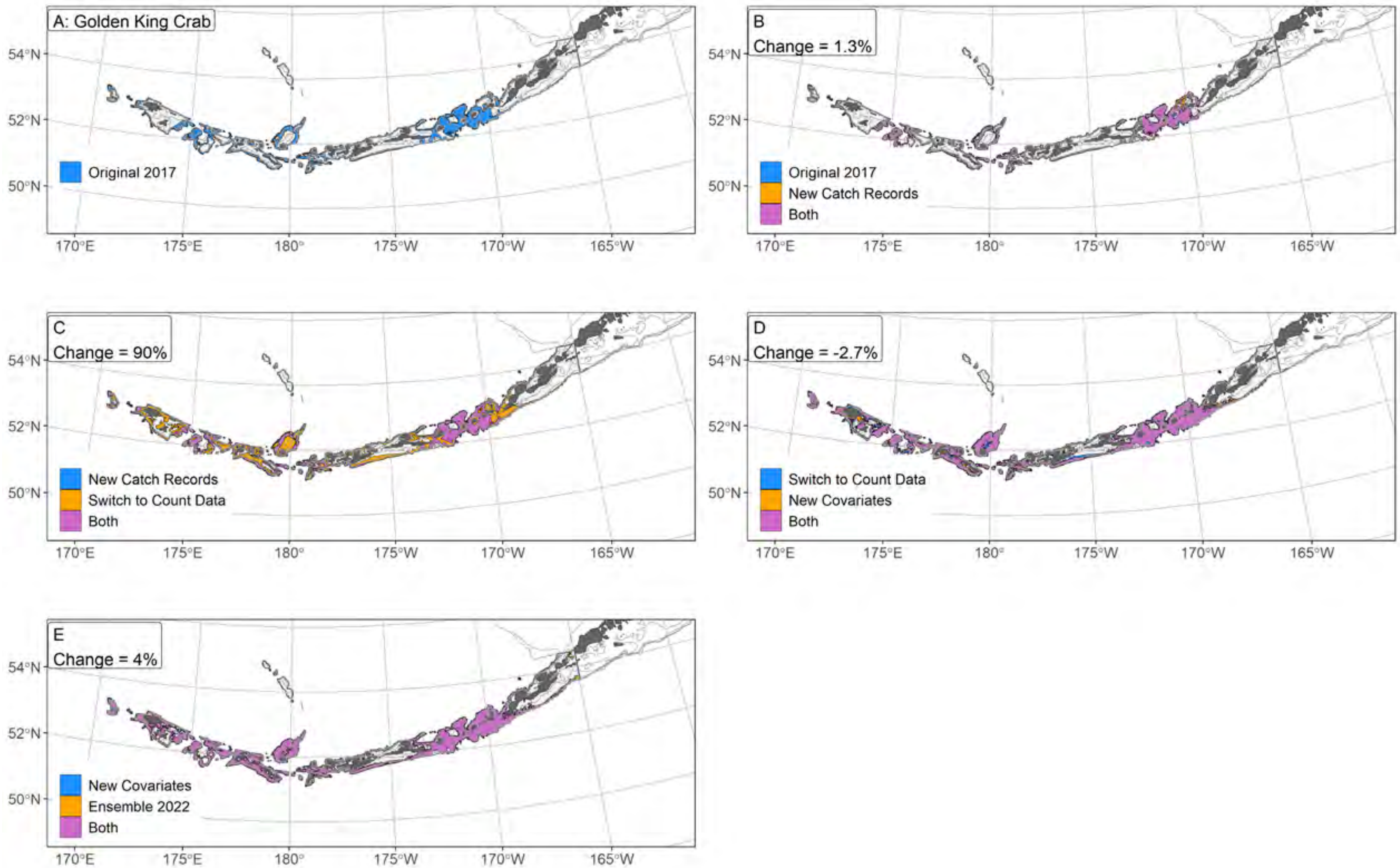

Figure 19. Change in EFH area for GKC as a result of successive changes to the SDM EFH mapping approach for the 2022 (2023) EFH 5-year Review. Panel A shows the 2017 EFH map. Panel B shows the addition of new catch records between 2015 and 2019. Panel C shows the results of changes to the modelling process, including using a count data model. Panel D shows the addition of new habitat covariates. Panel E shows the 2022 (2023) EFH map, derived from the combined predictions of four constituent SDMs in an ensemble. The 50 m, 100 m, and 200 m isobaths are indicated. The % change in area is calculated relative to the previous step, and is different from the overall change shown in Figure 19.

3.3.2.5 Pacific cod adults in the Gulf of Alaska

Pacific cod (*Gadus macrocephalus*) occur from the shoreline to 500 m depth throughout the RACE-GAP study area and support important multi-gear commercial fisheries in the GOA and BSAI (Barbeaux et al. 2020, Spies et al. 2020, Thompson et al. 2020). Pacific cod form aggregations during peak spawning season (Neidetcher et al. 2014) and lay demersal, adhesive eggs with a narrow thermal window for successful incubation (3–6°C). After hatching, pelagic larvae move downward in the water column as they grow and settle as early juveniles (40–150 mm FL; Doyle et al. 2019, Laurel et al. 2009), residing in nearshore nursery habitats (< 20 m depth) until undergoing ontogenetic migration to deeper depths (Abookire et al. 2007, Laurel et al. 2007, Pirtle et al. 2019). Length based life stage breaks distinguish between subadults (151–503 mm FL; Laurel et al. 2009) and adults (> 503 mm FL; Stark 2007). Pacific cod growth rates are affected by water temperatures. Laboratory studies demonstrate that Pacific cod can grow two to three times faster than other boreal and Arctic gadids over a range of temperatures, yet their populations are vulnerable to the effects of marine heat waves (Laurel et al. 2016, Barbeaux et al. 2020).

Adult Pacific cod (N = 4,476) were common and widely distributed across the GOA continental shelf throughout the survey area with most concentrations of high abundance catches south of the Kenai Peninsula and west (1993–2019; Figure 21). The five constituent SDMs to predict numerical abundance of adult Pacific cod in the GOA converged (Table 13); the GAM_P was eliminated by skill testing. The remaining four SDMs were equally weighted in the final ensemble, which attained a good fit to the observed adult Pacific cod distribution and abundance data. The ensemble was good at predicting catches ($\rho = 0.47$) and at discriminating presence-absence (AUC = 0.75), and fair at explaining deviance (PDE = 0.25). Bottom depth, geographic location, and bottom temperature accounted for 78.1% of the deviance explained by the ensemble (Table 14). Adult Pacific cod abundance predicted from the ensemble was highest west of the Kenai Peninsula (Figure 22). The CV of ensemble predictions was high in the glacial troughs, along the continental slope, and in the eastern GOA. The probability of encountering adult Pacific cod was high across the continental shelf and low along the continental slope and glacial troughs in the eastern GOA (Figure 23).

Habitat-related predictions of adult Pacific cod distribution and abundance from RACE-GAP bottom trawl surveys (1993–2019) was mapped as EFH areas and subareas (Figure 24). The EFH area for adult Pacific cod extended from southeast Alaska to the western GOA. EFH hot spots were most prominent on the continental shelf west of the Kenai Peninsula.

Table 13. Constituent species distribution models (SDMs) used to construct the ensemble predicting Essential Fish Habitat (EFH) for adult Pacific cod: MaxEnt = Maximum entropy; paGAM = presence-absence generalized additive model; hGAM = zero-adjusted Poisson hurdle GAM; GAM_P = standard Poisson GAM; GAM_{nb} = standard negative-binomial GAM; RMSE = root mean square error; ρ (*rho*) = Spearman's rank correlation coefficient; AUC = area under the receiver operating characteristic curve; and PDE = Poisson deviance explained *. The "–" indicates that this model was not included in the final ensemble.

Models	RMSE	Relative Weight	ρ	AUC	PDE	EFH area (km^2)
MaxEnt	71.6	0.25	0.45	0.75	0.05	272,800
paGAM	71.3	0.25	0.49	0.77	0.09	261,900
hGAM	71.1	0.25	0.40	0.77	0.18	257,500
GAM_P	71.1	–	–	–	–	–
GAM_{nb}	70.9	0.25	0.41	0.72	0.18	258,600
ensemble	70.2	1	0.47	0.75	0.25	264,700

* Refer to the Species Distribution Model Performance Metrics subsection within the Statistical Modeling section of the Methods for detailed descriptions of individual model performance metrics.

Table 14. Covariates retained in the species distribution model (SDM) final ensemble for adult Pacific cod with the percent contribution of each covariate to the deviance explained by the SDMs and the cumulative deviance explained: SD = standard deviation and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
bottom depth	53.1	53.1
geographic location	15.6	68.7
bottom temperature	9.4	78.1
tidal maximum	5.7	83.7
current	3.3	87.0
BPI	2.9	89.9
aspect eastness	2.6	92.5
current SD	2.1	94.6
slope	1.8	96.4
rockiness	1.3	97.7
sponge presence	1.1	98.8
aspect northness	0.9	99.7
coral presence	0.1	99.8
pennatulacean presence	0.1	99.9
curvature	0.1	100.0

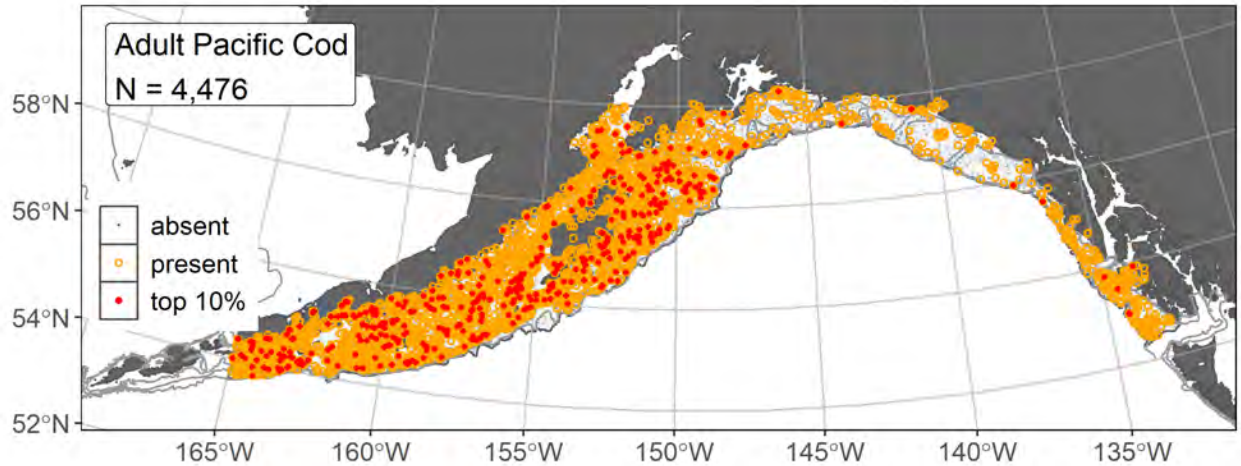

Figure 20. Distribution of adult Pacific cod catches (N = 4,476) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the Gulf of Alaska with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present.

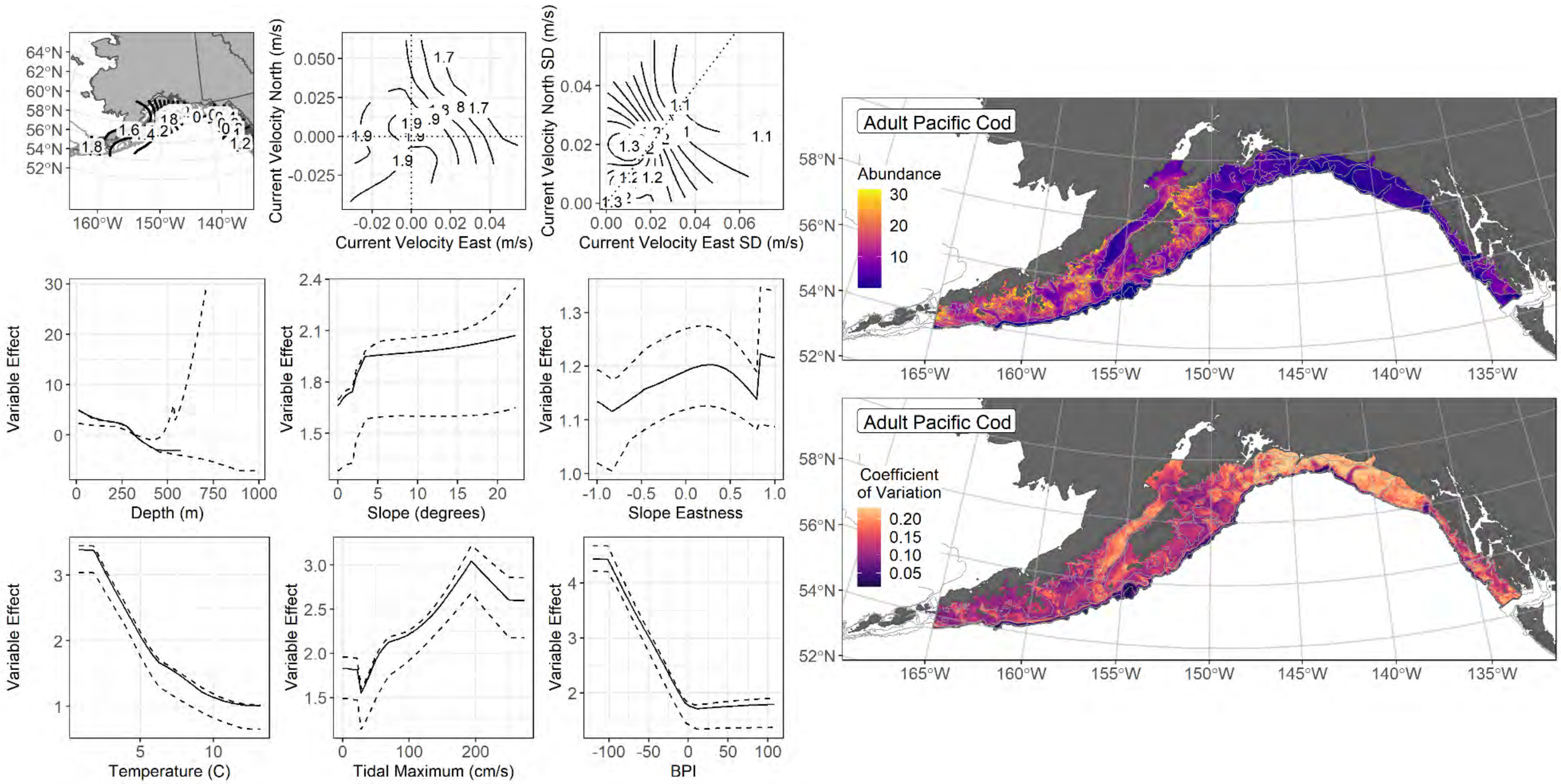

Figure 21. The top nine covariate effects (left panel) on ensemble-predicted adult Pacific cod numerical abundance across the Gulf of Alaska (upper right panel) along with the coefficient of variation (CV) of the ensemble predictions (lower right panel).

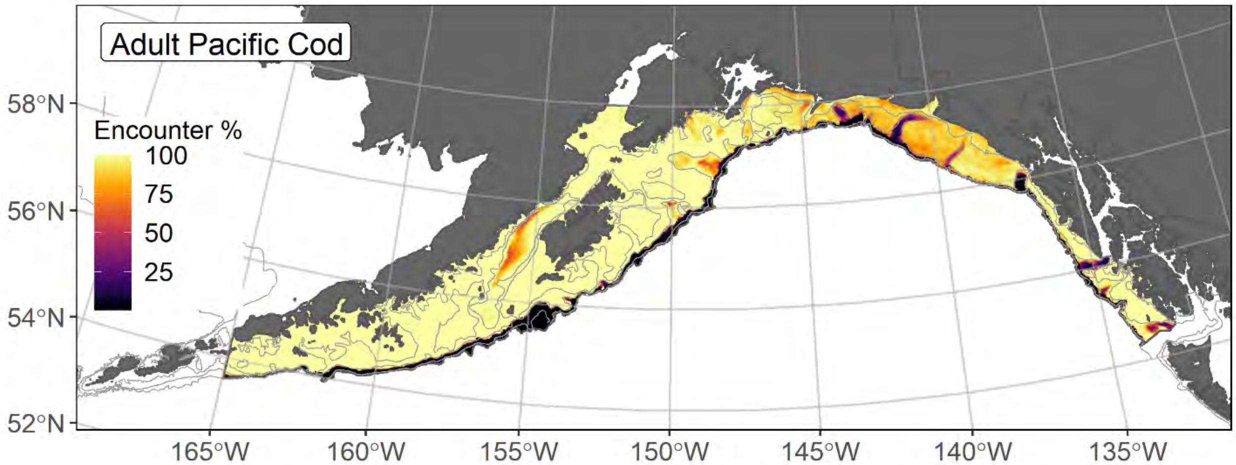

Figure 22. Encounter probability of adult Pacific cod from AFSC RACE-GAP summer bottom trawl surveys (1993–2019) of the Gulf of Alaska with the 100 m, 200 m, and 700 m isobaths indicated.

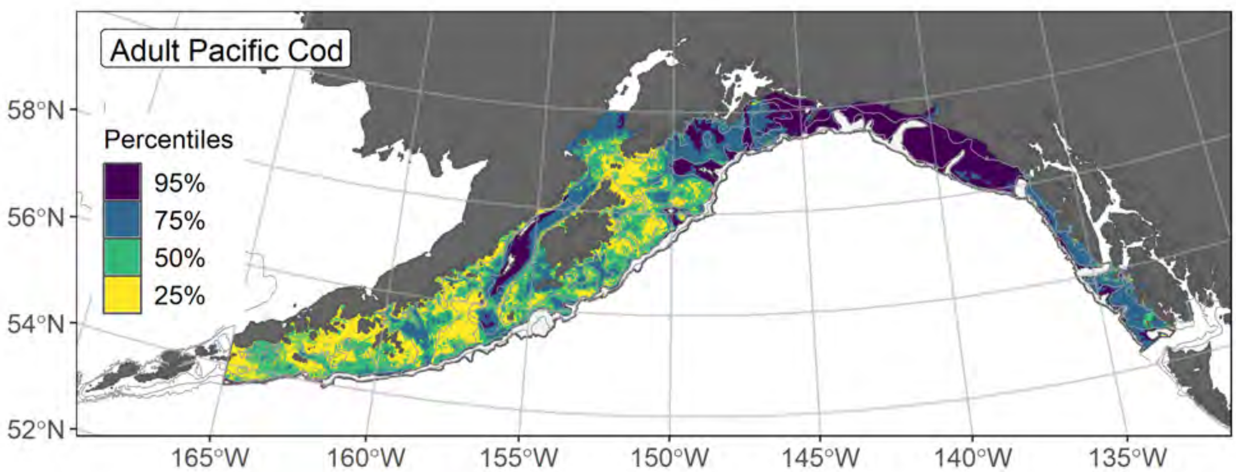

Figure 23. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from an SDM ensemble fitted to adult Pacific cod distribution and abundance in AFSC RACE-GAP GOA summer bottom trawl surveys (1993–2019) with 100 m, 200 m, and 700 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

3.3.2.6 Bridging the 2017 and 2023 EFH designations for adult Pacific cod in the Gulf of Alaska

The new ensemble produced for the 2023 EFH 5-year Review showed improved performance relative to the 2017 SDM (Table 16). The scores for ρ and AUC were nearly identical, but the 2023 ensemble showed improvement in terms of RMSE and deviance explained (PDE). These metrics suggest that the new 2023 ensemble is an improvement over the 2017 SDM.

The changes implemented during the 2023 EFH 5-year review resulted in a minor decrease in adult Pacific cod EFH area from 295,900 km^2 in 2017 to 264,700 km^2 in 2023; a change of -4.7% (Figure 25). The decrease in area is caused by the removal of locations in deep water along the continental slope, as well as some glacial troughs in the southeast GOA. This decrease was partially offset by the addition of continental shelf areas up to a depth of 200 m south of Yakutat Bay.

Refinements to our modeling approach altered adult Pacific cod EFH relative to the 2017 areal extent (Figure 26). Panel A shows the original EFH map for adult Pacific cod produced during the 2017 EFH 5-year Review. In Panel B, the life stage definition for adults was changed from all specimens greater than the length at first maturity (420 mm T.L.; Stark 2007) to the length at 50% maturity (503 mm T.L.; Stark 2007), and this resulted in a minor reduction in EFH area. In panel C, the addition of 5 more years of bottom trawl survey data, including 723 new catches of adult Pacific cod, had little effect on the EFH area. In panel D, shifting to the prediction of numerical abundance as the response variable and updating the EFH mapping approach based on the 2023 ensemble methods also resulted in a small reduction in EFH area in deeper areas and along the continental slope. In panel E, the addition of new terrain and bottom current covariates caused no net change in the size of the overall EFH area. Lastly, in panel F, the creation of the ensemble from four SDMs produced a minor increase in the EFH area.

Table 15. Comparison of performance metrics and area for SDM predictions and EFH areal extent from the 2017 and 2023 5-year Reviews of GOA adult Pacific cod. The metrics presented are Spearman's rank correlation coefficient (ρ), root-mean-square-error (RMSE), the area under the receiver operating characteristic (AUC), and the Poisson deviance explained (PDE). The 2017 SDM predictions were converted from 4th root CPUE to count abundance prior to calculating the performance metrics assessed in 2023. The percent change in area (km^2) is constant for the EFH area and core EFH area.

EFH Review	SDM method	N	RMSE	ρ	AUC	PDE	EFH area (km^2)	Core EFH area (km^2)	% Change in area
2017	GAM_{CPUE}	3,615	97.9	0.48	0.76	-0.36	295,900	155,700	
2023	Ensemble	4,476	70.2	0.47	0.75	0.25	264,700	139,300	-4.7%

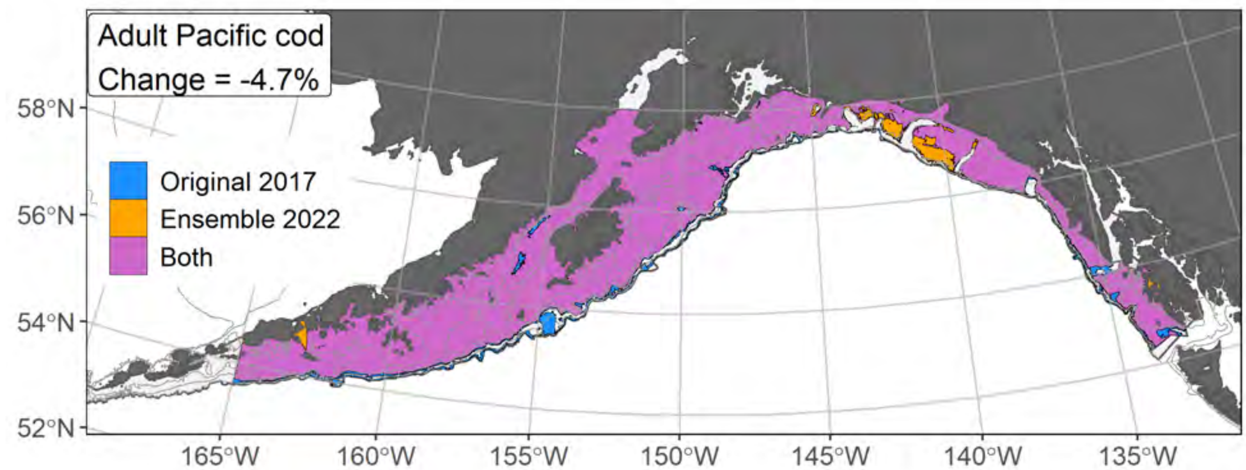

Figure 24. Change from 2017 to 2022 (2023) in essential fish habitat (EFH) area, which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from adult Pacific cod catches in AFSC RACE-GAP summer bottom trawl surveys (1993–2019) with 100 m, 200 m, and 700 m isobaths indicated. Colored areas represent EFH in 2017, 2022 (2023), or both.

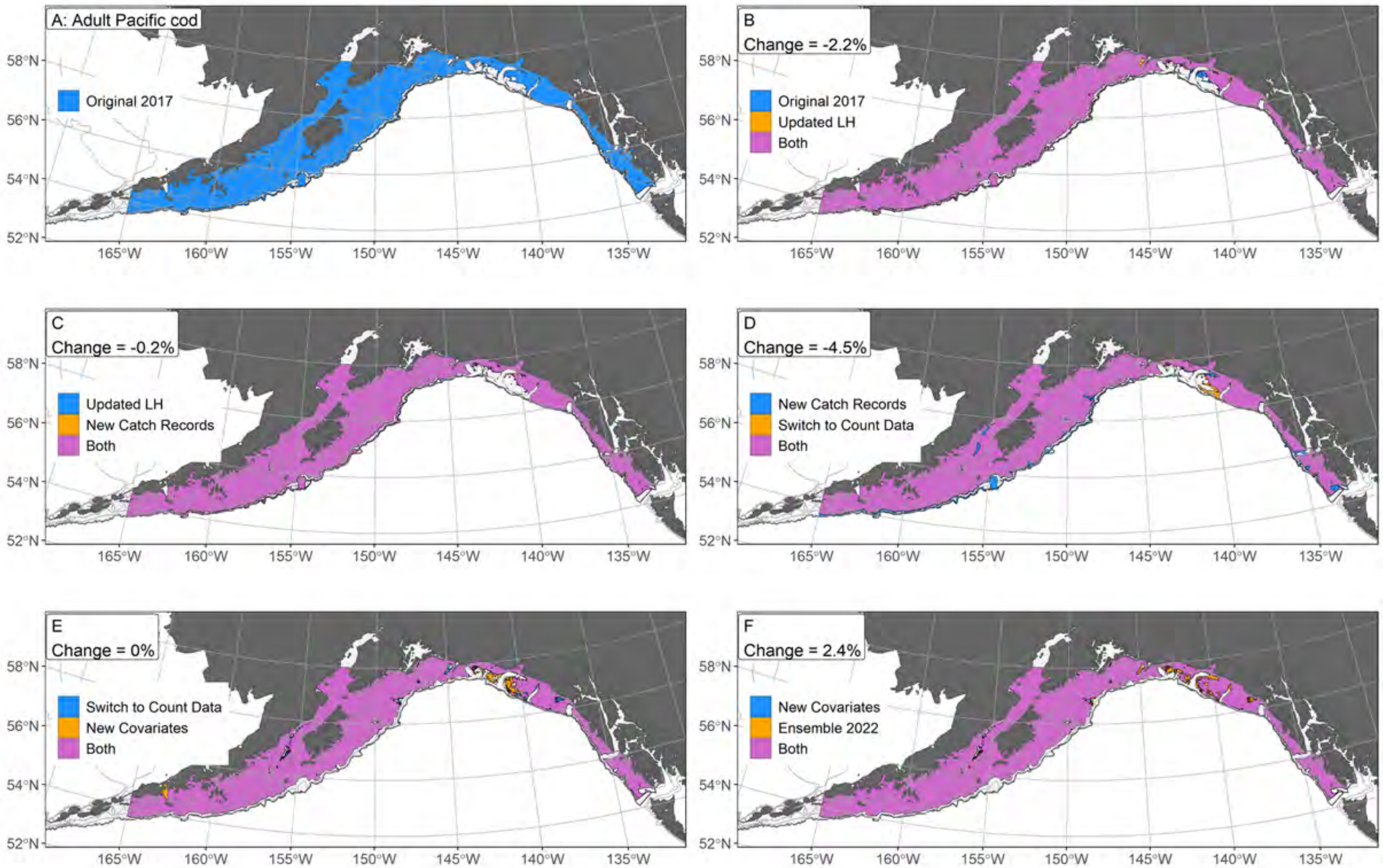

Figure 25. Change in EFH area for adult Pacific cod as a result of successive changes to the SDM EFH mapping approach for the 2023 EFH 5-year Review. Panel A shows the 2017 EFH map. Panel B shows the change resulting from the addition of new life history information. Panel C shows the addition of new catch records between 2015 and 2019. Panel D shows the results of changes to the modelling process, including using a count data model. Panel E shows the addition of new habitat covariates. Panel F shows the 2022 (2023) EFH map, derived from the combined predictions of four constituent SDMs in an ensemble. The 100 m, 200 m, and 700 m isobaths are indicated. The % change in area is calculated relative to the previous step, and is different from the overall change shown in Figure 25.

3.3.2.7 Pacific cod settled early juveniles in the Gulf of Alaska

Settled early juvenile Pacific cod (N = 354) caught in mixed gear-type summer surveys (1989–2019) were distributed primarily inshore throughout the GOA with some occurrences at shallower depths offshore on the continental shelf (Figure 27). Settled early juvenile Pacific cod presence records from multiple surveys were combined in a habitat-related MaxEnt model predicting suitable habitat probabilities for this life stage in the GOA. The best model had a β-multiplier of 2.5 and an AUC of 0.95 (Table 17). Bottom depth contributed the most (69.9%) to the MaxEnt model (Table 18). The highest probabilities of suitable habitat for early juvenile Pacific cod in the GOA were predicted in coastal nearshore areas and around islands throughout the GOA (Figure 28). The areas with the highest error around the MaxEnt predictions for settled early juvenile suitable habitat corresponded to the locations where high probabilities of suitable habitat were predicted.

Habitat-related predictions of settled early juvenile Pacific cod distribution from summer surveys of the GOA (mixed gear-type summer surveys (1989–2019) and RACE-GAP bottom trawl surveys (1993–2019)) was mapped as EFH areas and subareas (Figure 29). Settled early juvenile Pacific cod EFH included nearshore areas and bathymetric rises on the continental shelf most prevalent in the central and western GOA. Core EFH areas and EFH hot spots for settled early juveniles were generally associated with shallower nearshore areas and bathymetric rises. Pacific cod ontogenetic differences in depth distribution (e.g., Laurel et al. 2009, Pirtle et al. 2019) were reflected by the predicted EFH areas among life stages modeled, with the greatest difference between the early juveniles and older life stages (Figure 24).

Table 16. Maximum entropy model (MaxEnt) used to construct Essential Fish Habitat (EFH) for settled early juvenile Pacific cod: regularization multiplier (β); *k*-fold cross-validation root-mean-square-error (RMSE), area under the receiver operating characteristic curve (AUC), and areal extent of EFH (km^2).

Model	**β**	**RMSE**	**AUC**	**EFH area (km^2)**
MaxEnt	2.5	112.90	0.95	124,800

Table 17. Covariates retained in the habitat-related maximum entropy (MaxEnt) model for settled early juvenile Pacific cod with the percent contribution of each covariate to the deviance explained by the SDMs and the cumulative deviance explained: SD = standard deviation and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
bottom depth	69.9	69.9
aspect eastness	7.4	77.3
BPI	5.9	83.2
aspect northness	5.2	88.5
rockiness	3.9	92.4
tidal maximum	3.2	95.6
curvature	2.0	97.6
bottom temperature	0.9	98.5
coral presence	0.8	99.3
sponge presence	0.7	100.0

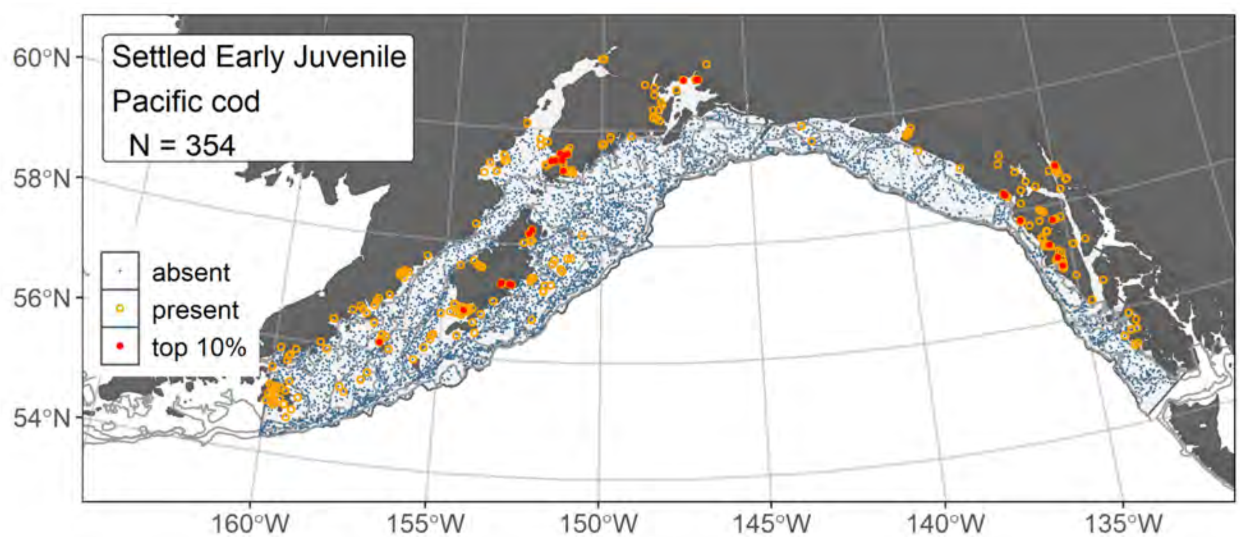

Figure 26. Distribution of settled early juvenile Pacific cod catches (N = 354) in mixed gear-type summer surveys of the Gulf of Alaska (1989–2019) with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present.

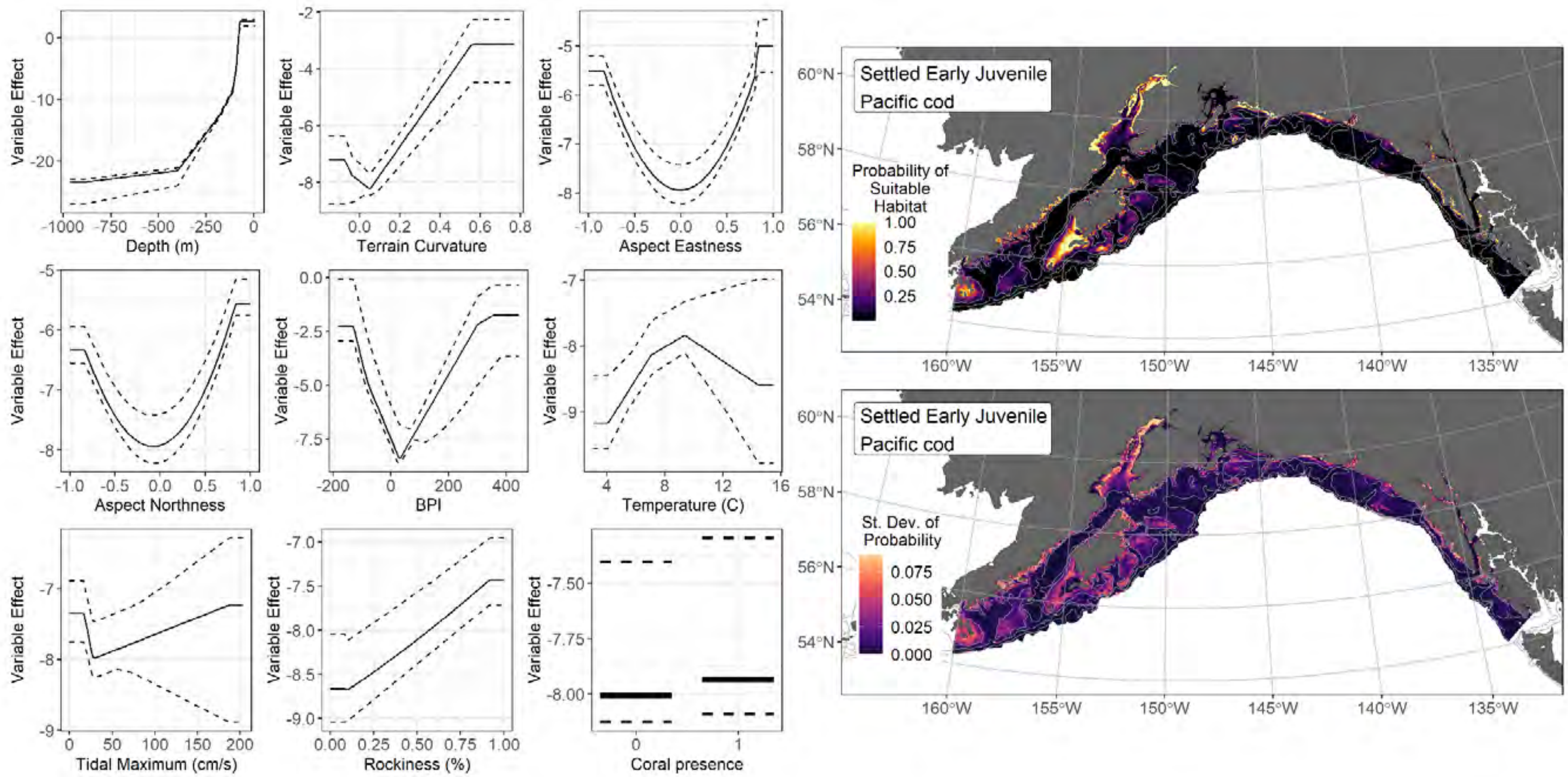

Figure 27. The top nine covariate effects (left panel) from a habitat-related SDM (MaxEnt) of settled juvenile Pacific cod probability of suitable habitat in the Gulf of Alaska (upper right panel) with the standard deviation of the probability predictions (lower right panel).

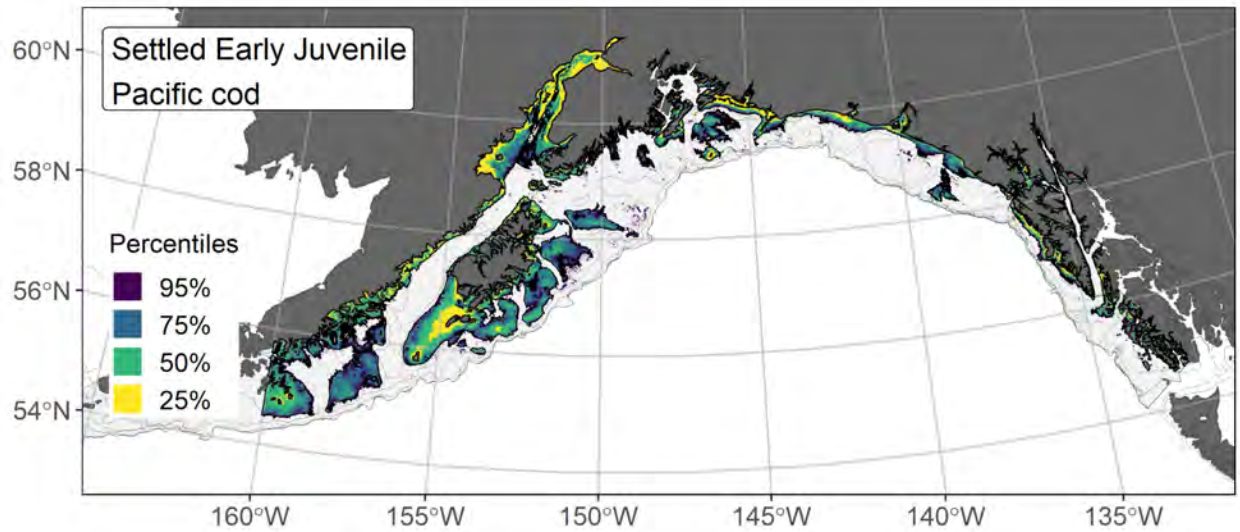

Figure 28. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat for settled early juvenile Pacific cod (defined as greater than 5% predicted probability of suitable habitat) from an SDM fitted to their distribution in Gulf of Alaska (GOA) mixed gear-type summer surveys (1989–2019) with 100 m, 200 m, and 700 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

3.3.2.8 EFH Level 3 of settled early juvenile Pacific cod in the Gulf of Alaska

Laboratory reared early juvenile Pacific cod temperature-dependent growth rate is described by the following equation (Laurel et al. 2016):

$$GR = 0.2494 + 0.3216 * T + 0.0069 * T^2 - 0.0004 * T^3$$

Where *GR* is the growth rate (% body weight (g) per day (d)), and *T* is the temperature. The raster product of early juvenile Pacific cod predicted probability of suitable habitat from a MaxEnt SDM (and their temperature-dependent growth is an EFH Level 3 map of habitat-related growth potential (Figure 30). The temperature of maximum growth for early juvenile Pacific cod is 11.5°C (Laurel et al. 2016), which is within the range (2.9–17.5°C) of the CGOA ROMS 3 km summer bottom temperature covariate raster (2000–2019) applied to the SDM and to the EFH Level 3 map of habitat-related growth potential (Attachment 5 Figure 3). The bottom temperature range at settled early juvenile Pacific cod catch locations contributing to the SDM was 3.0–15.5°C (Figure 27). In the map of temperature-dependent growth, the highest growth areas occurred inshore and along the coast, as well as on the banks and bathymetric rises on the GOA continental shelf (Figure 30). The SDM of settled early juvenile stage Pacific cod suitable habitat limited areas of high predicted habitat-related growth potential (Figure 28), notably to shallower depths, suggesting that temperature was not the only driver of distribution for this life stage in the GOA. EFH subareas of core EFH area and EFH hot spots corresponded with areas of high habitat-related growth potential for settled early juvenile stage Pacific cod, which adds value in interpreting the EFH Level 1 map (Figure 29).

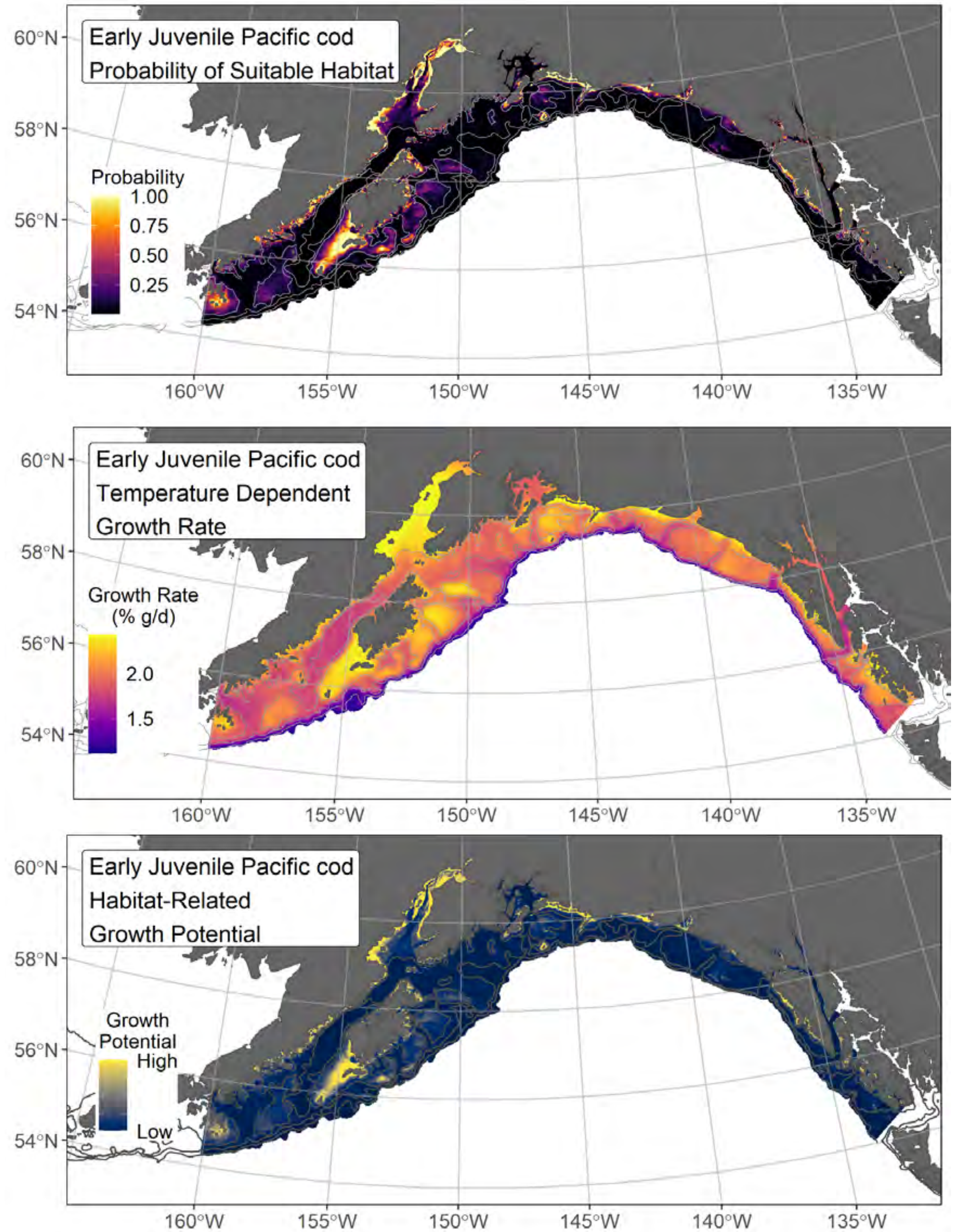

Figure 29. Settled early juvenile Pacific cod predicted probability of suitable habitat from a habitat-related SDM fitted to their distribution in Gulf of Alaska mixed gear-type summer surveys (1989–2019; top panel), temperature-dependent growth rate (GR = % body weight (g)·day-1; center panel), and EFH Level 3 map of habitat-related growth potential (bottom panel), which is the raster product of probability of suitable habitat and temperature-dependent growth rate.

3.3.3 Synthesis

3.3.3.1 Synthesis of findings regarding habitat related covariates and SDM predictions

One valuable feature of habitat-related SDMs is that they can provide insight into the environmental conditions that affect patterns of species distribution and abundance. The three most influential (highest percent contribution to the deviance explained by the SDM or ensemble) covariates for each species' life stage in the 2023 EFH 5-year Review are summarized in Table C1. Detailed figures and interpretations of the covariate effects are available in the corresponding chapters for each species' life stage in the three regional NOAA Technical Memoranda (Supporting Documents 5). The covariate contribution is estimated with a jack-knife process, whereby each covariate is removed from the SDM one at a time, and the resulting decline in model performance is measured. If the deviance explained by the SDM declines by a large amount, this suggests that the covariate is important for accurate prediction. The percent contribution of the covariates is an indication of their proportional contribution to the deviance explained by the ensemble. Overall ensemble performance is indicated by the model performance metrics for assessing model fit (see performance metric details in Statistical Modeling 3.2.7). Details for the explanation and data source for each covariate can be found in Habitat Covariates 3.2.3 and Table 5.

Summarized across all the species examined, the most influential covariates for species' life stages modeled in the 2023 EFH 5-year Review were geographic location and bottom depth. One or both of these were present in the top three contributing covariates for over 90% of the ensembles. Geographic location was the combination of latitude and longitude recorded for each haul in the RACE-GAP bottom trawl surveys. Location was included to reduce the effects of spatial autocorrelation as demonstrated by Rooper et al. (2021). Bottom depth is an important determinant of fish distributions for North Pacific species (e.g., Laman et al. 2018, Pirtle et al. 2019) and in other regions globally (e.g., Macpherson and Duarte 1991). Bottom currents and bottom temperature were less influential, but each appeared in the top three for approximately 25% of the SDMs and ensembles. Tidal maximum, BPI, *phi*, rockiness, and sponge presence were occasionally top contributors, and appeared in the top three in approximately 5–15% of SDMs and ensembles. Other covariates such as terrain aspect, terrain curvature, slope, coral presence, and pennatulacean presence were only rarely included in the top three covariates. The most influential covariates also varied by region, though location and bottom depth are influential in most SDMs and ensembles across all three regions. In the AI, bottom currents were relatively more influential and bottom temperature was relatively less influential. In the Bering Sea, temperature was more influential and tidal maximum was less influential. In the GOA, sponge presence and BPI were relatively more influential than in other regions.

3.3.3.2 Comparison of 2017 and 2023 SDM performance and EFH areas

Model performance and EFH area were summarized and compared (2017 single SDM compared to 2023 ensemble) between the SDMs and EFH maps of the 2017 and 2023 EFH 5-year Reviews (Appendix D). The SDM selected in 2017 had a strong influence on the resulting performance metrics and EFH areas. The MaxEnt models fitted from the *dismo* package used in the 2017 EFH 5-year Review have a different design and are not directly comparable to the MaxEnt models fitted from the *maxnet* package used for the 2023 EFH 5-year Review; only AUC can be computed for comparison between these cases. The 2017 EFH 5-year Review did not include SDMs for settled early juveniles so no comparison between years was possible. Neither did we compare species modeled where life stages were combined in 2017 (2023) with the same species modeled where those life stages were distinct in 2023 (2017); these species are absent from Table D2. However, the SDM and ensemble results by region for each species' life stage modeled in 2023 are in Table C2 along with the number of positive catches, RMSE, performance metrics (ρ, AUC, and PDE), EFH area, and the EFH subarea "core EFH area."

In the majority of cases, the performance metrics from the 2023 SDM ensembles demonstrated clear improvements over those from 2017. The 2023 ensembles showed improvement in RMSE in 88%

of models, improvement in Spearman's correlation (ρ) in 69% of models, improvement in area under the receiver operating characteristic curve (AUC) in 52% of models, and improvement in Poisson deviance explained (PDE) in 99% of models. In other cases, where clear improvement was not observed, the difference between the models was usually small, and in no instance was a decline observed across all metrics. When comparing SDMs from different years, it is important to consider that additional changes to the data, such as updated life history information, may have a large effect on model predictions. Therefore, the results (Table C2 and Table D2) should be considered in context with the more detailed results descriptions reported in each species' life stage in the three regional NOAA Technical Memoranda from this study (Supporting Documents 5). Approximately 25% of ensembles in the present work predicted EFH areas larger by 100% or more; in almost all of these cases the 2017 SDM was the restrictive hGAM. Approximately 18% of ensembles resulted in EFH areas that were smaller by at least 50%; in all cases the 2017 SDM was a MaxEnt model.

3.3.3.3 Summary of 2022 SDM performance with additional metrics

The 2023 EFH 5-year Review used four metrics to assess the predictive skill of SDM ensembles. The RMSE is a measure of the variance in predictions relative to the observed data, and was used to weight the constituent SDMs for each species life stage. The RMSE is useful for comparing different models, though it does not provide information about fit on its own. Spearman's rank order correlation (ρ) is a measure of whether an SDM predicts the relative ordering of high or low values in the data, and is used to assess model fit. Area under the receiver operating characteristic curve (AUC) is a measure of discrimination ability and is used to assess the ability of a model to correctly predict presence or absence. The Poisson deviance explained (PDE) is a measure of fit that adjusts for the non-normal errors expected from count data and is used to assess the ability of a model to predict the observed abundance. See the Statistical Modeling section of the Methods in this document for additional details.

The four model performance metrics selected in this project and described above are only a small sample of the total number of statistical measures available for assessing model fit. Five additional metrics investigated to describe ensemble performance are presented in Appendix E Table E1. These provide additional nuance when interpreting the validity and fit of the ensembles. The first of these is prevalence (Prev.), the number of positive catches divided by the total number of valid hauls for that species. This metric provides further information about the relative commonness or scarcity of a species in the RACE-GAP bottom trawl surveys. The Pearson correlation (r) is a commonly used statistic that measures the degree to which model predictions match observed data. It was not used in the 2023 EFH 5-year Review because it assumes that the data follow a normal distribution; count data modeled here follow a Poisson distribution. The Pearson correlation can take on values between negative one and one; higher absolute values indicate a better fit. The Precision-Recall area under the receiver operating characteristic curve (PR-AUC) is a variation of the AUC that focuses on predictive skill for presence locations. Whereas AUC measures the rate of true positives compared to the rate of false positives, PR-AUC measures the degree of precision (true positives/predicted positives) compared to recall (true positive/observed positives). PR-AUC values range from zero to one, with higher values indicating better performance. The F_1 score (F_1),

$$F_1 = 2 * \frac{precision*recall}{precision+recall},$$

is similar to PR-AUC in that it is a measure of classification skill for presence or absence data with a focus on presence locations. The F_1 score also has a value between zero and one and is typically similar to the PR-AUC. Both PR-AUC and F_1 scores were requested by the SSC at the October 2021 meeting (Table A1) and are reported here. The accuracy (Acc.) is the number of correct predictions divided by the total number of observations, and provides an easier to interpret metric that focuses equally on presence and absence in the data.

3.4 Conclusions

The completion of this project advancing EFH information for North Pacific groundfish and crab species within NPFMC FMPs meets the requirements of the EFH regulations and satisfies specific objectives of the Alaska EFH Research Plan. The MSA requires NMFS and the Councils to describe and identify EFH for managed species in FMPs. Federal regulations implementing the MSA require the Councils and NMFS to periodically review (at least every 5 years) the EFH components, FMPs and, potentially, to revise or amend these components with new information. The EFH descriptions and maps from this EFH 5-year Review satisfy these requirements. The two Alaska EFH Research Plan objectives met in the present work are 1) the development of EFH information for life stages and species not previously described and 2) the raising of EFH information levels from none or Level 1 (distribution) to Level 2 (habitat-related abundance) and Level 3 (habitat-related vital rates).

In addition to satisfying the requirements and objectives above, the present work addresses the MSA requirement to meet the standards of best available scientific information stipulated in NMFS National Standard 2 – Scientific Information 50 CFR 600.315. Among the steps we took to advance EFH descriptions in Alaska while meeting the standards of best available science were to update length-based life stage definitions from the extant scientific literature and to extend the dataset analyzed in the last EFH 5-year Review with the five most recent years of data collected on the RACE-GAP summer bottom trawl surveys. We refined and advanced the SDM modeling approaches endorsed in the last 5-year Review by adding two SDMs to the suite of constituent models. We added a negative binomial GAM (GAM_{nb}) to address overdispersion in the data and we included a presence-absence GAM (paGAM) to model binary distribution information. In addition, we shifted the response variable from transformed CPUE to numerical abundance which facilitated skill testing among the constituent SDMs. In response to SSC input and facilitated by the shift to abundance as the response variable, we instituted an ensemble modeling approach for describing EFH in this Review, using skill testing to identify the best performing SDMs. The SDM ensemble approach provides a robust modeling framework for predicting abundance. These advances and refinements improved the scope and quality of our data products.

As described in Iterative Review (Chapter 2), at key junctures during this project, after presenting methods and preliminary results to the SSC, we received and incorporated constructive feedback to improve the analyses and results of this project (Table A1). In June 2020, we presented many of the modeling refinements listed above and received the suggestion that led to using ensemble modeling to combine the best-performing constituent SDMs. In April 2021, we presented preliminary results from these ensembles to the SSC, discussed the use of model fit metrics, and demonstrated the application of Level 3 EFH information. All of the feedback we received was addressed and much of it was integrated into our subsequent modeling efforts. We also demonstrated methods and presented preliminary results to the Council's Plan Teams on several occasions (section 2.1.1), receiving and responding to their feedback and expert opinions.

An innovation we introduced in this review cycle was an extensive review of our modeling methods and preliminary EFH descriptions and maps by stock assessment scientists and other species experts early enough in the process to incorporate their feedback in the final results. We also worked closely with the stock assessment community to coordinate the timing of this review process with their rigid annual stock assessment cycle so that we could incorporate their reviews into our final products reported in this document and in the three regional NOAA Technical Memoranda (Supporting Documents 5). This was intentionally designed as an iterative process with EFH analysts in close and regular communication with stock assessment author reviewers to answer questions and to reach mutual agreement over issues raised in the review process. As with the feedback received from the SSC and the Plan Teams, this review process with the stock assessment authors improved our data products while strengthening collaboration and stock authors' confidence in our EFH descriptions. We are grateful for the large amount of effort these teams brought to bear to improve this work.

The ensemble modeling approach we used to describe EFH in the present work provides several advantages. Ensemble modeling combines multiple, best-performing constituent SDMs. We have learned from our work on this project that certain classes of SDMs have tendencies to over- or under-predict abundance (e.g., Appendix G and Harris et al. In preparation). For example, the MaxEnt model tends to over-estimate the total area of suitable habitat while the hGAM tends to be more restrictive. Since the ensemble provides what is essentially a weighted average of SDM outcomes, it often appears to produce more plausible predictions of EFH than single SDMs in isolation. We anticipate because of this that our ensemble framework will also be robust to changes in underlying data and will readily accept new or additional SDMs for testing and evaluation; both traits are advantageous for future EFH 5-year Reviews. One of our strong recommendations for future EFH ensembles is the addition of non-GAM SDMs to the suite of candidate models (e.g., boosted regression trees or random forest models) to expand the modeling perspectives represented in the present ensemble which favors GAMs (i.e., constituent model candidates in the present formulation are MaxEnt and four GAMs).

Predictor variables measured in or modeled from the habitats sampled were selected for their potential to influence species distribution and abundance in those areas. This provides a rationale for using SDMs containing habitat-related variables to predict North Pacific species distribution and abundance to model EFH in Alaska, and gives us confidence that the model predictions reflect the influences of habitat and environment on the distribution and abundance of the species modeled. For instance, in the Bering Sea, geographic location, bottom depth, and bottom temperature were the most common top contributors to the deviance explained by the ensembles confirming what is already known from other research (e.g., Laman et al. 2018, Stevenson and Lauth 2019) and supporting our intention that our models plausibly reflect reality. To expand the capabilities of the ensemble to link habitat factors with distribution and abundance, we added relevant terrain metrics to the suite of predictors used to parameterize the models (i.e., bathymetric position index and rockiness).

This body of work represents a significant advancement of the SDM approach for mapping EFH accepted after the 2017 EFH 5-year Review for Alaska. The ensemble modeling approach developed here, along with the other refinements described in this document, provides a robust and flexible framework for future EFH descriptions. In addition, the ensembles developed here provide valuable information that can be extended to stock assessment and other EBFM efforts; the Alaska EBFM Roadmap Implementation Plan (NMFS 2018) promotes this “value-added” concept around applying EFH and habitat science to areas of resource management. An example of extending the utility of this EFH work can be found in the GOA walleye pollock Ecosystem and Socioeconomic Profiles (ESP) in the Stock Assessment and Fishery Evaluation (SAFE) Reports. Shotwell et al. (2019) include SDMs developed for EFH component 1 during the 2017 EFH 5-Year Review (Laman et al. 2018) and GOAIERP (Pirtle et al. 2019) in their GOA walleye pollock ESP. Recent studies have also applied these SDMs to developing stock-specific indicators for the ESPs (Shotwell et al. 2022), to test hypotheses around groundfish recruitment processes in the GOA (Goldstein et al. 2020), and to assess changes in spatial-temporal species distribution and abundance in the Bering Sea under future climate scenarios (Rooper et al. 2021) and on more dynamic and short term time scales (Barnes et al. 2022).

3.5 Future Recommendations

As we developed our modeling approaches for the present work and participated in multiple peer and expert reviews in a variety of venues, we have identified recommendations that could be considered for future EFH 5-year Reviews. These recommendations fall into three categories:

1. Prioritize and improve EFH for select species
2. Increase the scope and applicability of EFH research
3. Improve process and communication.

The complete list of these recommendations is incorporated into the three regional NOAA Technical Memoranda (Supporting Documents 5), which provides more detailed descriptions of the pathways we, the EFH component 1 analysts, recommend. Table 1 of each Future Recommendations section of those reports summarizes recommendations about data sources that should be explored for improving SDM estimates of distribution and abundance, Table 2 contains covariates to explore and potential sources for covariate data, and Table 3 (reproduced below as Table 18) summarizes the recommendations. We summarize and briefly discuss key recommendations in the three categories below.

3.5.1.1 Prioritize and improve EFH for select species

The existing methodology for describing and mapping EFH works well for most species. For others, approaches need to be modified in order to better capture drivers of distribution and abundance and generate habitat descriptions and maps. These approaches may involve incorporating new datasets (for fish distribution, environmental covariates, or life history parameters), or the development of modeling approaches that are amenable to their distributions (e.g., modeling at a broader spatial scale). For some of these species, the need for model improvements has been discussed (e.g., Harris et al., Laman et al., Pirtle et al. In review and Appendix G); in the future it is important to have both modeling and communication processes in place for these species. These may include agreed-upon differences in the modeling approach depending on data needs and performance of ensembles developed in previous EFH 5-year Reviews. There are several pathways by which EFH could be improved for the species that need it; we recommend leveraging existing species distribution data, environmental data, and life history information in cases when more life stages could be modeled, investing in the means to combine disparate datasets (e.g., non bottom trawl surveys), and incorporating a broader diversity of models in the ensembles used to describe EFH. We also encourage the continued exploration of quantitative methods that allow for model fitting and fit comparisons when there are data limitation issues; e.g., using soap-film smoothers in *mgcv* to better model edge areas that are less frequently sampled and joint SDM applications.

3.5.1.2 Increase scope and applicability of EFH research

Ongoing discussions with the SSC and stock assessment authors have identified conceptual frameworks that should be considered in the future for developing, evaluating, and utilizing EFH descriptions and maps. Considering how EFH is defined in terms of scale and ecological function could improve the utility of this concept for management (e.g., Harris et al. In preparation). The present working definition of EFH equates the area containing 95% of the total estimated occupied habitat with EFH (NMFS 2005[51]), and core EFH area as the area containing 50% of occupied habitat. In the present work, occupancy was defined as areas with > 5% model-estimated encounter probability from SDM ensembles based on the RACE-GAP bottom trawl survey data. However, this definition may not be as ecologically meaningful for highly mobile species, or those with a high degree of uncertainty in the estimate of their population density. For example, the distribution of highly mobile predators might be more strongly impacted by prey availability than by environmental conditions. It may also not be a useful metric if a shrinking proportion of their population is available to the bottom trawl survey, as is the case for species with poleward-shifting distributions. As models describing and predicting species distribution and abundance (density or biomass) become more tightly and realistically linked to habitat and environmental change, there may be opportunity to reconsider how EFH area is defined and mapped.

[51] https://repository.library.noaa.gov/view/noaa/17391

3.5.1.3 Improve process and communication

Improving methodological approaches and clearly communicating them is a high priority. Review and input by the Council's SSC, Plan Teams, the stock assessment authors, and other stakeholders is an important part of the iterative EFH 5-year Review process. Expert peer-reviews in particular can help identify cases where methodological changes are needed to account for species with lower quality data or low availability to the surveys where survey data have been used to model and map EFH. Additionally, the EFH process involves communicating model results to a broad stakeholder audience and adapting models when appropriate based on feedback. For example, a species with poor model fits or low stock assessment author confidence in the EFH map might be evaluated using a different SDM, or certain data requirements might be identified early that would lead to that species being modeled differently. Each EFH 5-year Review is an opportunity to improve the process and communication.

We are proud of the process and communication improvements that we implemented during this EFH 5-year Review to improve coordination and collaboration between SDM EFH analysts and stock assessment authors. We implemented SSC suggestions from 2021 about communicating methods and results, including providing descriptions of ensemble modeling methods and probability thresholds, clear descriptions of data including data transformations and timeframes, and summaries of skill testing results. We (AKRO and AFSC) hosted a stock assessment author summit in January 2021 to discuss and co-develop the review process of the current and new EFH descriptions and maps. We set a timeline that worked for all parties and agreed on the content to be reviewed and the methods, which was well communicated and executed in an approachable process for the reviewers. In past EFH 5-year Reviews, current EFH descriptions and maps in the FMPs were provided to stock assessment authors with the new EFH maps for review. In this EFH Review, as the SDM ensemble EFH methods represent a significant advancement over the 2017 SDM EFH approach, and expert peer-review is an important part of the iterative EFH 5-year Review process; we provided the stock assessment authors with the complete set of regional SDM ensemble EFH methods (3 regions), species results chapters (112 chapters), and current FMP sections. Stock assessment authors are considered subject matter experts, whose input was used to groundtruth EFH information, including improving the modeling methodology in general and for their species. We recommend that an agreement also be reached at the beginning of next EFH 5-year Review regarding the process and scope for stock assessment author review, in a way that remains feasible for the EFH analytical team and reviewers.

In terms of carrying out and communicating throughout the EFH process, we recommend improvements to communicating uncertainty about estimates of species abundance and distribution. This involves improving ways to evaluate uncertainty in model predictions and ways to communicate that uncertainty in EFH descriptions. We recommended the development of scientific guidance for thresholds in EFH mapping and testing them, adding more avenues for communication (including communicating with stakeholders to develop simulation approaches for testing different management strategies and data collection practices), and streamlining workflows and reproducibility to make code accessible and reproducible.

Finally, we recommend forming an expert working group with the objective of developing and publishing a peer-reviewed manuscript providing clear and objective guidance to the SSC ahead of the next EFH 5-year Review for constructing EFH from SDMs within the regulatory framework of the MSA and EFH Final Rule. This may encompass an evaluation of thresholds and percentile areas applied to the SDMs and EFH maps, including the selection of the EFH area or subarea used to support the EFH component 2 fishing effects analysis.

Table 18. Summary table of future recommendations for EFH research to advance EFH component 1 descriptions and maps, and how EFH component 1 outputs are evaluated and applied to management.

Area of research	Improvement/advancement	Taxa with potential EFH improvement
Prioritize and improve EFH for select species	Leverage existing species distribution data to expand spatial scope and improve predictions in existing EFH maps	Species where higher-quality EFH information is needed (current maps contradict expert experience; model fits are relatively low compared to other species modeled)
	Leverage environmental data	All (especially species where higher-quality EFH information is needed)
	Improve life history information with best available science	All (especially crab species)
	Expand and improve existing SDM EFH mapping to include species and life stages in the nearshore (e.g., at appropriate spatial resolutions)	Many EFH species and their prey that inhabit nearshore habitats
	Develop methodology for combining disparate datasets	Species where higher-quality EFH information is needed
	Develop process studies to inform EFH descriptions and maps (e.g., vital rates, movement, population dynamics)	All
	Consider diverse constituent models	Species where higher-quality EFH information is needed; especially those with EFH level 1 information only
Increase scope and applicability of EFH research	Describe prey species habitat (EFH component 7)	Most groundfish, especially those with diets more specialized on forage
	Expand to EFH Levels 3 and 4	All
	Continue to advance and apply dynamic SDM methods in development to map and forecast shifts in EFH and spatial stock structure to improve climate responsive approaches to EFH and EBFM	All
Improve process and communication	Communicate confidence in EFH designations/boundaries	All
	Develop thresholds for mapping EFH with SDMs and SDM EFH applied to the Fishing Effects analysis (e.g., thresholds applied), through research and an expert work group, and communicate this guidance to the SSC prior to the launch of the next EFH 5-year Review.	All
	Add more opportunities for communication	All
	Streamline workflows and reproducibility	All

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5 Supporting Documents

Additional supporting documents are provided for the evaluation of EFH component 1 in the 2023 EFH 5-year Review. Please refer to the electronic agenda for this meeting to view and download the following documents—

- **Three documents prepared as NOAA Technical Memoranda** organized by the regions modeled by the Laman et al. study for the species life stages in the BSAI, GOA, and Crab FMPs. Refer to the individual documents for region-specific methods and the full set of species' life stage SDM EFH results, including the new 2023 summer distribution EFH maps showing the EFH area and percentile subareas (e.g., CEA used in the EFH component 2 FE evaluation), and research recommendations. The three documents have been reviewed by the stock assessment authors, additional NMFS reviewers, and by the SSC. The three documents were resubmitted for publication in September 2022.
    - **Al Advancing Model-based EFH** (Harris et al. In Review)
    - **EBS Advancing Model-based EFH** (Laman et al. In Review)
    - **GOA Advancing Model-based EFH** (Pirtle et al. In Review)
- **2023 SDM ensemble EFH maps and comparing the 2017 and 2023 CEAs as overlay maps** are in a collection of figures for the EFH component 2 FE evaluation of the 2023 5-year Review, organized by regional folders (AI, EBS, GOA) and also containing the FE model and analysis results.
- **EFH Component 2 Fishing Effects Evaluation Discussion Paper (January 2023)**, supports the review of the EFH component 2 FE evaluation of the 2023 5-year Review, and provides information for how the new EFH component 1 SDM ensemble EFH map CEAs were used in the FE evaluation, including details of stock author input on any SDM EFH map concerns and recommendations with EFH analyst responses on how those were addressed to the extent possible at this time.

Appendix A SSC and Plan Team Input and EFH Analyst Responses

Appendix A provides EFH component 1 analyst responses to requests and recommendations by the Council's Scientific and Statistical Committee (SSC), Joint meeting of the Groundfish Plan Teams (JGPT), and Crab Plan Team (CPT), provided in the minutes from meetings during the 2023 EFH 5-year Review from June 2020–November 2021 (Table A1) leading up to SSC review in February 2022.

Stages of the 2023 Review included in Table A1—

1. SSC June 2020: Review of the proposed EFH component 1 SDM methods and preliminary results examples for the 2023 EFH 5-year Review.
2. JGPT September 2020: Review of the proposed EFH component 1 SDM methods and preliminary results examples for the 2023 EFH 5-year Review.
3. SSC April 2021: Review of the EFH component 1 plan for the 2023 EFH 5-year Review.
4. CPT May 2021: Review of the EFH component 1 plan for the 2023 EFH 5-year Review.
5. JGPT September 2021: Review of the preliminary results of the stock assessment author review of EFH component 1 in the FMP EFH documents, 2017 EFH maps, draft ensemble SDM EFH methods and results, and draft 2022 EFH maps, with EFH component 1 analyst planned response and recommendations (Appendix F).
6. SSC October 2021: Review of JGPT report on EFH component 1 September 2021 agenda item.
7. JGPT November 2021: Review of the iterative review process of EFH component 1 and stock assessment author review report with EFH analyst responses (Appendix F).

As an opportunity to strengthen the new EFH component 1 information in preparation for the 2023 Review, SSC and Plan Teams provided input at these stages of the iterative review, regarding study methods, progress to date, and planned research products. The Laman et al. study and the other contributing EFH component 1 studies (Introduction 1) took this input into account to update their approach. EFH analyst responses to input summarized in Table A1 and referenced throughout this document. In some cases, more extensive responses from these stages of review are provided in other sections of the document (e.g., Appendix C).

Also included in Appendix A are EFH component 1 analyst responses to SSC's request for "an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle" (Table A1 item 6b). SSC minutes from the 2017 process include the following meetings: February 2015, April 2016, October 2016, December 2016, and April 2017 (Table A2).

Subsequent stages of the 2023 Review and EFH analyst responses are described elsewhere in the document—

8. CPT January 2022: Review of SDM EFH mapping results for crabs and stock assessment author review with EFH analyst responses (Appendix F).
9. EC January 2022: Review of SDM EFH mapping results and stock assessment author review with EFH analyst responses (Iterative Review 2).
10. SSC February 2022: Review of SDM EFH mapping results and stock assessment author review with EFH analyst responses (Iterative Review 2 and Appendix G).
11. EC October 2022: Review of EFH component 1 supplemental analysis supporting a comprehensive response by EFH analysts to the stock assessment author and SSC iterative

reviews of the 2023 SDM EFH mapping results (Appendix G and EFH Component 2 Fishing Effects Evaluation Discussion Paper[52]).

12. SSC October 2022: Review of EFH component 1 supplemental analysis supporting a comprehensive response by EFH analysts to the stock assessment author and SSC iterative reviews of the 2023 SDM EFH mapping results (Appendix G and EFH Component 2 Fishing Effects Evaluation Discussion Paper).

[52] EFH Component 2 Fishing Effects Evaluation Discussion Paper (revised January 2023) available on Council agenda for this meeting.

Table A1. EFH component 1 analyst responses to requests and recommendations (item) by the Council's Scientific and Statistical Committee (SSC), Joint meeting of the Groundfish Plan Teams (JGPT), and Crab Plan Team (CPT), provided in the minutes from meetings with an EFH agenda item scheduled or otherwise reported for review in 2020 and 2021, including (1) SSC June 2020, (2) JGPT September 2020, (3) SSC April 2021, (4) CPT May 2021, (5) JGPT September 2021, (6) SSC October 2021 (JGPT reporting to SSC; EFH agenda item not scheduled), (7) JGPT November 2021.

Item	Description	Response
1: SSC June 2020 Meeting		
1a	SSC requested justification for selection of the final models using RMSE (root mean square error) or other skill testing metrics.	Methods describe how RMSE is used as an indicator of the best-performing model and model elimination steps are clear (see Cross Validation and Skill Testing 3.2.5).
1b	SSC recommended consideration of error distributions that are better suited to over-dispersed data (e.g., negative binomial).	To address overdispersion in the data, a negative binomial Generalized Additive Models (GAM) is now included among ensemble constituents (see Statistical Modeling 3.2.4).
1c	SSC recommended that analysts define thresholds for excluding or denoting areas where uncertainty is high (e.g., ratio of estimated response to uncertainty).	Species distribution model (SDM) prediction uncertainty (coefficient of variation (CV)) was mapped and areas of high uncertainty were compared with the SDM prediction maps (see Ensemble Models and Uncertainty 3.2.6).
1d	SSC suggested consideration of ensemble methods that weight EFH prediction across candidate SDMs with similar out-of-sample predictive performance (weighting based on out-of-sample predictive skill may be the most applicable).	Out of sample skill testing was used to select the best performing models and relative RMSE weighting was used for constituent models in the ensemble (see Cross Validation and Skill Testing 3.2.5).
1e	SSC supported continued exploration of alternative SDM approaches across species, regions, and life stages (e.g., presence-absence GAM (paGAM), hurdle GAM, GAM, and MaxEnt).	A negative binomial GAM was added to address overdispersion. An ensemble method including skill testing of constituent models was applied (see Statistical Modeling 3.2.4).
1f	SSC supported the following: Response variable of numerical abundance with area swept (effort) as an offset in the SDM; Out-of-sample skill testing for arbitrating among candidate SDMs; Cross-validation through repeated sampling of testing and training datasets; Use of the complementary log-log (cloglog) link to relate abundance to occurrence, which facilitates skill testing; Use of RMSE for skill testing.	All of these supported methods are used in the Laman et al. SDM EFH approach for the 2023 EFH 5-year Review and SSC's support is appreciated. In addition to facilitating skill testing among models by standardizing model units, use of the cloglog link places formerly Level 1 (distribution) models producing a response variable in units of probability (paGAM and MaxEnt) in units of Level 2 (abundance) (see What's New 3.1 and Methods 3.2).
1g	SSC supported continued exploration of static and dynamic predictor covariates.	ROMS covariates have been updated for the Bering Sea and Gulf of Alaska (GOA; bottom temperature data only) based on ROMS data available at the time the SDMs needed to be run for the 2023

Item	Description	Response
		Review. Terrain covariates have also been added to the suite of predictors in this Review. Continued development of static and dynamic covariates for subsequent EFH Reviews is a priority (see Future Recommendations 3.5).
1h	SSC supported research permitting description of Level 3 EFH.	All three studies contributing new EFH component 1 information for the 2023 Review describe and identify Level 3 EFH for a subset of species in the Gulf of Alaska, Bering Sea, Aleutian Islands, and Arctic: Laman et al. *in prep* (Gulf of Alaska, Bering Sea, Aleutian Islands); Marsh et al. *in prep* (Arctic); Shotwell et al. *in prep* (Gulf of Alaska). The Laman et al. study will be presented to SSC in February 2022 and the other studies are currently scheduled for review in June 2022 (see Introduction 1). The Laman et al. study has included an EFH Level 3 mapping case study for Pacific cod settled early juveniles in the GOA in this Discussion Paper (see this Results Case Study 3.3.2.7).
1i	SSC encouraged expanded efforts to include additional sources of information to describe and define EFH.	Contributing studies have considered expanding approaches to include additional sources of information to describe and identify EFH for the 2023 Review. Given the timeline of the four contributing studies, most recommendations to expand efforts are best applied as new EFH component 1 information for a future EFH 5-year Review (e.g., additional SDM covariates, data types, and surveys; untrawlable and other underrepresented habitat areas).
1j	SSC encouraged consideration of EFH in timeblocks and discussed the need to move to a more dynamic definition of EFH given recent and rapid changes observed in the environment and species distributions.	EFH is currently described and identified for North Pacific Council managed species as habitat-related species distribution and abundance, using SDMs with survey data from the 1980s through 2014 (2017 Review) and SDM ensembles through 2019 (2023 Review). The EFH final rule requires EFH maps to be in FMPs, thus requiring an FMP amendment to change the maps (50 CFR 600.815(a)(1)(i) "FMPs must include maps of the geographic locations of EFH or the geographic boundaries within which EFH for each species and life stage is found."). NMFS Office of Sustainable Fisheries funded a separate study to develop dynamic SDM using species in the Bering Sea as a case study (e.g., at 1, 3, 5, 10, and 15-year timeblocks) to explore and map EFH at more

Item	Description	Response
		dynamic temporal scales (Barnes et al. 2022). These dynamic SDM methods may be another informative approach to describe and map habitat related species distribution and abundance and EFH, given recent and rapid changes observed in the environment and species distributions. In a future EFH Review, Barnes et al. (2022) can potentially complement the SDM EFH approach that the Laman et al. study has advanced for the 2023 Review. The Laman et al. study builds on the SDM EFH approach of the 2017 Review (Laman et al. 2018) with new data and refined methods.
1k	SSC encouraged consideration of whether co-mapping or directly incorporating vital rates (for EFH Level 3) within SDM is the best approach, while highlighting that it ultimately depends upon the underlying assumptions and questions.	All four studies that describe and identify EFH Level 3 for the 2023 Review use a *raster product approach*, where raster-1 is the SDM prediction of habitat-related abundance, raster-2 is temperature-dependent growth rate (or, another temperature-dependent vital rate), and the resulting product of the two rasters is an EFH Level 3 map (see EFH Level 3 3.2.8.6). These new EFH Level 3 maps can be used to further interpret the EFH Level 1 or Level 2 descriptions and maps, e.g., to consider corresponding areas of high growth and habitat-related abundance.
1l	SSC noted the immense progress in EFH modeling and hopes that these analyses will be considered in stock assessments and analyses supporting stock assessments, particularly habitat suitability and how it may pertain to recruitment and spawning locations. At a minimum, these efforts should be able to contribute to the stock assessment process and ongoing EBFM efforts, including through the ESPs.	Thank you. NMFS Alaska greatly appreciates SSC's review and input that has strengthened this work and the EFH 5-year Review process overall!
2: JGPT September 2020 Meeting		
2a	JGPT supported an ensemble modelling approach, but requested that authors also present each of the ensemble members so reviewers can see the influence or contribution and the variability associated with each.	Results of each ensemble constituent and the final ensemble are reported in the individual species results chapters in the three regional NOAA Technical Memoranda (Supporting Documents 5). The case study examples provided in this document use this reporting approach (see Regional Case Studies 3.3.2).
2b	JGPT noted that in the bridging example of sablefish EFH, it would be useful to see the iterative changes that result from each change or addition.	Additional bridging examples, similar to that presented for sablefish to SSC and JGPT in 2020, are provided in the case study examples (see Regional Case Studies 3.3.2, e.g., Figure 26) and

Item	Description	Response
		refined since 2020 to clarify the iterative changes that result from each major step in our approach.
2c	JGPT noted that all the information should be available to the stock assessment authors, in an easily accessible way (e.g., AKFIN).	Analysts provided the EFH component 1 information to individual stock assessment authors for their species for review of the draft methods and results and revisions were subsequently made available. We are publishing three regional NOAA Technical Memoranda with the final methods and results (Supporting Documents 5), our spatial data (e.g., SDM covariates and prediction rasters) will be archived at NOAA NCEI, the EFH maps will be available to visualize and download from the Alaska and National EFH Mappers, and our R code will be archived at GitHub; all sources are also accessible to the public.
3: SSC April 2021 Meeting		
3a	SSC requested review of the SDM model results.	This information is provided in the Results 3.3, Appendix C and Appendix D, and the complete methods and results in three regional NOAA Technical Memoranda, and EFH map overlay figures (Supporting Documents 5).
3b	SSC requested an overview of discussions or recommendations from stock assessment authors.	A timeline of the iterative review process with the stock assessment authors is provided in the Iterative Review section 2 and discussions and recommendations are provided in detail in the SA Review Report (Appendix F).
3c	SSC requested a summary of important covariates across species.	This information is comprehensively summarized in Appendix C Table C1, and provided in the Regional Case Studies 3.3.2 and Synthesis 3.3.3 sections of the Results. The three regional NOAA Technical Memoranda (Supporting Documents 5) provide this information for each species' life stage modeled by the Laman et al. study for the 2023 Review.
3d	SSC requested a report on model convergence issues and how these were addressed.	This information is provided in Cross Validation and Skill Testing 3.2.5 and in the three regional NOAA Technical Memoranda (Supporting Documents 5). SDM constituents were weighted by RMSE in the final ensembles.
3f	SSC requested a summary report on data limitations that created important model performance issues.	SDM performance was affected when species life stage prevalence was low (i.e., they were not commonly encountered). The SDMs developed for the 2017 and 2023 Reviews relied primarily on

Item	Description	Response
		RACE-GAP summer bottom trawl survey data to map EFH for species' life stages in the summer season. We recommend adding species data from additional surveys and seasons in a combined survey data approach for certain species' life stages in the SDM ensembles, which will require additional research to accomplish for a future EFH Review (see Conclusions 3.4 and Future Recommendations 3.5). In the 2017 Review, fishery-dependent data were used to map EFH in Fall, Winter, and Spring. Expanding how seasonality is addressed in EFH mapping and applied to the SDM ensembles will also require additional research. However, we are confident that expanding analyses to include additional data sources where appropriate and improving how seasonality is addressed will broaden our understanding of habitat related species distribution and abundance and spatial stock structure for North Pacific species.
3g	SSC requested a summary of results from the skill testing and resulting ensemble member weights, by species.	This information is comprehensively provided in each species results chapter of the three regional NOAA Technical Memoranda (Supporting Documents 5) and the Regional Case Studies 3.3.2.
3h	SSC requested that analysts highlight potential seasonality issues and large changes in core areas when compared to previous results.	The Laman et al. study provided a summary of ensemble performance and EFH areas compared to the single SDMs developed for the 2017 Review in Appendix C and visually with overlay maps of the 2017 and 2022 EFH areas (Regional Case Studies 3.3.2, and Supporting Documents 5). Addressing "seasonality issues" is beyond the scope of the 2023 Review and could be addressed if additional research on the topic is completed for a future EFH 5-year Review (see item 3f).
3i	SSC requested discussion on weighting issues encountered with the ensemble modeling.	See SSC June 2020 Meeting (item 1d) and methods on Cross Validation and Skill Testing 3.2.5.
3j	SSC requested discussion of other pertinent issues identified by the stock assessment and EFH authors.	This request is comprehensively addressed in the SA Review Report (Appendix F) and can be discussed during SSC review scheduled for February 2022.
4: CPT May 2021 Meeting		
4a	CPT noted that the timing of the stock assessment author review (May to September) works well for the crab stock assessment	EFH component 1 analysts prioritized development of crab EFH documents and provided the crab stock assessment author and

Item	Description	Response
	cycle and recommended that crab EFH documents be prioritized to allow assessment author-expert partnerships more time for review before September CPT deadlines.	expert reviewers with this information at the launch of the stock assessment author review of EFH component 1 in May ahead of the groundfish documents.
4b	CPT expressed concern that EFH is defined by species, and data products are of limited utility for identifying EFH specific to each crab stock. The CPT would be interested to see smaller scale SDMs produced for individual crab stocks.	EFH is described and identified by species within the management unit of the FMP (50 CFR 600.805(b)). Analysts would like to work with crab stock assessment authors and species experts to improve how EFH is described and mapped for crabs in preparation for a future EFH 5-year Review. Crab scientists are also encouraged to submit proposals to the NMFS AKRO and AFSC annual EFH Research Plan request for funding.
5: JGPT September 2021 Meeting		
5a	JGPT noted that the modeling efforts that are informing the 2022 EFH review were developed in the 2017 Alaska EFH Research Plan after the completion of the 2017 EFH review.	The Laman et al. study was funded by NMFS AKRO and AFSC to develop new EFH information and maps using new and existing data and modernized species distribution modeling methods (e.g., SDM ensembles and skill testing) for life stages of groundfish and crabs in the EBS, AI, and GOA, building on the SDM approach of the 2017 Review, and focusing on the summer season maps (applied to the FE analysis) using primarily RACE-GAP summer bottom trawl survey data. This approach reflects the Alaska EFH Research Plan objectives identified to accomplish, following the 2017 Review (Sigler et al. 2017).
5b	JGPT noted that the stock assessment authors were presented with only one performance metric for their EFH reviews. The EFH team presented three new performance metrics to the Teams, which they used to update the EFH descriptions. This information was not included for the assessment authors' reviews, and the EFH team does not plan to provide an opportunity for author review of that information.	Input received from SAs in their review of the Laman et al. study draft methods and results, combined with EFH component 1 analyst's own internal review, led to revised methods of assessing model performance which is described and reported in this Discussion Paper and in the three regional Technical Memoranda. Analysts clearly communicated to JGPT at this meeting that this information would be provided to SAs for additional review. Following this meeting, analysts worked closely with all eight SAs who had expressed concern over ensemble performance for their species and subsequently made the revised results available to all SAs in early November 2021 in an email invitation sent through their supervisors that revised materials were available upon request. EFH analysts note that no SDM performance metrics were

Item	Description	Response
		provided to SAs for review of the new EFH component 1 SDMs in the 2017 Review. EFH analysts and SAs co-developed the SA review approach for the 2023 Review to be more comprehensive, including review of the draft methods and results, which has improved the process overall, collaboration between EFH analysts and SAs, and the final results for the 2023 Review of EFH component 1. Details of this process and communications are available in Appendix F.
5c	JGPT noted that EFH analysts stated that with the exception of both of the Pacific sleeper shark EFH descriptions, all of the stocks were going to be put forward, including the poor performers. Stocks for which the models were poor performers will be reviewed on a case by case basis, and the EFH analysts will present results to the authors for further review.	Following this meeting and as clearly communicated at the meeting, EFH analysts contacted all eight stock authors who expressed concern over model performance in their review of the draft methods and results (see item 5b). In a limited number of cases where necessary (two stock authors and four species), EFH analysts worked with the stock author to come up with a revised plan for these species. Pacific sleeper sharks and two species in the GOA other rockfish complex that did not have an EFH map in 2017 were removed from consideration for the 2023 Review. GOA Atka mackerel ensemble constituents were examined and the ensemble was revised to improve the overall result. See Attachment 1 for the details of these iterative reviews and communications between stock authors and EFH analysts.
5d	JGPT noted that during the September 2020 JGPT review of EFH component 1, the Teams requested to see the following two items for the 2021 September JGPT review, and the Teams again recommended that they be provided: present each of the ensemble members so reviewers can see the influence or contribution of each ensemble member, and the variability associated with each, and see the iterative changes that result from each change or addition.	In response to the JGPT September 2020 requests, EFH analysts provided a table of SDM constituent and final ensemble performance in each species results chapter that was provided to the SAs for their review in May – September prior to the JGPT September 2021 meeting (see JGPT 2020 item 2a). In addition, bridging figures that show iterative changes that result from each method change or addition are provided in the Regional Case Studies 3.3.2. While it is beyond the capacity of the Laman et al. study to provide bridging examples for all species' life stages modeled, it may be possible to automate the development of these figures for a future EFH 5-year Review (see JGPT 2020 item 2b).
5e	JGPT noted that the inclusion of alternative data sources (e.g., AFSC longline survey) is critical for the definition of EFH for some species. This need, while noted in the 2017 EFH Review,	The Laman et al. study was funded by NMFS AKRO and AFSC to meet the objectives of the Alaska EFH Research Plan (Sigler et al. 2017), following the 2017 Review. The SAs pointed out in their

Item	Description	Response
	was not included in the 2017 EFH Research Plan. The Teams recommended that the inclusion of alternative data sources be prioritized for future EFH model developments.	review the importance of including additional data sources in the EFH SDMs for certain species, which was very helpful. The EFH analysts have included this recommendation for additional research needed for a future EFH 5-year Review. SAs are invited to participate in research proposals with EFH analysts or independently to see that this area of methods development is accomplished (see Future Recommendations 3.5).
5f	JGPT recommended adding comparison of previous SDMs (when available) to the EFH description documents (e.g., how has the spatial extent changed from the previous EFH?).	EFH analysts provided the 2017 and 2023 EFH maps to the SAs for their review (May–September 2021) prior to the JGPT September 2021 Meeting (Appendix F). As this comparison is important, EFH analysts have since provided a table to compare 2017 and 2023 model performance and changes in EFH area and the core EFH subarea as well as overlay maps to improve visual interpretation of EFH area changes (Appendix D and Supporting Documents 5).
5g	JGPT recommended consideration of the time series extent in future modeling efforts, as species distributions and habitat can shift over the 30+ year time series of the data.	Use of species catch data from a long time series (e.g., 1993-2019 for groundfish subadults and adults in the GOA) in SDMs to map EFH is for the purpose of ensuring that the EFH maps represent the long term distribution of the stock over a range of environmental conditions (and per SSC guidance in the 2017 Review). SSC noted (June 2020 item 1j) that developing EFH over more dynamic temporal scales would be helpful to see species distribution shifts when present. EFH analysts agree with SSC and JGPT that this information would be useful and extensible to other stock assessment and EBFM information needs beyond EFH. A study is in progress (Barnes et al. 2022) to develop dynamic SDM methods to address this for EFH species. Additional research should also be developed. SAs are invited to develop collaborative proposals with EFH analysts to help address this.
6: SSC October 2021 Meeting (based on JGPT reporting to SSC; an EFH agenda item was not scheduled)		
6a	SSC requested an updated timeline of EFH component 1 review/input be provided.	This is addressed in Chapter 21 Iterative Review and in detail in the SA Review Report (Appendix F).

Item	Description	Response
6b	SSC requested an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle.	This is provided for EFH component 1 in Appendix 1 Table A2. The EFH component 2 analysts should also address this request.
6c	SSC requested a summary of major EFH elements that have already been peer reviewed (e.g., the fishing effects model and research outlined in the initial June 2019 work plan).	See item 6a. The EFH component 2 analysts should also address this request.
6d	The SSC strongly recommends the EFH team incorporate author comments into the full review for February 2022 and requests a summary of detailed comments made by assessment authors and EFH team responses as appropriate.	The SA review of the Laman et al. study draft methods and results provided helpful input as part of the iterative review process of the 2023 Review. EFH component 1 analysts have incorporated SA review input that was possible to include at this time, and based on their input, have made several future research recommendations to develop for a subsequent EFH Review. EFH analysts have documented the details of communication with SAs during their review of EFH component 1 (see Future Recommendations 3.5 and the SA Review Report Appendix F).
6e	SSC requested a table showing the current EFH levels and proposed changes under the new methodology.	See the Results section 3.3 of this document for a summary of EFH Level advancements available for the 2023 Review and Appendix C compares EFH Levels between the 2017 and 2023 Reviews.
6f	SSC requested information on the importance of habitat covariates in the SDM for each species and life stage. The purpose of this request is to evaluate whether habitat covariates statistically influence the distribution and abundance of North Pacific groundfish and crab life stages.	This information is provided in Appendix C. See also SSC April 2021 item 3c.
6g	SSC requested a clear description of the data used for each model ensemble: e.g., description of data sources, data transformations, new data sets not previously considered, and input data time periods.	This information is provided in the Methods section 3.2 and the three regional NOAA Technical Memoranda (Supporting Documents 5) with detail for each region.
6h	SSC requested a description of how complexes are being treated in the analysis.	See the methods on EFH Maps 3.2.8 and three regional NOAA Technical Memoranda (Supporting Documents 5) where this information is provided in detail for each region. Please also refer to the SA review of EFH component 1 report (Appendix F) for how individual species complexes were addressed by region.
6i	SSC requested a description of the ensemble modeling methods and a summary of member model fits, including a description of	See the methods on Ensemble Models and Uncertainty 3.2.6, Regional Case Studies 3.3.2, and the three regional NOAA Technical Memoranda (Supporting Documents 5) where this

Item	Description	Response
	the probability thresholds used to characterize species presence and absence.	information (e.g., ensemble constituent performance) is provided in detail for each region and species' life stage modeled. Appendix C Table C2 is a comprehensive summary of 2023 model performance metrics and EFH areas.
6j	SSC requested consideration of using a Precision Recall (PR) AUC and F1 scores as an alternative to ROC AUC.	EFH analysts provided these additional model performance metrics in Table E1, which SSC requested be considered in October 2021 (first SSC review of draft methods was June 2020).
6k	SSC requested a table showing species and life stage-specific ensemble fit metrics (i.e., Spearman's rho, AUC, Deviance Explained) and including PR AUC and F1 metrics.	This information is comprehensively provided in Appendix B Table B2 for the three comprehensive and common performance metrics that the Laman et al. study chose for evaluating and presenting their final results, which were implemented following internal review and the SA review that concluded September 2021. See item 6j, regarding SSC's request to consider additional performance metrics PR AUC and F1, which are reported in Table E1, along with additional metrics that had also been considered by the Laman et al. study.
6l	SSC requested providing maps that allow comparison of new results with 2017 results and total changes in area values (e.g., total % change and km^2).	The Laman et al. study provided a summary of ensemble performance and EFH areas compared to the single SDMs developed for the 2017 Review in Appendix C and visually with overlay maps of the 2017 and 2022 EFH areas (see Regional Case Studies 3.3.2, and Supporting Documents 5) (see SSC April 2021 items 3f and 3h).
6m	SSC requested maps showing the regions used to extract spatial outputs (core EFH) for the fishing effects analyses and clear description of thresholds.	EFH area percentile maps showing the regions used to extract spatial outputs (core EFH area; CEA) for the fishing effects (FE) analysis are provided for each species' life stage modeled in the three regional NOAA Technical Memoranda (Supporting Documents 5) and in the Discussion Paper with the species case studies (see Results 3.3); thresholds applied are described in the methods on EFH Mapping 3.2.8. In addition, overlay maps of the 2017 and 2023 EFH areas are provided (Supporting Documents 5), with the species case studies (see Results 3.3 section). Overlay maps of the 2017 and 2022 CEA will be provided for SSC review of the EFH component 2 FE analysis. **An outcome of an EFH 5-year Review meeting of NMFS (G. Harrington, J. Olson, J. Pirtle) and Council (D. Evans) staff on November 16, 2021 was**

Item	Description	Response
		a recommendation that EFH component 2 analysts will present the 2017 and 2022 CEA overlay maps (provided by the EFH component 1 analysts in December 2021) with the FE analysis at the SSC's June 2022 meeting (canceled; presented in October 2022).
6n	Explain the data used to train the models and predict EFH and the changes in the data used in the 2017 and new EFH maps.	See Methods 3.2, where this information is comprehensively described in several subsections.
7: JGPT November 2021 Meeting		
7a	JGPT thanked the EFH analysts for the development and application of the EFH models, the responsiveness to stock assessment author reviews, and for the detailed report describing the review process.	Thank you. NMFS Alaska greatly appreciates JGPT's review and input and that of the stock assessment authors and species experts, which has strengthened this work and the EFH 5-year Review process overall.

Table A2. EFH component 1 (descriptions and identification) analyst responses to SSC's request for "an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle" (Table A1 item 6b). SSC minutes from the 2017 process include the following meetings: (1) February 2015[53], (2) April 2016[54], (3) October 2016[55], (4) December 2016[56], and (5) April 2017[57].

Item	Description	Response
1: SSC February 2015 Meeting		
1	SSC reviewed the document *Defining EFH for Alaska Groundfish Species using Species Distribution Modeling (SDM)*. "SSC supports the use of SDMs for predicting species distributions" and provided suggestions and comments to strengthen the proposed research to update to EFH designations based on the use of SDMs for the 2017 EFH 5-year Review.	At this early stage of the 2017 EFH 5-year Review EFH component 1 analysts had incorporated several SSC suggestions and comments into the SDM methods. SSC's February 2015 review of the proposed SDM EFH approach for the 2017 Review is similar to their review of the revised SDM EFH approach for the 2023 Review in June 2020.
2: SSC April 2016 Meeting		
2	SSC reviewed an update to EFH designations based on the use of SDMs to define EFH. **"SSC supports the use of SDMs for predicting species' distributions . . . revisions to EFH definitions in the FMPs are warranted and the FMPs should be amended"**. SSC acknowledged "there is still work to be done to allow this new approach to identifying EFH to reach its full potential" and the SSC provided comments and recommendations.	See items 2a-c relevant to EFH component 1.
2a	SSC is pleased to see the analysts' efforts to provide seasonal EFH maps. Given the immense array of data types by season that were employed, the SSC recommends that the authors develop a data-support-product to characterize the number, type and age of samples supporting model predictions. This will be particularly important for the identification of data gaps that warrant future research priority and clear acknowledgement when EFH is used in subsequent analyses.	EFH C1 analysts developed SDM-based EFH maps for four seasons in the 2017 EFH 5-year Review. Although a "data-support-product" was not necessarily developed for the 2023 EFH 5-year Review, analysts have comprehensively described the data used in their methods in text and Tables, which are provided in this document (see Methods 3.2) and in the three

53 SSC February 2015 Meeting
54 SSC April 2016 Meeting
55 SSC October 2016 Meeting
56 SSC December 2016 Meeting
57 SSC April 2017 Meeting

Item	Description	Response
		regional NOAA Technical Memoranda (Supoprting Documents 5).
2b	SSC understands that EFH information will become available online. The ability for users to select species for display and to overlay species' distributions would extend the value of this information.	NMFS AKR launched the Alaska EFH Mapper in November, 2018 (one year in advance of the new SDM-based EFH maps from the 2017 EFH 5-year Review being published on the NMFS National EFH Mapper). The AK Mapper allows users to select species' life stages for display and to overlay species' distributions and other features not available on the National Mapper such as displaying EFH maps by EFH Level. An update to the AK Mapper is underway by AKR in preparation for the new set of EFH maps from the 2023 EFH 5-year Review. This update is anticipated to significantly improve user experience and with new links to the spatial data used to develop the 2023 EFH maps. EFH component 1 analysts and AFSC HEPR are also working on an archiving workflow for EFH spatial data with NOAA NCEI.
2c	SSC is aware of considerable new information that is sufficient to warrant an update of EFH for the Arctic FMP. Although updating EFH for the Arctic may not be urgent owing to the lack of commercial fisheries in this region, this information may be timely with regards to other ongoing and planned activities in the Arctic.	The Arctic FMP was updated following the 2017 EFH 5-year Review with new EFH maps based on species distribution from surveys (Simpson et al. 2017). As Arctic EFH maps are not currently based on SDMs, a study by Marsh et al. (In Review) has developed SDMs for life stages of Arctic FMP species, including EFH Level 1, 2, and 3 descriptions and maps, concurrently with the Laman et al. study, to improve the quality of Arctic species EFH information. This study also provides interannual comparisons of EFH area in warm and cold years. New EFH component 1 information from this study will be presented in February 2023.
3: SSC October 2016 Meeting		
3	SSC reviewed information on EFH descriptions available for the 2017 EFH 5-year Review (component 1) and the analysis of the effects of fishing on EFH for component 2 at this meeting. In April 2016, SSC recommended that revisions to EFH definitions in the FMPs were warranted and the FMPs should be amended.	See items 3a-c as related to EFH component 1. EFH component 2 analysts will provide a Discussion Paper for the SSC February 2022 meeting that will address the SSC's October 2021 request for an overview of SSC

Item	Description	Response
		recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle.
3a	SSC encouraged the EFH component 1 analysts to examine the use of acoustic data as input to the EFH descriptions (e.g., for walleye pollock).	EFH component 1 analysts responded following the April 2016 meeting that the acoustic data were not considered in SDMs for the 2017 EFH 5-year Review because the analysts were trying to identify a common method that applied to all species. EFH component 1 analysts in the 2023 EFH 5-year Review agree that midwater acoustic data could be valuable to describe and map EFH for species such as walleye pollock and prey of EFH species such as capelin (EFH component 7 – habitat of EFH species' prey). Since e.g., AFSC MACE surveys also occur during Fall, Winter, and Spring in addition to Summer, these surveys could provide useful seasonal data for certain species. Additional research is required to integrate midwater acoustic survey data (i.e., collected along transects) within the SDM ensemble approach to mapping EFH in the 2023 EFH 5-year Review.
3b	SSC recommended that sediment type be considered as a co-variate in the GAM models.	EFH component 1 analysts included sediment grainsize (*phi*) as a covariate in for species' life stages modeled in the EBS, and a seafloor rockiness covariate for species' life stage modeled in the Aleutian Islands and the Gulf of Alaska in SDMs developed for the 2023 EFH 5-year Review (see the Habitat Covariates subsection of the Methods 3.2.3 and Supporting Documents 5).
3c	SSC encouraged evaluation of the predictive skill of the models (especially in the fall, winter and spring).	EFH C1 analysts introduced new model skill testing methods in the 2023 EFH 5-year Review (see What's New 3.1, Methods 3.2, and results summary Tables provided in the Appendices).
4: SSC December 2016 Meeting		
4	SSC reviewed revisions to the methods for assessing the impacts of habitat disturbance on fish and crab stocks for the component 2 fishing effects analysis, and the report on Impacts to Essential Fish Habitat from Non-fishing Activities in Alaska (EFH component 4) at this meeting.	EFH component 2 analysts will provide a Discussion Paper for the SSC February 2022 meeting that will address the SSC's October 2021 request for an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle.

Item	Description	Response
5: SSC April 2017 Meeting		
5	SSC reviewed the EFH Omnibus Amendment at this meeting. SSC agreed that the EFH Omnibus Amendment Environmental Assessment (EA) was ready for public review. SSC made several recommendations to improve EFH EA readability and access to all information necessary for decision making. Improved documentation of the information considered in the assessment will assist greatly in the 2022 EFH Review and the Center for Independent Expert review planned for 2019-20.	EFH analysts will take the SSC's recommendations into account as NMFS develops the 2023 EFH 5-year Review Summary Report (e.g., Simpson et al. 2017) and the 2022 EFH EA. We thank SSC for the comprehensive, iterative reviews of the EFH information in development for the 2017 and 2023 EFH 5-year Reviews, where input has strengthened the work products and process overall.

Appendix B SDM Survey Area Offset Correction

Regarding the correction, the following SDM ensemble EFH component 1 information was provided to the stock assessment authors in April 2022 to support their EFH component 2 fishing effects (FE) assessments:

- Explanation of the error correction to properly account for survey effort as an offset in the SDM ensembles and EFH maps.
- Metrics of species' life stage EFH maps where area was affected > 10% by this correction.
- An update to the EFH Component 1 Discussion Paper (March 2022 version) and the collection of new ensemble SDM EFH maps that were revised in March 2022.

B.1 The Reason for a Rerun

The full set of SDM ensembles were rerun in February 2022 to produce a revised set of EFH maps. The reason for this update is that a bug was found in modeling code related to the handling of the survey area swept offset when packaging the code for public sharing on GitHub following the February SSC meeting. Specifically, the area was unintentionally used in its untransformed state, instead of being log transformed to match the link-function being used in the SDMs. While the effect of this error is minor in most cases, the decision was made to rerun all the SDM ensembles and produce updated maps so as to provide the best possible basis for the EFH component 1 descriptions and maps and their application to the EFH component 2 FE evaluation.

B.2 Statistical Background and Methods

It is generally assumed that the observed count of fish in a survey is proportional to fishing effort employed in that survey. While this is often represented by dividing the count by the effort (CPUE), it is more appropriate to model the rate of catch directly, e.g., to allow area-swept to have an interpretable, parsimonious, and "scale-free" relationship on sampling variance and encounter probabilities. The offset term allows count predictions from a Poisson model (or similar model) to be modeled directly:

Standard Poisson modeling count (Equation B.1):

$$log(\lambda) = \beta_0 + BX$$

Poisson with Offset modeling count as a rate (Equation B.2):

$$log(\lambda) = \beta_0 + BX + log(effort)$$

where λ is the observed count, β_0 is the intercept, B is the set of coefficients and X is a matrix of predictors. This formulation allows λ to be modeled as a count with an appropriate distribution (i.e., λ cannot be negative) while still accounting for unequal sampling effort. It also allows for predictions to be made for the count that would be observed under different levels of effort. In the maps for this project, we made predictions at the average survey effort to facilitate direct comparison to the data.

EFH is the area containing the top 95% of occupied habitat. To explore the magnitude of changes from this update, we compute the core EFH area (CEA), defined as the area containing the top 50% of occupied habitat, for the previous set of 2023 EFH maps and the new set of 2023 EFH maps with the correction applied. We compare the change in CEA using two metrics:

Mean Percent Difference (MPD) (Equation B.3):

$$MPD = mean\left(\frac{new\ area - old\ area}{old\ area}\right)$$

Mean Absolute Percent Difference (MAP) (Equation B.4):

$$MAP = mean\left(\frac{|new\ area - old\ area|}{old\ area}\right)$$

We next interpret the consequences of these changes in terms of MPD and MAP.

B.3 Magnitude of Change Results

Equations B.1 and B.2 demonstrate that the effort variable should be log transformed. Because of the bug, nominal effort was used, which would result in a weak partial adjustment for effort. However, because standardized effort was applied to the vast majority of survey tows for a region, the observed effects on EFH area were close to zero for most species life stages (Figure B1). In all regions, the MPD and MAP were below 5% (Table B1). The region with the largest number of species' life stage EFH map areas affected was the eastern Bering Sea. Many of the most affected species maps were rockfishes or skates (Table B2), which are primarily caught near the continental shelf edge and upper slope. The AFSC RACE-GAP Bering Sea slope summer bottom-trawl survey uses different bottom trawl gear than the Bering Sea continental shelf summer bottom trawl survey with and tends to exert less effort per tow (mean BS = 0.05 km^2; mean slope = 0.04 km^2). As such, the previous set of model runs did not properly account for that difference in effort.

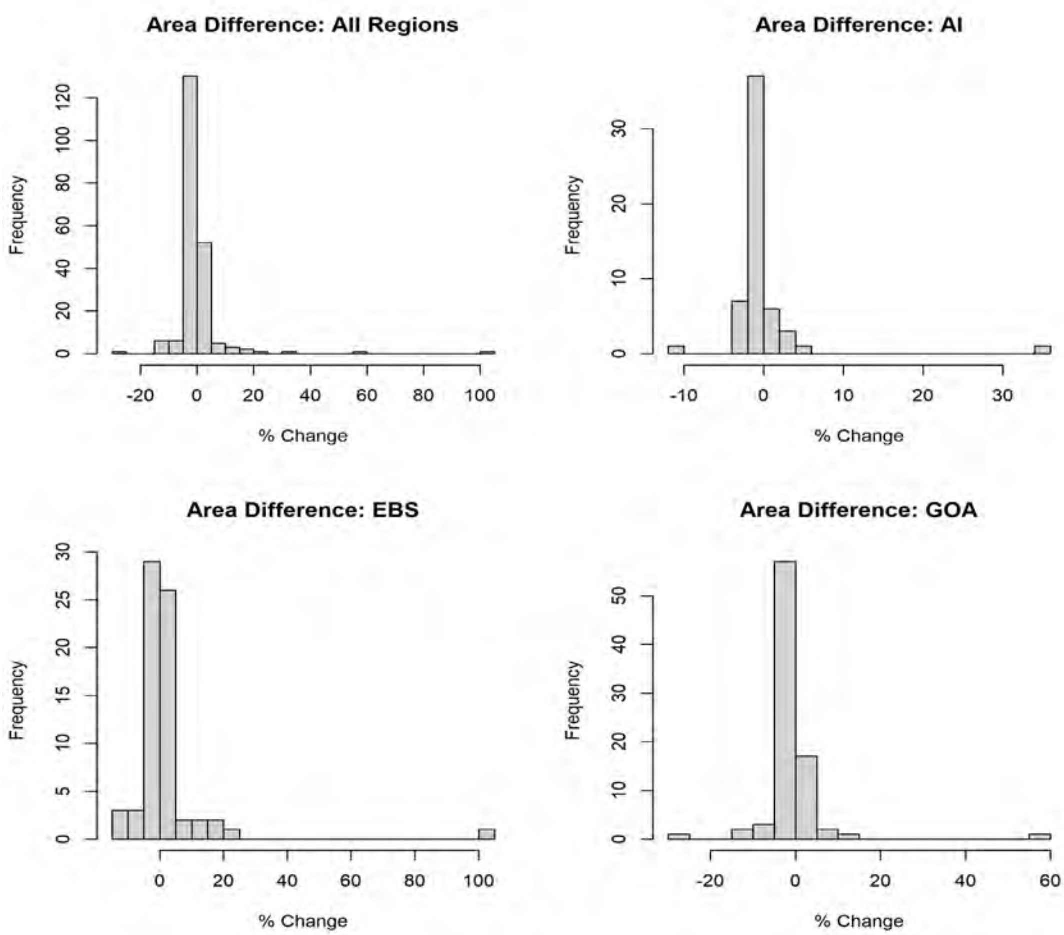

Figure B1. The number of species life stages (y-axis) having a Mean Percent Difference (MPD; Equation B.3) (x-axis) for each species life stage in all regions (top-left) or individual regions (Aleutian Islands (AI), eastern Bering Sea (EBS), Gulf of Alaska (GOA)), where a positive value indicates an increase in core EFH area (CEA).

Table B1. A comparison of Mean Percent Difference (MPD; Equation B.1) and Mean Absolute Percent Difference (MAP; Equation B.2) for each region (Aleutian Islands (AI), eastern Bering Sea (EBS), and Gulf of Alaska (GOA)) and all regions, the count of species life stages with a > 10% change in core EFH area (CEA) resulting from the correction, and those species listed by common name.

Region	MPD	MAP	Count of species life stage maps with > 10% change in CEA	Species life stage combinations with > 10% change in CEA
AI	0.1 %	1.8 %	2 out of 56	adult Kamchatka Flounder; subadult dusky rockfish
EBS	2.2 %	4.6 %	9 out of 69	adult dover sole; adult northern rockfish; subadult and adult shortraker rockfish; adult whiteblotched skate; subadult big skate; subadult mud skate; subadult Pacific ocean perch; early juvenile yellowfin sole
GOA	0.1 %	2.5 %	5 out of 84	subadult and adult Alaska skate; adult sand sole; subadult Alaska plaice; subadult starry flounder
All	0.7 %	3.0 %	16 out of 211	See stocks listed by Region (Table B2)

Table B2. Details regarding the 16 species life stage combinations having a > 10% change in core EFH area (CEA). Positive values represent an increase in the corresponding metric in the revised maps compared to the draft maps prior to the correction. Values are shown for the percent change in root mean square error (RMSE), and the change in the Spearman correlation coefficient (ρ), area under the receiver operating characteristic curve (AUC), and Poisson deviance explained (PDE).

Region	Species	Life Stage	% Diff RMSE	Δ ρ	Δ AUC	Δ PDE	CEA (km^2)	Revised CEA (km^2)	% Diff CEA
AI	Kamchatka flounder	adult	-6.7	0.04	0	0.03	30,500	27,300	-10.5
AI	dusky rockfish	subadult	-1.4	0.05	0	-0.02	14,400	19,400	34.3
EBS	Dover sole	adult	-11.9	0.18	0	0.04	5,700	7,000	23.4
EBS	northern rockfish	adult	-1.3	0	0	0.01	49,300	44,100	-10.6
EBS	shortraker rockfish	adult	5.1	0.04	0	0	8,000	7,200	-10.5
EBS	whiteblotched skate	adult	0	0	0	-0.01	14,600	16,200	10.8
EBS	yellowfin sole	early juvenile	0.5	-0.01	-0.01	-0.01	238,800	265,300	11.1
EBS	big skate	subadult	0	0.01	0.01	0.01	3,000	3,500	19.6
EBS	mud skate	subadult	-1.9	0	0	0	11,000	12,900	17.1
EBS	Pacific ocean perch	subadult	0	-0.03	0	0	50,800	44,100	-13.1
EBS	shortraker rockfish	subadult	-1.1	-0.02	-0.01	-0.03	7,200	14,600	102.9
GOA	Alaska skate	adult	0	-0.06	-0.01	-0.02	7,000	6,200	13.7
GOA	sand sole	adult	3.3	-0.05	0	0.01	30,100	26,600	-11.7
GOA	Alaska plaice	subadult	-3.5	0.06	0	0.02	9,400	15,000	59.2
GOA	Alaska skate	subadult	0	0.01	0.01	0	10,900	7,700	-29.5
GOA	starry flounder	subadult	3.9	-0.03	0	-0.01	14,100	12,200	-13.8

Appendix C SDM Results Summaries

Appendix C provides results summaries of the SDMs developed for the 2023 EFH 5-year Review—

- Table C1 is a summary of the most influential covariates by region and species' life stage for each ensemble or SDM produced during the 2023 EFH 5-year Review (Table A1 items 3c and 6f).
- Table C2 is a summary of the 2023 SDM results by region for each species' life stage modeled, including N, RMSE, performance metrics (ρ, AUC, and PDE), EFH area (km^2), and core EFH area (km^2).
- Section 3.3.3 is the SDM EFH Results Synthesis.

Table C1. Summary of the covariates that were most influential (highest percent contribution) by region and species' life stage for each model (ensemble or SDM) produced during the 2023 EFH 5-year Review (Table A1 items 3c and 6f). Terms is the total number of covariates in the model. First, Second, and Third represent the three most influential covariates for that model and their percent contribution (% Contrib.) to the deviance explained by the model. BPI = bathymetric position index, location = geographic location, and *phi* = sediment grainsize.

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
AI	Alaska skate	subadult	13	Location	Bottom Depth	Aspect Eastness	66.3
AI	Alaska skate	adult	15	Bottom Depth	Location	Bottom Current SD	51.4
AI	Aleutian skate	subadult	15	Location	Bottom Depth	Bottom Currents	59.0
AI	Aleutian skate	adult	14	Bottom Depth	Bottom Currents	Location	68.3
AI	arrowtooth flounder	early juvenile	15	Location	Tidal Maximum	Bottom Depth	54.2
AI	arrowtooth flounder	subadult	15	Location	Bottom Depth	Tidal Maximum	75.6
AI	arrowtooth flounder	adult	15	Bottom Depth	Location	Bottom Currents	67.5
AI	Atka mackerel	subadult	15	Bottom Depth	Location	Tidal Maximum	76.4
AI	Atka mackerel	adult	15	Bottom Depth	Location	Bottom Currents	67.6
AI	Dover sole	subadult	15	Location	Bottom Depth	Bottom Currents	56.3
AI	Dover sole	adult	15	Bottom Depth	Location	Bottom Currents	67.0
AI	dusky rockfish	subadult	14	Bottom Depth	Location	Bottom Currents	71.0
AI	dusky rockfish	adult	15	Location	Bottom Currents	Bottom Depth	51.2
AI	English sole	adult	15	Tidal Maximum	Bottom Depth	BPI	46.5
AI	flathead sole	early juvenile	15	Location	Bottom Depth	BPI	56.7
AI	flathead sole	subadult	15	Location	Bottom Depth	Tidal Maximum	58.0
AI	flathead sole	adult	15	Location	Bottom Depth	Tidal Maximum	61.0
AI	giant octopus	all	15	Sponge Presence	Bottom Temperature	Bottom Depth	45.5
AI	golden king crab	all	15	Bottom Depth	Bottom Currents	Location	55.8
AI	Greenland turbot	adult	13	Bottom Depth	Bottom Temperature	Location	72.9

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
AI	harlequin rockfish	adult	15	Location	Bottom Currents	Bottom Depth	43.7
AI	Kamchatka flounder	subadult	15	Bottom Currents	Location	Bottom Current SD	53.3
AI	Kamchatka flounder	adult	15	Bottom Depth	Location	Bottom Currents	54.7
AI	mud skate	subadult	15	Bottom Depth	Location	Rockiness	75.7
AI	mud skate	adult	15	Bottom Depth	Aspect Northness	Location	60.1
AI	northern rock sole	early juvenile	15	Bottom Depth	Location	Bottom Currents	68.1
AI	northern rock sole	subadult	15	Bottom Depth	Location	Bottom Currents	78.5
AI	northern rock sole	adult	15	Bottom Depth	Location	Bottom Current SD	74.2
AI	northern rockfish	subadult	14	Bottom Depth	Location	Bottom Currents	75.3
AI	northern rockfish	adult	15	Bottom Depth	Location	Bottom Current SD	73.7
AI	Pacific cod	subadult	15	Bottom Depth	Location	Bottom Current SD	67.1
AI	Pacific cod	adult	15	Bottom Depth	Location	Tidal Maximum	62.1
AI	Pacific ocean perch	early juvenile	15	Bottom Depth	Location	Bottom Currents	53.9
AI	Pacific ocean perch	subadult	15	Bottom Depth	Location	Aspect Eastness	54.8
AI	Pacific ocean perch	adult	15	Bottom Depth	Location	Bottom Currents	85.7
AI	red king crab	all	15	Location	Bottom Depth	Tidal Maximum	55.7
AI	rex sole	subadult	15	Bottom Depth	Location	Tidal Maximum	64.7
AI	rex sole	adult	15	Bottom Depth	Location	Aspect Northness	59.1
AI	rougheye blackspotted complex	subadult	15	Bottom Depth	Location	Bottom Currents	68.7
AI	rougheye blackspotted complex	adult	15	Bottom Depth	Location	Bottom Current SD	69.4
AI	sablefish	subadult	15	Bottom Depth	Location	Bottom Temperature	76.4
AI	sablefish	adult	15	Bottom Depth	Location	Curvature	69.3
AI	shortraker rockfish	subadult	15	Bottom Depth	Location	Bottom Currents	80.6

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
AI	shortraker rockfish	adult	15	Bottom Depth	Location	Bottom Current SD	67.8
AI	shortspine thornyhead	subadult	14	Bottom Depth	Location	Bottom Currents	74.0
AI	shortspine thornyhead	adult	14	Bottom Depth	Location	Aspect Northness	82.2
AI	southern rock sole	subadult	13	Location	Bottom Depth	Bottom Currents	97.2
AI	southern rock sole	adult	15	Location	Bottom Depth	Bottom Currents	93.5
AI	walleye pollock	early juvenile	15	Bottom Depth	Location	Aspect Northness	55.7
AI	walleye pollock	subadult	15	Bottom Depth	Location	Rockiness	62.6
AI	walleye pollock	adult	15	Bottom Depth	Location	Bottom Currents	74.3
AI	whiteblotched skate	subadult	14	Location	Bottom Currents	Tidal Maximum	73.8
AI	whiteblotched skate	adult	15	Location	Tidal Maximum	Bottom Depth	79.7
EBS	Alaska plaice	early juvenile	11	Location	Bottom Temperature	Bottom Currents	84.5
EBS	Alaska plaice	subadult	15	Bottom Depth	Location	Bottom Temperature	72.8
EBS	Alaska plaice	adult	15	Location	Bottom Depth	*phi*	73.9
EBS	Alaska skate	subadult	15	Location	Bottom Temperature	Bottom Depth	74.8
EBS	Alaska skate	adult	15	Bottom Temperature	Bottom Depth	Location	76.6
EBS	Aleutian skate	subadult	15	Location	Bottom Currents	Bottom Depth	58.1
EBS	Aleutian skate	adult	15	Bottom Depth	Location	*phi*	77.5
EBS	arrowtooth flounder	early juvenile	14	Location	Bottom Depth	Bottom Temperature	82.0
EBS	arrowtooth flounder	subadult	15	Location	Bottom Temperature	Bottom Depth	89.7
EBS	arrowtooth flounder	adult	15	Location	Bottom Temperature	Bottom Depth	84.0
EBS	Atka mackerel	adult	15	Location	Bottom Depth	Slope	78.6
EBS	Bering skate	subadult	15	Bottom Depth	Location	Bottom Currents	79.3
EBS	Bering skate	adult	15	Location	Bottom Depth	Bottom Currents	79.1
EBS	Bering flounder	subadult	14	Location	Bottom Temperature	Bottom Depth	80.4

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
EBS	Bering flounder	adult	15	Location	Bottom Temperature	Bottom Depth	81.5
EBS	big skate	subadult	14	Location	Bottom Temperature	Bottom Depth	82.8
EBS	blue king crab	all	14	Location	*phi*	Bottom Depth	62.0
EBS	butter sole	adult	14	Location	Bottom Currents	Bottom Temperature	63.8
EBS	deepsea sole	all	10	Bottom Depth	Bottom Currents	Bottom Current SD	87.0
EBS	Dover sole	subadult	14	Location	Bottom Depth	*phi*	71.9
EBS	Dover sole	adult	14	Bottom Depth	Location	Bottom Currents	72.0
EBS	flathead sole	early juvenile	15	Location	Bottom Depth	Bottom Temperature	66.5
EBS	flathead sole	subadult	15	Location	Bottom Depth	*phi*	83.6
EBS	flathead sole	adult	15	Location	Bottom Depth	Bottom Temperature	79.2
EBS	giant octopus	all	14	Location	Bottom Depth	Bottom Currents	75.0
EBS	Greenland turbot	subadult	15	Location	Bottom Temperature	Bottom Depth	72.0
EBS	Greenland turbot	adult	15	Bottom Depth	Location	Bottom Temperature	71.5
EBS	Kamchatka flounder	subadult	15	Location	Bottom Depth	Bottom Temperature	80.9
EBS	Kamchatka flounder	adult	15	Bottom Depth	Location	Bottom Temperature	84.2
EBS	longhead dab	all	12	Location	Bottom Depth	Bottom Currents	87.0
EBS	mud skate	subadult	15	Location	Bottom Depth	Bottom Currents	59.4
EBS	mud skate	adult	12	Location	Bottom Depth	Bottom Currents	64.3
EBS	northern rock sole	early juvenile	14	Bottom Depth	Location	Bottom Temperature	77.2
EBS	northern rock sole	subadult	13	Bottom Depth	Location	Bottom Temperature	80.4
EBS	northern rock sole	adult	13	Location	Bottom Depth	*phi*	79.8
EBS	northern rockfish	adult	14	Bottom Depth	Location	Bottom Currents	64.8
EBS	Pacific cod	early juvenile	15	Location	Bottom Temperature	Bottom Depth	77.1
EBS	Pacific cod	subadult	14	Location	Bottom Depth	Bottom Temperature	68.5

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
EBS	Pacific cod	adult	15	Bottom Temperature	Bottom Depth	Location	80.5
EBS	Pacific ocean perch	early juvenile	13	Bottom Depth	Location	Sponge Presence	70.4
EBS	Pacific ocean perch	subadult	15	Bottom Depth	Location	*phi*	72.2
EBS	Pacific ocean perch	adult	12	Bottom Depth	Location	Bottom Currents	86.5
EBS	red king crab	all	15	Tidal Maximum	Bottom Depth	Location	70.1
EBS	rex sole	early juvenile	14	Location	Bottom Depth	Pennatulacean Presence	54.3
EBS	rex sole	subadult	15	Location	Bottom Depth	Bottom Currents	72.3
EBS	rex sole	adult	15	Location	Bottom Depth	Bottom Currents	69.8
EBS	rougheye blackspotted complex	subadult	14	Bottom Depth	Location	Bottom Currents	78.0
EBS	rougheye blackspotted complex	adult	11	Bottom Depth	Location	Bottom Currents	89.2
EBS	sablefish	early juvenile	14	Location	Bottom Temperature	Pennatulacean Presence	77.9
EBS	sablefish	subadult	15	Location	Bottom Depth	Bottom Temperature	69.6
EBS	sablefish	adult	15	Bottom Depth	Location	Bottom Currents	79.0
EBS	Sakahalin sole	subadult	13	Location	Tidal Maximum	Bottom Temperature	81.1
EBS	Sakahalin sole	adult	13	Location	Tidal Maximum	Bottom Depth	77.1
EBS	shortraker rockfish	subadult	14	Bottom Depth	Location	Slope	79.5
EBS	shortraker rockfish	adult	15	Bottom Depth	Bottom Currents	Slope	58.2
EBS	shortspine thornyhead	subadult	11	Bottom Depth	Location	Bottom Currents	89.1
EBS	shortspine thornyhead	adult	15	Bottom Depth	Location	Bottom Currents	67.7
EBS	snow crab	all	15	Location	Bottom Depth	Bottom Temperature	77.4
EBS	starry flounder	subadult	15	Location	Bottom Temperature	*phi*	75.2
EBS	starry flounder	adult	15	Location	Bottom Depth	Bottom Temperature	61.8

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
EBS	Tanner crab	all	15	Location	Bottom Depth	*phi*	84.8
EBS	walleye pollock	early juvenile	13	Location	Bottom Depth	Tidal Maximum	76.8
EBS	walleye pollock	subadult	15	Location	Bottom Temperature	Bottom Depth	82.6
EBS	walleye pollock	adult	15	Location	Bottom Temperature	Bottom Depth	78.9
EBS	whiteblotched skate	subadult	11	Bottom Depth	Location	Tidal Maximum	88.5
EBS	whiteblotched skate	adult	13	Bottom Depth	Location	Tidal Maximum	81.4
EBS	yellowfin sole	early juvenile	15	Location	Bottom Depth	Bottom Currents	91.1
EBS	yellowfin sole	subadult	15	Bottom Depth	Location	Bottom Currents	84.1
EBS	yellowfin sole	adult	15	Bottom Depth	Location	Bottom Currents	80.4
GOA	Alaska plaice	subadult	15	Bottom Depth	Location	Tidal Maximum	67.1
GOA	Alaska plaice	adult	15	Location	Bottom Depth	Tidal Maximum	69.9
GOA	Alaska skate	subadult	15	Location	Bottom Depth	BPI	62.8
GOA	Alaska skate	adult	9	Location	Bottom Temperature	Bottom Current SD	76.5
GOA	Aleutian skate	subadult	14	Bottom Depth	Location	Bottom Temperature	79.9
GOA	Aleutian skate	adult	15	Location	Bottom Depth	Bottom Temperature	73.8
GOA	arrowtooth flounder	early juvenile	10	Tidal Maximum	Aspect Eastness	Aspect Northness	60.7
GOA	arrowtooth flounder	subadult	15	Bottom Depth	Location	Bottom Temperature	77.1
GOA	arrowtooth flounder	adult	15	Bottom Depth	Location	Bottom Temperature	62.3
GOA	Atka mackerel	subadult	14	Bottom Depth	Location	Sponge Presence	68.6
GOA	Atka mackerel	adult	14	Location	Bottom Depth	Bottom Currents	79.8
GOA	Bering skate	subadult	15	Location	Bottom Depth	Bottom Temperature	72.1
GOA	Bering skate	adult	15	Location	Bottom Depth	Bottom Temperature	73.3
GOA	big skate	subadult	15	Bottom Depth	BPI	Location	74.7
GOA	big skate	adult	14	Bottom Depth	Location	Bottom Temperature	67.8

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	butter sole	adult	15	Bottom Depth	Rockiness	Location	64.7
GOA	Dover sole	subadult	15	Location	Bottom Depth	Bottom Currents	79.7
GOA	Dover sole	adult	15	Bottom Depth	Location	Bottom Currents	72.2
GOA	dusky rockfish	subadult	15	Bottom Depth	Location	Tidal Maximum	57.7
GOA	dusky rockfish	adult	15	Bottom Depth	Rockiness	Location	62.6
GOA	English sole	early juvenile	8	Bottom Depth	Slope	Aspect Eastness	96.3
GOA	English sole	subadult	11	Bottom Depth	Tidal Maximum	Location	70.3
GOA	English sole	adult	15	Bottom Depth	Location	Tidal Maximum	63.2
GOA	flathead sole	early juvenile	12	BPI	Bottom Depth	Tidal Maximum	58.0
GOA	flathead sole	subadult	15	Location	Bottom Depth	Tidal Maximum	62.2
GOA	flathead sole	adult	15	Location	BPI	Bottom Depth	68.9
GOA	giant octopus	all	15	Location	Sponge Presence	Bottom Depth	62.2
GOA	greenstriped rockfish	adult	15	Location	Bottom Depth	Bottom Temperature	72.3
GOA	harlequin rockfish	subadult	15	Location	Bottom Depth	Sponge Presence	54.7
GOA	harlequin rockfish	adult	15	Bottom Depth	Location	Rockiness	51.3
GOA	longnose skate	subadult	15	Bottom Depth	Location	Bottom Temperature	68.8
GOA	longnose skate	adult	13	Location	Bottom Depth	BPI	74.2
GOA	northern/southern rock soles	early juvenile	10	Bottom Depth	Tidal Maximum	Slope	84.7
GOA	northern rock sole	subadult	15	Bottom Depth	Location	Bottom Temperature	87.7
GOA	northern rock sole	adult	15	Bottom Depth	Location	Bottom Temperature	89.8
GOA	northern rockfish	subadult	15	Bottom Depth	Location	Rockiness	60.6
GOA	northern rockfish	adult	15	Location	Bottom Depth	Bottom Currents	60.1
GOA	Pacific cod	early juvenile	11	Bottom Depth	Aspect Eastness	BPI	83.2

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	Pacific cod	subadult	15	Bottom Depth	Location	Tidal Maximum	75.5
GOA	Pacific cod	adult	15	Bottom Depth	Location	Bottom Temperature	78.1
GOA	Pacific ocean perch	early juvenile	10	Bottom Depth	Bottom Temperature	Tidal Maximum	64.2
GOA	Pacific ocean perch	subadult	15	Bottom Depth	Location	Rockiness	66.8
GOA	Pacific ocean perch	adult	15	Bottom Depth	Location	Tidal Maximum	69.6
GOA	Pacific sanddab	all	14	Location	Bottom Temperature	Tidal Maximum	72.3
GOA	Petrale sole	subadult	15	Location	Bottom Temperature	Tidal Maximum	52.5
GOA	Petrale sole	adult	15	Location	Bottom Depth	Bottom Temperature	72.4
GOA	pygmy rockfish	all	15	Rockiness	Location	Sponge Presence	58.3
GOA	quillback rockfish	adult	14	Bottom Depth	Bottom Temperature	Bottom Currents	59.0
GOA	redbanded rockfish	subadult	15	Bottom Depth	Location	Slope	75.7
GOA	redbanded rockfish	adult	15	Bottom Depth	Location	Bottom Temperature	68.7
GOA	redstripe rockfish	subadult	15	Location	Bottom Depth	Rockiness	64.7
GOA	redstripe rockfish	adult	15	Location	Bottom Depth	Rockiness	59.1
GOA	rex sole	early juvenile	12	Tidal Maximum	Aspect Northness	BPI	60.1
GOA	rex sole	subadult	15	Bottom Depth	Location	Tidal Maximum	79.7
GOA	rex sole	adult	15	Bottom Depth	Location	Tidal Maximum	72.7
GOA	rosethorn rockfish	subadult	14	Location	Bottom Depth	Bottom Temperature	70.2
GOA	rosethorn rockfish	adult	15	Location	Bottom Currents	Bottom Temperature	68.7
GOA	rougheye blackspotted complex	subadult	15	Bottom Depth	Location	Slope	77.3
GOA	rougheye blackspotted complex	adult	15	Bottom Depth	Slope	Location	84.1
GOA	sablefish	early juvenile	11	Tidal Maximum	Aspect Northness	Bottom Temperature	54.9
GOA	sablefish	subadult	15	Bottom Depth	Bottom Temperature	Location	67.2

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	sablefish	adult	15	Bottom Depth	Location	Bottom Currents	75.9
GOA	sand sole	adult	15	Bottom Depth	Bottom Temperature	Bottom Currents	66.5
GOA	sharpchin rockfish	subadult	14	Location	Bottom Depth	Sponge Presence	58.0
GOA	sharpchin rockfish	adult	14	Bottom Depth	Location	Rockiness	60.2
GOA	shortraker rockfish	subadult	14	Bottom Depth	Location	Bottom Currents	83.0
GOA	shortraker rockfish	adult	15	Bottom Depth	Bottom Currents	Location	78.5
GOA	shortspine thornyhead	subadult	15	Bottom Depth	Location	Sponge Presence	73.8
GOA	shortspine thornyhead	adult	15	Bottom Depth	Location	Bottom Currents	83.5
GOA	silvergray rockfish	subadult	14	Location	Bottom Depth	Rockiness	60.8
GOA	silvergray rockfish	adult	15	Location	Bottom Depth	Bottom Current SD	65.0
GOA	slender sole	all	15	Location	Bottom Depth	Bottom Temperature	70.2
GOA	southern rock sole	subadult	15	Bottom Depth	Location	Tidal Maximum	82.6
GOA	southern rock sole	adult	15	Bottom Depth	Location	Tidal Maximum	86.6
GOA	spiny dogfish	all	15	Location	Bottom Temperature	Bottom Currents	66.6
GOA	starry flounder	early juvenile	10	Bottom Depth	Curvature	Slope	92.0
GOA	starry flounder	subadult	15	Bottom Depth	Location	Bottom Temperature	63.5
GOA	starry flounder	adult	15	Bottom Depth	Location	BPI	76.6
GOA	walleye pollock	early juvenile	11	BPI	Bottom Depth	Aspect Eastness	58.9
GOA	walleye pollock	subadult	15	Bottom Depth	Location	Tidal Maximum	62.3
GOA	walleye pollock	adult	15	Bottom Depth	Location	Rockiness	73.9
GOA	yelloweye rockfish	subadult	15	Bottom Depth	Sponge Presence	Location	59.7
GOA	yelloweye rockfish	adult	14	Bottom Depth	Location	Rockiness	59.4
GOA	yellowfin sole	early juvenile	12	Bottom Depth	Aspect Northness	Tidal Maximum	84.5
GOA	yellowfin sole	subadult	15	Bottom Depth	Location	Tidal Maximum	77.3

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	yellowfin sole	adult	15	Location	Bottom Depth	Tidal Maximum	73.1

Table C2. SDM results by region for each species' life stage modeled for the 2023 EFH 5-year Review. Metrics shown are the number of positive catches (N), the root mean square error (RMSE), Spearman's rank order correlation (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). EFH area (spatial domain containing the top 95% of occupied habitat) and core EFH area (CEA) (containing the top 50% of occupied habitat and applied to the EFH component 2 Fishing Effects Evaluatoin) are provided (km^2).

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Alaska skate	subadult	102	0.42	0.20	0.80	0.25	25,700	13,500
AI	Alaska skate	adult	149	0.65	0.25	0.81	0.27	48,600	25,600
AI	Aleutian skate	subadult	367	0.61	0.26	0.76	0.19	56,000	29,500
AI	Aleutian skate	adult	221	0.35	0.21	0.76	0.18	23,400	12,300
AI	arrowtooth flounder	early juvenile	341	1.5	0.35	0.90	0.56	36,800	19,300
AI	arrowtooth flounder	subadult	3,503	84.5	0.63	0.79	0.40	77,700	40,900
AI	arrowtooth flounder	adult	3,118	42.9	0.49	0.75	0.29	77,700	40,900
AI	Atka mackerel	subadult	1,312	1,130	0.54	0.72	0.38	77,700	40,900
AI	Atka mackerel	adult	2,030	1,190	0.52	0.65	0.36	77,700	40,900
AI	Dover sole	subadult	396	1.5	0.30	0.83	0.35	44,900	23,600
AI	Dover sole	adult	232	0.87	0.27	0.88	0.43	29,200	15,400
AI	dusky rockfish	subadult	108	1.4	0.20	0.88	0.32	36,800	19,400
AI	dusky rockfish	adult	380	9.2	0.27	0.78	0.44	64,700	34,100
AI	English sole	adult	50	1.5	0.23	0.98	0.82	10,400	5,500
AI	flathead sole	early juvenile	183	5.5	0.28	0.94	0.81	30,400	16,000
AI	flathead sole	subadult	1,279	72.8	0.60	0.89	0.72	69,400	36,500
AI	flathead sole	adult	1,374	13.5	0.56	0.86	0.48	67,800	35,700

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	giant octopus	all	682	0.81	0.20	0.67	0.09	72,000	37,900
AI	golden king crab	all	1,148	6.1	0.56	0.89	0.48	51,400	27,100
AI	Greenland turbot	adult	359	11.6	0.41	0.96	0.70	26,600	14,000
AI	harlequin rockfish	adult	111	23.4	0.18	0.86	0.40	62,000	32,600
AI	Kamchatka flounder	subadult	2,207	22.6	0.58	0.81	0.51	77,600	40,900
AI	Kamchatka flounder	adult	918	19.4	0.54	0.90	0.74	51,800	27,300
AI	mud skate	subadult	488	2.1	0.46	0.90	0.63	34,200	18,000
AI	mud skate	adult	290	0.41	0.28	0.82	0.26	36,600	19,200
AI	northern rock sole	early juvenile	154	0.57	0.25	0.89	0.38	32,900	17,300
AI	northern rock sole	subadult	1,901	42.3	0.73	0.90	0.62	69,500	36,600
AI	northern rock sole	adult	2,923	58.8	0.72	0.88	0.47	74,700	39,300
AI	northern rockfish	subadult	832	271	0.43	0.82	0.50	75,200	39,600
AI	northern rockfish	adult	2,063	779	0.56	0.68	0.42	77,700	40,900
AI	Pacific cod	subadult	2,872	34.1	0.47	0.74	0.28	74,100	39,000
AI	Pacific cod	adult	3,084	40.4	0.50	0.76	0.37	77,600	40,800
AI	Pacific ocean perch	early juvenile	722	68.8	0.36	0.80	0.38	69,600	36,600
AI	Pacific ocean perch	subadult	1,016	175	0.40	0.78	0.39	77,500	40,800
AI	Pacific ocean perch	adult	2,908	1,570	0.71	0.68	0.46	77,700	40,900
AI	red king crab	all	83	1.6	0.15	0.85	0.27	29,900	15,800
AI	rex sole	subadult	1,145	8.1	0.48	0.83	0.47	68,900	36,300

Region	Species	Life stage	N	RMSE	*ρ*	AUC	PDE	EFH area	Core EFH area
AI	rex sole	adult	1,891	22.6	0.56	0.82	0.43	77,200	40,600
AI	rougheye blackspotted complex	subadult	1,058	10.9	0.53	0.88	0.51	65,600	34,500
AI	rougheye blackspotted complex	adult	711	19.4	0.52	0.94	0.76	34,800	18,300
AI	sablefish	subadult	472	9.7	0.43	0.93	0.54	41,400	21,800
AI	sablefish	adult	368	8.1	0.40	0.95	0.66	33,100	17,400
AI	shortraker rockfish	subadult	408	8.5	0.47	0.98	0.86	23,300	12,200
AI	shortraker rockfish	adult	514	6.1	0.48	0.96	0.76	27,400	14,400
AI	shortspine thornyhead	subadult	380	8.1	0.46	0.98	0.76	23,200	12,200
AI	shortspine thornyhead	adult	1,051	26.1	0.61	0.93	0.74	54,800	28,900
AI	southern rock sole	subadult	583	12.9	0.55	0.97	0.73	41,600	21,900
AI	southern rock sole	adult	763	11.0	0.62	0.97	0.81	42,300	22,200
AI	walleye pollock	early juvenile	198	4.8	0.23	0.86	0.37	54,300	28,600
AI	walleye pollock	subadult	1,525	324	0.41	0.75	0.40	77,700	40,900
AI	walleye pollock	adult	2,773	447	0.50	0.71	0.28	77,700	40,900
AI	whiteblotched skate	subadult	459	2.5	0.48	0.94	0.66	35,800	18,800
AI	whiteblotched skate	adult	544	2.1	0.49	0.92	0.72	37,000	19,500
EBS	Alaska plaice	early juvenile	272	4.1	0.25	0.97	0.69	2.00E+05	105,300
EBS	Alaska plaice	subadult	6,527	53.9	0.79	0.94	0.60	562,300	295,900
EBS	Alaska plaice	adult	8,684	111	0.81	0.92	0.56	660,400	347,600

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	Alaska skate	subadult	6,801	10.1	0.63	0.86	0.32	676,100	355,800
EBS	Alaska skate	adult	5,162	5.0	0.55	0.78	0.29	673,700	354,600
EBS	Aleutian skate	subadult	1,021	3.6	0.55	0.98	0.76	158,500	83,400
EBS	Aleutian skate	adult	207	0.44	0.30	0.96	0.57	59,000	31,000
EBS	arrowtooth flounder	early juvenile	1,975	8.6	0.56	0.93	0.55	339,100	178,500
EBS	arrowtooth flounder	subadult	5,669	119	0.84	0.95	0.69	524,200	275,900
EBS	arrowtooth flounder	adult	4,976	26.6	0.81	0.96	0.64	426,400	224,400
EBS	Atka mackerel	adult	72	0.69	0.09	0.85	0.28	26,200	13,800
EBS	Bering skate	subadult	1,232	2.0	0.52	0.93	0.60	240,300	126,400
EBS	Bering skate	adult	1,429	0.88	0.51	0.90	0.48	267,300	140,700
EBS	Bering sole	subadult	2,583	30.2	0.61	0.97	0.74	463,800	244,100
EBS	Bering sole	adult	2,966	29.6	0.64	0.96	0.67	458,500	241,300
EBS	big skate	subadult	62	0.11	0.17	0.96	0.58	6,700	3,500
EBS	blue king crab	all	1,650	8.0	0.47	0.93	0.52	472,600	248,700
EBS	butter sole	adult	177	13.7	0.20	0.98	0.60	124,000	65,200
EBS	deepsea sole	all	110	0.30	0.45	1.00	0.87	10,900	5,700
EBS	Dover sole	subadult	182	0.45	0.21	0.96	0.57	45,500	23,900
EBS	Dover sole	adult	91	0.37	0.30	0.99	0.73	13,200	7,000
EBS	flathead sole	early juvenile	4,794	36.6	0.60	0.86	0.44	629,500	331,300
EBS	flathead sole	subadult	9,501	186	0.83	0.90	0.66	680,900	358,300

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	flathead sole	adult	9,702	143	0.71	0.88	0.33	681,800	358,900
EBS	giant octopus	all	693	0.69	0.28	0.88	0.31	207,500	109,200
EBS	Greenland turbot	subadult	2,419	10.2	0.55	0.93	0.58	392,300	206,500
EBS	Greenland turbot	adult	1,974	4.2	0.53	0.95	0.70	241,800	127,300
EBS	Kamchatka flounder	subadult	5,055	23.4	0.77	0.94	0.55	443,700	233,500
EBS	Kamchatka flounder	adult	1,752	2.1	0.51	0.91	0.63	276,300	145,400
EBS	longhead dab	all	2,307	54.0	0.61	0.97	0.68	386,200	203,300
EBS	mud skate	subadult	169	0.52	0.31	0.98	0.83	24,600	12,900
EBS	mud skate	adult	147	0.43	0.28	0.98	0.69	25,700	13,500
EBS	northern rock sole	early juvenile	2,884	378	0.67	0.90	0.51	627,200	330,100
EBS	northern rock sole	subadult	7,020	716	0.86	0.82	0.65	674,800	355,100
EBS	northern rock sole	adult	7,790	472	0.82	0.89	0.49	672,800	354,100
EBS	northern rockfish	adult	89	9.1	0.15	0.97	0.71	83,800	44,100
EBS	Pacific cod	early juvenile	3,213	44.9	0.53	0.87	0.38	608,500	320,200
EBS	Pacific cod	subadult	12,889	118	0.58	0.80	0.24	680,500	358,200
EBS	Pacific cod	adult	11,853	20.5	0.48	0.79	0.15	675,700	355,600
EBS	Pacific ocean perch	early juvenile	95	1.2	0.17	0.97	0.59	61,500	32,400
EBS	Pacific ocean perch	subadult	131	1.9	0.18	0.98	0.56	83,900	44,100
EBS	Pacific ocean perch	adult	561	308	0.34	0.99	0.39	191,900	101,000
EBS	red king crab	all	3,376	74.6	0.67	0.95	0.52	363,900	191,500

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	rex sole	early juvenile	105	0.20	0.15	0.94	0.40	39,400	20,800
EBS	rex sole	subadult	1,849	9.1	0.52	0.95	0.65	262,100	137,900
EBS	rex sole	adult	2,171	9.8	0.56	0.95	0.77	233,100	122,700
EBS	rougheye blackspotted complex	subadult	208	0.82	0.28	0.99	0.78	40,500	21,300
EBS	rougheye blackspotted complex	adult	105	0.15	0.36	0.99	0.75	13,200	7,000
EBS	sablefish	early juvenile	59	0.21	0.12	0.94	0.37	28,300	14,900
EBS	sablefish	subadult	391	2.2	0.32	0.97	0.60	75,700	39,800
EBS	sablefish	adult	544	1.8	0.39	0.99	0.77	67,800	35,700
EBS	Sakhalin sole	subadult	476	16.5	0.29	0.98	0.63	309,900	163,100
EBS	Sakhalin sole	adult	225	2.1	0.22	0.97	0.68	199,900	105,200
EBS	shortraker rockfish	subadult	122	0.88	0.31	0.99	0.80	27,800	14,600
EBS	shortraker rockfish	adult	142	1.7	0.33	0.99	0.85	13,600	7,200
EBS	shortspine thornyhead	subadult	253	4.3	0.50	1.00	0.87	22,600	11,900
EBS	shortspine thornyhead	adult	696	16.0	0.55	1.00	0.92	47,700	25,100
EBS	snow crab	all	10,628	1,930	0.84	0.85	0.41	688,900	362,600
EBS	starry flounder	subadult	575	11.4	0.37	0.97	0.69	214,500	112,900
EBS	starry flounder	adult	1,619	19.2	0.51	0.96	0.58	357,000	187,900
EBS	Tanner crab	all	9,244	140	0.80	0.93	0.35	540,400	284,400
EBS	walleye pollock	early juvenile	9,367	463	0.55	0.75	0.14	672,200	353,800

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	walleye pollock	subadult	9,528	553	0.69	0.76	0.30	689,500	362,900
EBS	walleye pollock	adult	13,506	1,020	0.63	0.63	0.24	689,500	362,900
EBS	whiteblotched skate	subadult	224	1.8	0.34	0.99	0.72	33,300	17,500
EBS	whiteblotched skate	adult	201	0.34	0.33	0.98	0.69	30,800	16,200
EBS	yellowfin sole	early juvenile	2,134	191	0.57	0.97	0.65	504,100	265,300
EBS	yellowfin sole	subadult	9,289	977	0.90	0.95	0.63	617,900	325,200
EBS	yellowfin sole	adult	9,480	476	0.89	0.96	0.62	620,300	326,500
GOA	Alaska plaice	subadult	85	0.83	0.23	0.98	0.62	28,500	15,000
GOA	Alaska plaice	adult	442	3.6	0.38	0.97	0.71	87,500	46,100
GOA	Alaska skate	subadult	95	0.21	0.13	0.82	0.21	14,600	7,700
GOA	Alaska skate	adult	78	0.15	0.13	0.85	0.24	13,300	7,000
GOA	Aleutian skate	subadult	613	0.54	0.28	0.78	0.30	165,800	87,300
GOA	Aleutian skate	adult	147	0.19	0.17	0.83	0.25	30,600	16,100
GOA	arrowtooth flounder	early juvenile	1,825	--	--	0.79	--	242,500	127,600
GOA	arrowtooth flounder	subadult	7,390	276	0.64	0.70	0.28	281,800	148,300
GOA	arrowtooth flounder	adult	7,043	189	0.55	0.76	0.29	281,800	148,300
GOA	Atka mackerel	subadult	87	1.6	0.15	0.91	0.40	83,900	44,200
GOA	Atka mackerel	adult	700	143	0.33	0.85	0.35	233,800	123,100
GOA	Bering skate	subadult	401	0.33	0.27	0.84	0.28	113,600	59,800
GOA	Bering skate	adult	407	0.32	0.28	0.84	0.31	94,700	49,800

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	big skate	subadult	594	1.1	0.31	0.85	0.44	158,500	83,400
GOA	big skate	adult	195	0.20	0.19	0.86	0.27	37,300	19,600
GOA	butter sole	adult	881	30.1	0.46	0.93	0.54	204,900	107,900
GOA	Dover sole	subadult	3,710	17.4	0.61	0.83	0.46	281,300	148,000
GOA	Dover sole	adult	2,973	11.0	0.62	0.87	0.42	272,900	143,600
GOA	dusky rockfish	subadult	315	17.7	0.21	0.80	0.27	235,200	123,800
GOA	dusky rockfish	adult	1,061	53.1	0.40	0.83	0.28	264,000	138,900
GOA	English sole	early juvenile	56	--	--	0.99	--	39,300	20,700
GOA	English sole	subadult	116	2.3	0.20	0.95	0.57	55,700	29,300
GOA	English sole	adult	746	13.3	0.34	0.84	0.52	241,600	127,200
GOA	flathead sole	early juvenile	2,017	--	--	0.90	--	150,100	79,000
GOA	flathead sole	subadult	4,064	109	0.71	0.86	0.65	257,900	135,700
GOA	flathead sole	adult	4,201	63.3	0.72	0.88	0.54	257,900	135,700
GOA	giant octopus	all	459	0.33	0.20	0.75	0.15	134,900	71,000
GOA	greenstriped rockfish	adult	120	1.4	0.30	1.00	0.85	19,300	10,200
GOA	harlequin rockfish	subadult	102	14.6	0.16	0.92	0.50	170,600	89,800
GOA	harlequin rockfish	adult	514	71.3	0.31	0.88	0.44	254,800	134,100
GOA	longnose skate	subadult	1,058	0.63	0.28	0.74	0.15	233,800	123,100
GOA	longnose skate	adult	845	0.46	0.25	0.74	0.15	209,100	110,000
GOA	northern/southern rock sole	early juvenile	252	--	--	0.95	--	128,100	67,400

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	northern rock sole	subadult	1,854	57.3	0.68	0.96	0.68	182,200	95,900
GOA	northern rock sole	adult	1,980	25.0	0.68	0.95	0.58	190,700	100,400
GOA	northern rockfish	subadult	522	8.3	0.30	0.86	0.42	215,600	113,500
GOA	northern rockfish	adult	1,141	276	0.46	0.89	0.32	261,100	137,400
GOA	Pacific cod	early juvenile	354	--	--	0.95	--	124,800	65,700
GOA	Pacific cod	subadult	3,653	66.2	0.53	0.79	0.30	265,600	139,800
GOA	Pacific cod	adult	4,476	70.2	0.47	0.75	0.25	264,700	139,300
GOA	Pacific ocean perch	early juvenile	1,552	--	--	0.80	--	212,500	111,800
GOA	Pacific ocean perch	subadult	1,686	48.6	0.49	0.85	0.39	253,400	133,400
GOA	Pacific ocean perch	adult	2,992	692	0.65	0.81	0.39	281,500	148,100
GOA	Pacific sanddab	all	77	2.2	0.19	0.98	0.74	32,000	16,900
GOA	Petrale sole	subadult	59	0.32	0.18	0.98	0.56	15,400	8,100
GOA	Petrale sole	adult	271	1.3	0.29	0.96	0.65	64,600	34,000
GOA	pygmy rockfish	all	63	3.0	0.14	0.96	0.40	74,900	39,400
GOA	quillback rockfish	adult	73	0.44	0.17	0.96	0.51	17,600	9,300
GOA	redbanded rockfish	subadult	829	2.1	0.46	0.94	0.63	116,600	61,400
GOA	redbanded rockfish	adult	321	1.6	0.29	0.93	0.49	98,800	52,000
GOA	redstripe rockfish	subadult	133	7.2	0.20	0.95	0.52	95,400	50,200
GOA	redstripe rockfish	adult	234	47.9	0.25	0.94	0.65	214,500	112,900
GOA	rex sole	early juvenile	480	--	--	0.85	--	209,900	110,400

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	rex sole	subadult	4,744	33.6	0.56	0.80	0.32	281,800	148,300
GOA	rex sole	adult	4,455	36.3	0.59	0.80	0.37	280,100	147,400
GOA	rosethorn rockfish	subadult	132	0.93	0.30	0.99	0.76	25,900	13,700
GOA	rosethorn rockfish	adult	186	2.5	0.40	0.99	0.82	29,600	15,600
GOA	rougheye blackspotted complex	subadult	2,178	20.4	0.62	0.90	0.57	258,000	135,800
GOA	rougheye blackspotted complex	adult	878	9.9	0.46	0.93	0.70	128,700	67,700
GOA	sablefish	early juvenile	959	--	--	0.84	--	235,800	124,100
GOA	sablefish	subadult	2,812	47.0	0.56	0.84	0.34	278,400	146,500
GOA	sablefish	adult	2,011	18.9	0.65	0.94	0.61	216,700	114,100
GOA	sand sole	adult	109	4.4	0.22	0.97	0.60	50,600	26,600
GOA	sharpchin rockfish	subadult	498	47.0	0.37	0.95	0.69	191,800	100,900
GOA	sharpchin rockfish	adult	425	97.9	0.34	0.95	0.54	218,600	115,100
GOA	shortraker rockfish	subadult	316	1.4	0.45	0.99	0.77	24,800	13,000
GOA	shortraker rockfish	adult	679	7.6	0.47	0.97	0.73	65,200	34,300
GOA	shortspine thornyhead	subadult	1,634	24.4	0.65	0.97	0.76	186,900	98,400
GOA	shortspine thornyhead	adult	1,998	44.4	0.70	0.96	0.82	229,200	120,600
GOA	silvergray rockfish	subadult	159	1.4	0.18	0.88	0.21	104,500	55,000
GOA	silvergray rockfish	adult	557	33.3	0.37	0.93	0.63	184,300	97,000
GOA	slender sole	all	751	5.0	0.44	0.94	0.68	127,100	66,900

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	southern rock sole	subadult	2,213	30.2	0.71	0.94	0.64	198,100	104,300
GOA	southern rock sole	adult	2,772	22.1	0.76	0.94	0.64	212,100	111,700
GOA	spiny dogfish	all	1,291	10.0	0.42	0.84	0.48	273,900	141,800
GOA	starry flounder	early juvenile	61	--	--	0.98	--	63,800	33,600
GOA	starry flounder	subadult	68	0.80	0.19	0.98	0.65	23,100	12,200
GOA	starry flounder	adult	604	13.3	0.43	0.96	0.59	115,300	60,700
GOA	walleye pollock	early juvenile	2,958	--	--	0.82	--	254,200	133,800
GOA	walleye pollock	subadult	4,599	298	0.40	0.70	0.21	281,700	148,300
GOA	walleye pollock	adult	4,351	237	0.49	0.74	0.23	281,800	148,300
GOA	yelloweye rockfish	subadult	79	0.17	0.16	0.92	0.39	27,100	14,300
GOA	yelloweye rockfish	adult	186	0.46	0.22	0.91	0.43	64,500	33,900
GOA	yellowfin sole	early juvenile	66	--	--	0.98	--	54,600	28,700
GOA	yellowfin sole	subadult	401	46.9	0.38	0.98	0.78	101,600	53,500
GOA	yellowfin sole	adult	491	58.0	0.40	0.98	0.79	118,900	62,600

Appendix D SDM EFH Comparisons 2017 and 2023

Appendix D provides EFH comparisons between the SDMs, EFH areas and subareas, EFH maps, and EFH Levels of the 2017 and 2023 EFH 5-year Reviews—

- Table D1 lists the EFH Levels from the 2017 EFH 5-year Review and the new EFH Levels available for the 2023 Review, demonstrating EFH information level advancements.
- Table D2 provides a summary comparing SDM type, SDM performance, EFH area, and core EFH area between the SDMs produced for the 2017 and 2023 Reviews.
- Overlay maps (e.g., species case studies results; Figure 13), demonstrating the area extent of the 2017 and 2023 EFH maps are provided as image files for each species life stage where comparisons were possible (Supporting Documents 5; Laman et al. In review). An example is provided in this section for adult walleye pollock in the Bering Sea (Figure D1).

D.1 Comparison of 2017 and 2023 EFH Levels

Updates to data and methods used during the 2023 EFH 5-year Review have resulted in advancements in the EFH Level for many species' life stages (Table D1). This information is provided as an outcome of an EFH 5-year Review (e.g., Simpson et al. 2017) and SSC requested a summary of EFH Level advancements in the 2023 EFH 5-year Review for their February 2022 review of EFH component 1 (Table A1 item 6e).

EFH Level 1 is applied to species' life stages with a model that predicts distribution or presence/absence. EFH Level 2 is applied to species' life stages with a model that can also predict abundance. EFH Level 3 is applied to species' life stages where a vital rate has been combined with a model to supplement either Level 1 or Level 2 predictions. **Compared to 2017, the 2023 5-year Review resulted in the following advancements:**

- Across all regions, 61 new species' life stages were modelled for the first time, and their EFH level was advanced from none to Level 2.
- In the GOA, the settled early juvenile life stages for 11 species were modelled for the first time and their EFH level was advanced from none to Level 1.
- Eight species' life stages where the settled early juvenile life stage was modelled for the first time are presented with additional EFH Level 3 information, advancing their EFH level to Level 3. Two of these species were based on Level 2 SDM ensembles for the AI and EBS, while six were based on Level 1 SDMs for the GOA that use combined survey data.
- Seven species' life stages were not updated, and the EFH Level 1 designation from 2017 is retained. These cases refer to species/life stages where fewer than 50 positive survey catches were available in 2019 (e.g., hauls where the species was present).
- In total, 55 species' life stages were advanced from EFH Level 1 to 2.
- Across all regions, 84 species' life stages were modelled as EFH Level 2 in both 2017 and 2023, although the data and methods were updated and revised in the 2023 SDM ensemble EFH mapping approach.
- For the first time, EFH Level 2 models were combined for member species of each of 10 stock complexes in the BSAI (6) and GOA (4) groundfish FMPs to represent the EFH of member species where a model was not possible (i.e., fewer than 50 positive survey catches were available).

Table D1. Comparison of the EFH information levels accomplished from SDMs produced for the 2017 and 2023 EFH 5-year Reviews for species' life stages modeled in each region with model type, 2017 EFH Level, and the new 2023 EFH Level, demonstrating EFH information level advancements available for the 2023 EFH 5-year Review.

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2023	EFH Level 2023
AI	Alaska skate	subadult	MaxEnt	1	ensemble	2
AI	Alaska skate	adult	MaxEnt	1	ensemble	2
AI	Aleutian skate	subadult	MaxEnt	1	ensemble	2
AI	Aleutian skate	adult	MaxEnt	1	ensemble	2
AI	arrowtooth flounder	early juvenile	--	0	ensemble	2
AI	arrowtooth flounder	subadult	GAM	2	ensemble	2
AI	arrowtooth flounder	adult	GAM	2	ensemble	2
AI	Atka mackerel	subadult	hGAM	2	ensemble	2
AI	Atka mackerel	adult	GAM	2	ensemble	2
AI	Bering skate	subadult	MaxEnt	1	--	1
AI	Bering skate	adult	MaxEnt	1	--	1
AI	Dover sole	subadult	MaxEnt	1	ensemble	2
AI	Dover sole	adult	MaxEnt	1	ensemble	2
AI	dusky rockfish	subadult	MaxEnt	1	ensemble	2
AI	dusky rockfish	adult	MaxEnt	1	ensemble	2
AI	English sole	adult	--	0	ensemble	2
AI	flathead sole	early juvenile	--	0	ensemble	2
AI	flathead sole	subadult	hGAM	2	ensemble	2
AI	flathead sole	adult	hGAM	2	ensemble	2
AI	giant octopus	all	hGAM	2	ensemble	2
AI	golden king crab	all	hGAM	2	ensemble	2
AI	Greenland turbot	subadult	MaxEnt	1	--	1
AI	Greenland turbot	adult	MaxEnt	1	ensemble	2
AI	harlequin rockfish	subadult	MaxEnt	1	--	1
AI	harlequin rockfish	adult	MaxEnt	1	ensemble	2
AI	Kamchatka flounder	subadult	GAM	2	ensemble	2
AI	Kamchatka flounder	adult	hGAM	2	ensemble	2
AI	mud skate	subadult	hGAM	2	ensemble	2
AI	mud skate	adult	MaxEnt	1	ensemble	2
AI	northern rock sole	early juvenile	--	0	ensemble	2
AI	northern rock sole	subadult	GAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2023	EFH Level 2023
AI	northern rock sole	adult	GAM	2	ensemble	2
AI	northern rockfish	subadult	MaxEnt	1	ensemble	2
AI	northern rockfish	adult	GAM	2	ensemble	2
AI	Pacific cod	subadult	GAM	2	ensemble	2
AI	Pacific cod	adult	GAM	2	ensemble	2
AI	Pacific ocean perch	early juvenile	--	0	ensemble	2
AI	Pacific ocean perch	subadult	hGAM	2	ensemble	2
AI	Pacific ocean perch	adult	GAM	2	ensemble	2
AI	red king crab	all	--	0	ensemble	2
AI	rex sole	subadult	hGAM	2	ensemble	2
AI	rex sole	adult	GAM	2	ensemble	2
AI	rougheye blackspotted complex	subadult	--	0	ensemble	2
AI	rougheye blackspotted complex	adult	--	0	ensemble	2
AI	sablefish	subadult	MaxEnt	1	ensemble	2
AI	sablefish	adult	MaxEnt	1	ensemble	2
AI	shortraker rockfish	subadult	MaxEnt	1	ensemble	2
AI	shortraker rockfish	adult	hGAM	2	ensemble	2
AI	shortspine thornyhead	subadult	MaxEnt	1	ensemble	2
AI	shortspine thornyhead	adult	hGAM	2	ensemble	2
AI	southern rock sole	subadult	MaxEnt	1	ensemble	2
AI	southern rock sole	adult	MaxEnt	1	ensemble	2
AI	walleye pollock	early juvenile	--	0	ensemble	3
AI	walleye pollock	subadult	hGAM	2	ensemble	2
AI	walleye pollock	adult	GAM	2	ensemble	2
AI	whiteblotched skate	subadult	--	0	ensemble	2
AI	whiteblotched skate	adult	--	0	ensemble	2
EBS	Alaska plaice	early juvenile	--	0	ensemble	2
EBS	Alaska plaice	subadult	--	0	ensemble	2
EBS	Alaska plaice	adult	GAM	2	ensemble	2
EBS	Alaska skate	subadult	GAM	2	ensemble	2
EBS	Alaska skate	adult	hGAM	2	ensemble	2
EBS	Aleutian skate	subadult	hGAM	2	ensemble	2
EBS	Aleutian skate	adult	MaxEnt	1	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2023	EFH Level 2023
EBS	arrowtooth flounder	early juvenile	--	0	ensemble	2
EBS	arrowtooth flounder	subadult	GAM	2	ensemble	2
EBS	arrowtooth flounder	adult	GAM	2	ensemble	2
EBS	Atka mackerel	adult	MaxEnt	1	ensemble	2
EBS	Bering skate	subadult	hGAM	2	ensemble	2
EBS	Bering skate	adult	hGAM	2	ensemble	2
EBS	Bering flounder	subadult	--	0	ensemble	2
EBS	Bering flounder	adult	--	0	ensemble	2
EBS	big skate	subadult	--	0	ensemble	2
EBS	blue king crab	all	hGAM	2	ensemble	2
EBS	butter sole	all	--	0	ensemble	2
EBS	deepsea sole	all	--	0	ensemble	2
EBS	Dover sole	subadult	MaxEnt	1	ensemble	2
EBS	Dover sole	adult	MaxEnt	1	ensemble	2
EBS	dusky rockfish	adult	MaxEnt	1	--	1
EBS	flathead sole	early juvenile	--	0	ensemble	2
EBS	flathead sole	subadult	GAM	2	ensemble	2
EBS	flathead sole	adult	GAM	2	ensemble	2
EBS	giant octopus	all	MaxEnt	1	ensemble	2
EBS	Greenland turbot	subadult	hGAM	2	ensemble	2
EBS	Greenland turbot	adult	hGAM	2	ensemble	2
EBS	Kamchatka flounder	subadult	GAM	2	ensemble	2
EBS	Kamchatka flounder	adult	hGAM	2	ensemble	2
EBS	longhead dab	all	--	0	ensemble	2
EBS	mud skate	subadult	MaxEnt	1	ensemble	2
EBS	mud skate	adult	MaxEnt	1	ensemble	2
EBS	northern rock sole	early juvenile	--	0	ensemble	2
EBS	northern rock sole	subadult	GAM	2	ensemble	2
EBS	northern rock sole	adult	GAM	2	ensemble	2
EBS	northern rockfish	adult	MaxEnt	1	ensemble	2
EBS	Pacific cod	early juvenile	--	0	ensemble	3
EBS	Pacific cod	subadult	GAM	2	ensemble	2
EBS	Pacific cod	adult	GAM	2	ensemble	2
EBS	Pacific ocean perch	early juvenile	--	0	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2023	EFH Level 2023
EBS	Pacific ocean perch	subadult	MaxEnt	1	ensemble	2
EBS	Pacific ocean perch	adult	MaxEnt	1	ensemble	2
EBS	red king crab	all	hGAM	2	ensemble	2
EBS	rex sole	early juvenile	--	0	ensemble	2
EBS	rex sole	subadult	hGAM	2	ensemble	2
EBS	rex sole	adult	hGAM	2	ensemble	2
EBS	rougheye blackspotted complex	subadult	--	0	ensemble	2
EBS	rougheye blackspotted complex	adult	--	0	ensemble	2
EBS	sablefish	early juvenile	--	0	ensemble	2
EBS	sablefish	subadult	MaxEnt	1	ensemble	2
EBS	sablefish	adult	MaxEnt	1	ensemble	2
EBS	Sakhalin sole	subadult	--	0	ensemble	2
EBS	Sakhalin sole	adult	--	0	ensemble	2
EBS	shortraker rockfish	subadult	MaxEnt	1	ensemble	2
EBS	shortraker rockfish	adult	MaxEnt	1	ensemble	2
EBS	shortspine thornyhead	subadult	MaxEnt	1	ensemble	2
EBS	shortspine thornyhead	adult	MaxEnt	1	ensemble	2
EBS	snow crab	all	GAM	2	ensemble	2
EBS	southern rock sole	subadult	MaxEnt	1	--	1
EBS	southern rock sole	adult	MaxEnt	1	--	1
EBS	starry flounder	subadult	--	0	ensemble	2
EBS	starry flounder	adult	--	0	ensemble	2
EBS	Tanner crab	all	GAM	2	ensemble	2
EBS	walleye pollock	early juvenile	--	0	ensemble	2
EBS	walleye pollock	subadult	GAM	2	ensemble	2
EBS	walleye pollock	adult	GAM	2	ensemble	2
EBS	whiteblotched skate	subadult	--	0	ensemble	2
EBS	whiteblotched skate	adult	--	0	ensemble	2
EBS	yellowfin sole	early juvenile	--	0	ensemble	2
EBS	yellowfin sole	subadult	GAM	2	ensemble	2
EBS	yellowfin sole	adult	GAM	2	ensemble	2
GOA	Alaska plaice	subadult	--	0	ensemble	2
GOA	Alaska plaice	adult	hGAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2023	EFH Level 2023
GOA	Alaska skate	subadult	MaxEnt	1	ensemble	2
GOA	Alaska skate	adult	MaxEnt	1	ensemble	2
GOA	Aleutian skate	subadult	hGAM	2	ensemble	2
GOA	Aleutian skate	adult	MaxEnt	1	ensemble	2
GOA	arrowtooth flounder	early juvenile	--	0	MaxEnt	1
GOA	arrowtooth flounder	subadult	GAM	2	ensemble	2
GOA	arrowtooth flounder	adult	GAM	2	ensemble	2
GOA	Atka mackerel	subadult	--	0	ensemble	2
GOA	Atka mackerel	adult	--	0	ensemble	2
GOA	Atka mackerel	all	hGAM	2	--	--
GOA	Bering skate	subadult	MaxEnt	1	ensemble	2
GOA	Bering skate	adult	MaxEnt	1	ensemble	2
GOA	big skate	subadult	--	0	ensemble	2
GOA	big skate	adult	--	0	ensemble	2
GOA	butter sole	subadult/adult	--	0	ensemble	2
GOA	Dover sole	subadult	GAM	2	ensemble	2
GOA	Dover sole	adult	GAM	2	ensemble	2
GOA	dusky rockfish	subadult	MaxEnt	1	ensemble	2
GOA	dusky rockfish	adult	hGAM	2	ensemble	2
GOA	English sole	early juvenile	--	0	MaxEnt	1
GOA	English sole	subadult	--	0	ensemble	2
GOA	English sole	adult	--	0	ensemble	2
GOA	flathead sole	early juvenile	--	0	MaxEnt	1
GOA	flathead sole	subadult	GAM	2	ensemble	2
GOA	flathead sole	adult	GAM	2	ensemble	2
GOA	giant octopus	all	MaxEnt	1	ensemble	2
GOA	greenstriped rockfish	adult	--	0	ensemble	2
GOA	greenstriped rockfish	all	MaxEnt	1	--	--
GOA	harlequin rockfish	subadult	MaxEnt	1	ensemble	2
GOA	harlequin rockfish	adult	hGAM	2	ensemble	2
GOA	longnose skate	subadult	--	0	ensemble	2
GOA	longnose skate	adult	--	0	ensemble	2
GOA	northern/southern rock soles	early juvenile	--	0	MaxEnt	3
GOA	northern rock sole	subadult	hGAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2023	EFH Level 2023
GOA	northern rock sole	adult	hGAM	2	ensemble	2
GOA	northern rockfish	subadult	MaxEnt	1	ensemble	2
GOA	northern rockfish	adult	hGAM	2	ensemble	2
GOA	Pacific cod	early juvenile	--	0	MaxEnt	3
GOA	Pacific cod	subadult	GAM	2	ensemble	2
GOA	Pacific cod	adult	GAM	2	ensemble	2
GOA	Pacific ocean perch	early juvenile	--	0	MaxEnt	3
GOA	Pacific ocean perch	subadult	hGAM	2	ensemble	2
GOA	Pacific ocean perch	adult	GAM	2	ensemble	2
GOA	Pacific sanddab	all	--	0	ensemble	2
GOA	Petrale sole	subadult	--	0	ensemble	2
GOA	Petrale sole	adult	--	0	ensemble	2
GOA	pygmy rockfish	all	MaxEnt	1	ensemble	2
GOA	quillback rockfish	adult	--	0	ensemble	2
GOA	quillback rockfish	all	MaxEnt	1	--	--
GOA	redbanded rockfish	subadult	hGAM	2	ensemble	2
GOA	redbanded rockfish	adult	MaxEnt	1	ensemble	2
GOA	redstripe rockfish	subadult	MaxEnt	1	ensemble	2
GOA	redstripe rockfish	adult	MaxEnt	1	ensemble	2
GOA	rex sole	early juvenile	--	0	MaxEnt	1
GOA	rex sole	subadult	hGAM	2	ensemble	2
GOA	rex sole	adult	GAM	2	ensemble	2
GOA	rosethorn rockfish	subadult	MaxEnt	1	ensemble	2
GOA	rosethorn rockfish	adult	MaxEnt	1	ensemble	2
GOA	rougheye blackspotted complex	subadult	--	0	ensemble	2
GOA	rougheye blackspotted complex	adult	--	0	ensemble	2
GOA	sablefish	early juvenile	--	0	MaxEnt	3
GOA	sablefish	subadult	hGAM	2	ensemble	2
GOA	sablefish	adult	GAM	2	ensemble	2
GOA	sand sole	adult	--	0	ensemble	2
GOA	sharpchin rockfish	subadult	hGAM	2	ensemble	2
GOA	sharpchin rockfish	adult	MaxEnt	1	ensemble	2
GOA	shortraker rockfish	subadult	MaxEnt	1	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2023	EFH Level 2023
GOA	shortraker rockfish	adult	hGAM	2	ensemble	2
GOA	shortspine thornyhead	subadult	hGAM	2	ensemble	2
GOA	shortspine thornyhead	adult	hGAM	2	ensemble	2
GOA	silvergray rockfish	subadult	MaxEnt	1	ensemble	2
GOA	silvergray rockfish	adult	hGAM	2	ensemble	2
GOA	slender sole	all	--	0	ensemble	2
GOA	southern rock sole	subadult	hGAM	2	ensemble	2
GOA	southern rock sole	adult	GAM	2	ensemble	2
GOA	spiny dogfish	all	--	0	ensemble	2
GOA	starry flounder	early juvenile	--	0	MaxEnt	1
GOA	starry flounder	subadult	--	0	ensemble	2
GOA	starry flounder	adult	--	0	ensemble	2
GOA	walleye pollock	early juvenile	--	0	MaxEnt	3
GOA	walleye pollock	subadult	GAM	2	ensemble	2
GOA	walleye pollock	adult	GAM	2	ensemble	2
GOA	yelloweye rockfish	subadult	MaxEnt	1	ensemble	2
GOA	yelloweye rockfish	adult	MaxEnt	1	ensemble	2
GOA	yellowfin sole	early juvenile	--	0	MaxEnt	3
GOA	yellowfin sole	subadult	MaxEnt	1	ensemble	2
GOA	yellowfin sole	adult	hGAM	2	ensemble	2

D.2 Comparison of 2017 and 2023 SDMs

Table D2. Comparison of the SDMs produced for the 2017 and 2023 EFH 5-year Reviews. Model is the type of model used and is always "ensemble" when the year is 2023. Metrics shown are the number of positive catches (N), the root mean square error (RMSE), Spearman's rank order correlation (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). EFH area (spatial domain containing the top 95% of occupied habitat) and core EFH area (CEA) (containing the top 50% of occupied habitat and applied to the EFH component 2 Fishing Effects Evaluation) are provided (km^2). The "--" sign indicates where a metric could not be calculated.

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Alaska skate	subadult	2017	MaxEnt	149	--	--	0.75	--	58,600	30,800
AI	Alaska skate	subadult	2023	ensemble	102	0.42	0.2	0.8	0.25	25,700	13,500
AI	Alaska skate	adult	2017	MaxEnt	289	--	--	0.75	--	52,200	27,500
AI	Alaska skate	adult	2023	ensemble	149	0.65	0.25	0.82	0.27	48,600	25,600
AI	Aleutian skate	subadult	2017	MaxEnt	273	--	--	0.67	--	68,900	36,300
AI	Aleutian skate	subadult	2023	ensemble	367	0.61	0.26	0.76	0.19	56,000	29,500
AI	Aleutian skate	adult	2017	MaxEnt	173	--	--	0.73	--	59,200	31,200
AI	Aleutian skate	adult	2023	ensemble	221	0.35	0.21	0.76	0.18	23,400	12,300
AI	arrowtooth flounder	subadult	2017	GAM	2,182	52.5	0.61	0.8	0.07	68,900	36,300
AI	arrowtooth flounder	subadult	2023	ensemble	3,503	84.5	0.63	0.79	0.4	77,700	40,900
AI	arrowtooth flounder	adult	2017	GAM	2,805	90.9	0.57	0.81	-0.14	76,300	40,200
AI	arrowtooth flounder	adult	2023	ensemble	3,118	42.9	0.49	0.75	0.29	77,700	40,900
AI	Atka mackerel	subadult	2017	hGAM	575	789	0.53	0.89	-0.51	22,400	11,800
AI	Atka mackerel	subadult	2023	ensemble	1,312	1,131	0.54	0.73	0.38	77,700	40,900
AI	Atka mackerel	adult	2017	GAM	1,672	1,880	0.48	0.74	-0.6	71,700	37,700

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Atka mackerel	adult	2023	ensemble	2,030	1,190	0.52	0.65	0.36	77,700	40,900
AI	Dover sole	subadult	2017	MaxEnt	280	--	--	0.77	--	56,700	29,800
AI	Dover sole	subadult	2023	ensemble	396	1.5	0.3	0.83	0.35	44,900	23,600
AI	Dover sole	adult	2017	MaxEnt	252	--	--	0.81	--	54,900	28,900
AI	Dover sole	adult	2023	ensemble	232	0.87	0.27	0.88	0.43	29,200	15,400
AI	dusky rockfish	subadult	2017	MaxEnt	32	--	--	0.92	--	37,200	19,600
AI	dusky rockfish	subadult	2023	ensemble	108	1.4	0.2	0.88	0.32	36,800	19,400
AI	dusky rockfish	adult	2017	MaxEnt	293	--	--	0.73	--	65,900	34,700
AI	dusky rockfish	adult	2023	ensemble	380	9.2	0.27	0.78	0.45	64,700	34,100
AI	flathead sole	subadult	2017	hGAM	685	87.7	0.58	0.9	0.15	19,800	10,400
AI	flathead sole	subadult	2023	ensemble	1,279	72.8	0.6	0.89	0.72	69,400	36,500
AI	flathead sole	adult	2017	hGAM	1,188	30.5	0.65	0.87	0.1	21,500	11,300
AI	flathead sole	adult	2023	ensemble	1,374	13.5	0.56	0.86	0.48	67,800	35,700
AI	giant octopus	all	2017	hGAM	504	1.2	0.13	0.63	-2.32	19,400	10,200
AI	giant octopus	all	2023	ensemble	682	0.81	0.2	0.67	0.09	72,000	37,900
AI	golden king crab	all	2017	hGAM	908	6.5	0.57	0.88	-0.29	26,400	13,900
AI	golden king crab	all	2023	ensemble	1,148	6.1	0.56	0.89	0.48	51,400	27,100
AI	Greenland turbot	adult	2017	MaxEnt	320	--	--	0.93	--	27,400	14,400
AI	Greenland turbot	adult	2023	ensemble	359	11.6	0.41	0.96	0.7	26,600	14,000

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	harlequin rockfish	adult	2017	MaxEnt	82	--	--	0.77	--	52,900	27,800
AI	harlequin rockfish	adult	2023	ensemble	111	23.4	0.18	0.86	0.39	62,000	32,600
AI	Kamchatka flounder	subadult	2017	GAM	1,649	23.9	0.53	0.79	-0.65	69,100	36,400
AI	Kamchatka flounder	subadult	2023	ensemble	2,207	22.6	0.58	0.81	0.51	77,600	40,900
AI	Kamchatka flounder	adult	2017	hGAM	814	33.3	0.58	0.89	0.45	26,900	14,200
AI	Kamchatka flounder	adult	2023	ensemble	918	19.4	0.54	0.9	0.75	51,800	27,300
AI	mud skate	subadult	2017	hGAM	422	2.8	0.49	0.87	0.18	23,200	12,200
AI	mud skate	subadult	2023	ensemble	488	2.1	0.46	0.9	0.63	34,200	18,000
AI	mud skate	adult	2017	MaxEnt	130	--	--	0.74	--	52,700	27,700
AI	mud skate	adult	2023	ensemble	290	0.41	0.28	0.82	0.26	36,600	19,200
AI	northern rock sole	subadult	2017	GAM	1,487	55.8	0.7	0.88	0.02	63,900	33,600
AI	northern rock sole	subadult	2023	ensemble	1,901	42.3	0.73	0.9	0.62	69,500	36,600
AI	northern rock sole	adult	2017	GAM	2,277	71.4	0.69	0.89	-0.02	68,800	36,200
AI	northern rock sole	adult	2023	ensemble	2,923	58.8	0.72	0.88	0.47	74,700	39,300
AI	northern rockfish	subadult	2017	MaxEnt	375	--	--	0.82	--	51,300	27,000
AI	northern rockfish	subadult	2023	ensemble	832	271	0.43	0.82	0.5	75,200	39,600
AI	northern rockfish	adult	2017	GAM	1,529	958	0.43	0.71	-0.28	69,000	36,300
AI	northern rockfish	adult	2023	ensemble	2,063	779	0.56	0.67	0.42	77,700	40,900
AI	Pacific cod	subadult	2017	GAM	1,194	37.4	0.42	0.75	-0.45	68,600	36,100

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Pacific cod	subadult	2023	ensemble	2,872	34.1	0.47	0.74	0.28	74,100	39,000
AI	Pacific cod	adult	2017	GAM	2,567	56.3	0.49	0.76	-0.19	75,200	39,600
AI	Pacific cod	adult	2023	ensemble	3,084	40.4	0.5	0.76	0.37	77,600	40,800
AI	Pacific ocean perch	subadult	2017	hGAM	938	241	0.33	0.73	-0.22	18,500	9,800
AI	Pacific ocean perch	subadult	2023	ensemble	1,016	175	0.4	0.78	0.39	77,500	40,800
AI	Pacific ocean perch	adult	2017	GAM	2,158	1,765	0.68	0.82	-0.06	56,200	29,600
AI	Pacific ocean perch	adult	2023	ensemble	2,908	1,568	0.71	0.68	0.46	77,700	40,900
AI	rex sole	subadult	2017	hGAM	265	2.5	0.27	0.81	-0.19	18,200	9,600
AI	rex sole	subadult	2023	ensemble	1,145	8.1	0.48	0.83	0.47	68,900	36,300
AI	rex sole	adult	2017	GAM	1,525	28.7	0.52	0.8	-0.3	66,900	35,200
AI	rex sole	adult	2023	ensemble	1,891	22.6	0.56	0.82	0.43	77,200	40,600
AI	sablefish	subadult	2017	MaxEnt	18	--	--	0.9	--	19,900	10,400
AI	sablefish	subadult	2023	ensemble	472	9.7	0.43	0.93	0.54	41,400	21,800
AI	sablefish	adult	2017	MaxEnt	439	--	--	0.91	--	38,200	20,100
AI	sablefish	adult	2023	ensemble	368	8.1	0.4	0.95	0.66	33,100	17,400
AI	shortraker rockfish	subadult	2017	MaxEnt	286	--	--	0.96	--	21,900	11,500
AI	shortraker rockfish	subadult	2023	ensemble	408	8.5	0.47	0.98	0.86	23,300	12,200
AI	shortraker rockfish	adult	2017	hGAM	467	15.0	0.69	0.96	0.53	21,400	11,300
AI	shortraker rockfish	adult	2023	ensemble	514	6.1	0.48	0.96	0.76	27,400	14,400

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	shortspine thornyhead	subadult	2017	MaxEnt	306	--	--	0.96	--	22,800	12,000
AI	shortspine thornyhead	subadult	2023	ensemble	380	8.1	0.46	0.98	0.76	23,200	12,200
AI	shortspine thornyhead	adult	2017	hGAM	745	28.8	0.72	0.95	0.54	21,300	11,200
AI	shortspine thornyhead	adult	2023	ensemble	1,051	26.1	0.61	0.93	0.74	54,800	28,900
AI	southern rock sole	subadult	2017	MaxEnt	395	--	--	0.96	--	34,100	17,900
AI	southern rock sole	subadult	2023	ensemble	583	12.9	0.55	0.97	0.73	41,600	21,900
AI	southern rock sole	adult	2017	MaxEnt	616	--	--	0.95	--	47,700	25,100
AI	southern rock sole	adult	2023	ensemble	763	11.0	0.62	0.97	0.81	42,300	22,200
AI	walleye pollock	subadult	2017	hGAM	794	341	0.34	0.78	-0.06	30,300	16,000
AI	walleye pollock	subadult	2023	ensemble	1,525	324	0.41	0.75	0.4	77,700	40,900
AI	walleye pollock	adult	2017	GAM	2,173	488	0.52	0.76	-0.44	66,800	35,200
AI	walleye pollock	adult	2023	ensemble	2,773	447	0.5	0.71	0.28	77,700	40,900
EBS	Alaska plaice	adult	2017	GAM	6,982	150	0.79	0.91	0.37	610,900	321,500
EBS	Alaska plaice	adult	2023	ensemble	8,684	111	0.81	0.92	0.56	660,400	347,600
EBS	Alaska skate	subadult	2017	GAM	4,845	10.9	0.63	0.84	-0.03	651,800	342,700
EBS	Alaska skate	subadult	2023	ensemble	6,801	10.1	0.63	0.86	0.32	676,100	355,800
EBS	Alaska skate	adult	2017	hGAM	3,634	6.0	0.47	0.76	-1.13	324,000	170,500
EBS	Alaska skate	adult	2023	ensemble	5,162	5.0	0.55	0.78	0.29	673,700	354,600
EBS	Aleutian skate	subadult	2017	hGAM	773	3.7	0.8	0.98	0.7	42,100	22,200

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	Aleutian skate	subadult	2023	ensemble	1,021	3.6	0.55	0.98	0.76	158,500	83,400
EBS	Aleutian skate	adult	2017	MaxEnt	150	--	--	0.97	--	62,300	32,800
EBS	Aleutian skate	adult	2023	ensemble	207	0.44	0.3	0.96	0.57	59,000	31,000
EBS	arrowtooth flounder	subadult	2017	GAM	3,357	95.9	0.75	0.92	0.43	505,800	265,900
EBS	arrowtooth flounder	subadult	2023	ensemble	5,669	119	0.84	0.95	0.69	524,200	275,900
EBS	arrowtooth flounder	adult	2017	GAM	4,149	83.9	0.82	0.95	0.45	504,500	265,500
EBS	arrowtooth flounder	adult	2023	ensemble	4,976	26.6	0.81	0.96	0.64	426,400	224,400
EBS	Atka mackerel	adult	2017	MaxEnt	57	--	--	0.88	--	296,200	155,400
EBS	Atka mackerel	adult	2023	ensemble	72	0.69	0.09	0.85	0.28	26,200	13,800
EBS	Bering skate	subadult	2017	hGAM	962	2.3	0.61	0.93	0.19	110,500	58,200
EBS	Bering skate	subadult	2023	ensemble	1,232	2.0	0.52	0.93	0.6	240,300	126,400
EBS	Bering skate	adult	2017	hGAM	1,045	1.0	0.54	0.9	-0.18	136,400	71,800
EBS	Bering skate	adult	2023	ensemble	1,429	0.88	0.51	0.9	0.48	267,300	140,700
EBS	blue king crab	all	2017	hGAM	1,373	8.5	0.62	0.94	0.52	109,400	57,600
EBS	blue king crab	all	2023	ensemble	1,650	8.0	0.47	0.93	0.52	472,600	248,700
EBS	Dover sole	subadult	2017	MaxEnt	109	--	--	0.93	--	170,400	89,700
EBS	Dover sole	subadult	2023	ensemble	182	0.45	0.21	0.96	0.57	45,500	23,900
EBS	Dover sole	adult	2017	MaxEnt	114	--	--	0.99	--	30,700	16,100
EBS	Dover sole	adult	2023	ensemble	91	0.37	0.3	0.99	0.73	13,200	7,000

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	flathead sole	subadult	2017	GAM	6,386	142	0.75	0.89	0.34	471,900	248,400
EBS	flathead sole	subadult	2023	ensemble	9,501	186	0.83	0.9	0.66	680,900	358,300
EBS	flathead sole	adult	2017	GAM	8,351	251	0.79	0.89	0.26	477,000	251,200
EBS	flathead sole	adult	2023	ensemble	9,702	143	0.71	0.88	0.33	681,800	358,900
EBS	giant octopus	all	2017	MaxEnt	492	--	--	0.87	--	335,100	176,000
EBS	giant octopus	all	2023	ensemble	693	0.69	0.28	0.88	0.31	207,500	109,200
EBS	Greenland turbot	subadult	2017	hGAM	2,370	11.5	0.63	0.92	0.31	158,100	83,200
EBS	Greenland turbot	subadult	2023	ensemble	2,419	10.2	0.55	0.93	0.58	392,300	206,500
EBS	Greenland turbot	adult	2017	hGAM	1,395	4.0	0.65	0.95	0.51	97,100	51,100
EBS	Greenland turbot	adult	2023	ensemble	1,974	4.2	0.53	0.95	0.7	241,800	127,300
EBS	Kamchatka flounder	subadult	2017	GAM	3,614	25.8	0.76	0.94	0.29	510,100	268,300
EBS	Kamchatka flounder	subadult	2023	ensemble	5,055	23.4	0.77	0.94	0.55	443,700	233,500
EBS	Kamchatka flounder	adult	2017	hGAM	1,658	4.0	0.61	0.92	0.3	125,600	66,100
EBS	Kamchatka flounder	adult	2023	ensemble	1,752	2.1	0.51	0.91	0.63	276,300	145,400
EBS	mud skate	subadult	2017	MaxEnt	149	--	--	0.99	--	27,600	14,500
EBS	mud skate	subadult	2023	ensemble	169	0.52	0.31	0.98	0.84	24,600	12,900
EBS	mud skate	adult	2017	MaxEnt	93	--	--	0.97	--	65,600	34,400
EBS	mud skate	adult	2023	ensemble	147	0.43	0.28	0.98	0.69	25,700	13,500
EBS	northern rock sole	subadult	2017	GAM	4,232	790	0.8	0.89	0.48	553,100	290,800

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	northern rock sole	subadult	2023	ensemble	7,020	716	0.86	0.82	0.65	674,800	355,100
EBS	northern rock sole	adult	2017	GAM	6,005	824	0.84	0.91	0.52	624,700	328,900
EBS	northern rock sole	adult	2023	ensemble	7,790	472	0.82	0.89	0.49	672,800	354,100
EBS	northern rockfish	adult	2017	MaxEnt	66	--	--	0.95	--	107,500	56,400
EBS	northern rockfish	adult	2023	ensemble	89	9.1	0.15	0.97	0.71	83,800	44,100
EBS	Pacific cod	subadult	2017	GAM	9,218	127	0.64	0.82	0.02	608,500	320,400
EBS	Pacific cod	subadult	2023	ensemble	12,889	118	0.59	0.8	0.24	680,500	358,200
EBS	Pacific cod	adult	2017	GAM	10,203	51.0	0.47	0.82	-0.06	663,600	349,500
EBS	Pacific cod	adult	2023	ensemble	11,853	20.5	0.48	0.79	0.15	675,700	355,600
EBS	Pacific ocean perch	subadult	2017	MaxEnt	122	--	--	0.97	--	91,600	47,800
EBS	Pacific ocean perch	subadult	2023	ensemble	131	1.9	0.18	0.98	0.56	83,900	44,100
EBS	Pacific ocean perch	adult	2017	MaxEnt	447	--	--	0.99	--	77,600	41,200
EBS	Pacific ocean perch	adult	2023	ensemble	561	308	0.34	0.99	0.39	191,900	101,000
EBS	red king crab	all	2017	hGAM	2,696	80.9	0.75	0.95	0.36	189,500	99,700
EBS	red king crab	all	2023	ensemble	3,376	74.6	0.67	0.95	0.52	363,900	191,500
EBS	rex sole	subadult	2017	hGAM	677	2.5	0.45	0.93	0.11	85,200	44,800
EBS	rex sole	subadult	2023	ensemble	1,849	9.1	0.52	0.95	0.65	262,100	137,900
EBS	rex sole	adult	2017	hGAM	1,925	17.0	0.71	0.95	0.62	123,300	64,900
EBS	rex sole	adult	2023	ensemble	2,171	9.8	0.56	0.95	0.77	233,100	122,700

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	sablefish	subadult	2017	MaxEnt	34	--	--	0.89	--	313,100	164,800
EBS	sablefish	subadult	2023	ensemble	391	2.2	0.32	0.97	0.6	75,700	39,800
EBS	sablefish	adult	2017	MaxEnt	544	--	--	0.99	--	79,500	41,800
EBS	sablefish	adult	2023	ensemble	544	1.8	0.39	0.99	0.77	67,800	35,700
EBS	shortraker rockfish	subadult	2017	MaxEnt	75	--	--	0.99	--	20,500	10,800
EBS	shortraker rockfish	subadult	2023	ensemble	122	0.88	0.31	0.99	0.8	27,800	14,600
EBS	shortraker rockfish	adult	2017	MaxEnt	127	--	--	0.99	--	22,800	12,100
EBS	shortraker rockfish	adult	2023	ensemble	142	1.7	0.33	1	0.85	13,600	7,200
EBS	shortspine thornyhead	subadult	2017	MaxEnt	220	--	--	1	--	21,500	11,200
EBS	shortspine thornyhead	subadult	2023	ensemble	253	4.3	0.5	1	0.87	22,600	11,900
EBS	shortspine thornyhead	adult	2017	MaxEnt	567	--	--	1	--	30,500	16,300
EBS	shortspine thornyhead	adult	2023	ensemble	696	16.0	0.55	1	0.92	47,700	25,100
EBS	snow crab	all	2017	GAM	8,756	1,633	0.82	0.91	0.18	607,600	319,900
EBS	snow crab	all	2023	ensemble	10,628	1,932	0.84	0.85	0.41	688,900	362,600
EBS	Tanner crab	all	2017	GAM	7,528	152	0.78	0.93	0.02	476,900	251,000
EBS	Tanner crab	all	2023	ensemble	9,244	140	0.8	0.93	0.35	540,400	284,400
EBS	walleye pollock	subadult	2017	GAM	8,680	635	0.59	0.82	-0.33	646,600	340,400
EBS	walleye pollock	subadult	2023	ensemble	9,528	553	0.69	0.76	0.3	689,500	362,900
EBS	walleye pollock	adult	2017	GAM	10,741	1,252	0.67	0.77	0.08	593,100	312,200

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	walleye pollock	adult	2023	ensemble	13,506	1,021	0.63	0.63	0.24	689,500	362,900
EBS	yellowfin sole	subadult	2017	GAM	6,808	820	0.89	0.96	0.59	582,100	306,400
EBS	yellowfin sole	subadult	2023	ensemble	9,289	977	0.9	0.95	0.63	617,900	325,200
EBS	yellowfin sole	adult	2017	GAM	7,724	744	0.88	0.96	0.59	594,100	312,700
EBS	yellowfin sole	adult	2023	ensemble	9,480	476	0.89	0.96	0.62	620,300	326,500
GOA	Alaska plaice	adult	2017	hGAM	325	3.9	0.53	0.97	0.44	40,600	21,400
GOA	Alaska plaice	adult	2023	ensemble	442	3.6	0.38	0.97	0.71	87,500	46,100
GOA	Alaska skate	subadult	2017	MaxEnt	72	--	--	0.71	--	317,700	167,100
GOA	Alaska skate	subadult	2023	ensemble	95	0.21	0.13	0.82	0.21	14,600	7,700
GOA	Alaska skate	adult	2017	MaxEnt	67	--	--	0.61	--	317,700	167,100
GOA	Alaska skate	adult	2023	ensemble	78	0.15	0.13	0.85	0.25	13,300	7,000
GOA	Aleutian skate	subadult	2017	hGAM	418	0.81	0.3	0.79	-0.89	71,600	37,700
GOA	Aleutian skate	subadult	2023	ensemble	613	0.54	0.28	0.78	0.3	165,800	87,300
GOA	Aleutian skate	adult	2017	MaxEnt	119	--	--	0.81	--	317,700	167,200
GOA	Aleutian skate	adult	2023	ensemble	147	0.19	0.17	0.83	0.25	30,600	16,100
GOA	arrowtooth flounder	subadult	2017	GAM	4,929	155	0.56	0.81	-0.14	295,900	155,700
GOA	arrowtooth flounder	subadult	2023	ensemble	7,390	276	0.64	0.7	0.28	281,800	148,300
GOA	arrowtooth flounder	adult	2017	GAM	5,583	376	0.6	0.84	-0.14	302,700	159,300
GOA	arrowtooth flounder	adult	2023	ensemble	7,043	189	0.55	0.76	0.29	281,800	148,300

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	Bering skate	subadult	2017	MaxEnt	313	--	--	0.83	--	317,700	167,300
GOA	Bering skate	subadult	2023	ensemble	401	0.33	0.27	0.84	0.28	113,600	59,800
GOA	Bering skate	adult	2017	MaxEnt	319	--	--	0.79	--	317,700	167,100
GOA	Bering skate	adult	2023	ensemble	407	0.32	0.28	0.84	0.31	94,700	49,800
GOA	Dover sole	subadult	2017	GAM	2,396	12.4	0.53	0.8	-0.3	281,100	148,000
GOA	Dover sole	subadult	2023	ensemble	3,710	17.4	0.62	0.83	0.46	281,300	148,000
GOA	Dover sole	adult	2017	GAM	2,685	21.6	0.67	0.87	-0.02	263,800	138,900
GOA	Dover sole	adult	2023	ensemble	2,973	11.0	0.62	0.87	0.42	272,900	143,600
GOA	dusky rockfish	subadult	2017	MaxEnt	100	--	--	0.82	--	317,700	167,000
GOA	dusky rockfish	subadult	2023	ensemble	315	17.7	0.21	0.8	0.27	235,200	123,800
GOA	dusky rockfish	adult	2017	hGAM	783	67.7	0.37	0.81	-0.78	74,200	39,100
GOA	dusky rockfish	adult	2023	ensemble	1,061	53.1	0.4	0.83	0.28	264,000	138,900
GOA	flathead sole	subadult	2017	GAM	2,556	104	0.55	0.8	-0.25	262,200	138,000
GOA	flathead sole	subadult	2023	ensemble	4,064	109	0.71	0.86	0.65	257,900	135,700
GOA	flathead sole	adult	2017	GAM	3,313	125	0.65	0.84	-0.14	274,900	144,700
GOA	flathead sole	adult	2023	ensemble	4,201	63.3	0.72	0.88	0.54	257,900	135,700
GOA	giant octopus	all	2017	MaxEnt	286	--	--	0.75	--	317,700	167,100
GOA	giant octopus	all	2023	ensemble	459	0.33	0.2	0.75	0.15	134,900	71,000
GOA	harlequin rockfish	subadult	2017	MaxEnt	221	--	--	0.86	--	317,600	167,200

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	harlequin rockfish	subadult	2023	ensemble	102	14.6	0.16	0.92	0.5	170,600	89,800
GOA	harlequin rockfish	adult	2017	hGAM	344	70.0	0.29	0.86	0.05	64,600	34,000
GOA	harlequin rockfish	adult	2023	ensemble	514	71.3	0.31	0.88	0.44	254,800	134,100
GOA	northern rock sole	subadult	2017	hGAM	1,319	52.7	0.76	0.95	0.52	77,900	41,000
GOA	northern rock sole	subadult	2023	ensemble	1,854	57.3	0.68	0.96	0.68	182,200	95,900
GOA	northern rock sole	adult	2017	hGAM	1,546	28.3	0.78	0.95	0.45	88,500	46,600
GOA	northern rock sole	adult	2023	ensemble	1,980	25.0	0.68	0.95	0.58	190,700	100,400
GOA	northern rockfish	subadult	2017	MaxEnt	203	--	--	0.85	--	317,700	167,100
GOA	northern rockfish	subadult	2023	ensemble	522	8.3	0.3	0.86	0.42	215,600	113,500
GOA	northern rockfish	adult	2017	hGAM	942	318	0.51	0.88	0.11	56,600	29,800
GOA	northern rockfish	adult	2023	ensemble	1,141	276	0.46	0.89	0.32	261,100	137,400
GOA	Pacific cod	subadult	2017	GAM	1,947	143	0.52	0.81	-0.3	260,200	136,900
GOA	Pacific cod	subadult	2023	ensemble	3,653	66.2	0.53	0.79	0.3	265,600	139,800
GOA	Pacific cod	adult	2017	GAM	3,615	97.9	0.48	0.76	-0.36	295,900	155,700
GOA	Pacific cod	adult	2023	ensemble	4,476	70.2	0.47	0.75	0.25	264,700	139,300
GOA	Pacific ocean perch	subadult	2017	hGAM	1,612	68.5	0.51	0.85	-0.08	100,100	52,700
GOA	Pacific ocean perch	subadult	2023	ensemble	1,686	48.6	0.49	0.85	0.39	253,400	133,400
GOA	Pacific ocean perch	adult	2017	GAM	2,129	700	0.61	0.86	-0.38	248,000	130,500
GOA	Pacific ocean perch	adult	2023	ensemble	2,992	692	0.65	0.81	0.39	281,500	148,100

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	pygmy rockfish	all	2017	MaxEnt	54	--	--	0.89	--	317,700	166,900
GOA	pygmy rockfish	all	2023	ensemble	63	3.0	0.14	0.96	0.4	74,900	39,400
GOA	redbanded rockfish	subadult	2017	hGAM	599	2.3	0.55	0.93	0.26	50,100	26,400
GOA	redbanded rockfish	subadult	2023	ensemble	829	2.1	0.46	0.94	0.63	116,600	61,400
GOA	redbanded rockfish	adult	2017	MaxEnt	223	--	--	0.92	--	317,700	167,200
GOA	redbanded rockfish	adult	2023	ensemble	321	1.6	0.29	0.93	0.49	98,800	52,000
GOA	redstripe rockfish	subadult	2017	MaxEnt	72	--	--	0.86	--	317,600	167,100
GOA	redstripe rockfish	subadult	2023	ensemble	133	7.2	0.2	0.95	0.52	95,400	50,200
GOA	redstripe rockfish	adult	2017	MaxEnt	163	--	--	0.91	--	317,700	167,100
GOA	redstripe rockfish	adult	2023	ensemble	234	47.9	0.25	0.94	0.65	214,500	112,900
GOA	rex sole	subadult	2017	hGAM	1,907	6.4	0.39	0.77	-0.94	127,100	66,900
GOA	rex sole	subadult	2023	ensemble	4,744	33.6	0.56	0.8	0.32	281,800	148,300
GOA	rex sole	adult	2017	GAM	3,962	64.6	0.57	0.82	-0.32	286,500	150,800
GOA	rex sole	adult	2023	ensemble	4,455	36.3	0.59	0.8	0.37	280,100	147,400
GOA	rosethorn rockfish	subadult	2017	MaxEnt	105	--	--	0.97	--	317,700	167,300
GOA	rosethorn rockfish	subadult	2023	ensemble	132	0.93	0.3	0.99	0.76	25,900	13,700
GOA	rosethorn rockfish	adult	2017	MaxEnt	141	--	--	0.97	--	317,600	167,200
GOA	rosethorn rockfish	adult	2023	ensemble	186	2.5	0.4	0.99	0.82	29,600	15,600
GOA	sablefish	subadult	2017	hGAM	463	4.5	0.31	0.84	-0.22	117,700	61,900

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	sablefish	subadult	2023	ensemble	2,812	47.0	0.56	0.84	0.34	278,400	146,500
GOA	sablefish	adult	2017	GAM	2,383	58.3	0.71	0.9	-0.13	245,300	129,100
GOA	sablefish	adult	2023	ensemble	2,011	18.9	0.65	0.94	0.61	216,700	114,100
GOA	sharpchin rockfish	subadult	2017	hGAM	405	59.7	0.47	0.93	0.43	56,600	29,800
GOA	sharpchin rockfish	subadult	2023	ensemble	498	47.0	0.37	0.96	0.69	191,800	100,900
GOA	sharpchin rockfish	adult	2017	MaxEnt	337	--	--	0.91	--	317,700	167,200
GOA	sharpchin rockfish	adult	2023	ensemble	425	97.9	0.34	0.95	0.54	218,600	115,100
GOA	shortraker rockfish	subadult	2017	MaxEnt	164	--	--	0.98	--	317,700	167,400
GOA	shortraker rockfish	subadult	2023	ensemble	316	1.4	0.45	0.99	0.77	24,800	13,000
GOA	shortraker rockfish	adult	2017	hGAM	526	9.3	0.67	0.97	0.65	36,000	19,000
GOA	shortraker rockfish	adult	2023	ensemble	679	7.6	0.47	0.97	0.73	65,200	34,300
GOA	shortspine thornyhead	subadult	2017	hGAM	1,258	27.3	0.84	0.98	0.71	66,500	35,000
GOA	shortspine thornyhead	subadult	2023	ensemble	1,634	24.4	0.65	0.97	0.76	186,900	98,400
GOA	shortspine thornyhead	adult	2017	hGAM	1,490	47.5	0.85	0.98	0.77	84,900	44,700
GOA	shortspine thornyhead	adult	2023	ensemble	1,998	44.4	0.7	0.96	0.82	229,200	120,600
GOA	silvergray rockfish	subadult	2017	MaxEnt	124	--	--	0.83	--	317,700	167,200
GOA	silvergray rockfish	subadult	2023	ensemble	159	1.4	0.18	0.88	0.21	104,500	55,000
GOA	silvergray rockfish	adult	2017	hGAM	384	40.7	0.45	0.94	0.29	63,500	33,400
GOA	silvergray rockfish	adult	2023	ensemble	557	33.3	0.37	0.93	0.63	184,300	97,000

Region	Species	Life stage	Year	Model	N	RMSE	*ρ*	AUC	PDE	EFH area	Core EFH area
GOA	southern rock sole	subadult	2017	hGAM	1,451	24.5	0.69	0.92	0.22	98,700	51,900
GOA	southern rock sole	subadult	2023	ensemble	2,213	30.2	0.71	0.94	0.65	198,100	104,300
GOA	southern rock sole	adult	2017	GAM	2,154	37.4	0.72	0.91	0.21	248,900	131,000
GOA	southern rock sole	adult	2023	ensemble	2,772	22.1	0.76	0.94	0.64	212,100	111,700
GOA	walleye pollock	subadult	2017	GAM	3,271	300	0.43	0.73	-0.68	301,200	158,500
GOA	walleye pollock	subadult	2023	ensemble	4,599	298	0.4	0.7	0.21	281,700	148,300
GOA	walleye pollock	adult	2017	GAM	3,259	259	0.55	0.8	-0.79	277,200	145,900
GOA	walleye pollock	adult	2023	ensemble	4,351	237	0.49	0.74	0.23	281,800	148,300
GOA	yelloweye rockfish	subadult	2017	MaxEnt	53	--	--	0.85	--	317,700	167,000
GOA	yelloweye rockfish	subadult	2023	ensemble	79	0.17	0.16	0.92	0.39	27,100	14,300
GOA	yelloweye rockfish	adult	2017	MaxEnt	142	--	--	0.86	--	317,600	167,200
GOA	yelloweye rockfish	adult	2023	ensemble	186	0.46	0.22	0.91	0.43	64,500	33,900
GOA	yellowfin sole	subadult	2017	MaxEnt	225	--	--	0.97	--	317,700	167,200
GOA	yellowfin sole	subadult	2023	ensemble	401	46.9	0.38	0.98	0.78	101,600	53,500
GOA	yellowfin sole	adult	2017	hGAM	367	88.7	0.62	0.97	0.61	35,000	18,400
GOA	yellowfin sole	adult	2023	ensemble	491	58.0	0.4	0.98	0.79	118,900	62,600

D.3 Comparisons of 2017 and 2023 EFH

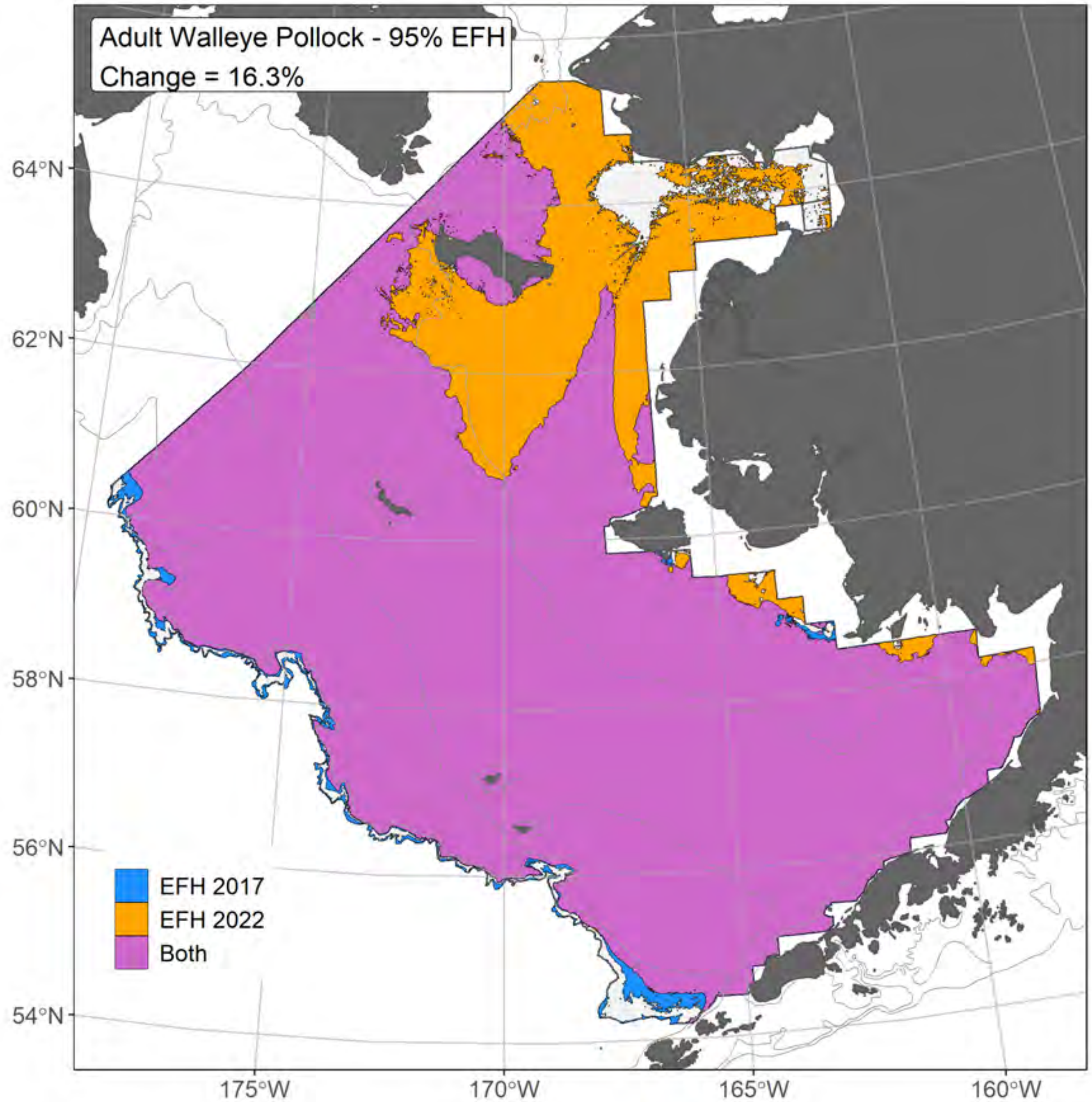

Figure D1. Change from 2017 to 2023 in essential fish habitat (EFH), which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from adult walleye pollock catches in AFSC RACE-GAP summer bottom trawl surveys (1992–2019) with 50 m, 100 m, and 200 m isobaths indicated. Colored areas represent EFH in 2017, 2022 (2023), or both (see Supporting Documents 2 for additional species and life stage maps).

Appendix E SDM Performance Metrics

Appendix E provides metrics chosen by the Laman et al. study to comprehensively report SDM performance for the 2023 EFH 5-year Review, additional metrics considered by this study, and additional metrics that the SSC requested for consideration at the October 2021 meeting—

- Table E1 provides metrics for the models (SDM or ensemble) produced for the 2023 EFH 5-year Review.
  - Metrics chosen by the Laman et al. study developing the SDMs for the 2023 Review are the number of positive catches (N), the root mean square error (RMSE), Spearman's rank order correlation (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE).
  - Additional metrics considered by the Laman et al. study were the prevalence of positive catches (Prev.), the Pearson correlation (r), and accuracy (Acc.).
  - Additional metrics that the SSC requested be considered in October 2021 are the area under the precision-recall receiver operating characteristic curve (PR-AUC) and the F_1 score (F_1) (Table A1 items 6j and 6k).
  - See the Synthesis section 3.3.3 of the Results.

The 2023 EFH 5-year Review used four metrics to assess the predictive skill of SDM ensembles. The RMSE is a measure of the variance in predictions relative to the observed data, and was used to weight the constituent SDMs for each species life stage. The RMSE is useful for comparing different models, though it does not provide information about fit on its own. Spearman's rank order correlation (ρ) is a measure of whether an SDM predicts the relative ordering of high or low values in the data, and is used to assess model fit. Area under the receiver operating characteristic curve (AUC) is a measure of discrimination ability and is used to assess the ability of a model to correctly predict presence or absence. The Poisson deviance explained (PDE) is a measure of fit that adjusts for the non-normal errors expected from count data and is used to assess the ability of a model to predict the observed abundance. See the Statistical Modeling section of the Methods in this document for additional details.

The four model performance metrics selected in this project and described above are only a small sample of the total number of statistical measures available for assessing model fit. Five additional metrics investigated to describe ensemble performance are presented in Appendix E Table E1. These provide additional nuance when interpreting the validity and fit of the ensembles. The first of these is prevalence (Prev.), the number of positive catches divided by the total number of valid hauls for that species. This metric provides further information about the relative commonness or scarcity of a species in the RACE-GAP bottom trawl surveys. The Pearson correlation (r) is a commonly used statistic that measures the degree to which model predictions match observed data. It was not used in the 2023 EFH 5-year Review because it assumes that the data follow a normal distribution; count data modeled here follow a Poisson distribution. The Pearson correlation can take on values between negative one and one; higher absolute values indicate a better fit. The Precision-Recall area under the receiver operating characteristic curve (PR-AUC) is a variation of the AUC that focuses on predictive skill for presence locations. Whereas AUC measures the rate of true positives compared to the rate of false positives, PR-AUC measures the degree of precision (true positives/predicted positives) compared to recall (true positive/observed positives). PR-AUC values range from zero to one, with higher values indicating better performance. The F_1 score (F_1),

$$F_1 = 2 * \frac{precision * recall}{precision + recall},$$

is similar to PR-AUC in that it is a measure of classification skill for presence or absence data with a focus on presence locations. The F_1 score also has a value between zero and one and is typically similar to the PR-AUC. Both PR-AUC and F_1 scores were requested by the SSC at the October 2021 meeting (Table A1 items 6j and 6k) and are reported here. The accuracy (Acc.) is the number of correct predictions divided by the total number of observations, and provides an easier to interpret metric that focuses equally on presence and absence in the data

Table E1. Performance metrics for the SDMs and ensembles produced for the 2023 EFH 5-year Review. Metrics shown are the number of positive catches (N), the prevalence of positive catches (Prev.), the root mean square error (RMSE), the Pearson correlation (*r*), Spearman's rank order correlation (*ρ*), the area under the receiver operating characteristic curve (AUC), the area under the precision-recall receiver operating characteristic curve (PR-AUC), the F_1 score (F_1), the accuracy (Acc.), and the Poisson deviance explained (PDE). The "--" sign indicates circumstances where a statistic could not be calculated, which occurs for some MaxEnt models for early juveniles in the GOA. Metrics chosen by the study developing the SDMs for the 2023 EFH 5-year Review are in bold text. Additional metrics considered by this study (Prev., *r*, Acc.) are in italics. Additional metrics that the SSC requested be considered in October 2021 (PR-AUC, F_1) are underlined.

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
AI	Alaska skate	subadult	102	0.04	0.42	0.27	0.20	0.80	0.24	0.17	0.74	0.25
AI	Alaska skate	adult	149	0.06	0.65	0.30	0.25	0.81	0.22	0.25	0.75	0.27
AI	Aleutian skate	subadult	367	0.09	0.61	0.28	0.26	0.76	0.26	0.29	0.71	0.19
AI	Aleutian skate	adult	221	0.05	0.35	0.29	0.21	0.76	0.18	0.19	0.71	0.18
AI	arrowtooth flounder	early juvenile	341	0.07	1.5	0.52	0.35	0.90	0.45	0.41	0.84	0.56
AI	arrowtooth flounder	subadult	3,503	0.70	84.5	0.44	0.63	0.79	0.88	0.84	0.75	0.40
AI	arrowtooth flounder	adult	3,118	0.62	42.9	0.31	0.49	0.75	0.81	0.78	0.72	0.29
AI	Atka mackerel	subadult	1,312	0.24	1,130	0.30	0.54	0.72	0.38	0.41	0.31	0.38
AI	Atka mackerel	adult	2,030	0.38	1,190	0.40	0.52	0.65	0.47	0.56	0.41	0.36
AI	Dover sole	subadult	396	0.07	1.5	0.29	0.30	0.83	0.31	0.31	0.76	0.35
AI	Dover sole	adult	232	0.04	0.87	0.41	0.27	0.88	0.32	0.26	0.80	0.43
AI	dusky rockfish	subadult	108	0.02	1.4	0.19	0.20	0.88	0.19	0.16	0.80	0.32
AI	dusky rockfish	adult	380	0.08	9.2	0.42	0.27	0.78	0.30	0.29	0.71	0.44
AI	English sole	adult	50	0.01	1.5	0.78	0.23	0.98	0.54	0.20	0.93	0.82
AI	flathead sole	early juvenile	183	0.03	5.5	0.73	0.28	0.94	0.55	0.27	0.84	0.81
AI	flathead sole	subadult	1,279	0.24	72.8	0.70	0.60	0.89	0.70	0.68	0.81	0.72

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
AI	flathead sole	adult	1,374	0.26	13.5	0.47	0.56	0.86	0.66	0.65	0.78	0.48
AI	giant octopus	all	682	0.13	0.81	0.17	0.20	0.67	0.21	0.29	0.62	0.09
AI	golden king crab	all	1,148	0.21	6.1	0.40	0.56	0.89	0.67	0.65	0.81	0.48
AI	Greenland turbot	adult	359	0.07	11.6	0.49	0.41	0.96	0.71	0.58	0.91	0.70
AI	harlequin rockfish	adult	111	0.02	23.4	0.18	0.18	0.86	0.13	0.13	0.78	0.40
AI	Kamchatka flounder	subadult	2,207	0.44	22.6	0.62	0.58	0.81	0.76	0.70	0.73	0.51
AI	Kamchatka flounder	adult	918	0.18	19.4	0.71	0.54	0.90	0.70	0.62	0.82	0.74
AI	mud skate	subadult	488	0.12	2.1	0.65	0.46	0.90	0.58	0.52	0.82	0.63
AI	mud skate	adult	290	0.07	0.41	0.35	0.28	0.82	0.25	0.28	0.74	0.26
AI	northern rock sole	early juvenile	154	0.03	0.57	0.33	0.25	0.89	0.29	0.21	0.80	0.38
AI	northern rock sole	subadult	1,901	0.41	42.3	0.59	0.73	0.90	0.86	0.80	0.82	0.62
AI	northern rock sole	adult	2,923	0.63	58.8	0.49	0.72	0.88	0.91	0.86	0.81	0.47
AI	northern rockfish	subadult	832	0.16	271	0.35	0.43	0.82	0.41	0.36	0.47	0.50
AI	northern rockfish	adult	2,063	0.39	779	0.42	0.56	0.68	0.50	0.58	0.44	0.42
AI	Pacific cod	subadult	2,872	0.54	34.1	0.30	0.47	0.74	0.71	0.76	0.71	0.28
AI	Pacific cod	adult	3,084	0.58	40.4	0.45	0.50	0.76	0.77	0.77	0.70	0.37
AI	Pacific ocean perch	early juvenile	722	0.14	68.8	0.34	0.36	0.80	0.37	0.40	0.67	0.38
AI	Pacific ocean perch	subadult	1,016	0.19	175	0.37	0.40	0.78	0.42	0.40	0.45	0.39
AI	Pacific ocean perch	adult	2,908	0.54	1,570	0.50	0.71	0.68	0.65	0.70	0.54	0.46
AI	red king crab	all	83	0.02	1.6	0.15	0.15	0.85	0.10	0.10	0.77	0.27

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
AI	rex sole	subadult	1,145	0.21	8.1	0.55	0.48	0.83	0.60	0.56	0.75	0.47
AI	rex sole	adult	1,891	0.35	22.6	0.46	0.56	0.82	0.71	0.67	0.74	0.43
AI	rougheye blackspotted complex	subadult	1,058	0.20	10.9	0.51	0.53	0.88	0.63	0.61	0.80	0.51
AI	rougheye blackspotted complex	adult	711	0.13	19.4	0.81	0.52	0.94	0.71	0.62	0.86	0.76
AI	sablefish	subadult	472	0.09	9.7	0.35	0.43	0.93	0.66	0.51	0.86	0.54
AI	sablefish	adult	368	0.07	8.1	0.78	0.40	0.95	0.56	0.50	0.88	0.66
AI	shortraker rockfish	subadult	408	0.08	8.5	0.82	0.47	0.98	0.85	0.68	0.93	0.86
AI	shortraker rockfish	adult	514	0.10	6.1	0.81	0.48	0.96	0.75	0.63	0.90	0.76
AI	shortspine thornyhead	subadult	380	0.07	8.1	0.55	0.46	0.98	0.83	0.64	0.93	0.76
AI	shortspine thornyhead	adult	1,051	0.20	26.1	0.74	0.61	0.93	0.80	0.70	0.85	0.74
AI	southern rock sole	subadult	583	0.13	12.9	0.56	0.55	0.97	0.82	0.75	0.92	0.73
AI	southern rock sole	adult	763	0.17	11.0	0.72	0.62	0.97	0.90	0.79	0.92	0.81
AI	walleye pollock	early juvenile	198	0.04	4.8	0.22	0.23	0.86	0.21	0.20	0.77	0.37
AI	walleye pollock	subadult	1,525	0.28	324	0.38	0.41	0.75	0.49	0.54	0.55	0.40
AI	walleye pollock	adult	2,773	0.52	447	0.30	0.50	0.71	0.66	0.68	0.52	0.28
AI	whiteblotched skate	subadult	459	0.11	2.5	0.61	0.48	0.94	0.62	0.60	0.87	0.66
AI	whiteblotched skate	adult	544	0.13	2.1	0.73	0.49	0.92	0.70	0.57	0.84	0.72
EBS	Alaska plaice	early juvenile	272	0.02	4.1	0.53	0.25	0.97	0.61	0.32	0.93	0.69
EBS	Alaska plaice	subadult	6,527	0.42	53.9	0.53	0.79	0.94	0.90	0.85	0.86	0.60

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
EBS	Alaska plaice	adult	8,684	0.56	111	0.54	0.81	0.92	0.91	0.84	0.80	0.56
EBS	Alaska skate	subadult	6,801	0.72	10.1	0.41	0.63	0.86	0.93	0.86	0.81	0.32
EBS	Alaska skate	adult	5,162	0.55	5.0	0.31	0.55	0.78	0.80	0.72	0.70	0.29
EBS	Aleutian skate	subadult	1,021	0.11	3.6	0.69	0.55	0.98	0.84	0.74	0.93	0.76
EBS	Aleutian skate	adult	207	0.02	0.44	0.35	0.30	0.96	0.30	0.33	0.92	0.57
EBS	arrowtooth flounder	early juvenile	1,975	0.16	8.6	0.44	0.56	0.93	0.69	0.67	0.86	0.55
EBS	arrowtooth flounder	subadult	5,669	0.47	119	0.65	0.84	0.95	0.93	0.88	0.88	0.69
EBS	arrowtooth flounder	adult	4,976	0.41	26.6	0.54	0.81	0.96	0.94	0.87	0.89	0.64
EBS	Atka mackerel	adult	72	0.00	0.69	0.08	0.09	0.85	0.05	0.02	0.71	0.28
EBS	Bering skate	subadult	1,232	0.13	2.0	0.58	0.52	0.93	0.66	0.62	0.86	0.60
EBS	Bering skate	adult	1,429	0.15	0.88	0.50	0.51	0.90	0.56	0.59	0.83	0.48
EBS	Bering sole	subadult	2,583	0.17	30.2	0.60	0.61	0.97	0.87	0.76	0.91	0.74
EBS	Bering sole	adult	2,966	0.19	29.6	0.46	0.64	0.96	0.85	0.78	0.90	0.67
EBS	big skate	subadult	62	0.00	0.11	0.57	0.17	0.96	0.35	0.09	0.94	0.58
EBS	blue king crab	all	1,650	0.11	8.0	0.35	0.47	0.93	0.70	0.57	0.86	0.52
EBS	butter sole	adult	177	0.01	13.7	0.32	0.20	0.98	0.34	0.24	0.93	0.60
EBS	deepsea sole	all	110	0.01	0.30	0.84	0.45	1.00	0.70	0.48	0.98	0.87
EBS	Dover sole	subadult	182	0.01	0.45	0.40	0.21	0.96	0.38	0.14	0.87	0.57
EBS	Dover sole	adult	91	0.01	0.37	0.47	0.30	0.99	0.48	0.33	0.98	0.73
EBS	flathead sole	early juvenile	4,794	0.31	36.6	0.35	0.60	0.86	0.72	0.67	0.77	0.44

Region	**Species**	**Life stage**	**N**	***Prev.***	**RMSE**	***r***	***ρ***	**AUC**	**PR-AUC**	**F_1**	***Acc.***	**PDE**
EBS	flathead sole	subadult	9,501	0.61	186	0.66	0.83	0.90	0.90	0.86	0.81	0.66
EBS	flathead sole	adult	9,702	0.62	143	0.26	0.71	0.88	0.89	0.86	0.81	0.33
EBS	giant octopus	all	693	0.04	0.69	0.28	0.28	0.88	0.30	0.26	0.80	0.31
EBS	Greenland turbot	subadult	2,419	0.15	10.2	0.47	0.55	0.93	0.73	0.64	0.85	0.58
EBS	Greenland turbot	adult	1,974	0.13	4.2	0.50	0.53	0.95	0.77	0.66	0.88	0.70
EBS	Kamchatka flounder	subadult	5,055	0.42	23.4	0.46	0.77	0.94	0.92	0.85	0.87	0.55
EBS	Kamchatka flounder	adult	1,752	0.15	2.1	0.67	0.51	0.91	0.67	0.58	0.83	0.63
EBS	longhead dab	all	2,307	0.15	54.0	0.57	0.61	0.97	0.80	0.76	0.91	0.68
EBS	mud skate	subadult	169	0.02	0.52	0.90	0.31	0.98	0.72	0.39	0.95	0.83
EBS	mud skate	adult	147	0.02	0.43	0.49	0.28	0.98	0.54	0.30	0.93	0.69
EBS	northern rock sole	early juvenile	2,884	0.27	378	0.34	0.67	0.90	0.66	0.65	0.70	0.51
EBS	northern rock sole	subadult	7,020	0.67	716	0.66	0.86	0.82	0.85	0.86	0.78	0.65
EBS	northern rock sole	adult	7,790	0.74	472	0.44	0.82	0.89	0.93	0.91	0.85	0.49
EBS	northern rockfish	adult	89	0.01	9.1	0.40	0.15	0.97	0.35	0.11	0.92	0.71
EBS	Pacific cod	early juvenile	3,213	0.21	44.9	0.19	0.53	0.87	0.58	0.62	0.80	0.38
EBS	Pacific cod	subadult	12,889	0.83	118	0.29	0.58	0.80	0.93	0.93	0.88	0.24
EBS	Pacific cod	adult	11,853	0.76	20.5	0.21	0.48	0.79	0.91	0.88	0.81	0.15
EBS	Pacific ocean perch	early juvenile	95	0.01	1.2	0.28	0.17	0.97	0.23	0.11	0.91	0.59
EBS	Pacific ocean perch	subadult	131	0.01	1.9	0.29	0.18	0.98	0.23	0.17	0.92	0.56
EBS	Pacific ocean perch	adult	561	0.04	308	0.09	0.34	0.99	0.80	0.57	0.95	0.39

Region	**Species**	**Life stage**	**N**	***Prev.***	**RMSE**	***r***	***ρ***	**AUC**	**PR-AUC**	**F_1**	***Acc.***	**PDE**
EBS	red king crab	all	3,376	0.22	74.6	0.21	0.67	0.95	0.84	0.73	0.86	0.52
EBS	rex sole	early juvenile	105	0.01	0.20	0.26	0.15	0.94	0.12	0.08	0.87	0.40
EBS	rex sole	subadult	1,849	0.12	9.1	0.50	0.52	0.95	0.71	0.66	0.89	0.65
EBS	rex sole	adult	2,171	0.14	9.8	0.75	0.56	0.95	0.76	0.69	0.89	0.77
EBS	rougheye blackspotted complex	subadult	208	0.01	0.82	0.80	0.28	0.99	0.63	0.32	0.95	0.78
EBS	rougheye blackspotted complex	adult	105	0.01	0.15	0.71	0.36	0.99	0.56	0.31	0.97	0.75
EBS	sablefish	early juvenile	59	0.00	0.21	0.19	0.12	0.94	0.10	0.06	0.91	0.37
EBS	sablefish	subadult	391	0.02	2.2	0.40	0.32	0.97	0.60	0.37	0.92	0.60
EBS	sablefish	adult	544	0.04	1.8	0.64	0.39	0.99	0.83	0.57	0.95	0.77
EBS	Sakhalin sole	subadult	476	0.03	16.5	0.32	0.29	0.98	0.65	0.44	0.93	0.63
EBS	Sakhalin sole	adult	225	0.01	2.1	0.47	0.22	0.97	0.48	0.23	0.91	0.68
EBS	shortraker rockfish	subadult	122	0.01	0.88	0.52	0.31	0.99	0.64	0.27	0.96	0.80
EBS	shortraker rockfish	adult	142	0.01	1.7	0.83	0.33	0.99	0.76	0.46	0.98	0.85
EBS	shortspine thornyhead	subadult	253	0.02	4.3	0.63	0.50	1.00	0.88	0.59	0.98	0.87
EBS	shortspine thornyhead	adult	696	0.04	16.0	0.80	0.55	1.00	0.93	0.83	0.98	0.92
EBS	snow crab	all	10,628	0.68	1,930	0.34	0.84	0.85	0.88	0.87	0.79	0.41
EBS	starry flounder	subadult	575	0.04	11.4	0.47	0.37	0.97	0.55	0.45	0.92	0.69
EBS	starry flounder	adult	1,619	0.10	19.2	0.33	0.51	0.96	0.69	0.66	0.90	0.58
EBS	Tanner crab	all	9,244	0.59	140	0.30	0.80	0.93	0.94	0.88	0.84	0.35

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
EBS	walleye pollock	early juvenile	9,367	0.60	463	0.11	0.55	0.75	0.76	0.79	0.68	0.14
EBS	walleye pollock	subadult	9,528	0.61	553	0.27	0.69	0.76	0.77	0.78	0.66	0.30
EBS	walleye pollock	adult	13,506	0.87	1,020	0.31	0.63	0.63	0.90	0.94	0.88	0.24
EBS	whiteblotched skate	subadult	224	0.02	1.8	0.45	0.34	0.99	0.62	0.46	0.95	0.72
EBS	whiteblotched skate	adult	201	0.02	0.34	0.59	0.33	0.98	0.60	0.42	0.94	0.69
EBS	yellowfin sole	early juvenile	2,134	0.14	191	0.40	0.57	0.97	0.78	0.70	0.89	0.65
EBS	yellowfin sole	subadult	9,289	0.60	977	0.54	0.90	0.95	0.93	0.91	0.88	0.63
EBS	yellowfin sole	adult	9,480	0.61	476	0.54	0.89	0.96	0.95	0.92	0.89	0.62
GOA	Alaska plaice	subadult	85	0.01	0.83	0.34	0.23	0.98	0.44	0.22	0.94	0.62
GOA	Alaska plaice	adult	442	0.05	3.6	0.59	0.38	0.97	0.68	0.53	0.92	0.71
GOA	Alaska skate	subadult	95	0.01	0.21	0.22	0.13	0.82	0.08	0.07	0.72	0.21
GOA	Alaska skate	adult	78	0.01	0.15	0.23	0.13	0.85	0.08	0.08	0.83	0.24
GOA	Aleutian skate	subadult	613	0.09	0.54	0.46	0.28	0.78	0.37	0.28	0.69	0.30
GOA	Aleutian skate	adult	147	0.02	0.19	0.24	0.17	0.83	0.15	0.12	0.77	0.25
GOA	arrowtooth flounder	early juvenile	1,825	0.23	--	--	--	0.79	0.58	0.53	0.71	--
GOA	arrowtooth flounder	subadult	7,390	0.87	276	0.35	0.64	0.70	0.92	0.93	0.88	0.28
GOA	arrowtooth flounder	adult	7,043	0.83	189	0.32	0.55	0.76	0.92	0.92	0.85	0.29
GOA	Atka mackerel	subadult	87	0.01	1.6	0.21	0.15	0.91	0.14	0.09	0.82	0.40
GOA	Atka mackerel	adult	700	0.08	143	0.10	0.33	0.85	0.31	0.36	0.77	0.35
GOA	Bering skate	subadult	401	0.06	0.33	0.37	0.27	0.84	0.28	0.27	0.76	0.28

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
GOA	Bering skate	adult	407	0.06	0.32	0.40	0.28	0.84	0.33	0.27	0.76	0.31
GOA	big skate	subadult	594	0.07	1.1	0.48	0.31	0.85	0.32	0.32	0.77	0.44
GOA	big skate	adult	195	0.02	0.20	0.29	0.19	0.86	0.15	0.15	0.80	0.27
GOA	butter sole	adult	881	0.10	30.1	0.47	0.46	0.93	0.61	0.55	0.85	0.54
GOA	Dover sole	subadult	3,710	0.44	17.4	0.51	0.61	0.83	0.78	0.73	0.75	0.46
GOA	Dover sole	adult	2,973	0.35	11.0	0.43	0.62	0.87	0.75	0.71	0.78	0.42
GOA	dusky rockfish	subadult	315	0.04	17.7	0.09	0.21	0.80	0.17	0.17	0.72	0.27
GOA	dusky rockfish	adult	1,061	0.14	53.1	0.23	0.40	0.83	0.40	0.47	0.76	0.28
GOA	English sole	early juvenile	56	0.01	--	--	--	0.99	0.89	0.22	0.95	--
GOA	English sole	subadult	116	0.01	2.3	0.28	0.20	0.95	0.30	0.20	0.90	0.57
GOA	English sole	adult	746	0.09	13.3	0.50	0.34	0.84	0.40	0.35	0.76	0.52
GOA	flathead sole	early juvenile	2,017	0.24	--	--	--	0.90	0.80	0.68	0.82	--
GOA	flathead sole	subadult	4,064	0.48	109	0.66	0.71	0.86	0.83	0.76	0.71	0.65
GOA	flathead sole	adult	4,201	0.49	63.3	0.60	0.72	0.88	0.87	0.79	0.75	0.54
GOA	giant octopus	all	459	0.05	0.33	0.24	0.20	0.75	0.16	0.20	0.70	0.15
GOA	greenstriped rockfish	adult	120	0.01	1.4	0.70	0.30	1.00	0.81	0.51	0.97	0.85
GOA	harlequin rockfish	subadult	102	0.01	14.6	0.26	0.16	0.92	0.18	0.11	0.84	0.50
GOA	harlequin rockfish	adult	514	0.06	71.3	0.50	0.31	0.88	0.33	0.33	0.80	0.44
GOA	longnose skate	subadult	1,058	0.12	0.63	0.24	0.28	0.74	0.25	0.34	0.67	0.15
GOA	longnose skate	adult	845	0.10	0.46	0.25	0.25	0.74	0.21	0.29	0.67	0.15

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
GOA	northern/southern rock soles	early juvenile	252	0.03	--	--	--	0.95	0.65	0.32	0.87	--
GOA	northern rock sole	subadult	1,854	0.24	57.3	0.58	0.68	0.96	0.85	0.79	0.88	0.68
GOA	northern rock sole	adult	1,980	0.25	25.0	0.46	0.68	0.95	0.85	0.79	0.88	0.58
GOA	northern rockfish	subadult	522	0.06	8.3	0.31	0.30	0.86	0.30	0.30	0.78	0.42
GOA	northern rockfish	adult	1,141	0.13	276	0.12	0.46	0.89	0.50	0.43	0.66	0.32
GOA	Pacific cod	early juvenile	354	0.05	--	--	--	0.95	0.76	0.40	0.88	--
GOA	Pacific cod	subadult	3,653	0.43	66.2	0.23	0.53	0.79	0.68	0.72	0.72	0.30
GOA	Pacific cod	adult	4,476	0.53	70.2	0.21	0.47	0.75	0.71	0.76	0.70	0.25
GOA	Pacific ocean perch	early juvenile	1,552	0.21	--	--	--	0.80	0.51	0.54	0.73	--
GOA	Pacific ocean perch	subadult	1,686	0.20	48.6	0.30	0.49	0.85	0.54	0.57	0.78	0.39
GOA	Pacific ocean perch	adult	2,992	0.35	692	0.35	0.65	0.81	0.60	0.57	0.48	0.39
GOA	Pacific sanddab	all	77	0.01	2.2	0.52	0.19	0.98	0.55	0.18	0.92	0.74
GOA	Petrale sole	subadult	59	0.01	0.32	0.30	0.18	0.98	0.28	0.14	0.92	0.56
GOA	Petrale sole	adult	271	0.03	1.3	0.54	0.29	0.96	0.57	0.38	0.90	0.65
GOA	pygmy rockfish	all	63	0.01	3.0	0.09	0.14	0.96	0.15	0.10	0.88	0.40
GOA	quillback rockfish	adult	73	0.01	0.44	0.34	0.17	0.96	0.35	0.13	0.90	0.51
GOA	redbanded rockfish	subadult	829	0.10	2.1	0.58	0.46	0.94	0.65	0.56	0.87	0.63
GOA	redbanded rockfish	adult	321	0.04	1.6	0.47	0.29	0.93	0.36	0.30	0.85	0.49
GOA	redstripe rockfish	subadult	133	0.02	7.2	0.24	0.20	0.95	0.42	0.18	0.88	0.52
GOA	redstripe rockfish	adult	234	0.03	47.9	0.54	0.25	0.94	0.44	0.24	0.85	0.65

Region	**Species**	**Life stage**	**N**	***Prev.***	**RMSE**	***r***	***ρ***	**AUC**	**PR-AUC**	**F_1**	***Acc.***	**PDE**
GOA	rex sole	early juvenile	480	0.06	--	--	--	0.85	0.33	0.31	0.77	--
GOA	rex sole	subadult	4,744	0.56	33.6	0.41	0.56	0.80	0.78	0.81	0.75	0.32
GOA	rex sole	adult	4,455	0.52	36.3	0.44	0.59	0.80	0.81	0.76	0.70	0.37
GOA	rosethorn rockfish	subadult	132	0.02	0.93	0.52	0.30	0.99	0.70	0.40	0.96	0.76
GOA	rosethorn rockfish	adult	186	0.02	2.5	0.72	0.40	0.99	0.75	0.50	0.96	0.82
GOA	rougheye blackspotted complex	subadult	2,178	0.26	20.4	0.60	0.62	0.90	0.76	0.69	0.81	0.57
GOA	rougheye blackspotted complex	adult	878	0.10	9.9	0.58	0.46	0.93	0.67	0.55	0.85	0.70
GOA	sablefish	early juvenile	959	0.13	--	--	--	0.84	0.54	0.44	0.75	--
GOA	sablefish	subadult	2,812	0.33	47.0	0.40	0.56	0.84	0.67	0.68	0.77	0.34
GOA	sablefish	adult	2,011	0.24	18.9	0.47	0.65	0.94	0.82	0.73	0.85	0.61
GOA	sand sole	adult	109	0.01	4.4	0.21	0.22	0.97	0.33	0.22	0.92	0.60
GOA	sharpchin rockfish	subadult	498	0.06	47.0	0.61	0.37	0.95	0.63	0.47	0.88	0.69
GOA	sharpchin rockfish	adult	425	0.05	97.9	0.26	0.34	0.95	0.53	0.40	0.87	0.54
GOA	shortraker rockfish	subadult	316	0.04	1.4	0.60	0.45	0.99	0.80	0.58	0.95	0.77
GOA	shortraker rockfish	adult	679	0.08	7.6	0.58	0.47	0.97	0.82	0.64	0.92	0.73
GOA	shortspine thornyhead	subadult	1,634	0.19	24.4	0.70	0.65	0.97	0.90	0.82	0.92	0.76
GOA	shortspine thornyhead	adult	1,998	0.23	44.4	0.78	0.70	0.96	0.89	0.81	0.90	0.82
GOA	silvergray rockfish	subadult	159	0.02	1.4	0.05	0.18	0.88	0.13	0.13	0.81	0.21
GOA	silvergray rockfish	adult	557	0.06	33.3	0.54	0.37	0.93	0.63	0.43	0.85	0.63

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
GOA	slender sole	all	751	0.09	5.0	0.78	0.44	0.94	0.64	0.53	0.86	0.68
GOA	southern rock sole	subadult	2,213	0.28	30.2	0.57	0.71	0.94	0.86	0.80	0.88	0.64
GOA	southern rock sole	adult	2,772	0.36	22.1	0.58	0.76	0.94	0.89	0.83	0.87	0.64
GOA	spiny dogfish	all	1,291	0.15	10.0	0.34	0.42	0.84	0.43	0.47	0.75	0.48
GOA	starry flounder	early juvenile	61	0.01	--	--	--	0.98	0.88	0.24	0.95	--
GOA	starry flounder	subadult	68	0.01	0.80	0.38	0.19	0.98	0.41	0.26	0.96	0.65
GOA	starry flounder	adult	604	0.07	13.3	0.38	0.43	0.96	0.73	0.57	0.90	0.59
GOA	walleye pollock	early juvenile	2,958	0.33	--	--	--	0.82	0.76	0.65	0.74	--
GOA	walleye pollock	subadult	4,599	0.54	298	0.23	0.40	0.70	0.69	0.72	0.59	0.21
GOA	walleye pollock	adult	4,351	0.51	237	0.17	0.49	0.74	0.70	0.69	0.55	0.23
GOA	yelloweye rockfish	subadult	79	0.01	0.17	0.49	0.16	0.92	0.21	0.10	0.85	0.39
GOA	yelloweye rockfish	adult	186	0.02	0.46	0.41	0.22	0.91	0.23	0.19	0.85	0.43
GOA	yellowfin sole	early juvenile	66	0.01	--	--	--	0.98	0.61	0.26	0.95	--
GOA	yellowfin sole	subadult	401	0.05	46.9	0.68	0.38	0.98	0.71	0.61	0.94	0.78
GOA	yellowfin sole	adult	491	0.06	58.0	0.71	0.40	0.98	0.71	0.64	0.94	0.79

Appendix F Stock Assessment Author Review of EFH Component 1

A report of the stock assessment author (SA) review of EFH components 1 (descriptions and identification) and 7 (prey species habitat) was prepared as a draft ahead of the Council's November 2021 joint meeting of the Groundfish Plan Teams and provided as a final version for the February 2022 SSC meeting. This report explains the SA review process, timeline, and methods. The SAs completed species or species complex-specific reviews of—

- Current EFH text and tables in the BSAI, GOA, and Crab FMPs,
- SDM EFH maps from the 2017 EFH 5-year Review to compare to the new SDM EFH maps for the 2023 Review,
- SDM EFH mapping methods described in the three regional draft NOAA Technical Memoranda prepared for the 2023 Review (Supporting Documents 5), and
- SDM EFH mapping results chapters for individual species and species complexes (text, SDM results, and EFH maps) reported in the three regional NOAA Technical Memoranda prepared for the 2023 Review.

This report also summarizes the communications between stock assessment authors and EFH analysts receiving and responding to comments, questions, and critiques. This report also details the changes recommended to EFH component 1 information in the FMPs based on the stock assessment author review, which is summarized in the 2023 EFH 5-year Review Summary Report[58].

At the time of the stock assessment author review, the EFH analysts were also reviewing their draft methods and results. An initial approach to evaluating SDM ensemble performance using the performance metric Spearman's rho-squared (ρ^2) was determined to be insufficient by analysts and reviewers. ρ^2 was replaced in the final methods with the metric ρ (section F.2.2). The communication reported below reflects this discussion that led to improving the final results, along with other recommended changes often jointly developed between reviewers and EFH analysts.

F.1 Review Process

Review by SAs and species experts is a critical element of the iterative EFH 5-year Review process and serves to strengthen the evaluation. SA recommendations in their review are based on new information and the guidance of National Standard 2 and the EFH Final Rule to describe EFH based on the best scientific information available at the highest level of detail possible (50 CFR 600.815(a)(1)(iii)(B)).

For the 2017 Review, each SA was asked to review current FMP EFH component 1 information for each species or species complex for which they have responsibility. SAs were asked to review and update, if appropriate, EFH text descriptions, EFH levels, habitat association tables, habitat-related life history information that also included prey of EFH species (component 7), and the list of literature. SAs were provided with the new SDM maps developed for the 2017 Review and compared the new maps to the old maps from the 2010 EFH Review. Following their review, SAs were provided output from the Fishing Effects model and asked to evaluate the effects of fishing on their stocks following a method developed during the 2017 Review for EFH component 2 (fishing activities that may adversely affect EFH). This information was summarized and presented to the Plan Teams and the Council.

The 2023 Review provided an opportunity to improve the SA review process of the 2017 Review. NMFS launched the SA review with a workshop in January 2021 and concluded the process by

[58] EFH Component 1 (Chapter 2) in EFH 5-year Review Summary Report (January 2023) available on Council agenda for this meeting.

presenting the SA review report to the SSC in February 2022. Improvements to the SA review process for the 2023 EFH 5-year Review included reaching agreement with SAs regarding the timing of the document review period (achieved in the January 2021 workshop) and access to both SDM EFH mapping methods and draft results in their review. Comprehensive methods and results were not provided to the SAs in the 2017 Review. The following sections describe the SA review timeline and methods.

F.1.1 Timeline

This section provides a detailed timeline of the SA review of EFH component 1.

January 2021: NMFS AKR and AFSC EFH analysts and senior stock assessment scientists convened a summit of SAs with the following goals—

1. Inform SAs of the 2023 EFH 5-year Review process, tools in development to provide new EFH component 1 (descriptions and identification) and component 7 (prey species) information for their stocks, and their role.
2. Reach shared understanding and agreement on what is required of SAs for EFH components 1 and 7 of the 2023 EFH 5-year Review and their evaluation process.
3. Establish a timeline for SA review that accommodates their annual stock assessment cycle.
4. Discuss the connections between EFH components 1 and 7 research and stock assessment.
5. Identify opportunities to strengthen our work products to support shared management needs.

Outcomes of this meeting include the presentation of the goals listed above, discussions about how to achieve the goals, and co-development of an approach and timeline for the 2023 Review SA review of these two EFH components. Agreement was reached on the timeline to coordinate review of EFH results with existing stock assessment workload (review period from May–September 2021). Agreement was also reached on the content of the review, which was to provide an extensive, expert peer review of the current information available for components 1 and 7 and, in particular, the new information for component 1

April 2021: A paper describing the 2023 EFH 5-year Review Plan was presented to the SSC and Council. The paper described the ten EFH components, work related to the components and the FMPs, and what types of new information will be included in the EFH 5-year Review summary report. The SSC highlighted the importance of SA review in their minutes from April 2021: “*The SSC considers consultation with assessment authors to be a critical link in evaluating model configuration and output, and was pleased to hear the EFH team was involving assessment authors early in the EFH review process.*”

May 2021: The 2023 EFH 5-year Review Plan was presented to the Crab Plan Team in May 2021, which included SDM ensemble methods and preliminary results for crabs. The presentation also introduced the opportunity for the Crab Plan Team members to participate in the review process as stock experts, in partnership with the SAs. All species except for Tanner crab had at least two reviewers to offer edits, updates, and suggestions. This SA-stock expert partnership was new for this review and offered more opportunities for feedback. The Crab Plan Team requested that the crab SAs and experts receive the EFH components 1 and 7 review materials first to accommodate the timing of the crab stock assessments. The EFH analyst team agreed and provided crab SDM EFH results chapters for SA review in May 2021.

May–September 2021: The agreed upon SA review period was from May–September 1. New EFH component 1 information was provided to the SAs for their review, revisions, and recommendations.

In May 2021, EFH analysts provided all SAs with:

- Excerpts of the current FMP text, tables, and literature for their species,
- 2017 EFH maps for comparison with the new EFH maps, and
- Draft ensemble SDM EFH methods sections.

From May–July, EFH analysts provided each SA and stock expert with complete drafts of their species results chapters to review, as the model results were available each chapter was completed. EFH analysts received comments back on nearly all of the chapters provided for review by the agreed upon deadline of September 1. This approach allowed for a comprehensive and meaningful expert peer review, which greatly improved this body of work for the 2023 EFH 5-year Review and the process overall.

September 2021: The joint meeting of the Groundfish Plan Teams in September 2021 was an opportunity for the EFH analysts to circle back with the SAs following their review. At this meeting, the EFH analysts summarized the SA reviews received as well as the analysis team's responses to the leading concerns and questions from the SAs. This included an explanation of replacing the single ensemble fit metric, Spearman's rho-squared, with 3 conventional metrics to more comprehensively assess ensemble performance, which was reevaluated and revised for all species life stage ensembles and included in the species chapter revisions.

EFH analysts communicated at the meeting that they would be following up with all SAs who expressed concern over model performance in their reviews to further communicate the updated model performance metrics, revised results for their species, and to address other concerns if needed. Although EFH analysts had been following up with SAs as their reviews were returned over the summer, SAs with concerns that affected their confidence in the models and outcomes were prioritized for more in-depth follow-up to address concerns.

EFH analysts communicated at the meeting that they would revise the ensemble SDM EFH methods and species results chapters and share those with all of the SAs should they be interested in seeing the chapter revisions prior to the SSC February Meeting when the full set of revised methods, results, and EFH area comparisons with 2017 would be shared with the SSC and stakeholders.

October 2021: The SSC reviewed the joint meeting of the Groundfish Plan Teams September Meeting report, which included the Team's report on the EFH presentation. The SSC provided additional guidance on component 1 that NMFS incorporated into this report and into the materials for the SSC in February 2022.

November 2021: The joint meeting of the Groundfish Plan Teams in November 2021 was an opportunity to provide an overview of the iterative review process for EFH components 1 and 7 at that time of the 2023 Review and to share the final stages of the SA review, including the EFH analyst's response to all SAs. A draft of this Report was provided as an attachment for this meeting and posted on November 9, 2021 to provide time to review the report prior to the presentation on November 15, 2021. From the meeting's minutes: "The Teams thanked the EFH analysts for the development and application of the EFH models, the responsiveness to stock assessment author reviews, and for the detailed report describing the review process." The next steps of the 2023 Review process are presentations to the Crab Plan Team and Ecosystem Committee in January 2022 and to the SSC in February 2022.

F.1.2 Methods

EFH analysts provided each SA the current FMP text and 2017 maps, the tables from the FMP, SDM methods, and the new draft regional Technical Memorandum species results chapters with the SDM results and EFH maps. A detailed instruction and guidance document for this review was provided to SAs at the beginning of the review period. The SAs had an opportunity to review information for EFH components 1 and 7 between May and September 1, 2021. The SAs either reviewed documents through a Google Drive folder system or email. As a note on process, some SAs found emailed documents easier or more accessible than the Google Drive system.

Instructions to the authors were as follows for each of the documents under review:

Current FMP Text and 2017 Maps

- Update necessary information for life history, habitat, and prey components, as well as supporting literature that is relevant to management, including research in development.
- Compare the new EFH maps provided in the new draft species results chapters to the 2017 EFH maps and offer comments or input.

Current FMP Tables

- Review the FMP tables for your species and provide any suggested species-specific changes to those summary tables.

Preliminary SDM EFH Mapping Methods and Results

- Review the new preliminary component 1 information included draft SDM EFH mapping methods and species results chapters with text updating the literature and life history information, SDM results tables and figures, and EFH percentiles maps. The methods and species results were included as section in the three regional NOAA Technical Memoranda from the Laman et al. study (Chapter 5), incorporating recommended revisions and suggestions from the SA review as appropriate. The SDM EFH mapping methods and results that had been revised following the SA review were provided to the SSC for further review in February 2022 and were advanced to the Council by the SSC in October 2022 (Chapter 2).
- New information in the Laman et al. study species results chapters will be used to inform recommendations to update the FMP EFH descriptions. New EFH information levels available for the 2023 Review include Levels 1, 2, and 3 (section 3.2)
    - Level 1 (habitat-related distribution): EFH is the area containing the top 95% of occupied habitat (defined as greater than 5% predicted probability of suitable habitat) for settled early juveniles from an SDM fitted to their distribution in GOA mixed gear-type summer surveys. Within the EFH area maps are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).
    - Level 2 (habitat-related density or relative abundance): EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from an SDM ensemble fitted to their distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys. Within the EFH area maps are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).
    - Level 3 (habitat-related vital rates): EFH maps were developed for a small set of species in all regions modeled by combining SDMs with vital rates (e.g., temperature-dependent growth rate). Level 3 EFH maps may be used to further interpret the Level 1 or Level 2 EFH maps of distribution or habitat-related abundance.
- Additional guidance provided: new EFH maps were developed for the 2023 Review for demersal groundfish (settled early juvenile, subadult, and adult) and crab species (immature/mature life stages combined) where possible in the summer season. **New ensemble SDM EFH maps were not developed for the other seasons (fall, winter, spring) or for pelagic early life history stages (pelagic juvenile, larvae, egg) during this EFH 5-year Review and will remain in the FMPs.**

F.1.3 Analysis of Reviews Received

Once SAs and stock experts had completed their reviews of the documents listed in section F.1.2, they were asked to inform the analysts and to provide any additional input either through a shared document or email. EFH analysts recorded the comments received, as well as our responses to those comments. Section F.3 reports the iterative communication between reviewers and analysts.

Overall, we are very appreciative of the engagement by the SAs and stock experts in their reviews, and, in particular, when additional communication was required to address their concerns. Some SAs and stock experts raised concerns in their reviews. These concerns included model performance and sources of data, both the data included in the analyses and data with the potential to be included in future analyses. The EFH analysts engaged with the SAs in further communications to understand their recommendations and address these concerns. Due to the timing of events in fall 2021 (i.e., the SA review deadline was September 1, 2021 and the September joint meeting of the Groundfish Plan Teams was held the week of September 20, 2021), much of the EFH analyst team communication with SAs took place between the September Groundfish Plan Teams meeting week and November 1, 2021, prior to providing a first draft of this report for the November Groundfish Plan Teams meeting as an attachment posted on November, 9 2021.

EFH analysts responded to SAs and species expert reviewers who communicated concern about the new SDMs or EFH maps either through collaboration and replies in shared documents, through emails, or in conversations between reviewers and analysts. As indicated above, these communications have been retained for future reference and summarized in this report.

When additional communication was necessary, EFH analysts contacted the SA(s), providing them with revised model fit metrics, methods, and revised results for their species along with a request for a conversation or an email response indicating that their concern had or had not been met. **In all cases, a resolution was reached when additional communication was required**.

The EFH analyst team feels that this iterative review process, and SA engagement in it, has strengthened collaboration and improved the results to be presented in the 2023 Review.

F.2 Results Overview

There were 30 SAs and species experts that participated in the review of current and new EFH component 1 information for the 2023 5-year Review. They reviewed current FMP sections and 115 draft species or species complex results chapters described above with separate chapters for species in different regions. Nearly every species or species complex had at least one reviewer, though some species had two or more and there was overlap for some species with similar concerns across multiple regions.

Most SAs provided edits and recommendations for the current FMPs sections and new draft species results chapters. The edits and recommendations to the species results chapters where possible were incorporated in the three regional draft NOAA Technical Memooranda (Chapter 5) and will be used to update the EFH sections of the FMPs (2023 EFH 5-year Review Summary Report[59]). Of the information edited or updated in the existing FMP text documents, most of the focus was on component 1 descriptions and identification. In the next EFH 5-year Review, a greater focus on updating component 7 prey species will make this SA and species expert review stronger. In particular, a goal will be updating existing Habitat and Biological Associations information in the FMPs and providing a separate prey species summary table for component 7.

The following sections (F.2.1 and F.2.2) are a summary of the SA review results across species and regions. Review metrics are provided first (section F.2.1) and followed by a short list of common concerns with EFH analyst responses (section F.2.2). The SA reviews are reported in section F.3.

F.2.1 Review Metrics across Regions and Species

EFH analysts received a 100% response rate from the **30 SAs** and other expert reviewers who were contacted to participate. Reviewers provided input as comments, questions, or concerns. We responded to all reviewers to discuss concerns, answer questions, and offer or receive future research

[59] EFH Component 1 (Chapter 2) in EFH 5-year Review Summary Report (January 2023) available on Council agenda for this meeting.

recommendations when applicable. We responded to some reviewers with more in-depth communication when needed to address concerns where possible within the scope of the 2023 Review.

We addressed concerns from **eight SAs** over ensemble performance or confidence in EFH maps requiring more in-depth communication. In these communications we provided the revised ensemble performance methods and results, offered a meeting, and/or requested agreement that their concerns had been addressed to the extent possible in the 2023 Review. **In all instances of concern resolution was reached for proceeding with the new information for 2023 Review.**

Concerns from **one SA** led to consultation resulting in removal of three species draft EFH maps from those recommended to advance in the 2023 Review. These were all data-limited species that do not currently have an EFH map, including Pacific sleeper sharks in all regions (sections F.3.1.8, F.3.2.13) and darkblotched and yellowtail rockfishes in the GOA (section F.3.2.8). However, the EFH regulations require FMPs to include EFH description and identification for all EFH species in the fishery management unit, even when there is limited data. We will work with the SA to develop EFH information for these species for the next 5-year Review. In another case, concerns from **one SA** for GOA Atka mackerel (section F.3.2.2) led to consultation and iterative communication. We investigated ensemble constituent performance, removed one constituent, re-ran the ensemble, and revised the EFH map.

The SA review period from May–September also provided time for comprehensive internal review of the full draft set of new SDM ensembles and EFH maps. Of the 60 unique species that made up the species and stock complexes in the EBS, AI, and GOA, models were re-run for 27 species. Some were re-run for the species across all regions and some were limited to specific life history stages and regions. Some were re-run as a result of SA comments and many were a result of the comprehensive internal review. For example, life stage breaks were revised for 22 species, including those identified and recommended by the SAs. Although often relatively minor adjustments, we feel it is important to have the life stages established correctly and supported by the literature. For one species, the SA review and further communication with the SA led to a more in-depth investigation of the ensemble constituents (GOA Atka mackerel). Other reasons to re-run models were identified from internal review, such as coding issues (Appendix B) and adjustments to the survey data included for certain species.

Revisions of the regional methods sections and individual species results chapters for all species modeled were made available to interested SAs and expert reviewers starting in November, 2021 and were provided for the February 2022 SSC Meeting. We thank all SAs and species experts for their engagement and collaboration that has improved this work and the process overall.

F.2.2 Common Recommendations across Regions and Species

Summarized versions of common concerns that were raised in the SA review are provided in this section. Species-specific responses and details regarding these concerns that were communicated with the reviewers and are summarized in the section F.3.

Designating EFH

- SA concern: How does NMFS and the Council designate what is ‘essential’ fish habitat?
  - General response: Essential Fish Habitat is designated based on the definition in the MSA: “Essential fish habitat (EFH) means those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” For the purpose of interpreting the definition of essential fish habitat, NMFS published regulations further specifying that: “Waters” include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; “substrate” includes sediment, hard bottom, structures underlying the waters, and associated biological communities; “necessary” means the habitat required to support a sustainable fishery and the managed species' contribution to

a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle (50 CFR 600.10).

Federal regulations at 50 CFR 600.815(a)(1) provide more detailed guidance on designating EFH for each species managed under an FMP. The regulations require that each FMP must describe and identify EFH for each life stage of the managed species. FMPs must identify the specific geographic location or extent of habitats described as EFH. FMPs must include maps of the geographic locations of EFH or the geographic boundaries within which EFH for each species and life stage is found.

The Council designated EFH for the species under its FMPs with the 2005 EFH EIS (NMFS 2005). Since then, the Council, SSC, and NMFS have further refined how EFH is designated in the North Pacific with each 5-year Review. Details on the current EFH designations are provided in the summary report for the last EFH 5-year Review (Simpson et al 2017). Any changes to how the Council designates EFH based on this current review will be described in the summary report for this 5-year Review.

- SA concern: Bering Sea crab SAs expressed concerns about the nexus between describing EFH regionally for a species that is managed on smaller, regional scales by stock (e.g., Bristol Bay red king crab).
  - General response: The EFH regulations specify that EFH must be designated and mapped by species (50 CFR 600.815(a)(1)(i)). We welcome the interest of crab scientists to work with EFH analysts to assist in refining the crab EFH designations in the future. Our goal is to keep refining EFH information for species with each EFH 5-year Review as the science and data available progresses over time.

    Note that in this 5-year Review, we will have new SDM EFH maps for snow crab in the Arctic Management Area that combines the Chukchi and Beaufort Seas as well as new EFH maps for golden king crab and red red king crab in the Aleutian Islands.

Model Performance

- SA concern: Stock authors were concerned about low ensemble performance in the first drafts of our results where we reported the single fit metric Spearman's rho-squared (ρ^2).
  - General response: As a result of the SA review and our own internal review happening concurrently, we recognized that the single SDM performance metric we reported was flawed and have pivoted to reporting three traditional metrics (Spearman's rank correlation coefficient or rho (ρ), area under the receiver operating characteristic curve (AUC), and deviance explained based on the Poisson distribution (PDE)), which will provide a more comprehensive view of where the model performs well and where it does not.

    Due to concerns raised in some SA reviews of ensemble performance and identified by the EFH analyst team's own comprehensive assessment of the draft results, the single performance metric presented in the preliminary results reviewed by SAs (ρ^2) was re-evaluated and a set of three traditional fit metrics are now provided in the revised results to replace the single, draft metric. Spearman's ρ indicates how well the ensemble distinguishes between locations of high and low abundance, AUC indicates the ensemble's ability to discriminate between presence and absence locations, and the PDE provides a measure of how good of a job the ensemble does explaining deviance.
  - Performance metric rubric:

    ρ: < 0.20 (poor), 0.21 – 0.40 (fair), 0.41 – 0.60 (good), 0.61 – 0.99 (excellent)
    AUC: < 0.70 (poor), 0.71 – 0.90 (good), 0.90 – 0.99 (excellent)

PDE: < 0.20 (poor), 0.21 – 0.40 (fair), 0.41 – 0.60 (good), 0.61 – 0.99 (excellent)

Survey Data

- SA concern: Several stock authors communicated concern about relatively low numbers of catches used to describe EFH for some species. In some cases (e.g., shortraker rockfish, sablefish), SAs communicated their suppositions that to augmenting RACE-GAP bottom trawl survey data from other sources (e.g., longline survey data, fishery-dependent data, or optical survey data) could provide more comprehensive EFH descriptions. In other cases, SAs communicated that using a low number of incidences to describe EFH over a large area could be cause for concern or for low confidence in the EFH extent described.
    - General response: SAs raised concerns in their reviews of particular species about the efficacy and value of including sources of data in addition to the RACE-GAP summer bottom trawl survey data used in our analyses. The RACE-GAP surveys collect data from locations in the study areas where the bottom trawl can be successfully deployed. Areas that are untrawlable or out of range of the RACE-GAP samplers (e.g., too deep and too nearshore) are underrepresented in the data we analyzed. In addition, seasonality is not represented in the RACE-GAP summer survey data. For species that reside in these areas not successfully trawled by the RACE-GAP survey (e.g., sablefish or shortraker rockfish), this lack of sampling is a concern when describing EFH.

      SAs and others communicated that there are other data, from both fishery-independent and fishery-dependent sources, which could augment the RACE-GAP summer trawl survey data and potentially improve the accuracy of SDMs to support EFH descriptions and maps. Combining data from disparate data sources is not a trivial analytical effort and was beyond the scope of the present SDM EFH effort (Laman et al. study). Our response to requests from SAs to include additional data at this time have been to provide statements in the species results chapter text where we/they believe additional data could be helpful to more comprehensively describe species distribution and abundance, and to strongly recommend that research effort be expended in a future EFH 5-year Review to combine relevant data sets for a subset of species. SAs were invited to participate in the anticipation of this effort by submitting proposals to begin establishing methodology for combining disparate data sets for the species in question.

Life History

- SA concern: Some life history specifics (e.g., length at 50% maturity) were identified as needing updates during the SA review.
    - General response: The EFH analyst team was pleased to collaborate with SA subject experts and receive updated life history information. When an update was recommended, we integrated the updated life history information into new model runs of the SDMs and EFH maps.

      In addition, closer examination of life stage definitions in our own internal reviews of the current literature also led to updates of length-based life history definitions applied to the model reruns following the SA review and provided in the revised results.

F.3 Stock Author Reviews for Species in the BSAI, GOA, and Crab FMPs

SA reviews are provided in the following sections for BSAI Groundfish (section F.3.1), GOA Groundfish (section F.3.2), and BSAI Crabs (section F.3.3).

F.3.1 BSAI Groundfish

This section summarizes conversations between reviewers and EFH analysts for each EBS or AI groundfish species where the reviewer provided written comments. These comments and responses were either recorded through the shared Google folder system within the documents provided or captured through conversation and follow-up emails, including iterative communication after SAs had a chance to finish their initial review and look over any updates to the new draft species results chapters (e.g., revised SDM performance metrics). The species that have review communication are reported below are:

- ***Arrowtooth flounder*** (F.3.1.1)
- ***Atka mackerel*** (F.3.1.2)
- ***Greenland turbot and Kamchatka flounder*** (F.3.1.3)
- ***Northern rock sole*** (F.3.1.4)
- ***Other flatfish complex*** (F.3.1.5)
- ***Other rockfish complex*** (F.3.1.6)
- ***Pacific cod*** (F.3.1.7)
- ***Pacific sleeper shark*** (F.3.1.8)
- ***Sablefish*** (F.3.1.9)
- ***Shortraker rockfish*** (F.3.1.10)
- ***Skate complex*** (F.3.1.11)
- ***Walleye pollock*** (F.3.1.12)
- ***Yellowfin sole*** (F.3.1.13)

The species that did not include SA comments and are not reported below are:

- ***Alaska plaice***
- ***Blackspotted/Rougheye rockfish complex***
- ***Flathead sole/Bering flounder complex***
- ***Northern rockfish***
- ***Octopus***
- ***Pacific ocean perch***

F.3.1.1 Arrowtooth flounder

Comments for BSAI arrowtooth flounder were:

- We now use only data starting from 1992 in the BSAI arrowtooth flounder assessment. The survey crew did not have moderate confidence levels for arrowtooth flounder identification until 1992 in the EBS bottom trawl survey and so we do not use data from the earlier surveys. Given the large number of years over which the EFH model covers, this may not be a concern, but if the distribution of samples was really different in those earlier years this might cause some issues as the model might be showing locations where there were Kamchatka flounder instead of arrowtooth.
    - Response: This is a typo in citing the data analysis set date range and has been corrected. We are analyzing Kamchatka and arrowtooth flounder separately from 1992-2019 for this EFH review. We are not using data prior to 1992 in these analyses for these two species.
- Adult arrowtooth are commonly caught on the longline survey and the IPHC survey. It might be worth including in a future update since the slope bottom trawl survey might not happen for a while.
    - Response: It would be interesting to include other data sources for many species, but will likely be the focus of data poor species in the next review and may be less of an issue for data rich species like arrowtooth flounder.
- There seems to be a low number of data points for several decades of surveys for Aleutian Island early juvenile arrowtooth flounder. These maps might be misleading for this life stage.

  - Response: In the next EFH Review we would like to expand the combined survey data approach taken for GOA early juveniles (i.e., incorporating additional data sources) to the EBS and AI regions and a goal is to develop the methods to do that within the ensemble framework.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.1.2 Atka mackerel

Comments for BSAI Atka mackerel were:

- The results are not meaningful given the lack of data and lack of fit in the models.
  - Response: We realized, thanks to this review and others, that our application of the Spearman's R-squared was flawed and that providing a single metric for an ensemble of multiple models was insufficient to comprehensively describe ensemble performance. In the revisions of the Methods and Results under development for all regions modeled (EBS, AI, and GOA), we have replaced the Spearman's R-squared with model performance metrics rho, AUC, and deviance to provide a more comprehensive view of model performance (section F.2.2).
- There is a general concern for these maps and the GOA Atka mackerel maps when it comes to extrapolating results from very few observations.
  - Response: We are recommending that a working group should be formed to revisit and potentially revise scientific guidance for any thresholds applied in EFH mapping and the fishing effects analysis and to provide this guidance to the SSC ahead of the 2027 5-year EFH Review. The current SSC guidance used for the 2017 and 2023 EFH 5-year Reviews was that N > 50 species occurrences was a sufficient threshold for developing an SDM EFH map (e.g., Laman et al. 2017).

Further communication:

- EFH analysts contacted the lead SA to let them know that the model performance metrics for this species had been updated and that a plan was in process to investigate improving the Atka mackerel ensemble models by e.g., removing a model constituent. The SA was invited to have a conversation.
- EFH analysts contacted the SA again to share a document with the updated model performance metrics and results for all regions (AI, EBS, GOA), suggested an alternative EFH map for GOA adult Atka mackerel based on a revised ensemble, and provided a response to the larger concerns shared (above) in the review.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that the revised Atka mackerel EFH NOAA Technical Memo chapters (AI, EBS, and GOA) and the final version of this report with detailed comments/responses would be shared with them when available before the February 2022 SSC meeting. The SA was invited to have a conversation and, if unavailable to meet, requested to let the EFH analysts know if the information provided has helped address their concerns.

- Note: See GOA Atka mackerel for the comments/responses from the follow-up communication between the EFH analysts and the SA, upon sharing the revised Atka mackerel results for all regions.

F.3.1.3 Greenland turbot and Kamchatka flounder

Comments for BSAI Greenland turbot were:

- The R-squared values are fairly low for Greenland turbot and Kamchatka flounder life history stages. Is there a standard for what constitutes a reasonable model fit/R-squared value for these types of models?
    - Response: We are pivoting from the single metric of Spearman's R-squared to a tripartite view of model performance utilizing rho, AUC, and deviance to provide a more comprehensive view of model performance. For example, for Greenland turbot and Kamchatka flounder, using the 3 metric approach, the models are all "good" performers though they would've been classified as "fair" under the previous Spearman's R-squared rubric we presented in the first draft of results.
- How is "total deviance" calculated?
    - Response: "Total deviance" was a confusing term. It is the percent contribution of the covariate to the deviance explained by the ensemble. A more appropriate term would be "explained deviance" or "deviance explained by the ensemble". These revisions were incorporated into the draft species results chapters.

Further communication:

- EFH analysts shared the updated model performance methods and results for the EBS Greenland turbot and Kamchatka flounder due to concerns raised about model fit in the review of these species.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in a summary report of the SA Review of EFH component 1 and that the revised NOAA Technical Memorandum species results chapters would be shared with them when available before the February 2022 SSC meeting.
    - The SA had no more remaining comments or questions.

F.3.1.4 Northern rock sole

Comments for BSAI northern rock sole were:

- A concern is that only data from 1996 onward were used because that is when northern and southern rock sole were identified separately. The Bering Sea is nearly all northern rock sole, not southern rock sole. The stock assessment includes data prior to 1996.
    - Response: Most of the rock sole in EBS are northern rock sole. There have been around 50 catches from the shelf of southern rock sole since 1996. These few catches were insufficient to parameterize an SDM for southern rock sole EFH at this time. We have established a stanza of confident discrimination between these two species and are modeling northern rock sole since 1996 on this basis.

    - Further SA comment: If EFH changed significantly, that would be interesting to explore whether northern rock sole habitat has changed over time as a separate issue from whether there were enough southern rock sole to change the EFH maps.
    - Response: We attempted to model all southern rock sole catches as a single life stage in the EBS, but, even combined, there were insufficient catches (n<50) to parameterize an SDM.
    - Note: AI southern rock sole are part of the other flatfish stock complex.

Further communication:

- The EBS and AI are thought to have few southern rock sole. The 2017 documents note that 95% of rock sole in the EBS are northerns. The stock assessment uses all the data, not just 1996 onward, so this is a disconnect between the SAFE and EFH.
    - Response: We acknowledge that there is a disconnect between the SAFE data set and the EFH data set where northern rock sole are concerned, but we are cautious combining multiple species into a single data set unless doing so to intentionally map a species complex. Modeling northern rock sole for EFH since 1996 offers more confidence of field distinctions being made between the two species and provides a high number of years included in the analyses (1996-2019) to mitigate concerns. However, it would be interesting to compare combined northern and southern rock sole SDM maps (1982-1995) to northern rock sole SDM maps (1996-2019) at some future date. For future consideration, we may look at the frequency of northern and southern rock sole catches in the EBS through time to determine if we could align our data set with the SAFE data set in the future.
- The SA noted some potential problems with length-based stage categories for GOA species. BSAI northern rock sole have also exhibited changes in growth over time. They noted that the length-based categories may introduce some effects that may need to be addressed in the next round of EFH.
    - Response: We are recommending that future EFH descriptions try to account for subregional growth and size-at-age differences for applicable species

EFH analyst’s communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.1.5 Other flatfish complex

The BSAI other flatfish complex includes the following species:

- ***Butter sole***
- ***Deepsea sole***
- ***Dover sole***
- ***Longhead dab***
- ***Rex sole***
- ***Sakhalin sole***
- ***Southern rock sole***
- ***Starry flounder***

Comments for the BSAI other flatfish stock complex were:

Dover sole

- Analyst note: SA comments about subregional growth differences for GOA Dover sole and GOA rex sole may affect EBS Dover sole.

Southern rock sole

- Could an error in the Aleutian Island subadult southern rock sole model be from an extreme covariate value, essentially extrapolating beyond the observed range?
    - Response: Due to an error in the length at maturity, the southern rock sole chapter was rerun. The problematic area is no longer present in the ensemble. This original problem appears to have been caused by the maxnet model, which was eliminated from the ensemble during the second run.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.1.6 Other rockfish complex

The other rockfish stock complex includes the following species for each region:

- *Dark rockfish*
- ***Dusky rockfish***
- ***Harlequin rockfish***
- ***Shortspine thornyhead rockfish***

In the EBS, only shortspine thornyhead rockfish merited an SDM and EFH map to represent the other rockfish stock complex. This is because, of the rockfishes that could contribute to EFH for the EBS other rockfish stock complex, only shortspine thornyhead was caught in sufficient prevalence (> 50 catches) in RACE-GAP summer bottom trawl surveys (1982-2019) to parameterize a species distribution model (SDM). Dark, dusky, harlequin, and shortspine thornyhead rockfish represented the other rockfish stock complex in the AI, but dark rockfish did not have sufficient data for an SDM and EFH map. That said, the species-specific chapter detailing the shortspine thornyhead SDM EFH suffices as the proxy for the other rockfish stock complex in the BSAI at this time. Comments and notes for the other rockfish stock complex were therefore focused on shortspine thornyhead rockfish.

- The EBS shortspine thornyhead rockfish SA addressed two common concerns: incorporation of the longline survey data and model fit.
    - Response: EFH analysts let them know that their suggestion to add longline survey data to the EFH mapping effort for slope species would be included in the future recommendations and that a "data caveat" statement would be added to the revised species results chapters indicating that including data from this additional survey may improve the SDM EFH descriptions and maps for these species. Model fit concerns were addressed in further communication between the SA and EFH analysts (see below).
- It might be helpful to state that shortspine thornyhead rockfish are not sampled on the EBS shelf and therefore haven't been sampled since 2016. I included this same comment in Fig 1 and 4 since it lists all surveys and the full 1982-2019 time series.
    - Response: There have been samples collected on the EBS slope survey from the EBS shelf in waters around 200 m deep which are also sampled on the EBS shelf survey (i.e., shortspine thornyheads could occur in shelf survey catches even though they haven't yet). However, the EBS shortspine thornyhead rockfish chapter will explicitly state that the slope survey hasn't happened since 2016 so technically only one more survey's worth of

shortspine thornyhead rockfish presence data were added when the new SDM methods added 5 more years of survey data.

Further communication:

- EFH analysts shared the updated model performance methods and results for all of the SA's species in the BSAI and GOA FMPs (i.e., concern over model fit for the BSAI species).
- The SA raised concerns about the use of the EBS shelf survey for EBS shortspine thornyhead maps despite that species being rarely present in the survey. They offered, "While I acknowledge that zeros are data, it may be helpful for readers to know that results are dependent on the EBS slope survey that ended in 2016."
    - Response: There is now text in the chapter that emphasizes the point raised about shortspine thornyhead rockfish only being collected on slope surveys and most recently in 2016 (the most recent slope survey). While assessments focus on positive catches, this effort was interested in positive and zero catches to understand not only where species are, but where they are not. There is also text added to highlight our recommendation to include other data sources in the future (e.g., fishery dependent data or longline survey data). Adding these data in the future should provide better temporal coverage of shortspine thornyheads, and better spatial coverage of the other rockfishes in this stock complex.
- Other statements provided through correspondence with the SA included: Given that EFH is an iterative process, it would be helpful to see how EFH estimates have changed over time.
    - Response: We will be providing more detailed comparisons to the 2017 EFH SDMs at a later stage of this EFH 5-year Review and we provided the extant (2017) maps in the FMPs for the most recent SA Review. Previous maps (for example from the 5-year Review from 2010) are available as part of the public record, though were not included in the documents folders provided the SAs.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in this report and that the revised NOAA Technical Memoranda species results chapters would be shared with them when available before the February 2022 SSC meeting.
    - SA responded that their concerns about poor model fits for both stocks were satisfied through analyst communication. They offered, "Although I understand its challenges, I'm happy to hear this team will consider using the longline survey data for slope species in the future."

F.3.1.7 Pacific cod

Comments for BSAI Pacific cod were:

- What and where is the schedule of "poor", "good", "fair", and "excellent" fit when referencing Spearman's r-squared results
    - Response: This question is partly addressed by the comment on use of Spearman's rho-squared (section F.2.2). With the three metrics used in the new methods, the rubric is:

      ρ (rho): <0.20 (poor), 0.21 – 0.40 (fair), 0.41 – 0.60 (good), 0.61 – 0.99 (excellent)
      AUC: <0.70 (poor), 0.71 – 0.90 (good), 0.90 – 0.99 (excellent)
      PDE: <0.20 (poor), 0.21 – 0.40 (fair), 0.41 – 0.60 (good), 0.61 – 0.99 (excellent)

- Further response: This detail now also appears in the revised Methods sections prepared for the SDM EFH NOAA Technical Memorands.

- The definition of "growth potential" as used in the draft species result chapter is unfamiliar. As defined, it sounded more like population growth rate than "growth potential".
    - Response: This is a novel definition of “growth potential” where the population growth potential is considered since it is the spatially mapped product of ensemble-predicted abundance and temperature-dependent growth. It could be considered a type of population growth rate as well. As a result of this SA clarifying question, the section referring to “growth potential” was rewritten to indicate that the outcome is the result of the multiplication of growth rate and abundance rasters and that, given the definition of “growth potential”, it was important to point out that for population growth potential to be high, high potential growth rates and high predicted abundance must coincide.

Further communication:

- EFH analysts shared the updated model performance methods and results for BSAI Pacific cod (i.e., concern over model fit).

EFH analyst’s communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA’s concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised species EFH NOAA Technical Memo chapters would be shared with them when available before the February 2022 SSC meeting.
    - The SA had no remaining comments or questions.

F.3.1.8 Pacific sleeper shark

Comments for Pacific sleeper shark were:

- Only the slope survey has consistent catches in the EBS, and it's a small component of the species distribution. Also, the fishery distribution is much larger than that observed in survey data. For a more accurate distribution model, fishery data and surveys with higher catchability needs to be included for this species.
    - Response: After more conversations with the SA, the outcome is a shared agreement that Pacific sleeper shark EFH maps will not be advanced by the EFH analysts in the 2023 EFH 5-year Review with an understanding that research should take place to include longline survey data in future EFH mapping efforts for this species. The SA will update the FMP text description. Pacific sleeper sharks are a data-limited species that do not have EFH maps, including SDM EFH maps from the 2017 Review.
- The slope and shelf surveys are different gears, different catchabilities, and inconsistent time series.
    - Response: There is a future need to better equate the slope and shelf effort to more validly combine the two surveys. The methods for the SDM models describe combining distinct surveys (EBS shelf, EBS slope, and northern Bering Sea (NBS)) and also clarify that the surveys are jointly referred to as the EBS RACE-GAP bottom trawl survey in the EFH Review documents.

Further communication:

- EFH analysts shared the updated model performance methods and results for EBS Pacific sleeper sharks due to concerns raised about model performance in the review of these species. We also discussed options for this species where an EFH map had not been advanced in 2017 and future research recommendations.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised species EFH NOAA Technical Memo chapters would be shared with them when available before the February 2022 SSC meeting.
    - The SA appreciated the shared updates and found them helpful for understanding model performance more comprehensively for these species in the BSAI as well as the GOA.
    - There was agreement that Pacific sleeper shark EFH maps would not be developed in any region for this EFH 5-year Review. Pacific sleeper sharks also did not have an EFH map in 2017.
    - The SA and EFH analysts recommend that research should take place to include longline survey data in future EFH mapping efforts for shark species.
    - See also the GOA sharks summary (section F.3.2.13).

F.3.1.9 Sablefish

Comments for BSAI sablefish were:

- The main concern was the lack of incorporation of the longline survey data. This concern was repeated for GOA sablefish in section F.3.2.11, particularly adults, are not consistently surveyed by the trawl gear due to depth, habitat, and potentially tow speed limitations. The longline survey is designed explicitly to survey sablefish abundance. It seems like the inclusion of longline survey data would be necessary to adequately identify EFH for sablefish using SDMs.
    - Response: The addition of longline data is an appropriate inclusion for the next EFH review. We anticipate that in the next review trawl data could be combined with longline and pot data to give a more accurate picture of sablefish in Alaska. The inclusion of different data sources was a common concern across species (section F.2.2).
- Consistency in summary descriptions across chapters would be useful not just to ensure consistent message, but also to reduce workload for authors and reviewers.
    - Response: We are taking the SA's advice and converging summary descriptions for sablefish (and other species) where possible. However, there are some regional concerns in many cases so that introductory paragraphs will require some customization.
- Some caveats to using the trawl survey data, particularly in the BSAI regions, are warranted. Mainly, the trawl gear does not always survey adult sablefish habitat (i.e., depths > 500m) and adult sablefish might be able to outswim the gear.
    - Response: Caveats affecting confidence in EFH descriptions based on RACE bottom trawl survey data will be incorporated into our results chapters where appropriate as will taking note of any future recommendations to improve the models or outcomes. Also note

that the Bering slope surveys which sample prime sablefish habitat are included in the present SDMs, ensemble, and EFH maps.

- The SA raised concerns about model fit and asked a clarifying question about the consistency of ranking model results for all regions.
    - Response: The new model fit metrics should provide a more comprehensive view of model performance. This should help build confidence in the modeling approach with the given data, but will not mitigate the need for additional data indicated by comments about incorporating longline survey data. We have addressed consistently reporting model performance metrics among regional authors for the revised species results chapters and provided the revisions to the SA (section F.2.2). This has also been addressed through better coordination among the writing team.
- It would be good to note the lack of genetic structure, wide distribution, and large scale movement capabilities along with management as a single resource in Alaska. Much of this is noted in the AI chapter, but not elsewhere. Mainly, I think it is important to identify that sablefish are widely distributed and so the EFH is really a large-scale issue not a regional issue.
    - Response: This is partly addressed through better coordination and the text has been altered to accommodate the suggested revisions. Note: EFH is described and mapped for targeted species (not stocks) in the fishery management units corresponding to the Fishery Management Plans (50 CFR 600.805(b)). There are regional introductions because the BSAI and GOA groundfish FMPs are regional.

EFH analyst’s communication summary:

- EFH analysts contacted the lead SA to share a document with the updated model performance results for all regions (AI, EBS, GOA), and provided responses to the larger concerns shared (above) in the review. EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA’s concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that the revised NOAA Technical Memorandum sablefish results chapters (AI, EBS, and GOA) and the final version of this report with detailed comments/responses would be shared with them when available before the February 2022 SSC meeting. The SA was invited to have a conversation and, if unavailable to meet, requested to let the EFH analysts know if the information provided has helped address their concerns.
    - The SA had no more remaining comments or questions.

F.3.1.10 Shortraker rockfish

Comments for BSAI shortraker rockfish were:

- In future iterations of the BSAI shortraker stock assessment, we plan to include the AFSC longline and potentially the IPHC longline survey data as additional indices in the random effects model since the longline surveys consistently catch shortraker in the AI. So in future versions of EFH models and maps can they include this data? Perhaps this data source is useful to mention here?
    - Response: We are including future recommendations in the results sections of the new NOAA Technical Memo chapters and will mention the intention for BSAI shortraker rockfish to include AFSC/IPHC longline survey data if possible. Incorporating other surveys into EFH models is a request for other species as well (section F.2.2).

EFH analyst’s communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.1.11 Skate complex

The BSAI skate complex is made up of the following species:

- ***Alaska skate***
- ***Aleutian skate***
- ***Bering skate***
- ***Big skate***
- *Leopard skate*
- ***Mud skate***
- ***Whiteblotched skate***

There was not sufficient data for a leopard skate SDM, though there are likely sufficient numbers to include the leopard skate in an ensemble map in the future. Comments for the rest of the BSAI skate complex were:

- The sections on the aggregate habitat modeling for skates were confusing due to the use of the term "other skates". In each area, "other skates" has a specific meaning from a management perspective (in the BSAI it is all species except Alaska skate; in the GOA it is all skates except for big and longnose skates). It is confusing to use "other skates" in a different context and the SA recommended just calling it the skate complex.
    - Response: Make certain that the region-specific members of “the skate complex” are listed in the introductory paragraph or a table and, once defined in the introductory paragraph, take SA’s advice to use “skate complex” in the results sections to refer to the composite.

EFH analyst’s communication summary:

- EFH analysts contacted the SA and confirmed the species lists for the “skate complex” combined species maps are correct. Any other remaining concerns were addressed.

F.3.1.12 Walleye pollock

Comments for BSAI walleye pollock were:

- There is need for clarity on figure captions for the new maps in the draft species results chapter with phrases like, “top 10%”, and which data is used.
    - Response: The figure caption language was reworded to more clearly describe what top 10% is and what the remaining 90% is. This will be a global change to the presence figures across all regions. E.g., “Distribution of settled early juvenile walleye pollock catches (N = 9,367) in 1982–2019 AFSC RACE-GAP summer bottom trawl surveys of the EBS shelf, slope, and NBS with the 50 m, 100 m, and 200 m isobaths indicated. Each circle on the map indicates where this species life stage was present in trawl catches; filled red circles indicate individual catches with numerical abundance in the top 10% of all catches observed and open orange circles indicate catches with lower abundance.”

EFH analyst’s communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.1.13 Yellowfin sole

Comments for BSAI yellowfin sole were:

- Rather than qualitative "good" or "excellent" consider expressing correlation quantitatively, such as "strongly positive".
    - Response: Since this quantity was the square of the Spearman's correlation coefficient stating the direction of the correlation is not indicated which is why we used a qualitative descriptor. Model performance is being measured by three fit metrics in the revised methods (section F.2.2).
- The SA asked a clarifying question: Does "95% of locations" in the EFH figure caption refer to probability?
    - Response: No, this is the upper 95% of locations based on abundance predictions reduced by 5% encounter probability.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.2 GOA Groundfish

This section summarizes conversations between SAs and EFH analysts for each GOA groundfish species where the SA provided written comments. These comments and responses were either recorded through the shared Google folder system within the documents provided or captured through conversational follow-up emails, including iterative communication after SAs had a chance to finish their initial review and look over any updates to the new draft species result chapters such as model fit metrics (section F.2.2). The species that have communication reported below are:

- ***Arrowtooth flounder*** (F.3.2.1)
- ***Atka mackerel*** (F.3.2.2)
- ***Blackspotted/Rougheye rockfish complex*** (F.3.2.3)
- ***Deepwater flatfish complex*** (F.3.2.4)
- ***Dusky rockfish*** (F.3.2.5)
- ***Flathead sole*** (F.3.2.6)
- ***Other rockfish complex demersal sub-group*** (F.3.2.7)
- ***Other rockfish complex slope sub-group*** (F.3.2.8)
- ***Pacific ocean perch*** (F.3.2.9)
- ***Rex sole*** (F.3.2.10)
- ***Sablefish*** (F.3.2.11)
- ***Shallow water flatfish complex*** (F.3.2.12)
- ***Shark complex*** (F.3.2.13)
- ***Shortraker rockfish*** (F.3.2.14)
- ***Skate complex*** (F.3.2.15)
- ***Thornyhead complex*** (F.3.2.16)
- ***Walleye pollock*** (F.3.2.17)

The species that did not include SA comments and are not reported below are:

- ***Northern rockfish***
- ***Octopuses***
- ***Pacific cod***

F.3.2.1 Arrowtooth flounder

Comments and suggestions for GOA arrowtooth flounder were:

- Edits provided for the EFH text descriptions in the FMP and the Habitat and Biological Associations Table.
- Clarifying question: what surveys were used?
  - Response: The surveys of mixed gear type are described in detail in the SDM methods section. Arrowtooth flounder early juvenile occurrence data used in the SDM were from the RACE GAP summer bottom trawl survey, ADFG small mesh bottom trawl survey, and nearshore bottom trawl surveys in the updated Nearshore Fish Atlas database. If helpful, we can report the surveys where the species' early juvenile data contributed to the SDM in the results sections.
- The AFSC longline survey and IPHC survey catch arrowtooth flounder with annual sampling in the GOA. Perhaps this information could be included in the next update?
- Response: This is a common concern raised across species (section F.2.2). We will work on adding combined survey data to the SDM Ensembles for the next 5-year Review. We will include a data caveat statement in the species results section to indicate that this additional survey data would likely improve the EFH maps for this species in the GOA.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.2.2 Atka mackerel

Comments and suggestions for GOA Atka mackerel were:

- Edits provided for the EFH text descriptions in the FMP and substantial updates were provided to the Literature Cited section.
- In reference to length-based life stage breaks: Female maturity-at-length and were determined for GOA Atka mackerel (McDermott and Lowe 1997). The age at 50% maturity is 3.6 years and the length at 50% maturity is 38.2 cm.
  - Response: Atka mackerel were re-run in all regions because we switched the subadult break from a reference where the value was based on the central and eastern Aleutians, to McDermott and Lowe (1997). This outcome came from the SA review.
- The SA addressed concerns of the model results. These concerns were also reflected with the BSAI Atka mackerel and discussion between the SA and analysts covered all regions.
  - Response: We are revisiting how model performance is reported and will revise this for the revised species chapters to provide a more comprehensive picture (section F.2.2 and BSAI Atka mackerel (section F.3.1.2))
  - Note: See the EFH analyst's further communication and summary for GOA Atka mackerel below for more information relating to model fit.
- Is there a threshold for the amount of data needed for running the models? This question was in reference to concern for low sample size for mapping subadult GOA Atka mackerel.
  - Response: The current threshold for inclusion in an SDM for EFH mapping is > 50 hauls with individual occurrences (carried over from the SDM EFH approach from the 2017 5-

year Review). This concern was addressed through direct contact and discussion (see below in the EFH analyst's further communication and summary for GOA Atka mackerel for more).

- In reference to the adult encounter probabilities map in the draft species results chapter: Recent survey data shows about a 25% chance of encounter (hauls with catch) in the Shumagin area since 2009 and the percent hauls with catch in the Chirikof and Kodiak areas are even less; the probabilities in the eastern GOA in this map are way more optimistic than the recent survey data. Why?
    - Response: In the EFH working group, we are tackling a lot of the same issues having to do with model fits, limited data sets, and how to assess the results. We will be working to achieve consensus around these issues and your comments will help us to focus our discussions and next steps.

Further communication:

- EFH analysts contacted the lead SA to let them know that the model performance metrics for this species had been updated and that a plan was in process to investigate improving the Atka mackerel ensemble models by e.g., removing a model constituent. The SA was invited to have a conversation.
- EFH analysts contacted the SA to share a document with the updated model performance results for all regions (AI, EBS, GOA), suggested an alternative EFH map for GOA adult Atka mackerel, and provided a detailed response to the larger concerns shared (above) in the review.
- EFH analysts provided the updated model performance metrics for Atka mackerel in all three regions, including the revised GOA adult ensemble with one constituent removed from the ensemble first draft. They included the following: in the revisions of the Methods and Results under development for all regions modeled (AI, EBS, and GOA), we have replaced the Spearman's r-squared with the more traditional Spearman's rank correlation coefficient (rho) and have added the area under the receiver-operator curve (AUC) as well as the deviance explained by the ensemble under the Poisson distribution (PDE). These three fit metrics interpreted together allow a more comprehensive interpretation of where the ensemble performs well and where it does not. Spearman's rho indicates how well the ensemble distinguishes between locations of high and low abundance, AUC indicates the ensemble's ability to discriminate between presence and absence locations, and the PDE provides a measure of how good of a job the ensemble does explaining deviance.
    - SA response was positive.
- EFH analysts responded to concerns raised for the subadult SDM ensemble EFH map: that an N of 87 for subadults was not sufficient. They offered: We understand your concern. While 87 hauls with occurrences is a relatively low number, the overall ensemble performance for this life stage is decent (rho = 0.15 (poor), AUC = 0.91 (excellent), and PDE = 0.41 (good)), and the ensemble is doing very well discriminating between locations of presence and absence in the RACE GAP summer bottom-trawl survey area (i.e., AUC). SSC guidance for the 2017 EFH 5-year Review was that N > 50 species occurrences was a sufficient threshold for developing an SDM EFH map (e.g., Laman et al. 2017). We have applied this species occurrence threshold to all species life stages modeled for the 2023 EFH 5-year Review. Our approach to develop the 2022 SDM ensemble EFH maps was supported by the SSC.
    - SA response, raised continued concerns over sample size, while expressing understanding around use of the occurrence threshold.

        - EFH analyst response: Thank you for clearly explaining your concerns about describing subadult Atka mackerel EFH in the GOA (and for this species in general in the AI and EBS). We feel that it is important to provide this description as a first step to describing some portion of the EFH for this life stage and species in this region (e.g., EFH Level 1 "Distribution data are available for some or all portions of the geographic range of the species" (50 CFR 600.815(a)(1)(iii)(1)). We also agree that it is important to communicate concerns and caveats about model outcomes that are difficult to explain ecologically (i.e., in the revised species results chapters) and to start a conversation to determine how to continue to improve the EFH descriptions and maps for this species and others in the next EFH 5-year Review.
        - EFH analyst follow-up: We are recommending that an expert working group should be formed to revisit and potentially revise scientific guidance for any thresholds applied in EFH mapping, the fishing effects model, and the fishing effects analysis of the EFH maps, and to provide this guidance to the SSC ahead of the 2027 5-year EFH Review. Please let us know if you have an interest in participating.
            - SA responded with interest in participating in the working group.
- The SA indicated disagreement that anywhere a species has ever been observed over the whole time period is relevant to EFH designations. They agreed that exploration of EFH over time and space is very important and it would be an interesting area of research to explore EFH over different time blocks representing different environmental conditions, and also regulations in place over the time series.
    - EFH analyst response: They explained the use of survey catch from 1993–2019 to model and map EFH is intended to map the long term distribution of the stock over a range of environmental conditions. We agree that this is a good area of research to explore. We will add this to the future recommendations. They provided the following information: SSC noted (June 2020; April 2021) that EFH mapped at more temporally dynamic scales may be helpful to include in future EFH mapping efforts to identify potential species range shifts in fishery management areas under climate change. We agree and have a NMFS Office of Sustainable Fisheries funded project underway that develops methods to map and forecast EFH using dynamic environmental covariates and compares this approach to map and forecast EFH using the current static and long term approach (Barnes, Thorson, Pirtle, Rooper, Laman, Aydin, Holsman, Essington in preparation). In addition, this research need was included in the AFSC Regional Action Plans for Climate Science 2.0 for the EBS and GOA. Thank you for your input which will strengthen our approach to SDM EFH mapping for future EFH 5-year Reviews. We hope that research will progress to be able to support these ideas.
    - SA response was positive.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that the SA's concerns were addressed to the extent possible as offered by the EFH analysts at this time. The SA was also informed that the revised NOAA Technical Memoranda Atka mackerel results chapters (AI, EBS, and GOA) and the final version of this report with detailed comments/responses would be shared with them when available before the February 2022 SSC meeting. The SA was invited to have a conversation and, if unavailable to meet, requested to let the EFH analysts know if the information provided has helped address their concerns.

   - Overall SA response (all regions): The SA offered appreciation for addressing concerns, improving EFH maps, and revising the Atka mackerel results chapters. They offered, "The new information and revisions provide much needed clarification and help in the interpretation of results from this update." They will have more comments for future updates and/or future research but approve this draft for the 2023 5-year Review.
   - Note: See also BSAI Atka mackerel for the comments/responses from the follow-up communication between the EFH analysts and the SA, upon sharing the revised Atka mackerel results for the BSAI.

F.3.2.3 Blackspotted/Rougheye rockfish complex

Comments and suggestions for GOA blackspotted/rougheye rockfish were:

- The AFSC longline survey has a high encounter rate of rougheye and blackspotted rockfish and may be a useful data set in this context.
   - Response: The SA was assured their suggestion to add longline survey data to the EFH mapping effort for slope species would be included in the future recommendations and that a "data caveat" statement would be added to the revised species results chapters indicating that including additional data sources may improve the SDM EFH descriptions and maps for these species. See section 3.1 common recommendations for more.

Further communication:

- EFH analysts shared the updated model performance methods and results with the SA for all of their species in the BSAI and GOA FMPs (i.e., concern over model fit for the BSAI species).
- Other statements provided through correspondence with the SA included: Given that EFH is an iterative process, it would be helpful to see how EFH estimates have changed over time.
   - Response: We will be providing more detailed comparisons to the 2017 EFH SDMs at a later stage of this EFH 5-year Review and we provided the extant (2017) maps in the FMPs for the most recent SA Review.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in this report and that the revised NOAA Technical Memoranda species results chapters would be shared with them when available before the February 2022 SSC meeting.
   - SA responded that their concerns about poor model fits for both stocks were satisfied through analyst communication. They offered, "Although I understand its challenges, I'm happy to hear this team will consider using the longline survey data for slope species in the future."

F.3.2.4 Deepwater flatfish complex

The GOA deepwater flatfish complex is made up of the following species:

- *Deepsea sole*
- ***Dover sole***
- *Greenland turbot*

Neither deepsea sole nor Greenland turbot presented sufficient data for SDMs. If possible they should have an EFH text description, which is a requirement of the MSA EFH regulations. If information is not available, the Dover sole EFH text description can be used as a proxy. Comments for the GOA deepwater flatfish complex were therefore limited to Dover sole:

- The analysis shows the subadults' top 10% are offshore at the deepest depths, however the SA noted it looked suspect. Dover sole appear to have cohort-specific changes in maximum size/growth rates over time. The oldest cohorts have small size-at-age. They move ontogenetically, so the old fish are offshore as well. There is also smaller size-at-age in the eastern GOA as compared to the rest of the GOA. The length-stage definitions may therefore need to be revisited. The 2020 September Groundfish Plan Team documents presented research models addressing this.
    - Response: We are recommending based on SA comments that future EFH descriptions and maps try to account for subregional growth and size-at-age differences for applicable species, if possible.
    - Note: The SA raised that a similar problem may be happening for mapping rex sole. See the GOA rex sole section for more.
- The SA raised concerns similar to other species about model fit.
    - Response: See section F.2.2 common recommendations on model fit. Specific to Dover sole, the revised model performance metrics were shared with the SA, and they were informed they will be provided with the revised methods and species results chapters when available.

Further communication:

- EFH analysts shared the updated model performance methods and results for GOA Dover sole (i.e., concern over model fit) and the future recommendation to address temporal and subregional growth differences for this species in a future EFH 5-year Review.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised species EFH NOAA Technical Memo chapters would be shared with them when available before the February 2022 SSC meeting.
    - The SA had no more remaining comments or questions.

F.3.2.5 Dusky rockfish

Comments for GOA dusky rockfish were:

- The SA raised concerns similar to other species that GOA dusky rockfish may not be fit for these analyses given the sparsity of data and gaps in life history knowledge.
    - Response: While we won't be able to address data and life history gaps in this EFH 5-year Review, we recommend that efforts be made to include additional survey data for this species, if possible, in the next EFH Review. See section F.2.2 common recommendations on survey data use for more.
- The SA also raised concerns similar to other species about model fit.
    - Response: Specific to dusky rockfish, the revised model performance metrics were shared with the SA, and they were informed they will be provided with the revised methods and species results chapters when available (section F.2.2).

Further communication:

- EFH analysts shared the updated model performance methods and results for GOA dusky rockfish and the future recommendation to address survey data availability for this species in a future EFH 5-year Review.
    - SA response: We will communicate future revisions of the 2022 GOA dusky rockfish EFH to the other author now working on this stock.
        - EFH analysts responded by sending a document to the new SA with GOA dusky rockfish information in order to share what is planned to help address concerns raised by the first SA in this EFH 5-year Review and asked for questions or comments.
- In response to reaching out to the second SA for dusky rockfish, analysts were able to have more discussions and opportunities to answer the following questions:
    - Why are fishery catches excluded from these analyses, particularly for species that are poorly represented by the survey.
        - EFH analyst response: Fishery observer data were used to model/map Fall/Winter/Spring in 2017 using a single presence-only MaxEnt model due to the nature of those data and the SDM approach to EFH at the time. In the present study, we focused our limited resources on updating the SDM approach and developed the ensemble methods that we are now using; demonstrating these to make new summer maps using the RACE GAP survey data. We will be recommending the development of methods to include other data sources (section F.2.2).
    - Have these EFH outputs been passed by the fleets/industry/stakeholders?
        - EFH analyst response: We agree that the fleet/industry/stakeholders have valuable insights and information that could be brought to bear to describe and map EFH. Our methods and draft results examples have been made available to the public through the SSC and Plan Team meetings at earlier stages of the Council's EFH 5-year Review, which is an iterative review process. The updated methods and complete set of results for species in all regions will be available as NOAA Technical Memos in the near future and accompanied by a Discussion Paper with further comparative analysis and in depth examples provided for the subsequent stages of the Council process, including the February 2022 SSC meeting.
    - The second SA raised similar questions on model fit and the performance metric rubric, and sample size.
        - EFH analyst response: The SA was provided with information specific to dusky rockfish and an explanation of the performance metric rubric (section F.2.2). A recommendation that may come from this EFH 5-year Review will be to revisit the previously established guidelines to describe and map EFH using SDMs and the related Fishing Effects model analysis and develop an objective set of potentially revised scientific guidelines ahead of the next EFH 5-year Review. The SSC approved a minimum sample size of > 50 species occurrences (e.g., hauls where the species was present) during the 2017 EFH 5-year Review to support SDM-based EFH descriptions. The recommended guidelines research would examine whether this or another sampling adequacy cut off would be appropriate.

- Carrying on concerns with sample size, is it appropriate to use a survey that poorly samples a species as the vehicle for determining EFH?
  - EFH analyst response: This is a fair question that can be answered with more research. We invite SAs and other researchers to submit proposals for research that would help to illuminate and answer questions of this nature. Note that EFH designations in the FMPs have two parts: the EFH text descriptions, meant to provide the best possible comprehensive overview of what is understood to be the EFH of each species, and the EFH maps, which identify the geographic locations of EFH for a species within the fishery management units of the FMPs. The MSA EFH regs provide that EFH can be defined based on ". . . some or all portions of the geographic range of the species." (50 CFR 600.815 (a)(1)(i)(iii)(1)), and so we start there and refine this with each 5-year Review.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised species EFH NOAA Technical Memo chapters would be shared with them when available before the February 2022 SSC meeting.
  - The SA had no more remaining comments or questions.

F.3.2.6 Flathead sole

Comments and suggestions for GOA flathead sole were:

- Edits provided for the EFH text descriptions in the FMP with helpful editorial revisions and reference changes.
- The SA asked a clarifying question for EFH areas reported in the new draft species results chapter for subadult and adult flathead sole to understand if they were reached by multiplying relative weight by area then summing.
  - Response: It would be incorrect to interpret the ensemble area as a weighted average of the constituent areas. The ensemble abundance was calculated as a weighted average of the constituents, and then we recalculated the EFH map and area from that abundance. We will revisit how this step is described in the methods to see if we can state this more clearly.
- The SA also asked some clarifying questions regarding the new SDM maps which led to making caption described more clearly. For example, the SA asked what, "top 10% of overall abundance" had referred to in Figure 1: "Does this just mean the top 10% of observed catches? Or catches in the top 10% of predicted EFH?"
  - Response: That refers to the RACE GAP hauls in the top 10% of those with survey catches. We will clarify that in the caption for the early juveniles with combined surveys.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.2.7 Other rockfish complex demersal sub-group

The demersal sub-group is made up of the following species:

- *Canary rockfish*
- *China rockfish*
- *Copper rockfish*
- ***Quillback rockfish***
- ***Rosethorn rockfish***
- *Tiger rockfish*
- ***Yelloweye rockfish***

Sufficient data to develop SDMs was available for quillback, rosethorn, and yelloweye rockfish. Comments for those three species were:

Quillback and rosethorn rockfish

- Currently quillback or rosethorn rockfish are not mapped out for the GOA Southeast Outside (SEO) management area but, looking at ADF&G ROV data, their abundance is higher in the SEO than what the map is showing. The distinction is likely due to the fact that the ROV surveys are conducted closer to shore than what the bottom trawl survey can cover.
    - Response: The use of ROV survey data would make aid the maps and incorporation of additional data sources is a future recommendation for development. See section 3.1 common recommendations for more.

Yelloweye rockfish

- In regard specifically to yelloweye rockfish, ADF&G can provide additional data in regard to subadult presence locations from the Southeast Alaska (SEAK) ROV surveys from the SEO ADF&G management areas in the future. Additional data can be provided in regard to adult yelloweye presence locations from ADF&G.
- A question: why isn't juvenile habitat included in EFH designations and is it due to the size being too small to obtain in trawl surveys? ADF&G also documents juvenile locations in SEO SEAK ROV surveys.
- It would be helpful to see where the bottom trawl survey was conducted in relation to the documented presence points. Yelloweye rockfish abundance/presence may be higher in SEO than what the SDM map shows. This is a similar observation to the quillback and rosethorn rockfish maps.

Complex chapter

- We (ADF&G) hope that the SSC considers including this updated EFH designation data for DSR (yelloweye, quillback, and rosethorn rockfish) for the future. They appear to be much better defined than previous maps.
- Response: We will add a data caveat statement to the chapters about species availability to the RACE GAP survey. We will also make a future research recommendation to develop methods to combine survey data in the SDM ensemble framework to map EFH when helpful for certain species and life stages. The GOA DSR species EFH maps would be more comprehensive if the ADFG ROV survey data was also included.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion. We also thank ADF&G staff for review of new and current EFH information for the GOA demersal rockfish complex and providing helpful input.

F.3.2.8 Other rockfish complex slope sub-group

The slope sub-group is made up of the following species:

- *Aurora rockfish*
- *Blackgill rockfish*
- *Bocaccio rockfish*
- *Chilipepper rockfish*
- *Darkblotched rockfish*
- ***Greenstriped rockfish***
- ***Harlequin rockfish***
- ***Pygmy rockfish***
- ***Redbanded rockfish***
- ***Redstripe rockfish***
- ***Sharpchin rockfish***
- *Shortbelly rockfish*
- ***Silvergray rockfish***
- *Splitnose rockfish*
- *Stripetail rockfish*
- *Vermilion rockfish*
- *Yellowmouth rockfish*
- *Yellowtail rockfish*

Of the slope sub-group other rockfish complex species, greenstriped, harlequin, pygmy, redbanded, redstripe, rosethorn, sharpchin, and silvergray rockfish had sufficient data for SDMs. Originally darkblotched and yellowtail rockfish were also included and reviewed, but were removed on SA's advice due to too little data. These data-limited species did not have an SDM EFH map in 2017 and will be reevaluated in a future EFH 5-year Review. Comments for the seven remaining rockfish were:

Greenstriped rockfish

- There was a consistent concern across Other rockfish complex - slope subgroup species over low spearman's rho square values reported.
    - Response: This comment was included in each of the individual species chapters so, while we report it for greenstriped rockfish, the response is true for all species. We have revised our methods to assess and report model performance more comprehensively. We shared the updated methods and performance results for the GOA OR with you when we met to discuss a path ahead on 09/28/21 given your concerns over the GOA OR and GOA sharks draft results (*discussion outcome reported below*).
- This is a pretty rare species in all surveys and fishery data. That said, it is pretty consistent, in small numbers, in the longline survey each year. The adult EFH map may be representative, but data are so sparse it is hard to judge. Looking at the IPHC data, it strongly suggests that this species is more southern and the GOA is the very extent of it's range, supporting these results.
    - Response: It is helpful when the SA can provide some ecological context for what the resulting SDM EFH maps are showing us (or not). It is also good to know that longline survey data may also be helpful for this species and other GOA OR complex species, which we will include as a future recommendation. We discuss the use of other data sources in section F.2.2.

Harlequin rockfish

- Important point: harlequin rockfish not only associate with high relief habitat, but have high affinity, which really impacts survey catchability.
- Clarifying question: why did the 2017 EFH maps include spring, but not the new SDM maps?
    - Response: In 2017 they modeled summer with RACE GAP bottom trawl survey data (single SDM) and other seasons using fishery observer data with a single presence-only model. We were funded to advance the 2017 EFH maps by advancing the SDM methods using an ensemble approach and new data for the summer season. The other seasonal maps may also benefit from additional data sources if available in the combined survey data approach we would like to develop for the next EFH 5-year Review. The other seasonal maps should be updated sometime.
- These maps seem reasonable, there are some model issues with such low model results and the high affinity for untrawlable habitat that need to be dealt with.
    - Response: We will include a data caveat statement in the species results chapters for harlequin rockfish and other species with similar behavior. Additional presence-absence data from underwater images would be a helpful addition to the SDM ensemble framework for species that associate with untrawlable habitat, if possible, in future mapping efforts. Research will be required from this recommendation to develop the combined survey data methods for the ensembles.

Pygmy rockfish

- The SA commented they would prefer all life stages combined into a single SDM for pygmy rockfish over the other considered method using a length-based break between subadult and adult life stages.
    - Response: We have revised the SDM ensemble to combine the subadult and adult life stages.
- With the poor model fits and the extreme data-limited it's hard to gauge how reasonable the EFH map is. Pygmy rockfish do not show up in the longline survey and are limited in the fishery, but the fishery data is mostly in NMFS area 630, which appears to agree with this map. I would be hesitant to advance this one.
    - Response: The revised ensemble combining both life stages (subadults and adults) is poor at distinguishing between locations with high and low abundance, excellent at discriminating between locations of presence and absence from the RACE GAP summer survey data, and fair at explaining deviance. (Qualitative values refer to the performance metric rubric described in section F.2.2) Revised ensemble performance for this species is fair and adding additional species survey data sources to future mapping efforts will be recommended as a possible improvement.

Redbanded rockfish

- Add a few sentences about how the survey catches both subadult and adults, and mention the frequency of catch. This is one of the better sampled species, relatively speaking. This species is really a longline species, with good sampling on both the IPHC and AFSC longline surveys. One common concern with a lot of these is that the catchability/susceptibility of a species to the survey gear is not discussed.
    - Response: We will add data caveat statements where appropriate to the revised species chapters based on your input. If you were able to provide us with a table of survey catchability values that would be very helpful, thank you.

- The SA advised a follow-up to the phrase, "should be used with some caution" for this and the other species in this complex. The follow-up should have a few sentences addressing the concerns about the data, catchability, etc.
    - Response: We are now being more comprehensive about adding data caveat statements to the revised species chapters and future recs for developing methods to combine survey data in the SDM ensembles well.
- The SA voiced concern about lack of data with this species as well.
    - Response: EFH regulations for EFH Level 1 "Distribution data are available for some or all portions of the geographic range of the species." (50 CFR 600.815(a)(1)(iii)(1)). We provided the SA with revised ensemble results and, while the currently revised ensemble performance for this species is good, adding additional species survey data sources to future mapping efforts will be recommended. We also feel that it is important to include data caveat statements in the results chapters and we will include a future recommendation to develop methods to combine survey data in the SDM ensemble framework.

Redstripe rockfish

- The adult map is supported by fishery data, however, the fishery data does not have sizes, so it is impossible to gauge sub-adults. I would guess that the sub-adult map is not quite accurate.
    - Response: Thanks for connecting the SDM ensemble EFH maps to your understanding of the fishery data. We provided model results from the revised ensembles (summer season) for both life stages (subadults and adult). Although currently ensemble performance for this species is good, following similar suggestions from the other species in this complex, we will recommend adding additional species survey data sources to future mapping efforts.

Sharpchin rockfish

- The SA asked a similar question about seasonal data, specifically data used for a spring map that was also asked for harlequin rockfish.
    - Response: The other seasonal maps from 2017 (not summer) used fishery observer data. It is outside the scope of this study to update the other seasonal maps. However, the maps for the other seasons should be updated at some point and included in the effort to combine additional survey data to the extent possible in the SDM ensemble framework.
- This species is rarely caught by hook and line gears, so the bottom trawl survey is likely the best survey for this species. The model fits are poor, but on the scale of Other rockfish, not bad.
    - Response: Thanks for connecting the SDM ensemble EFH maps to your understanding of the ecology of this species and the fishery data, which is very helpful. Overall, ensemble performance for this species is good. The analysts supplied the SA with new ensemble performance metrics for review.

Silvergray rockfish

- The SA offered this species is also a good species to be represented with AFSC longline survey data. They noted silvergray rockfish are not a huge fishery bycatch species, but their distribution seems to match the adult map.
    - Response: This is a good candidate for adding longline survey data to future mapping efforts. We will add a data caveat for this species.

Complex Chapter

- The only caveat that has not been addressed in the complex chapter is that the trawl survey can't sample untrawlable habitat, which is primary habitat for one of the primary species in the complex (harlequin rockfish).
    - Response: We have included data caveat statements in the revised species results chapters where needed e.g., for harlequin. Additional presence-absence data from underwater images would be a helpful addition to the SDM ensemble framework for species that associate with untrawlable habitat, if possible, in future mapping efforts. Research will be required from this recommendation to develop the combined survey data methods for the ensembles.
- Should the EFH text descriptions have references?
    - Response: Something will need to be provided more clearly this time in the FMP species complex chapters for the EFH sections. References are usually provided in the Life History sections.

Further communication:

- EFH analysts shared the updated model performance methods and results for the GOA other rockfish complex member species due to SA concerns raised about model performance in the review of these species. We also discussed options for species of concern where an EFH map had not been advanced in 2017, data caveats to report, and future research recommendations.
    - EFH analyst and SA shared response:
        - Updated model performance metrics were shared and discussed for GOA other rockfish complex, which was helpful and appreciated by theSA in understanding model performance more comprehensively for these species.
        - There was agreement that EFH maps for darkblotched and yellowtail rockfishes would not be developed for this EFH 5-year Review. These species members of the complex also did not have an EFH map in 2017.
        - The SA and EFH analysts recommend that research should take place to include data from the longline surveys and underwater images from uncrawlable habitats in future EFH mapping efforts for these rockfish species.

EFH analyst's communication summary:

- As a follow up, EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised NOAA Technical Memoranda species results chapters would be shared with them when available before the February 2022 SSC meeting.
    - Proceed based on agreements from further communication.

F.3.2.9 Pacific ocean perch

Comments for GOA Pacific ocean perch were:

- These maps may lead to a bit of over-confidence in what we actually know about distribution, in particular for the subadult/juvenile life stages. The SA wanted to make sure we identify and are aware of places where it might be overstating confidence in the models.

    - Response: We agree with identifying loci where we may be overstating confidence in our model output and carrying that forward for future improvement.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.2.10 Rex sole

Comments for GOA rex sole were:

- Similar to notes for Dover sole size-at-age comment, rex sole may need to be revisited: there are a lot of subadults in the Eastern GOA where fish have smaller size-at-age. The stock assessment is actually a 2-area assessment with growth estimated separately by area for this reason.
    - Response: Thanks for pointing out these regional and temporal growth differences (i.e., rex sole, Dover sole, and possibly northern rock sole). We recommend that this be addressed in the next 5-year Review cycle, if possible, as there is not time to dig into this well in the current cycle and it was not flagged as a concern in 2017. We invite the SA to participate in working through a revised approach for this species and Dover sole.

Further communication:

- EFH analysts shared the updated model performance methods and results for GOA rex sole (although fit concerns were not raised in their review of this species) and the future recommendation to address temporal and subregional growth differences for this species in a future EFH 5-year Review.
- EFH analyst's note: We are recommending based on SA comments that future EFH descriptions and maps try to account for subregional growth and size-at-age differences for applicable species, if possible.

EFH analyst's communication summary:

- EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised NOAA Technical Memoranda species results chapters would be shared with them when available before the February 2022 SSC meeting.
    - The SA had no more remaining comments or questions.

F.3.2.11 Sablefish

Comments for GOA sablefish were:

- The SA echoed comments and concerns between BSAI and GOA sablefish. See the BSAI responses to general sablefish comments (section F.3.1.9).
- The main concern was the lack of incorporation of the longline survey data. Sablefish, particularly adults, are not consistently surveyed by the trawl gear due to depth, habitat, and potentially tow speed limitations. The longline survey is designed explicitly to survey sablefish abundance. It seems like the inclusion of longline survey data would be necessary to adequately identify EFH for sablefish using SDMs.
    - Response: There are several efforts in the works for combining disparate survey data into single species distribution models so we anticipate that in the next review trawl data

could be combined with longline and pot data to give a more accurate picture of sablefish in Alaska. The inclusion of different data sources was a common concern across species (section F.2.2).

- It might be worth some consideration of whether the trawl data is reliable enough for sablefish and/or the optics created by not incorporating the longline survey data.
    - Response: We will add a survey data caveat statement to the sablefish SDM ensemble results chapters. We will include as a future recommendation from the 2023 EFH 5-year Review that longline survey data be included if possible in future SDM ensemble EFH mapping efforts for this species. Research will be required to develop methods to combine survey data sets in the SDM ensemble framework.
- Caveats about the use of trawl data to define EFH is warranted, especially since trawl gear does not necessarily consistently survey common habitat/depths of adult sablefish and it would also be good to mention potential use of longline survey data in the future
    - Response: I will add this data caveat statement and a footnote indicating the future recommendation for research to develop methods for a combined survey data approach for certain species within the new SDM ensemble framework that we are putting forth this year. Your review and others are emphasizing how important using more than just the RACE GAP bottom trawl survey data is to more comprehensively map EFH for slope and untrawlable habitat species.
- The SA asked a clarifying question about the early juvenile stage mixed gear SDM methods. They noted that other sablefish chapters do not use other gears and also emphasized the use of longline survey data.
    - Response: The regional methods were revised and shared with the SA. The sablefish early juvenile SDMs were presence-only (MaxEnt) models that combined RACE GAP bottom trawl, ADFG small mesh bottom trawl, Auke Bay Laboratory Nearshore Fish Atlas, holdings from small mesh nearshore trawls, beach and purse seines, and the MESA sablefish tagging program jigging catch locations. To combine survey data well to map EFH we need to develop combined survey/gear methods to be applied within the SDM ensemble framework (e.g., with GAMs) that is new in the 2022 EFH Review for the subadult
- The SA asked a clarifying question about the consistency of ranking model results for all regions.
    - Response: We have addressed consistently reporting model performance metrics among regional authors for the revised species results chapters and provided the revisions to the SA (section F.2.2).

EFH analyst’s communication summary:

- EFH analysts contacted the lead SA to share a document with the updated model performance results for all regions (AI, EBS, GOA), and provided responses to the larger concerns shared (above) in the review. EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA’s concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that the revised Sablefish EFH NOAA Technical Memo chapters (AI, EBS, and GOA) and the final version of this report with detailed comments/responses would be shared with them when available before the February 2022 SSC meeting. The SA was invited to have a conversation and, if unavailable to meet, requested to let the EFH analysts know if the information provided has helped address their concerns.
    - The SA had no more remaining comments or questions.

F.3.2.12 Shallow water flatfish complex

The shallow water flatfish complex is made of the following species:

- ***Alaska plaice***
- ***Butter sole***
- ***English sole***
- ***Northern rock sole***
- ***Southern rock sole***
- *Sand sole*
- ***Starry flounder***
- ***Yellowfin sole***

Additional other flatfish species are also included in this complex:

- ***Pacific sanddab***
- ***Petrale sole***
- ***Slender sole***

Not all species had comments that were substantial for reporting here or concerns raised are responded to for the entire complex, like model fit. Sand sole did not have 2017 documents to review or a new draft species results chapter. Comments for the shallow water flatfish complex were summarized for English sole, northern rock sole, and the overall complex:

English sole

- In reference to life stage breaks, the study used to delineate stages focused on yellowfin sole and northern rock sole in the Bering Sea. Did you assume English sole and yellowfin sole had similar length stratification regarding subadults and adults?
    - Response: Yes, this is the best information that we could find to set length-based life history breaks for this species and clearly report that studies of similar species are being used as proxies until better life history information is available for this species. Similarly, we used a study of yellowfin sole, Alaska plaice, and flathead sole for distinguishing between subadults and adults as a proxy for English sole. We will clarify in these sections that this study of other flatfish species in Alaska is used as a proxy.

Northern rock sole

- Which models in the ensemble were applied to the mixed survey data, like the early juvenile life stage?
    - Response: The GOA early juvenile models are presence-only MaxEnt models, which we use as an approach to combine survey data and gear types for the GOA early juvenile life stage only in the study. We developed the SDM ensemble framework (MaxEnt and 4 types of GAMs) for the 2023 EFH 5-year Review, which is an improvement over the single model approach of the 2017 Review. Combining survey data and gear types in the ensembles is beyond what we can accomplish with time and staff capacity now. We realize, thanks to your review and others, that combining survey data in the ensembles is needed for certain species and life stages and recommend research to develop this for the next EFH 5-year Review.
- How representative is northern rock sole distribution prior to 1996 if northern and southern rock sole were separately identified consistently until 1996? Did you run models starting in 1996 to see if this impacted the model results? These questions apply to southern rock sole as well.
    - Response: Northern and southern rock sole were modeled separately (for all regions) using RACE GAP survey data from 1996-2019. These two species are combined in a

presence-only model of the settled early juvenile life stages in the GOA, where earlier years sampled by the nearshore surveys are included.

Complex chapter

- Overall the SA raised questions for each of the species regarding model fit and sample size, and discussed the inclusion of some of the species in mapping.
    - Response: The revised model performance methods and results were shared with the SA with an explanation (section F.2.2). The EFH analyst shared, "Using the expanded approach to assess model performance, the results for GOA shallow water flatfish overall ensemble performance for each species life stage is considered 'good' for most and none are considered 'poor'."

Further communication:

- EFH analysts shared the updated model performance methods and results for the GOA shallow water flatfish stock complex species due to concerns raised about model fit in the review of these species. Clarification was provided on the first survey year applied (1996) to model subadult and adult northern and southern rock soles as individual species in the GOA (and other regions).

EFH analyst's communication summary:

- EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA's concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised NOAA Technical Memoranda species results chapters would be shared with them when available before the February 2022 SSC meeting.
    - The SA had no more remaining comments or questions.

F.3.2.13 Shark complex

The GOA shark complex includes:

- ***Pacific sleeper shark***
- ***Spiny dogfish***
- *Salmon shark*
- *Other sharks*

Only Pacific sleeper shark and spiny dogfish were common enough in catches to support SDMs, so comments on the GOA shark complex are limited to those species.

Pacific sleeper shark

- The survey data applied to develop the SDM ensemble is inadequate to represent this species. It does not accurately represent the true distribution of the species, only the survey distribution, from one survey. It would be a misrepresentation of the species distribution to put this in an official EFH for the species.
    - Response: Through discussions with the SA and EFH analysts, there was agreement that Pacific sleeper shark EFH maps would not be developed for this EFH 5-year Review.
    - SA note: It might be interesting to look at the spatial distribution of the lengths. While the survey is very poor for this species and not adequate for this type of modelling, the length data are useful.
- If this gets put forward, the SA suggested adding notes to the effect that this survey is ineffective for this species and specify other surveys that may provide more representative data. The SA

suggested changing the wording from "with some caution" to "as a minimally informed SDM only showing a slice of the habitat used by the species" to hit the point home. The SA did not recommend putting this model forward.

- Response: The model results were relatively low performance values. Model fit concerns were partially addressed with the new metrics (section F.2.2), and through communication with the SA, Pacific sleeper shark EFH maps will not be advanced by the EFH analysts for this 5-year Review. This data-limited species did not have an SDM EFH map in 2017 and will be reevaluated in a future EFH 5-year Review.

Spiny dogfish

- The SA offered edits including updating references and resources.
- The SA raised concerns about the model fit and noted it makes sense that the sub-adult dogfish would be the best fitting model because the trawl survey tends to get smaller dogfish.
    - Response: We are revisiting how we assess and report model performance and supplied the SA with new model metrics (section F.2.2).
- Making the phrase, "with some caution" more direct reiterate that this model is informed only by a survey that has poor catchability for this species and that other surveys may be more informative.
    - Response: Spiny dogfish results will be reported with a data caveat about use of bottom trawl survey data alone. There was more discussion summarized below.
- It makes sense that there would be some hotspots shown in the EFH maps, but not that there are none in the rest of the GOA.
    - Response: This is a good point. Currently, the ensemble model of predicted habitat-related abundance is an EFH Level 2 model and map. These models and maps are still in development, and we plan to find ways to improve in the future (e.g., add other surveys if possible in a GAM framework), and see offering some species/life stage maps as a helpful place to start. Here is the definition of EFH Level 1: "Distribution data are available for some or all portions of the geographic range of the species. At this level, only distribution data are available to describe the geographic range of a species (or life stage). Distribution data may be derived from systematic presence/absence sampling and/or may include information on species and life stages collected opportunistically. In the event that distribution data are available only for portions of the geographic area occupied by a particular life stage of a species, habitat use can be inferred on the basis of distributions among habitats where the species has been found and on information about its habitat requirements and behavior. Habitat use may also be inferred, if appropriate, based on information on a similar species or another life stage." Do you support putting forth EFH maps for the sharks as a place to begin in this 5-year EFH Review?
        - SA response: This is a place to start for Level 1 subadult spiny dogfish, and maybe for adults if the appropriate caveats are included in the text. For Pacific sleepers sharks, the data does not support it yet.

Complex chapter

- The SA asked a clarifying question that there was no text to review for the GOA shark complex from 2017.
    - Response: The GOA FMP has sparse text for the shark complex (and no individual species at all) to indicate that there is no EFH text description. There are also no EFH maps for GOA sharks and there was not enough data to make an SDM in 2017 so no EFH

model and map were attempted. Now, there are more data, so an EFH model and map were attempted for both spiny dogfish and Pacific sleeper sharks. Working with the SA, we are in agreement that the spiny dogfish maps and text description should be developed for the 2023 EFH 5-year Review.

Further communication:

- EFH analysts shared the updated model performance methods and results for the GOA shark complex species due to concerns raised about model performance in the review of these species. We also discussed options for species where an EFH map had not been advanced in 2017, data caveats to report, and future research recommendations.

EFH analyst’s communication summary:

- EFH analysts asked for confirmation that their efforts were an improvement that helped address the SA’s concerns to the extent possible as offered by the EFH analysts at this time. The SA was also informed that our detailed responses to all of their comments would be provided in the final version of this summary report and that the revised species EFH NOAA Technical Memo chapters would be shared with them when available before the February 2022 SSC meeting.
    - EFH analyst and SA shared response:
        - Updated model performance metrics were shared and discussed for GOA sharks, which was helpful and appreciated by the SA in understanding model performance more comprehensively for these species.
        - There was agreement that spiny dogfish EFH maps will be developed for this EFH 5-year Review for both subadults and adults in the GOA and the EFH text description will also be updated with current information by the SA. Spiny dogfish results will be reported with a data caveat about use of bottom trawl survey data alone.
        - There was agreement that Pacific sleeper shark EFH maps would not be developed for this EFH 5-year Review. Pacific sleeper sharks also did not have an EFH map in 2017.
        - The SA and EFH analysts recommend that research should take place to include longline survey data in future EFH mapping efforts for shark species.
- EFH analysts do not need to develop a GOA Sharks Complex EFH map, as spiny dogfish are the only species mapped in this complex (see our new, proposed methods for mapping stock complexes as a proxy for unmapped member species).

F.3.2.14 Shortraker rockfish

Comments for GOA shortraker rockfish were:

- The suggestion would be to add the use of the longline survey in the future. The SA added they would not expect the inclusion of that data to change the model results.
    - Response: We agree it would be very helpful to include the longline survey data in the SDM and this is a commonly requested data source to include for several species. We are sorting out how to include information from additional surveys as well as untrawlable habitat (section F.2.2).

EFH analyst’s communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.2.15 Skate complex

The GOA skate complex is made up of the following species:

- ***Alaska skate***
- ***Aleutian skate***
- ***Bering skate***
- ***Big skate***
- ***Longnose skate***
- *Whiteblotched skate*

There was not sufficient data for an individual whiteblotched skate SDM ensemble EFH map, Comments for the of the GOA skate stock complex were:

- Similar to the comment made for BSAI skates, the sections on the aggregate habitat modeling for skates were confusing due to the use of the term "other skates". In each area, "other skates" has a specific meaning from a management perspective. The SA recommended calling it the skate complex.
    - Response: We received confirmation from the SA that the species lists for the “skate complex” combined species maps are correct. See also the BSAI skate stock complex discussion.

EFH analyst’s communication summary:

- EFH analysts contacted the SA and confirmed the species lists for the “skate complex” combined species maps are correct. There were extensive editorial suggestions provided to the SDM Chapter, which will be addressed upon revision. Any other remaining concerns were addressed.

F.3.2.16 Thornyhead complex

The GOA thornyhead complex includes:

- ***Longspine thornyhead rockfish***
- ***Shortspine thornyhead rockfish***

There was not sufficient data for a GOA longspine thornyhead individual species SDM ensemble EFH map. Comments for the complex and shortspine thornyhead rockfish were:

- Why was the longline survey data not used to assist with this analysis? The longline survey is now used in the random effects model, in addition to the trawl survey, to estimate the biomass of shortspine thornyhead.It also is more consistent in sampling this species.
    - Response: It would be very helpful to include the longline survey data in the SDM and we are tracking for which species this is requested (section F.2.2).

EFH analyst’s communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.2.17 Walleye pollock

Comments for GOA walleye pollock were:

- The SA offered edits and recommendations for updating the life history section.
- The methods for the new models only describe nearshore mixed gear-type surveys, which are mostly beach seines. The SA asked for clarification of which survey this is.
    - Response: The surveys were updated NMFS Auke Bay Laboratory Nearshore Fish Atlas beach seine and nearshore trawl data, and the ADF&G small mesh trawl survey. We also used RACE GAP bottom trawl survey data from hauls where this life stage was caught. In reference to the juvenile pollock mixed survey mapping, a paper used mixed nearshore only survey data from the updated Nearshore Fish Atlas to make some finer resolution and very nearshore SDM maps for pollock in SEAK and PWS (Grüss et al. 2021). Although this is not part of what is being put forward for the 2022 EFH Review, we hope that their approach will be a helpful starting place to mapping EFH for species and life stages in the nearshore (using combined survey data of mixed gear types) to be paired with the fishery management unit wide EFH maps in a future EFH 5-year Review.
- The SA asked the relevance of lab results to pollock habitat in reference to the EFH Level 3 habitat-related vital rate methods/results.
    - Response: We will add a caveat sentence about the lab studies, however they are a helpful contribution and a good place to begin assessing these relationships with respect to EFH Level 3 information (habitat-related vital rates) and others.
- The SA also had several clarifying questions in regards to growth, temperature, and lipid accumulation data used for the EFH Level 3 habitat-related vital rate methods/results. They noted some relationships looked odd.
    - Response: A one size fits all approach to fitting the SDM ensembles is easiest with so many species life stages and limited staff capacity and time. However, we are considering that in some cases a species specific approach might be warranted to get under the hood of some of the models and make adjustments to possibly improve the overall result.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.3 BSAI Crabs

This section summarizes conversations between SAs and stock experts with EFH analysts for each BSAI crab species where the reviewers provided written comments. These comments and responses were either recorded through the shared Google folder system within the documents provided or captured through conversation and follow-up emails, including iterative communication after reviewers had a chance to finish their initial review and look over any updates to the new draft species result chapters. The species that have communication reported below are:

- ***Blue king crab*** (F.3.3.1)
- ***Golden king crab*** (F.3.3.2)
- ***Red king crab*** (F.3.3.3)
- ***Snow crab*** (F.3.3.4)
- ***Tanner crab*** (F.3.3.5)

F.3.3.1 Blue king crab

Comments for EBS blue king crab were:

- Could the EFH maps be provided in more detail by stock? For example: around St. Matt's and Pribilof Islands in greater detail could inform the ESP/ stock assessment process.
    - Response: We map EFH for targeted species (not stocks) in the fishery management units corresponding to the Fishery Management Plans (50 CFR 600.805(b)).
- If an encounter probability of 50% means blue king crab are caught once out of every 2 years at a station, then this is probably overestimating in a lot of areas.
    - Response: We agree that the SDM approach and use of encounter probability presently overpredicts the likely area of EFH for blue king crab especially with regard to predicting EFH in areas historically without any blue king crab occurrence. There are a number of avenues to be pursued in improving this result (e.g., using a cumulative frequency distribution instead of an encounter probability to shape the distribution of predictions, exploring additional covariates like salinity that may help structure populations, and spatio-temporal modeling in place of GAMs or Maxent) that we can explore.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.3.2 Golden king crab

Comments for BSAI golden king crab were:

- The SA asked a clarifying question about the weighting given to individual models in the ensemble model analysis.
    - Response: This was a lesson in document access for SAs from different agencies and something we will be sure to provide all information, including the SDM methods section, to all SAs and stock experts in the future. We provided the model methodology to the SA and they appreciated the information on the ensemble methods and weighting approaches.
- The SA identified difficulty in assessing golden king crab populations noting the lack of fishery-independent surveys for this stock. Also, the AI trawl survey is not able to trawl in golden king crab habitat. They noted there are other data streams including observer sample pots in the fishery and a pot survey in the eastern portion of the grounds.
    - Response: Thank you for suggesting a supplemental source of data to include. We would like to develop methods to combine survey data sources and gear types in the SDM ensemble framework for the next EFH 5-year Review, if possible. AI GKC would be a good candidate for a combined species survey data approach (section F.2.2).

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.3.3 Red king crab

Comments for BSAI red king crab were:

- SAs offered several edits updating existing EFH descriptions and adding new references in the FMP.
- Like snow crab, it might be useful to parse juvenile and mature crab out at some point in the future.
    - Response: We will be exploring separately modeling immature/mature crabs in the EBS in the next EFH 5-year Review using the crab maturity data stored in Kodiak. We will include the suggestion to utilize Kodiak Lab crab maturity data as a future recommendation.
- Multiple red king crab SAs and stock experts raised questions about the differences for stocks compared to the regional differences mapped for EFH. Topics included potential differences in biology; differences in habitat conditions, needs, or preferences; differences in survey efforts between the EBS and NBS
    - Response: We are not specifically addressing those differences in this work because we map EFH for targeted species (not stocks) in the fishery management units corresponding to the Fishery Management Plans (50 CFR 600.805(b)). This is why EFH is mapped for red king crab as a species and not separately by subarea stocks such as Norton Sound red king crabs. There is potential to improve the BSAI red king crab EFH descriptions and maps in the next EFH 5-year Review, such as working on getting more species presence-absence data for red king crab in Norton Sound to the extent possible and improving the environmental covariates applied to the models.
    - Response: A future recommendation will be to address survey effort differences with weighting the stations to standardize effort.

Further communication:

- Why is Norton Sound only important habitat in summer when there are summer and winter (extending into spring in some years) fisheries, and some tracking data?
    - Response: Observer data from commercial fishery catches of red king crab in fall, winter, and spring commercial fisheries were applied when the 2017 EFH maps (currently in the FMP) were developed using the species distribution modeling approach of the 2017 EFH 5-year Review. Observer data available at that time from catches on the middle shelf near Bristol Bay and around the Pribilof Islands and were applied to the seasonal models (other than summer). See NOAA Technical Memorandum 357 (Laman et al. 2017, Fig. 152) for the seasonal fishery observer data maps. Although we did not revise the seasonal maps (other than summer) for the 2023 EFH 5-year Review in the present study, it is possible that the other seasonal maps will be revised in a future EFH 5-year Review when additional data, if available, could be applied to the models to improve the BSAI red king crab EFH maps, including inside Norton Sound. We suggest that a research priority for the next EFH 5-year Review be developing an approach to combine data from different surveys and gear types in the SDM ensemble framework if possible to potentially improve the EFH maps for crabs.
        - SA response: There is existing data on red king crab winter distribution at the scale of ADF&G statistical harvest area for retained legal male crab, and potentially additional observer data for other crab categories and seasons. There was confusion over the need to wait for the next review for seasonal maps.

- Response: Similar concerns have been raised for crabs by other reviewers and the EFH analysts have been working to address those concerns to the extent that is possible at this time. The species distribution modeling (SDM) EFH study for the 2023 EFH 5-year Review was funded to update the 2017 SDM methods with a new SDM ensemble approach and revise the summer EFH maps for groundfish and crabs in the GOA and BSAI to advance EFH information levels from none to Level 1 (distribution) and from Level 1 to Level 2 (density or abundance) and to add Level 3 (habitat-related vital rates) for the first time to demonstrate a Level 3 approach for a small set of species, as were the priorities of the Alaska EFH Research Plan recommended from the 2017 EFH 5-year Review. As the EFH 5-year Review process is iterative, there is an opportunity to keep improving each time.
- Further response: The seasonal maps (other than summer) from the 2017 EFH 5-year Review were developed using fishery observer data and, due to the nature of those data and the SDM EFH methods at that time, modeled using presence-only (MaxEnt) models (i.e., not presence-absence GAMs). We agree that there is a need to update the other seasonal maps for crabs when possible. To do this well, we have realized that a combined survey data approach is needed to include multiple data sources in the SDM ensemble framework for certain species and seasons. Thanks to your input and that of other stock authors/experts in this review, we have identified that developing this combined survey data approach within the SDM ensemble framework should be recommended as one of the research priorities for the next EFH 5-year Review.

EFH analyst’s communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.3.4 Snow crab

Comments for EBS snow crab were:

- There are many small snow crab up north (NBS) and it’s unclear if they come south, grow enough to be impacted by the EBS fishery, or contribute to the population dynamics of the EBS, given the prevailing currents. As such, it's a little hard to designate what is 'essential' habitat.
    - Response: We designate Essential Fish Habitat based on the definition in the MSA EFH provisions, “Essential fish habitat (EFH) means those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” See section 3.1 common recommendations for more information on the definition. We welcome the interest of crab scientists to work with EFH analysts to assist in refining the crab EFH designations in the future. Our goal is to keep refining EFH information for species with each EFH 5-year Review as the science and data available progresses over time.
    - Further response: In this 5-year Review we will have new SDM EFH maps for snow crab in the Arctic management area that combines the Chukchi and Beaufort seas.
- Bottom temperature would likely shake out as much more important if snow crab was split by life stage: the juveniles are stenothermic, but there is an ontogenetic migration in which older mature

crab end up in warmer, deeper waters. Given the ontogenetic migration observed, it might make sense to separately model snow crab life stages.

- Response: We will be exploring separately modeling immature and mature crabs in the EBS in the next EFH 5-year Review using the crab maturity data stored in Kodiak.

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.3.3.5 Tanner crab

Comments for EBS Tanner crab were:

- The EFH map indicates "core" habitat in eastern Norton Sound but the map of survey catches does not show any Tanner caught close to the area in question. Is this a consequence of what one might call "extrapolation" by the SDM?
  - Response: This is an example of the SDM extrapolating Tanner abundance into eastern Norton Sound. Given the habitat covariates underlying the ensemble SDM, I interpret this to indicate that conditions are favorable for Tanner's to be found in that part of Norton Sound whether they appeared there in the survey data or not.
  - Note: The SA noted Tanner crab were caught in Norton Sound in 1985 and 1988. However, no NBS data prior to 2010 were included in the SDMs.
- The designation of EFH for Tanner crab in eastern Norton Sound is somewhat problematic and probably revolves on the meaning of "essential" in EFH. The EFH maps were based on surveys in the NBS starting in 2010. None of these surveys found Tanner crab in Norton Sound, so the designation of EFH in eastern Norton Sound must be based strictly on habitat characteristics.
  - Response: We are aware of this concern and are developing a strategy to recommend scientific guidance for mapping EFH under the MSA EFH regulations before the next EFH 5-year Review (section F.2.2).

EFH analyst's communication summary:

- EFH analysts addressed remaining concerns in species chapter revision as the SA indicated in previous communication that there was not an immediate concern or need for additional discussion.

F.4 Closing Summary

The SA and species expert review of EFH components 1 and 7 for the 2023 Review was a successful way to engage stock assessment community and other species experts, gain insights into new information for their species to update the EFH sections of the FMPs, receive extensive expert peer review of the new ensemble SDM EFH methods, results, and maps that will be reported in the three regional NOAA Technical Memoranda (Chapter 5), and participate in constructive and collaborative conversations.

EFH analysts are carrying forward reviewer comments and concerns that could not be addressed in 2023 Review as research recommendations to address leading up to a future EFH 5-year Review. The results of the SA review were originally reported to the SSC in February 2022 (Chapter 2). Table F1 provides a summary of the SA review input that will be included as recommended changes to the EFH sections of the FMPs, including the text descriptions and maps. These recommended updates are provided in detail in the EFH 5-year Review Summary Report[60].

Table F1. Recommended updates provided by the SA review for the current EFH component 1 sections of the BSAI, GOA, and Crab FMPs. In all cases the new summer distribution EFH maps were recommended to replace the current maps. Not all species and species complexes included in the 2023 Review had an EFH description in the 2017 Review. The top row of the table shows the total number of species and species complexes reviewed for each FMP and region.

EFH Description Recommended Changes	**EBS**		**AI**		**GOA**	**TOTAL**
	Groundfish	**Crabs**	**Groundfish**	**Crabs**	**Groundfish**	
Species and Species Complexes Reviewed	**35**	**4**	**28**	**2**	**46**	**115**
Edits to EFH text description	21	5	19	2	30	**77**
Expanded on existing text description	5	3	4	1	3	**16**
Updates to life history	14	4	11	1	7	**37**
Updates to general distribution	8	4	7	1	5	**25**
Updates to literature	13	5	13	2	11	**44**
Comments on 2017 maps	5	2	4	1	2	**14**
Updates to habitat association tables	3	1	2	1	2	**9**

F.5 Preparers and Persons Consulted

NMFS Alaska Fisheries Science Center

- Ned Laman, RACE GAP, EFH Component 1 SDM Project Lead Principal Investigator
- Jeremy Harris, RACE GAP, EFH Component 1 SDM Project, Contractor (Lynker)
- Margaret Siple, RACE GAP, EFH Component 1 SDM Project, Analyst
- Jim Thorson, HEPR Program Lead

NMFS Alaska Region

- Jodi Pirtle, HCD, EFH Component 1 Descriptions and Identification Lead; EFH Component 1 SDM Project Principal Investigator
- Molly Zaleski, HCD, EFH Component 2 Fishing Effects and Component 7 Prey Species Lead
- Gretchen Harrington, HCD, Assistant Regional Administrator

Stock Authors and Experts

[60] EFH Component 1 (Chapter 2) in EFH 5-year Review Summary Report (January 2023) available on Council agenda for this meeting

- Refer to Table F1 for the full list of SAs and stock experts who reviewed species information documents for this EFH 5-year Review.

F.5.1 Stock Assessment Author and Species Expert Reviewers

This section contains information on the stock assessment authors and species experts who provided reviews of EFH component 1 information. Below is a list of the 30 SAs and species experts that participated in the SA review of current and new EFH component 1 information for the 2023 Review (Table F2). The species or species complexes, with species within the complexes listed parenthetically, are divided by the regions each participant reviewed.

Table F2. Stock assessment authors and species expert reviewers by region (EBS, AI, and/or GOA) and species or species complexes reviewed.

Name	Affiliation	Region	Species
Steve Barbeaux	NMFS	AI	Walleye pollock
		GOA	Pacific cod
Bill Bechtol	University of Alaska Homer	EBS	Red king crab
Meaghan Bryan	NMFS	EBS	Greenland turbot, Kamchatka flounder
		AI	Greenland turbot, Kamchatka flounder
		GOA	Shallow water flatfish complex (Alaska plaice, butter sole, English sole, northern rock sole, Pacific sanddab, petrale sole, sand sole, slender sole, southern rock sole, starry flounder, yellowfin sole)
Ben Daly	ADFG	EBS	Golden king crab, red king crab
		AI	Golden king crab, red king crab
Martin Dorn	NMFS	GOA	Walleye pollock
Katy Echave	NMFS	GOA	Shortraker rockfish, Thornyhead complex (longspine thornyhead rockfish, shortspine thornyhead rockfish)
Kari Fenske	NMFS	GOA	Dusky rockfish
Jennifer Gardner	ADFG	EBS	Snow crab
Dan Goethel	NMFS	EBS	Sablefish
		AI	Sablefish
		GOA	Sablefish
Pete Hulson	NMFS	GOA	Pacific ocean perch
Jim Ianelli	NMFS	EBS	Walleye pollock
Chris Long	NMFS	EBS	Blue king crab
Sandra Lowe	NMFS	EBS	Atka mackerel

		AI	Atka mackerel
		GOA	Atka mackerel
Carey McGilliard	NMFS	EBS	Northern rock sole
		AI	Northern rock sole
		GOA	Deepwater flatfish complex (Dover sole), Rex sole
Cole Monnahan	NMFS	EBS	Flathead sole-Bering flounder complex (Bering flounder, flathead sole), Other flatfish complex (butter sole, deepsea sole, Dover sole, longhead dab, rex sole, Sakhalin sole, starry flounder)
		AI	Flathead sole-Bering founder complex (flathead sole), Other flatfish complex (Dover sole, rex sole, southern rock sole)
		GOA	Flathead sole
Olav Ormseth	NMFS	EBS	Alaska plaice, Octopuses (giant octopus), Skate complex (Alaska skate, Aleutian skate, Bering skate, big skate, mud skate, whiteblotched skate)
		AI	Octopuses (giant octopus), Skate complex (Alaska skate, Aleutian skate, Bering skate, mud skate)
		GOA	Octopuses (giant octopus), Skate complex (Alaska skate, Aleutian skate, Bering skate, mud skate)
Katie Palof	ADFG	EBS	Blue king crab
Kalei Shotwell	NMFS	EBS	Arrowtooth flounder, shortraker rockfish
		AI	Arrowtooth flounder, shortraker rockfish
		GOA	Arrowtooth flounder
Shareef Siddeek	ADFG	EBS	Golden king crab
		AI	Golden king crab
Paul Spencer	NMFS	EBS	Blackspotted/Rougheye complex (blackspotted rockfish, rougheye rockfish), northern rockfish, Pacific ocean perch
		AI	Blackspotted/Rougheye complex (blackspotted rockfish, rougheye rockfish), northern rockfish, Pacific ocean perch
Ingrid Spies	NMFS	EBS	Yellowfin sole
		AI	Pacific cod

William Stockhausen	NMFS	EBS	Blue king crab, Tanner crab
Jane Sullivan	NMFS	EBS	Other rockfish complex (shortspine thornyhead rockfish)
		AI	Other rockfish complex (dusky rockfish, harlequin rockfish, shortspine thornyhead rockfish)
		GOA	Blackspotted/Rougheye complex (blackspotted rockfish, rougheye rockfish)
Cody Szuwalski	NMFS	EBS	Red king crab, Snow crab
Grant Thompson	NMFS	EBS	Pacific cod
Cindy Tribuzio	NMFS	EBS	Pacific sleeper shark
		GOA	Other rockfish complex - Demersal subgroup (quillback rockfish, rosethorn rockfish, yelloweye rockfish), Other rockfish complex - Slope subgroup (darkblotched rockfish, greenstriped rockfish, harlequin rockfish, pygmy rockfish, redbanded rockfish, redstripe rockfish, sharpchin rockfish, silvergray rockfish, yellowtail rockfish), Shark complex
Miranda Westphal	ADFG	EBS	Golden king crab
		AI	Golden king crab
Ben Williams	NMFS	GOA	Dusky rockfish, northern rockfish
Kellii Wood	ADFG	GOA	Other Rockfish complex - Demersal subgroup (quillback rockfish, rosethorn rockfish, yelloweye rockfish)
Leah Zacher	ADFG	EBS	Red king crab

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Appendix G Addressing EFH Component 1 Reviews

This section addresses additional reviewing stock author input on the SDM EFH maps collected during the 2023 EFH component 2 Fishing Effects Evaluation, as requested by the SSC in February 2022, and how EFH analysts have addressed these concerns and recommendations.

The requirements for EFH component 1 are that some or all portions of the geographic range of the species are mapped (50 CFR 600.815(a)(1)(iii)(1)). These mapping requirements have been comprehensively met for the new SDM ensemble EFH maps, representing the upper 95% of the area of occupied habitat for the summer distribution of groundfishes and crabs in the BSAI, GOA, and Crab FMPs. The new summer distribution SDM ensemble EFH maps represent the best available science for mapping EFH for these species' life stages at this time and provide a substantial improvement over the 2017 summer distribution SDM EFH maps. **NMFS recommends that the complete set of new summer distribution SDM ensemble EFH maps advance for EFH component 1 in the 2023 5-year Review.** The above sections of this document provide the complete methods and results of the 2023 SDM ensemble EFH mapping approach and iterative review stages. Three additional documents prepared as NOAA Technical Memoranda (Harris et al., Laman et al., and Pirtle et al. In review) provide region specific methods, species results chapters, and future recommendations (Chapter 5). Improving EFH component 1 mapping is possible through research leading up to a future EFH 5-year Review; these Reviews are by design are an iterative process occurring at least every five years (50 CFR 600.815(a)(10)).

G.1 Stock Assessment Author Review of EFH Component 1

In May–September 2021, stock authors reviewed the new SDM ensemble EFH mapping methods and results, including a total of 229 new and revised EFH descriptions and maps for the BSAI, GOA, and Crab FMPs available for the 2023 EFH 5-year Review (197Appendix F). For a subset of species (N = 34), reviewing stock assessment authors provided a concern and/or recommendation regarding how the EFH map could be improved. **Following the stock author review, EFH analysts worked with individual stock authors in September–December 2021 to address concerns and incorporate their recommendations to the extent possible—**

- We removed EFH maps for three data limited species that did not have an EFH map in 2017 (Pacific sleeper shark, yellowtail rockfish, and darkblotched rockfish).
- We revised the SDM ensembles when the reviewer provided updated length-based life stage breaks (e.g., EBS Arrowtooth flounder).
- We revised the GOA Atka mackerel SDM ensemble to remove one constituent.
- We added data caveat statements and recommendations to the applicable species results chapters of the three regional draft NOAA Technical Memoranda by the Laman et al. study to acknowledge stock author recommendations to add data sources and/or life history information if possible in future EFH mapping for those species and to communicate uncertainties surrounding those EFH maps in plain language.

The EFH component 1 materials provided to the SSC in February 2022 reflected the outcomes of the EFH analysts working with the stock authors to address their concerns and recommendations as provided in their 2021 EFH component 1 review.

The details of the stock author review process of EFH component 1 and EFH analyst responses to address concerns from this initial review are discussed in detail in the Appendix F. Sections F.2 and F.3 of the stock author review report are relevant to inform understanding of the stock author EFH map concerns and future recommendations and how the EFH analysts worked with the stock authors to address concerns to the extent possible leading up to the February 2022 SSC review. Section G.5 Table G3 is a summary of SDM ensemble performance and species life stages where reviewing stock authors provided a concern and/or future recommendation in their 2021 review to improve the EFH maps for those species.

In February 2022, the SSC reviewed the new SDM ensemble EFH mapping methods and EFH component 1 maps (Chapter 2). Overall, the SSC noted that a majority of the new and revised EFH maps reflect the best available science for characterizing EFH component 1 (Appendix A Table A1). **The SSC also provided recommendations to clarify the new information provided for EFH component 1 and requested information to more clearly identify those species where stock authors have concerns with the SDMs and EFH maps, which we provide in the following section.**

G.2 Addressing Reviewer Concerns and Recommendations

To address SSC requests and to more clearly identify those species where stock authors have concerns with the SDMs and EFH maps, we compiled a questionnaire as part of the FE evaluation asking stock authors to restate their SDM EFH concerns and provide a qualitative plain language score of *low, medium, or high concern*. Table G1 lists the species where reviewing stock authors provided a concern in the FE assessment questionnaire based on the SDM ensemble EFH maps. Details of the stock author responses to the complete questionnaire are provided in the stock author FE assessment results for individual species in Appendix 5 of the EFH Component 2 FE Discussion Paper[61]. It is important to note for reviewers that although the SDM EFH component 1 maps and EFH component 2 FE model results are developed through separate processes and currently by separate analytical teams (NMFS and Alaska Pacific University), they are combined to estimate the percent CEA disturbed by fishing and to complete the EFH component 2 FE evaluation.

To address the SSC recommendation to include additional data sources in the SDM ensemble EFH maps to the extent possible, we requested that stock authors indicate in the FE assessment questionnaire if additional summer species data are available and to list those sources (Table G1). While the addition of more species/life stage information is not possible at this time, analysts continued conversations with stock authors to gain insight on data sources and research recommendations that could add value to the SDM ensemble EFH maps for a subsequent EFH 5-year Review. EFH Reviews are an iterative process by design, creating opportunity for incremental and continued improvements over time to incorporate new information and techniques as they become available.

Stock authors provided SDM EFH map concerns and recommendations for 34 species/region combinations (Table G1) out of 103 evaluated (Table G3) in their responses to the FE assessment questionnaire. Reviewing stock author SDM EFH concerns and recommendations can be summarized as three primary response themes: *1) add species data; 2) life history considerations; and 3) ongoing (other) data issues*. **In the following sections, we review stock author concerns and recommendations under each theme and describe what analysts have done to address those concerns and recommendations for the 2023 EFH 5-year Review and future EFH Reviews.**

G.2.1 Add Species Data

The majority of the concerns and recommendations reported by stock authors in their 2021 EFH component 1 review (Table G3) and in the FE assessment questionnaire were under the theme *add species data* (N = 24), where their qualitative plain language scores for two-thirds were *low concern*, one-third were *medium concern*, and none were *high concern* (Table G1). In two-thirds of the *add data* concerns,

[61] Appendix 5 in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

stock authors reported that additional summer species data were available that could be used to augment the AFSC RACE-GAP summer bottom trawl survey data in the SDM ensemble EFH maps.

G.2.1.1 Longline Survey Data

Stock authors reported that additional summer data for their species/regions were available from the longline surveys conducted by AFSC[62] and/or the International Pacific Halibut Commission (IPHC)[63] (N = 13) (Table G1). The 2023 SDM ensemble EFH maps for groundfishes and crabs were mapped to a maximum depth of 500 m in the AI and to 1000 m depth in the EBS and GOA based on available AFSC RACE-GAP summer bottom trawl survey species data. AFSC longline survey stations in the AI, EBS, and GOA sample depths from approximately 150–1000 m. **As an interim step to understand this issue better**, we created maps that overlay the longline survey station coverage[64] with the EFH maps to see the extent of potential gaps in the species distribution. Although we were not able to add longline survey data or other summer species data to the SDM ensembles at this time, in many cases the 2023 SDM ensemble EFH maps overlap or encompass the longline survey station coverage, including the upper percentiles of the predicted area of occupied habitat such as the core EFH area (CEA, upper 50% of EFH area used in the 2023 FE evaluation) and EFH hotspots (upper 25% of EFH area). As an example, we provide overlay maps of the AFSC longline survey historic haul locations (*without attribution to species data*) at stations along the continental shelf and slope in the AI, EBS, and GOA for species where the reviewing stock authors recommended that species data from this survey be included in future SDM ensemble EFH mapping in section G.6.

We provide an example in this section for EBS adult Greenland turbot (Figures G1–G2), where the reviewing stock author reported *medium concern*, recommended that longline survey data be included to add value to the EFH map for this species at deeper depths, and expressed interest in collaborating to improve the EFH map for a future 5-year Review (Table G1). They stated, “The EBS slope bottom trawl survey has not been conducted since 2016. Given Greenland turbot ontogeny, as they age they move from the continental shelf to the slope. The EFH analysis includes adult data, but over time there will be less information about adult habitat.” [65] EFH analysts agree that adding longline survey data could add value to the EFH maps for a subset of these species and are interested in working with stock authors and other longline survey data experts to develop a combined survey data approach if possible for a future EFH 5-year Review.

[62] NMFS AFSC longline survey https://www.fisheries.noaa.gov/resource/map/alaska-longline-survey-data-map
[63] IPHC longline survey https://iphc.int/management/fisheries
[64] The AFSC MESA program provided the file of historic haul locations at longline survey stations
[65] Appendix 5 (Greenland turbot section 5.1.6) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

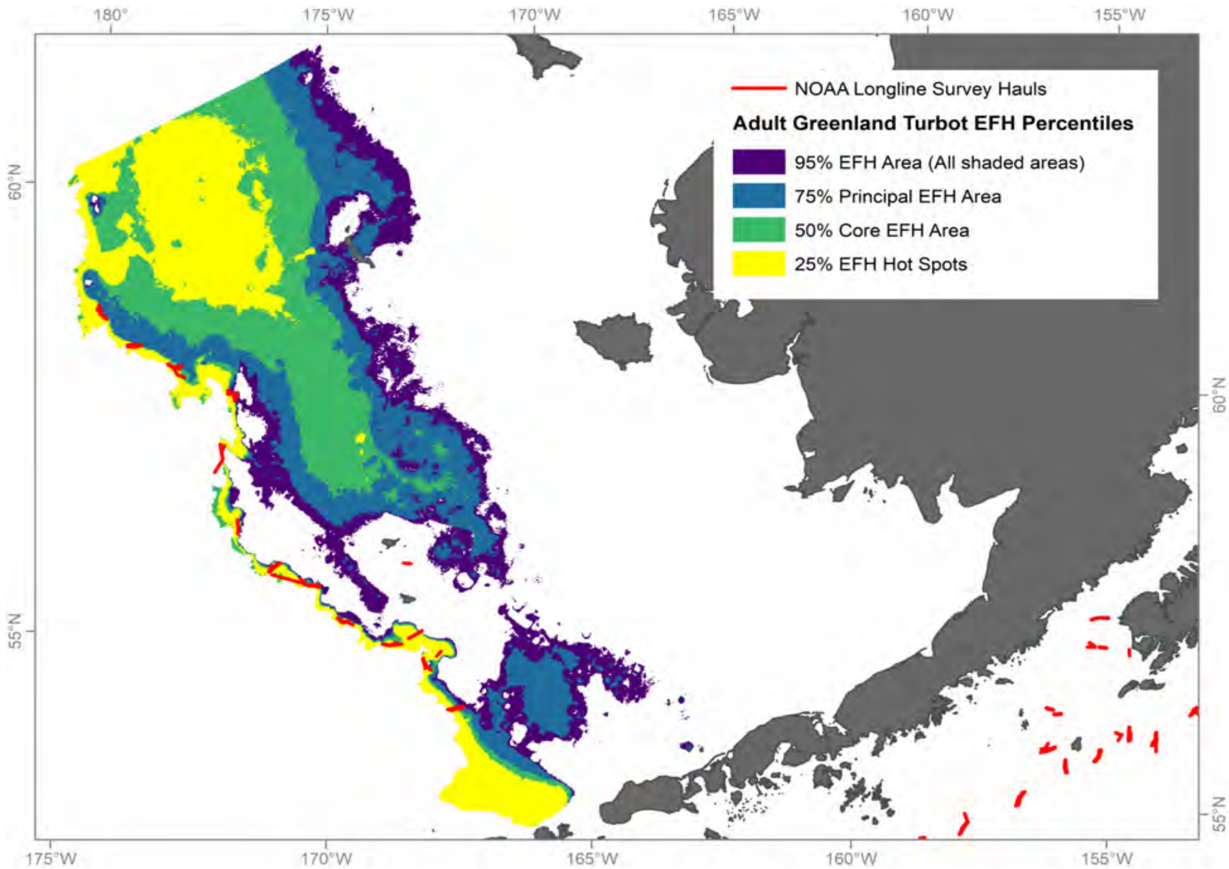

Figure G1. EFH map of adult Greenland turbot in the EBS with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to adult Greenland turbot catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult Greenland turbot distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1992–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

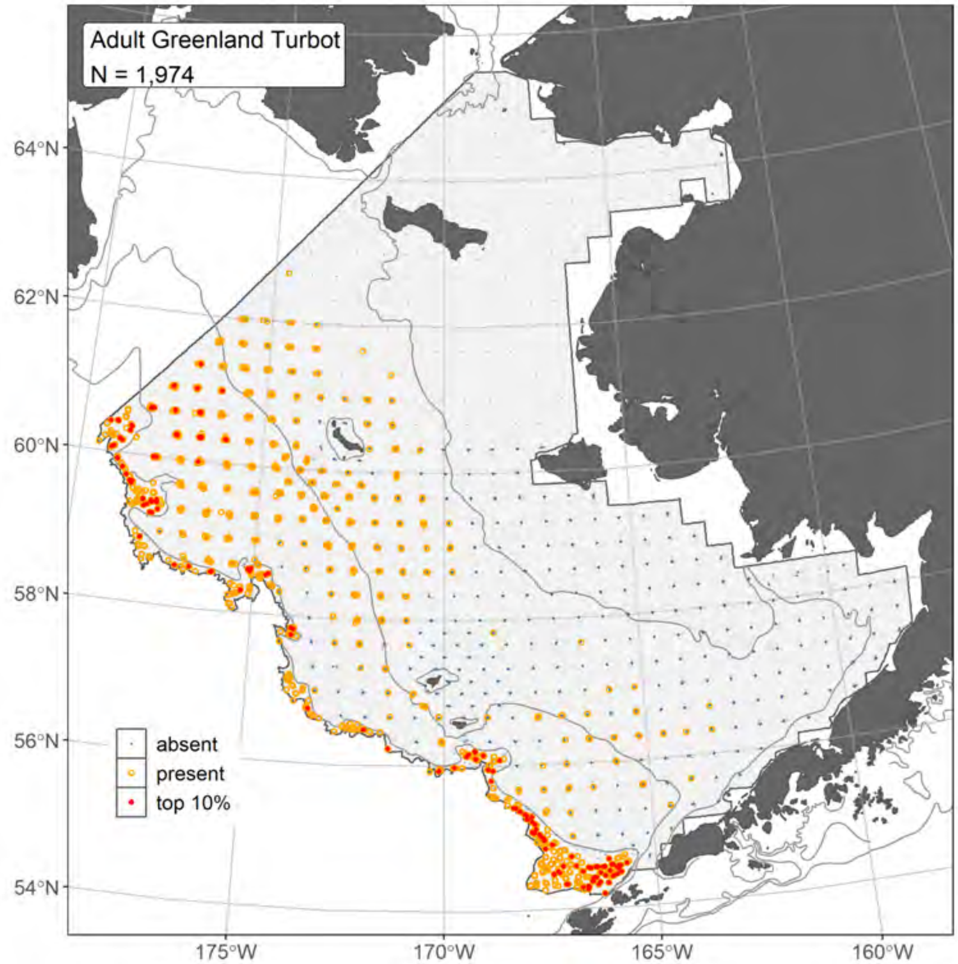

Figure G2. Distribution of adult Greenland turbot catches (N = 1,974) in 1982–2019 AFSC RACE-GAP summer bottom trawl surveys of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present. Each datum at a station represents a year of sampling at that location; multiple years are overplotted at each station.

G.2.1.2 Other Data Sources

Reviewing stock authors also reported that AFSC fishery observer data[66] may add value to the EFH maps for their species/regions (N = 7) (Table G1). Fishery observer data was used as a single data source in presence-only MaxEnt SDMs to map EFH for groundfishes and crabs in fall, winter, and spring seasons for the 2017 EFH 5-year Review (Laman et al. 2017, Simpson et al. 2017). The maps of other seasons that used fishery observer data will remain in the FMP and are not being revised with this action. Fishery observer data is also available for the summer season for some species (e.g., rockfishes). Fishery dependent observer data has not been used in SDMs requiring presence-absence data (i.e., GAMs), or combined in SDMs with fishery independent survey data to map EFH for Alaska species to date. Combining these two sources of data will require additional research to develop these analytical methods.

[66] NMFS AFSC Fisheries Monitoring and Analysis Division https://www.fisheries.noaa.gov/about/fisheries-monitoring-and-analysis

Other reviewing stock authors reported concern that their species associate with untrawlable seafloor habitats and were not able to identify additional summer data sources that could be used in EFH mapping (N = 17) (Table G1). Optical images from underwater surveys could be a source of species presence-absence data from untrawlable habitats (e.g., Winship et al. 2020, ICES 2021, Jones et al. 2021). Species presence-absence data would need to be available or developed from the image data holdings of AFSC (and/or external partners) to begin using data from images in a robust manner in the SDMs ensemble framework. There are ongoing efforts to begin establishing a linkage between camera-based abundance estimates over untrawlable ground and RACE-GAP bottom trawl survey trawl-based abundance estimates over trawlable ground. When available, this research could be integrated with other research supporting EFH component 1 mapping.

G.2.1.3 Summary of Addressing Add Species Data

Adding data sources and gear types to the SDM ensemble EFH mapping framework will be challenging, as this is not computationally straightforward and requires additional research to develop the analytical methods to do this well. It is possible however, that a "data robust" approach could be developed for a subset of species, where additional data sources have high potential to add value to the EFH maps for those species. Future efforts to meet this need would benefit greatly from collaboration between EFH analysts who are SDM, habitat, and survey data experts, and stock authors and/or other species and survey data experts. With respect to addressing reviewing stock author concerns and recommendations under the theme *add species data*:

- We advanced a research recommendation to develop methods to include additional species data sources in the SDM ensemble framework in future EFH mapping efforts (e.g., EBS EFH NOAA Technical Memorandum; Laman et al. In review[67] and Future Recommendations section 3.5.1.1).
- We added data caveat statements to the applicable species results chapters in the three regional NOAA Technical Memoranda by the Laman et al. study (Supporting Documents 5) to acknowledge stock author recommendations to add data sources if possible in future EFH mapping for those species and to better communicate uncertainties in plain language surrounding that portion of the EFH maps;
    - e.g., EBS sablefish, "For these reasons, and because the AFSC longline surveys target adult sablefish . . . , we recommend that AFSC longline survey data be integrated with AFSC RACE-GAP summer bottom trawl survey data into future EFH reviews.", and "A request from the stock author review to include additional sources of data in future EFH mapping efforts for this species will be recommended as a focus of future research coming out of this 2023 EFH 5-year Review." (EBS EFH NOAA Technical Memorandum; Laman et al. In review[68]).
- Other EFH component 1 reporting from the 2023 5-year Review could also include these data caveat statements and recommendations, including and any FMP amendments if warranted as an outcome of the EFH Review.

[67] Future Recommendations (page 498) in EBS Laman Advancing Model-based EFH; available on Council agenda for this meeting

[68] EBS sablefish (page 283) in EBS Laman Advancing Model-based EFH; available on Council agenda for this meeting

G.2.2 Life History Considerations

G.2.2.1 Crab Life History

Reviewing stock authors reported concerns and recommendations surrounding life history information for crabs in their 2021 EFH component 1 review (Table G3) and in the FE assessment questionnaire (Table G1). Currently, EFH is mapped for crabs in the AI and EBS by combining all life stages (benthic juveniles and adults) from the RACE-GAP summer bottom trawl survey data. Stock authors reporting *low concern* recommend added value in mapping crab EFH for individual life history stages and/or sexes (e.g., AI and EBS red king crab (RKC))[69]. Crab maturity data regularly collected on Bering Sea RACE-GAP bottom trawl surveys could inform life stage-specific SDMs for crabs in the next EFH 5-year Review. This effort should involve collaboration with scientists from the AFSC Kodiak Laboratory and the Alaska Department of Fish and Game (ADFG), both of which have crab size measurements and maturity data. These data could be used to apportion crab catches to mature and immature life stages and by sex to describe and map EFH.

Crab stock authors also emphasized the importance of mapping EFH and evaluating EFH fishing effects for crabs in other seasons (e.g., EBS snow crab). The new SDM ensemble EFH maps for the 2023 5-year Review were developed for the summer season and EFH fishing effects are currently evaluated using the SDM ensemble EFH maps. EFH was described and mapped for crabs in other seasons for the 2017 5-year Review[70], using fishery observer data in presence-only MaxEnt SDMs[71]. The maps of other seasons that used fishery observer data will remain in the FMP and are not being revised with this action. Fishery dependent observer data has not been used in SDMs requiring presence-absence data (i.e., GAMs), or combined in SDMs with fishery independent survey data to map EFH for Alaska species to date. Combining these two sources of data will require additional research to develop robust analytical methods to do this well. NMFS funded a study in FY22 (Alaska EFH Research Plan request for proposals) to develop SDMs for EBS RKC and snow crab life history stages in the summer, fall, and winter. The SDM maps and/or methods from this study could be incorporated in a future EFH 5-year Review.

The only *high concern* with respect to crab life history and the SDM EFH maps was reported for AI golden king crab (GKC). The reviewing stock author reported *high concern* with the FE model for this species and no SDM EFH concern. However, we reported their concern in Table G1 as they mentioned species data concerns relative to the life history of this species affecting data available for EFH mapping. This concern was also reported and discussed in the stock author 2021 EFH component 1 review (section F.3.3.2). GKC are generally thought to associate with rugged and high relief habitats between 300–1,000 m depth and are targeted by the fishery using pot gear[72]. AI GKC are caught by the AFSC RACE-GAP summer bottom trawl survey to a maximum depth of 500 m and by ADFG pot surveys to a maximum depth of approximately 600 m. AI GKC EFH was mapped in 2017 and in 2023, using SDMs with AFSC RACE-GAP summer bottom trawl survey data and included as a case study example for SSC review in February, 2022 (section 3.3.2.3). EFH component 1 mapping requirements have been met for AI GKC (i.e., some or all portions of the geographic range of the species) (Figure G3). However, this species is an example of how the EFH map and EFH component 2 FE evaluation may be improved by the addition of other species data sources to the SDM ensemble for a future EFH 5-year Review.

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[69] Appendix 5 (RKC section 5.3.3 and Snow crab section 5.3.4) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

[70] Crab FMP Amendment 49 https://media.fisheries.noaa.gov/BSAICrabFMPAmendment49.pdf

[71] Laman et al. 2017 EBS EFH NOAA Technical Memorandum https://apps-afsc.fisheries.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-357.pdf

[72] AI GKC Draft SAFE Report May 2022 https://meetings.npfmc.org/CommentReview/AIGKCSAFE2022.pdf

NMFS agrees that improving the SDM ensemble EFH maps and other EFH information for crabs is a priority. The only two HAPC considerations raised by reviewing stock authors in the 2022 FE evaluation were for crabs, including EBS blue king crab (BKC) EFH around St. Matthew Island and the Pribilof Islands and western AI RKC EFH[73], which would be further informed by crab EFH component 1 information for life history stages and other seasons. EFH mapping can also support EBFM for crabs beyond EFH (e.g., Shotwell et al. 2022). Success will depend on resources for additional research, data availability, and collaboration between EFH analysts and stock authors, species experts, and/or survey data and fishery experts. ADFG stock authors reported collaborative interest in future EFH mapping efforts for crabs in their 2022 FE assessment questionnaire and NMFS stock authors have indicated interest in other communication

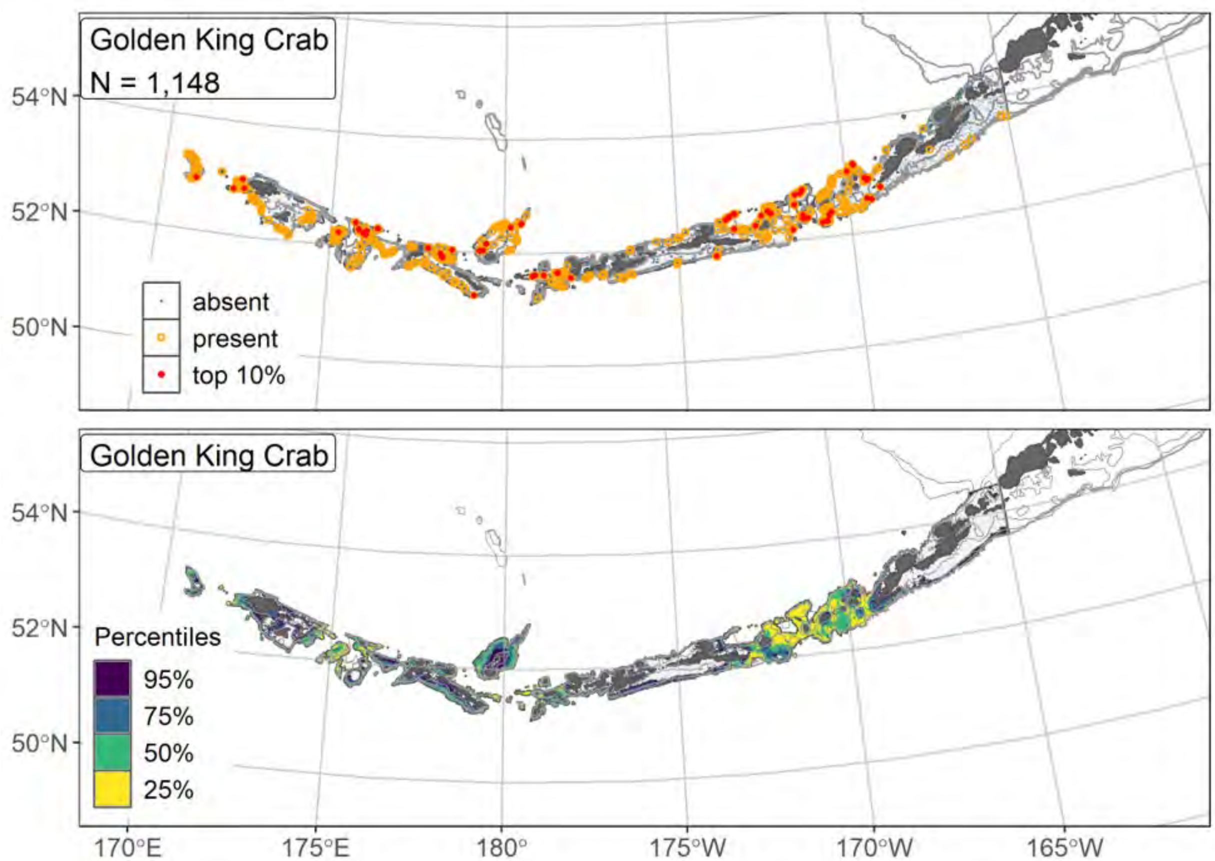

Figure G3. Distribution of golden king crab (GKC) catches (N = 1,148) in 1991–2019 AFSC RACE-GAP summer bottom trawl surveys of the AI with the 100 m, 300 m, and 500 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and small blue dots indicate absence, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station (upper panel). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to GKC distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) (lower panel).

[73] Appendix 5 (EBS BKC section 5.3.1 and AI RKC section 5.3.3) in EFH Component 2 Fishing Effects Discussion Paper September, 2022 https://meetings.npfmc.org/Meeting/Details/2947

G.2.2.2 Flatfishes with Spatially Varying Growth

The reviewing stock author reported *high concern* for GOA rex sole SDM EFH information in their 2022 FE assessment (Table G1). Their explanation stated "It looks to me like the EFH map encompasses the summer distribution of adults, but it still would be wise to revisit whether the splitting of adults and subadults by length categories miscategorizes some older rex sole as subadults, which might change the percentile rankings over space, or maybe it wouldn't"[74]. Continued conversation with flatfish stock authors regarding their FE assessments provided opportunity to discuss that rex sole, Dover sole, and other flatfishes exhibit spatially varying growth, which affects length at age observations across the regions due to sub-regional spatial growth rate variation, and so it is concerning to use one length-based life stage break for subadults and adults for the entire region. This presents a challenge when mapping EFH, as EFH is mapped by species life stages for the area of the fishery management units corresponding to the FMPs and not sub-regionally (50 CFR 600.805(b)).

The flatfish stock authors are currently looking into flatfish spatially varying growth differences in the GOA, which should help inform future SDM EFH mapping efforts for these species. SDM EFH maps for subadult and adult rex and Dover soles were advanced for the 2017 EFH 5-year Review and SDM ensemble EFH maps were developed for the 2023 EFH Review using the best available length-based life stage breaks for these species at this time. If sub-regional life stage information is available, this could be incorporated into the regional SDM ensembles (e.g., based on catch location). EFH analysts will work with the stock authors to improve the EFH maps for flatfishes as more information becomes available.

G.2.2.3 Summary of Addressing Life History Considerations

EFH analysts are interested in working with the stock authors and other species experts to incorporate new research on crabs, flatfishes, and other species, including SDM methods development, field observations, and process studies of life history and ecological mechanisms to support future EFH 5-year Reviews. With respect to addressing reviewing stock author concerns and recommendations under the theme *life history considerations*:

- We advanced research recommendations to accomplish for future EFH 5-year Reviews, including map EFH for crabs by life history stages and improve the maps for other seasons, develop methods to include additional species data sources for crabs in the SDM ensembles, and update the life stage breaks when partitioning data for the SDMs ensembles for certain flatfishes when that information is available (e.g., EBS EFH NOAA Technical Memoranduml; Laman et al. In review[75] and Future Recommendations section 3.5.1.1).
- We added data caveat statements to the applicable species results chapters in the three regional EFH NOAA Technical Memoranda by the Laman et al. study to acknowledge stock author recommendations and to better communicate uncertainties in plain language surrounding that portion of the EFH maps;
    - e.g., AI GKC, "The RACE-GAP summer bottom trawl surveys used trawl gear that is not ideally suited for surveying crab species, so this EFH description should be used with caution. However, the ensemble showed good performance across multiple metrics, so this

[74] Appendix 5 (GOA rex sole section 5.2.10) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting
[75] Future Recommendations (page 498) in EBS Laman Advancing Model-based EFH; available on Council agenda for this meeting

map should be a useful resource until additional data sources can be incorporated into the EFH process." (AI EFH NOAA Technical Memorandum; Harris et al. In review[76]).

  - e.g., GOA rex sole, "A request from the stock author review to redefine the life stage breaks for this species based on sub-regional growth differences in future SDM ensemble EFH mapping efforts has been included as a future research recommendation from the 2022 EFH 5-year Review." (GOA EFH NOAA Technical Memorandum; Pirtle et al. In review[77]).

- Other EFH component 1 reporting from the 2023 5-year Review could also include similar data caveat statements and recommendations, including the forthcoming EFH Review Summary report and any FMP amendments if warranted as an outcome of the EFH Review.

G.2.3 Ongoing Data Issues

Ongoing data issues exist for a subset of species that affected the 2023 SDM ensemble EFH maps. These ongoing data issues likely persisted for species with an SDM EFH map 2017. The reviewing stock authors reported these issues in their 2021 EFH component 1 review (Table G3) and in completing the FE assessment questionnaire. These concerns are grouped under the theme *data other* in Table G1. These ongoing data issues were the primary concern for data limited species such as Atka mackerel and giant octopus (octopus are addressed in section G.3.2 and the reviewing stock author was not able to identify additional summer data sources to augment the RACE-GAP summer bottom trawl survey data in EFH mapping for these species. Ongoing data issues were an important concern for rockfishes in the GOA Other Rockfish complex slope sub-group and for spiny dogfish, however the reviewing stock author identified additional summer data sources for these species that could potentially be used to improve the EFH maps for these species.

Mapping requirements for EFH component 1 are some or all portions of the geographic range of the species (50 CFR 600.815(a)(1)(iii)(1)). Although ongoing data issues are present for some species, the 2023 SDM ensemble EFH maps provide the best available science for mapping EFH for these species at this time and represent an improvement over the 2017 SDM EFH maps. Improvements are clear in particular due to the 2023 SDM ensembles mitigating the influence of any one SDM method on the resulting EFH map. We are now aware of how the different SDM types applied to the single SDM mapping approach in 2017 affected the EFH component 1 maps, which would have also influenced the EFH component 2 FE evaluation of the 2017 EFH 5-year Review (section 3.3.3). **Moving from using single SDMs to SDM ensembles should reduce the magnitude of the change in EFH area attributable to modeling methods in future EFH mapping efforts and provides a universal SDM application across multiple FMPs that can be easily expanded to consider additional constituent models in the future**.

It is possible that the EFH maps may be improved for those species where additional data sources are available if the methods can be developed to include those sources in the SDM ensembles (i.e., data from different surveys, different gear types, and fishery independent and dependent data), which is not computationally straightforward and requires additional research to develop robust quantitative methods. Opportunity for continued improvements of EFH component 1 is possible through research leading up to a future EFH 5-year Review, which are by design an iterative process and occurring at least every five years (50 CFR 600.815(a)(10)). Success in further improving the SDM EFH maps for species with ongoing data issues depends on the availability of other high quality data sources, resources for additional research, and collaboration between EFH analysts and the stock authors, and/or other species experts, and survey and fishery data experts.

[76] AI GKC (page 340) in AI Harris Advancing Model-based EFH; available on Council agenda for this meeting
[77] GOA rex sole (page 85) in GOA Pirtle Advancing Model-based EFH; available on Council agenda for this meeting

In all cases of species with ongoing data issues, the EFH component 1 materials provided to the SSC in February 2022 reflected the outcomes of the EFH analysts working with the stock authors to address the concerns and recommendations reported in their 2021 EFH component 1 review; record of that communication is available (Appendix F). The SSC's February 2022 request to more clearly identify those species where stock authors have concerns with the SDMs and EFH maps provided opportunity for continued conversation between EFH analysts and the reviewing stock authors to improve the SDM ensemble EFH maps, EFH component 1 reporting, and clarity on future SDM EFH mapping research needs for this subset of species (Table G1). In the following section, we discuss ongoing data issues and how we have addressed those in the 2023 EFH 5-year Review for Atka mackerel, the GOA Other Rockfish complex slope sub-group, and spiny dogfish in the GOA.

G.2.3.1 Atka mackerel

Atka mackerel EFH was mapped in the AI, EBS, and GOA in the 2017 EFH 5-year Review and new SDM ensemble EFH maps are available for the 2023 Review. The reviewing stock author reported SDM EFH map concerns in their 2021 EFH component 1 review (Table G3) and in the FE assessment questionnaire (Table G1), including *low concern* (AI), *medium concern* (EBS), and *high concern* (GOA)[78], regarding ongoing data issues for this species. Overall, they commented "Atka mackerel are a very patchily distributed species in time and space. Those factors may affect the determination of EFH with survey data which are highly variable." Despite these concerns, they completed Atka mackerel FE assessments for the 2023 FE evaluation—

- AI Atka mackerel **did not exceed** the threshold of ≥ 10% CEA disturbed in the FE analysis. The SA chose a *quantitative* FE assessment using the FE model and the 50% CEA and recommended **no further action**.
- EBS Atka mackerel **exceeded** the threshold of ≥ 10% CEA disturbed in the FE analysis in 2023 but not in 2017, because the 2017 SDM would have led to exceeding ≥ 10% CEA disturbed in November 2016 using the corrected 2023 FE model[79]; the SA chose a *quantitative* FE assessment using the FE model and 50% CEA and recommended **no further action**.
- GOA Atka mackerel **did not exceed** the threshold of ≥ 10% CEA disturbed in the FE analysis. The SA chose a *qualitative* FE assessment using other sources of information and recommended **no further action**.

We discuss ongoing data issues for Atka mackerel in the GOA because the stock author reported *high concern* for the SDM EFH map and chose a qualitative FE assessment, as they were not confident using the CEA from the GOA map to evaluate fishing effects to EFH for this species. Although they concluded no further action needed for EFH component 2, it is helpful to understand their concerns for the EFH component 1 SDM ensemble EFH maps in the context of the mapping methods and results. Their explanation for *high concern* was:

- "There was a 250% increase in the CEA in 2022! The 2022 results are not meaningful due the sparse data used over a timeframe that is not appropriate.", and commenting further in their qualitative FE assessment,
- "The GOA represents the western-most margin of the Atka mackerel population. Their center of abundance is the Aleutian Islands. Observations in the GOA of Atka mackerel are very

[78] Appendix 5 (Atka mackerel sections 5.1.2 and 5.2.2) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting
[79] Species with ≥ 10% CEA disturbed (section 4.3) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

sparse, and there is no directed fishery for Atka mackerel in the GOA. However, there is a lot of fishing activity in the GOA."

- "Due to the very low occurrences of Atka mackerel in the GOA, the CEA disturbance is likely very low as determined by the fishing effects analysis. It is noted that the data is not sufficient to appropriately conduct a quantitative analysis, but a qualitative assessment supports the < 10% CEA disturbance determined by the fishing effects analysis."

The reviewing stock author reported similar *species data concerns* for GOA Atka mackerel in their 2021 EFH component 1 review (section F.3.2.2). EFH analysts worked with them following their review to understand and address these concerns. Analysts revised the SDM ensemble by removing the MaxEnt constituent that may have been overpredicting the area of occupied habitat in the eastern GOA, where hauls with positive catches were present, yet occurring infrequently from 1993–2019 (Figure G4). The 2022 CEA from the revised SDM ensemble EFH map is now centered on the main distribution of the RACE-GAP haul locations for Atka mackerel in the GOA (N = 700), including hauls in the top 10% of samples occurring east of Kodiak Island, and was used in the FE evaluation. The 2023 GOA adult Atka mackerel SDM ensemble had fair performance (RMSE = 143, ρ = 0.33, AUC = 0.85, and PDE = 0.35) and the 2017 GOA combined subadult and adult hGAM (N = 593) also had fair performance (RMSE = 168, ρ = 0.36, AUC = 0.85, and PDE = 0.22) (Table G3). Given that the stock author was not able to recommend additional summer data sources to augment the RACE-GAP summer bottom trawl survey data in EFH mapping for these species, it is likely that the ongoing issue of Atka mackerel data availability will persist.

Regarding the stock author's *concerns with the 2022 CEA* for GOA Atka mackerel (Figure G4, Table G3), Comparing the 2017 SDMs and 2022 ensembles demonstrated that the type of model used in 2017 had a large effect on the performance metrics and calculated EFH area. We took the time to explain these changes to the stock author. Approximately 25% of ensembles predicted EFH areas larger by 100% or more; in almost all of these cases the 2017 SDM was hGAM. Approximately 18% of ensembles resulted in EFH areas that were smaller by at least half; in each of these cases the 2017 SDM was a MaxEnt model (e.g., EBS Atka mackerel Table D2). The large increase in CEA observed in the 2022 GOA Atka mackerel map compared to the 2017 map was largely attributed to moving from the single use of an hGAM in 2017 to an SDM ensemble in 2023, and shifting from 4th root transformed CPUE in 2017 to the prediction of numerical abundance as the response variable in 2023 (i.e., predicting numbers of animals instead of a heavily derived abundance index). Mapping EFH using SDM ensembles rather than single SDMs helped mitigate the influence of any one SDM method on the EFH area and should reduce the magnitude of the change in EFH area attributable to modeling methods in future EFH mapping, making it easier to detect changes in species distribution or habitat impacts.

The approach to mapping EFH using SDMs in the 2017 and 2023 5-year Reviews takes into account the long term time series of species habitat-related distribution and abundance (e.g., GOA 1993–2019). The stock author raised concern about the time series over which EFH is mapped for Atka mackerel. Future EFH mapping for Atka mackerel and other species may be able to explore mapping EFH over smaller time series (e.g., 5 year hindcasts), which may improve ability to identify events in shifting species distributions due to climate change or other impacts to habitat, which will also be enhanced with improved SDM forecasting methods (e.g., Rooper et al. 2021, Barnes et al. 2022).

EFH is designated and mapped for each FMP species (50 CFR 600.815(a)(1)(i)). Although ongoing data issues are present for Atka mackerel, the 2023 SDM ensemble EFH maps provide the best available science for mapping EFH for these species at this time. **NMFS recommends that the revised 2023 EFH component 1 map for Atka mackerel advances in the 2023 EFH Review.**

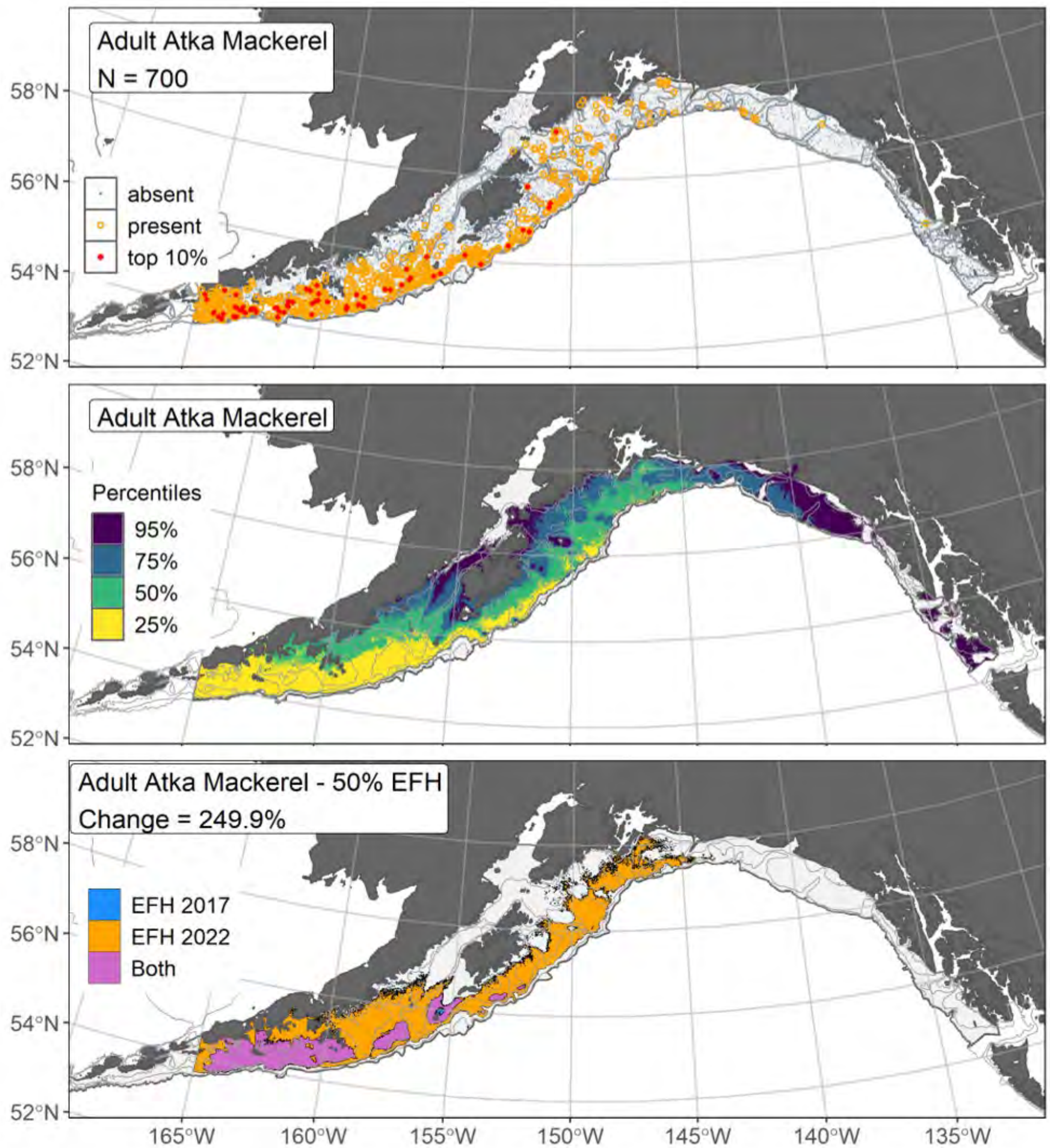

Figure G4. Distribution of adult Atka mackerel catches (N = 700) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and small blue dots indicate absence, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station (upper panel). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult Atka mackerel distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area (CEA)), and top 75% (principal EFH area) (middle panel). Change from 2017 to 2022 (2023) in GOA adult Atka mackerel CEA; colors represent CEA in 2017, 2022 (2023), or both (lower panel).

G.2.3.2 Gulf of Alaska Other Rockfish complex slope sub-group

In the GOA, the Other Rockfish (OR) stock complex includes the slope sub-group that is comprised of the following species: aurora, blackgill, darkblotched, greenstriped, harlequin, northern, pygmy, redbanded, redstripe, sharpchin, shortbelly, silvergray, splitnose, stripetail, vermilion, widow, yellowmouth, yellowtail rockfishes, boccacio, and chilipepper (Tribuzio et al. 2021). Northern rockfish are only included in this complex in the eastern GOA and their EFH is described and mapped separately from the GOA OR complex. While stocks are managed differently depending on the species (either across regions or at smaller scales), EFH is designated and mapped for each FMP species (50 CFR 600.815(a)(1)(i)). Species including greenstriped, harlequin, pygmy, redbanded, redstripe, sharpchin, and silvergray rockfishes were common enough (N > 50) in GOA RACE-GAP summer bottom trawl survey catches (1993–2019) to support individual species life stage SDM ensembles of habitat-related abundance to map EFH (Table G2).

The reviewing stock author reported concerns regarding species data in the SDM ensemble EFH maps in their 2021 EFH component 1 review (Table G3) and in the FE assessment questionnaire (Table G3). They ranked their concerns based on the three qualitative ranking options, as *low concern* for the sub-group and *low (5), medium (1), and high (1) concerns* for the seven member species with a 2023 SDM ensemble EFH map. They commented, “As a complex, the EFH for the slope sub-group likely encompasses the distribution of the combined species. However, as noted in the individual species reviews, there is a wide variety of data availability and catchability that come into play.” [80] Most of the slope sub-group species are at the northern extent of their range and/or associate with untrawlable habitats that are difficult to survey (Love et al. 2002, Mecklenberg 2002), lending to the challenges of mapping EFH for this subset of species.

All species in the slope sub-group with a new SDM ensemble EFH map in 2023 also had an SDM EFH map in 2017 with the exception of greenstriped rockfish (Table G2). Analysts worked with the stock author to address concerns following their review of the draft SDM EFH methods and results in 2021. Due to data limitations, analysts and the stock author agreed on not advancing the SDM ensemble EFH maps for two species (darkblotched and yellowtail rockfishes), although those species met the minimum sample size threshold and the SDMs did not raise red flags for the EFH analysts (section F.3.2.8). Analysts continued to work towards a solution for mapping EFH of data limited species to the extent possible at this time for the 2023 EFH 5-year Review.

As a new approach in 2023, NMFS provided maps for species complexes, including the GOA OR complex slope sub-group, to represent the EFH of member species where an SDM was not possible (e.g., due to low sample size and/or other reasons) (Figure G5)[81]. EFH component 1 requires individual species maps for the fishery management unit (FMU) corresponding to the FMP (50 CFR 600.805(b)). However, where appropriate EFH may be designated for assemblages of species or life stages that have similar habitat needs and requirements (50 CFR 600.815(a)(1)(iv)(E)). These **complex EFH maps** are an additive map of the area of occupied habitat from the combined individual species 2023 SDM ensemble EFH maps (section 3.2.8.3). The complex EFH maps are intended for reporting with the other new EFH component 1 SDM ensemble EFH maps for member species of those complexes in the 2023 EFH 5-year Review, and were also provided to the stock authors as an option for completing their 2023 EFH component 2 FE assessments.

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[80] Appendix 5 (Other Rockfish complex slope sub-group section 5.2.9) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

[81] GOA OR complex slope sub-group (page 321) in GOA Pirtle Advancing Model-based EFH; available on Council agenda for this meeting

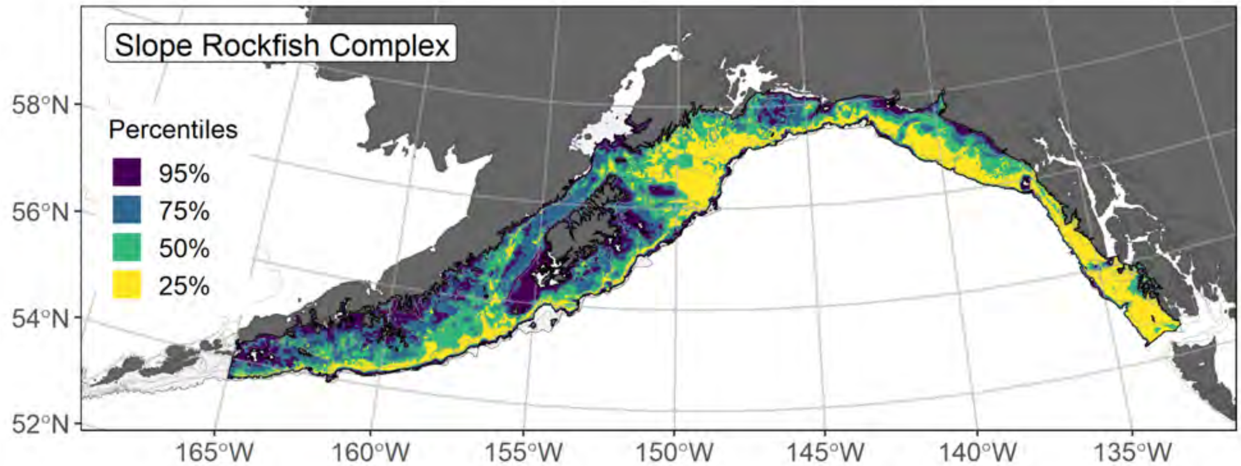

Figure G5. EFH (the area containing the top 95% of occupied habitat defined as encounter probabilities greater than 5%) of the Other Rockfish complex slope sub-group from the GOA in AFSC RACE-GAP summer bottom trawl surveys (1993–2019) with 100 m, 200 m, and 700 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of composite habitat-related, ensemble-predicted numerical abundance.

While the stock author identified additional summer data sources for the slope sub-group species, including longline survey data, and fishery-dependent observer data, to augment the RACE-GAP summer bottom trawl survey data in the SDM ensemble EFH maps (Table G1), adding other species data sources to the SDM ensembles will be challenging, as this is not computationally straightforward and requires additional research to develop methods to do this well. It is possible however, that a "data robust" approach could be developed specifically for the GOA OR complex slope sub-group for a future EFH 5-year Review, where additional data sources have high potential to add value to the EFH maps for those species. Collaboration between EFH analysts and the stock author and/or other species and survey/fishery data experts will help ensure that future EFH mapping efforts for the slope sub-group are successful in helping to close data gaps with respect to the EFH maps.

NMFS recommends the following approach for the GOA OR complex slope sub-group to meet the requirements of and advance EFH component 1 in the 2023 EFH 5-year Review:

- Use the new SDM ensemble EFH maps available for individual species for harlequin, greenstriped, pygmy, redbanded, redstripe, sharpchin, and silvergray rockfishes.
- Use the new composite SDM ensemble EFH map for the slope sub-group for darkblotched and yellowtail rockfishes, and other species in the GOA OR complex slope sub-group without an EFH map.

With this recommendation, all individual slope sub-group species EFH maps advancing for EFH component 1 would be based on SDM ensembles with good performance, with the exception of Pygmy rockfish where the SDM ensemble had fair performance, and none with poor performance (Table G3). While this may not be a permanent solution for all slope sub-group species, it is a solution to meet the EFH component 1 mapping requirements and include the new SDM ensemble EFH maps for species where available. Although ongoing data issues are present for the slope sub-group, the 2023 SDM ensemble EFH maps provide the best available science for mapping EFH at this time.

NMFS also offers a proposed approach for using a combination of the individual species CEAs and the complex map CEA for the **EFH component 2 FE evaluation** of the GOA OR complex slope-subgroup in the 2023 EFH 5-year Review[82]. As EFH component 1 and EFH component 2 have separate requirements, the recommended approaches for the 2023 Review are different (i.e., use the complex EFH map more broadly for the FE evaluation of individual species, for greenstriped, pygmy, redbanded, and silvergray rockfishes, as the stock author chose a qualitative FE assessment and reported insufficient information to make the decision to elevate or not elevate for these species).

G.2.3.3 Spiny dogfish in the Gulf of Alaska

Spiny dogfish are a member of the shark complex (spiny dogfish, Pacific sleeper shark, salmon shark, and other/unidentified sharks) in the GOA (Tribuzio et al. 2020). Spiny dogfish EFH was not mapped in the 2017 EFH 5-year Review, nor was the EFH for any other shark complex species. SDM ensemble EFH maps were developed for subadult and adult spiny dogfish and combined subadult and adult Pacific sleeper shark. The stock author reported concerns over data limitations in the SDM EFH maps in their 2021 review of the draft SDM EFH methods and results (section F.3.2.13). Following that review, EFH analysts and the stock author agreed to remove the Pacific sleeper shark EFH map from consideration in the 2023 Review.

The stock author noted *medium concern* in the FE assessment questionnaire and commented, “The adult [spiny dogfish] model doesn't make sense. This outcome is likely due to the issues with catchability and only using bottom trawl survey data. Adults are far more abundant across the GOA than these maps suggest. Incorporate the AFSC and IPHC longline surveys, with their length data and the models will likely change substantially.”[83]

To address data limitation concerns for spiny dogfish in the GOA to the extent possible at this time, EFH analysts combined the subadult (N = 1,262) and adult (N = 127) life stages for this species into a revised SDM ensemble EFH map (Figure 10)[84]. EFH component 1 requires individual species maps for the fishery management unit corresponding to the FMP (50 CFR 600.805(b)). However, where appropriate, EFH may be designated for assemblages of species or life stages that have similar habitat needs and requirements (50 CFR 600.815(a)(1)(iv)(E)). The draft adult spiny dogfish EFH area was encompassed by the area of the upper percentiles of the draft subadult EFH area (EFH hot spots and CEA) and so it was plausible that combining the two life stages would be an improvement in mapping EFH for this species until other data sources can be combined in the SDM ensemble. This combined life stages map is intended to replace the individual draft subadult and adult spiny dogfish SDM ensemble EFH maps that the SSC reviewed in February 2022 for the EFH 5-year Review. **NMFS recommends that the new combined life stages spiny dogfish EFH component 1 map advance for the 2023 EFH 5-year Review.** NMFS also offers a proposed approach that **EFH component 2 FE evaluation** uses the FE model and the 50% CEA from the new combined life stages spiny dogfish EFH map[85].

[82] Section 4.2.1 in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting
[83] Spiny dogfish (section 5.2.2) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting
[84] Spiny dogfish (page 405) in GOA Pirtle Advancing Model-based EFH; available on Council agenda for this meeting
[85] Section 4.2.3 in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

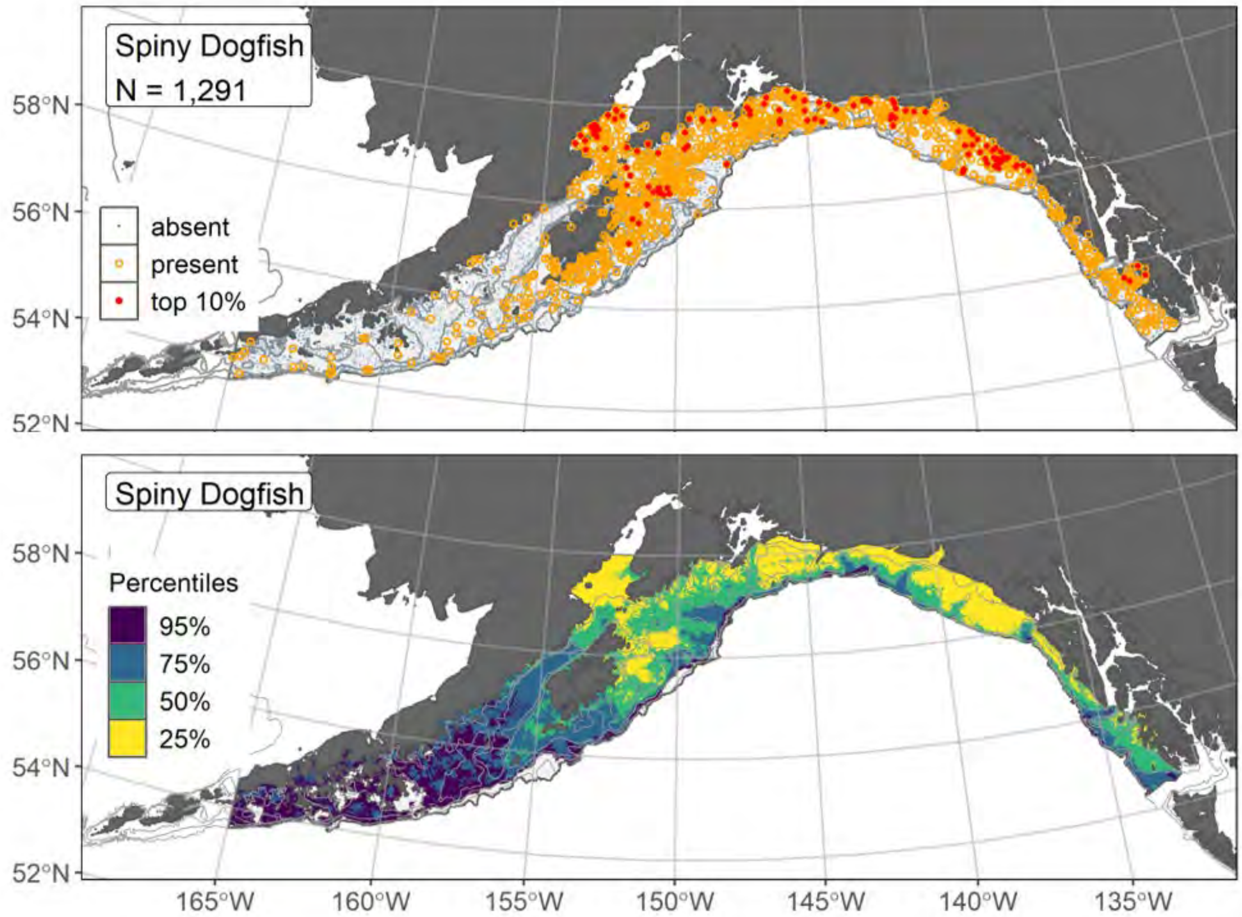

Figure G6. Distribution of spiny dogfish catches (N = 1,291) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station (upper panel). EFH is the top 95% of locations where the species' life stage is present, ordered by numerical abundance from a habitat-based ensemble fitted to spiny dogfish distribution and abundance from GOA RACE-GAP summer bottom trawl surveys; integral to the EFH map are the shapes of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of habitat-related, ensemble-predicted numerical abundance (lower panel).

G.2.3.4 Summary of Addressing Ongoing Data Issues

The SSC's February 2022 request for more information on the subset of species where stock authors reported SDM EFH map concerns, created opportunity for the EFH analysts and stock authors to continue conversation towards deeper understanding of the concerns and recommendations and how to address them in the 2023 EFH 5-year Review and in future EFH Reviews. With respect to reviewing stock author concerns and recommendations under the theme *ongoing data issues*:

- We revised the GOA Atka mackerel SDM ensemble to remove one constituent and continued conversation with the stock author to help them understand the changes in the EFH map between 2017 and 2023.

- We removed the SDM ensemble EFH maps from consideration in the 2023 5-year Review for three data limited GOA OR complex slope sub-group species that did not have an EFH map in 2017 (yellowtail and darkblotched rockfishes).
- We advanced the composite SDM ensemble EFH map for the GOA OR complex slope sub-group to represent EFH for the species in the complex without an EFH map at this time.
- We removed the Pacific sleeper shark EFH map from consideration in the 2023 5-year Review; this species did not have an EFH map in 2017 and so it remains unmapped with respect to EFH component 1 requirements.
- We combined subadult and adult life stages of GOA spiny dogfish in the SDM ensemble to help mitigate the effects of species data limitations on the EFH map until additional summer data sources can be included in EFH mapping for this species; this species will be the only member of the shark complex with an EFH map if advanced in the 2023 EFH 5-year Review.
- We offered a future recommendation to develop methods to include additional data sources in the SDM ensembles in future EFH mapping efforts, in particular for data limited species where other high quality data sources are available to add value to the EFH map (e.g., EBS EFH NOAA Technical Memorandum; Laman et al. In review[86] and Future Recommendations section 3.5.1.1).
- We added data caveat statements to the applicable species results chapters in the three regional EFH NOAA Technical Memoranda by the Laman et al. study to acknowledge stock author concerns and recommendations for species with ongoing data issues and to better communicate uncertainties in plain language surrounding this portion of the EFH maps.
    - e.g., GOA spiny dogfish, “As spiny dogfish are also caught by the longline surveys, including additional data from these surveys may be helpful in future SDM EFH mapping for this species.”, “A request from the stock author review to include additional sources of data in future SDM ensemble EFH mapping efforts for this species will be included as a future research recommendation from the 2023 EFH 5-year Review.” (GOA EFH NOAA Technical Memorandum; Pirtle et al. In review)[87].
- Other EFH component 1 reporting from the 2023 5-year Review could also include these data caveat statements and recommendations, including any FMP amendments if warranted as an outcome of the EFH Review.

[86] Future Recommendations (page 498) in EBS Laman Advancing Model-based EFH; available on Council agenda for this meeting
[87] GOA spiny dogfish (page 405) in GOA Pirtle Advancing Model-based EFH; available on Council agenda for this meeting

Table G1. SDM concerns reported as a qualitative score (low, medium, high) selected by individual reviewing stock authors (SAs) for their species in the EFH component 2 SA FE assessment questionnaire to clarify reviewer concerns and recommendations regarding the 2022 SDM ensemble EFH component 1 maps, as requested by the SSC in February 2022. Concerns are listed by theme (add data, life history, data other). The theme *add data* has an added specification for data concerns regarding species in untrawlable habitats (UT). Stock authors listed additional summer species data sources if available for possible addition to future EFH mapping efforts and whether or not they are interested in either assisting with or informing future SDM development given their concerns and recommendations.

Region	Species	Concern qualitative score	Concern theme	Additional summer data available?	Additional summer data sources	Can assist with new models?
AI	Greenland turbot	Low	Add Data	Yes	longline surveys	Yes
EBS	Greenland turbot	Medium	Add Data	Yes	longline surveys	Yes
EBS	Kamchatka flounder	Low	Add Data	Yes	longline surveys	Yes
GOA	Shortspine thornyhead	Low	Add Data	Yes	longline surveys	Yes
AI	Sablefish	Medium	Add Data	Yes	longline surveys	No
EBS	Sablefish	Medium	Add Data	Yes	longline surveys	No
GOA	Sablefish	Medium	Add Data	Yes	longline surveys	No
GOA	Spiny dogfish	Medium	Add Data/Data Other	Yes	longline surveys, fishery observers	No
GOA	Shortraker rockfish	Low	Add Data (UT)	Yes	longline surveys	Yes
AI	Northern rockfish	Low	Add Data (UT)	No		
EBS	Northern rockfish	Low	Add Data (UT)	No		
GOA	Northern rockfish	Medium	Add Data (UT)	No		
AI	Pacific ocean perch	Low	Add Data (UT)	No		
EBS	Pacific ocean perch	Low	Add Data (UT)	No		
AI	Rougheye Blackspotted Rockfish Complex	Low	Add Data (UT)	No		
EBS	Rougheye Blackspotted Rockfish Complex	Low	Add Data (UT)	No		
GOA	Dusky rockfish	Medium	Add Data (UT)	No		
GOA	*Other Rockfish Complex Slope Sub-group*	Low	Add Data (UT)/Data Other	Yes	longline surveys, fishery observers	No
GOA	Greenstriped rockfish	Medium	Add Data (UT)/Data Other	Yes	longline surveys, fishery observers	No
GOA	Harlequin rockfish	Low	Add Data (UT)/Data Other	Yes	fishery observers	No
GOA	Pygmy rockfish	High	Data Other/Add Data (UT)	No		No
GOA	Redbanded rockfish	Low	Add Data (UT)/Data Other	Yes	longline surveys	No
GOA	Redstripe rockfish	Low	Add Data (UT)/Data Other	Yes	fishery observers	No
GOA	Sharpchin rockfish	Low	Add Data (UT)/Data Other	Yes	fishery observers	No
GOA	Silvergray rockfish	Low	Add Data (UT)/Data Other	Yes	longline surveys, fishery observers	No
EBS	Snow crab	Low	Life History	No		No
EBS	Red king crab	Low	Life History	No		
AI	Red king crab	Low	Life History/Data Other	No		Yes

Region	Species	Concern qualitative score	Concern theme	Additional summer data available?	Additional summer data sources	Can assist with new models?
AI	Golden king crab	High	Life History/Add Data (UT)	No		
GOA	Rex sole	High	Life History	No		
AI	Atka mackerel	Low	Data Other	No		
EBS	Atka mackerel	Medium	Data Other	No		
GOA	Atka mackerel	High	Data Other	No		
EBS	Giant octopus	Medium	Data Other	No		

Table G2. Gulf of Alaska (GOA) Other Rockfish complex slope sub-group haul records and EFH maps available or *explored for species members in the 2023 EFH 5-year Review. Each record represents a haul with a positive catch of the listed rockfish species. The SSC's 2017 minimum sample size in the EFH SDMs was N = 50 hauls with positive catches, which was retained in their June 2020 review of the proposed SDM methods for the 2023 Review. Species with and without an SDM EFH map in 2023 and 2017 are noted. Species without an SDM EFH map in 2023, including those where an EFH map was not explored due to data limitations, are accounted for by proxy in the 2023 GOA Other Rockfish complex slope sub-group map that is an additive map of the area of occupied habitat from the combined individual species 2023 SDM ensemble EFH maps for this sub-group.

Species	**Subadult Records (n)**	**Adult Records (n)**	**2023 EFH Map**	**2017 EFH Map**
Harlequin rockfish	102	514	Y	Y
Redbanded rockfish	829	321	Y	Y
Redstripe rockfish	133	234	Y	Y
Sharpchin rockfish	498	425	Y	Y
Silvergray rockfish	159	557	Y	Y
Pygmy rockfish	63 (N = 54 2017 SDM)		Y	Y
Greenstriped rockfish	–	120	Y	–
Darkblotched rockfish *	54	–	–	–
Yellowtail rockfish *	–	58	–	–
Total	1721	2234	–	–
Combined Total	3955		Y	–

G.3 Species EFH map changes attributed to exceeding the FE habitat disturbance threshold

The EFH Component 2 FE Discussion Paper[88] reports the methods and results of the 2023 FE model and the FE analysis of the percentage of the core EFH area (CEA) disturbed by fishing, which combines the FE model results with the SDM ensemble EFH map CEA (upper 50% of the EFH area). A total of 16 species in the EBS exceeded the SSC's threshold of ≥ 10% of the CEA disturbed in the 2023 EFH FE analysis. No species in the AI, EBS, or GOA regions met this threshold in the EFH FE analysis supporting the FE evaluation of the 2017 EFH 5-year Review. Following the 2017 EFH Review:

- The FE model error that was identified in 2018 was corrected with additional model updates for the 2023 FE evaluation.
- The 2017 SDM EFH mapping methods were revised to the 2023 SDM ensemble approach.
- Commercial fishing activities continued.

To identify whether or not the habitat disturbance threshold was met due to either changes in the FE model, changes in the SDM EFH map, or changes in fishing effort, an analysis compared the 2017 FE

[88] EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

model and 2017 SDM EFH maps, 2023 corrected FE model and 2017 SDM EFH maps, and 2023 corrected FE model and 2023 SDM EFH maps and was reported in the EFH Component 2 FE Discussion Paper [89].

The results describe that the habitat disturbance threshold was exceeded due to FE model changes (9 species), fishing effort changes (3 species), and EFH map changes (2 species). The two species where this threshold was exceeded due to changes in the EFH maps between 2017 and 2023 were arrowtooth flounder (ATF) and giant octopus in the EBS. **We describe how the EFH maps changed between 2017 and 2023 for these species in the following sections.** Details of the SDM ensemble EFH mapping methods of the 2023 EFH 5-year Review are provided in section 3.2 and in the three regional EFH NOAA Technical Memoranda (Supporting Documents 5).

G.3.1 Arrowtooth flounder in the Bering Sea

The habitat disturbance threshold (≥ 10% CEA disturbed) was exceeded for EBS ATF in the FE analysis (10.3%) and was attributed to changes in the SDM EFH map CEA between 2017 and 2023. The CEA was reduced by 15.5% from the 2017 CEA (Figure G7). The 2017 SDM for adult ATF in the EBS was a generalized additive model (GAM). The 2023 SDM ensemble included the GAM_P, hGAM, paGAM, and MaxEnt models. Overall, the ensemble fit to observed adult ATF distribution and abundance was excellent and an improvement over the 2017 GAM (section 3.3.2.1). The ensemble was excellent at predicting catches of high and low adult ATF abundance (ρ = 0.81), presence-absence (AUC = 0.96), and at explaining deviance (PDE = 0.64). Habitat-related ensemble-predicted numerical abundance of ATF life stages collected in RACE-GAP summer bottom trawl surveys of the EBS (1992–2019) was translated into EFH areas and additional habitat-related subareas (Figure G8). The EFH area of adult ATF was focused over the middle and outer shelf domains with core EFH area and EFH hot spots in deeper waters. EFH area was reduced on the continental shelf, including inside Norton Sound, and expanded in patchy areas inside Bristol Bay. Comparing the 2017 SDM and 2023 ensemble for EBS adult ATF demonstrated that shifting the response variable from 4th root transformed CPUE in 2017 to the prediction of numerical abundance in 2023 had the largest effect on reducing the CEA in 2023. Although comparing the 2017 SDMs and 2023 ensembles overall demonstrated that the type of model used in 2017 had a large effect on the performance metrics and calculated EFH area, this was a larger difference when the 2017 SDM was an hGAM or MaxEnt model.

The reviewing stock author did not report a concern with the SDM EFH map or FE model in their FE assessment. In their 2021 EFH component 1 review, they provided a future research recommendation to include longline survey data to potentially account for more ATF habitat on the continental slope (section 11.3.1.1). The reviewing stock author chose a quantitative FE assessment using the FE model and 50% CEA and provided a written assessment with further supporting analysis. Based on their assessment, they reported **no further action and recommended that fishing has not had an impact on EBS ATF habitat that is more than minimal and not temporary.**

Mapping requirements for EFH component 1 are some or all portions of the geographic range of the species (50 CFR 600.815(a)(1)(iii)(1)). **EFH mapping requirements have been met for EBS ATF. The 2023 SDM ensemble EFH map provides the best available science for mapping EFH for this species at this time and represents an improvement over the 2017 SDM EFH map.** If possible, EFH component 1 may be improved for this species through research leading up to a future EFH 5-year Review, which are by design an iterative process and occurring at least every five years (50 CFR 600.815(a)(10)).

[89] Species with ≥ 10% CEA Disturbed (section 4.3) in EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting

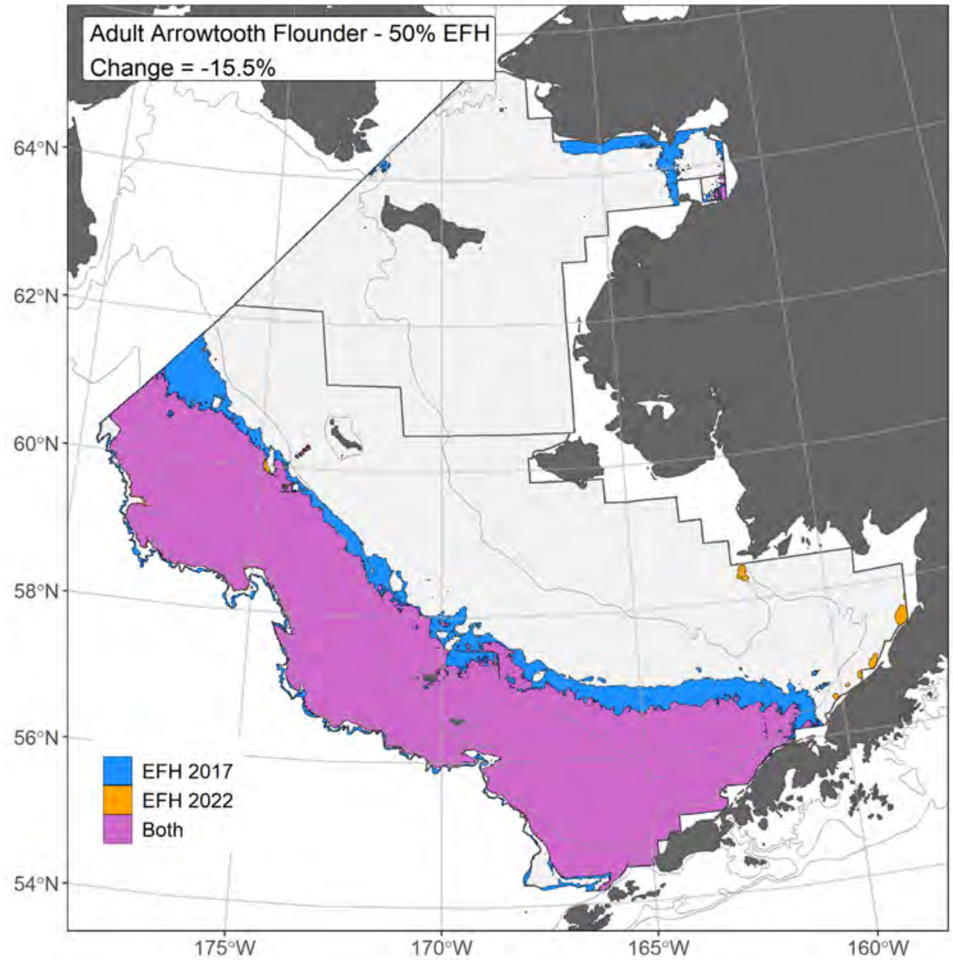

Figure G7. Change from 2017 to 2022 (2023) in EBS adult arrowtooth flounder core EFH area (CEA, top 50% of EFH area); colors represent CEA in 2017, 2022 (2023), or both.

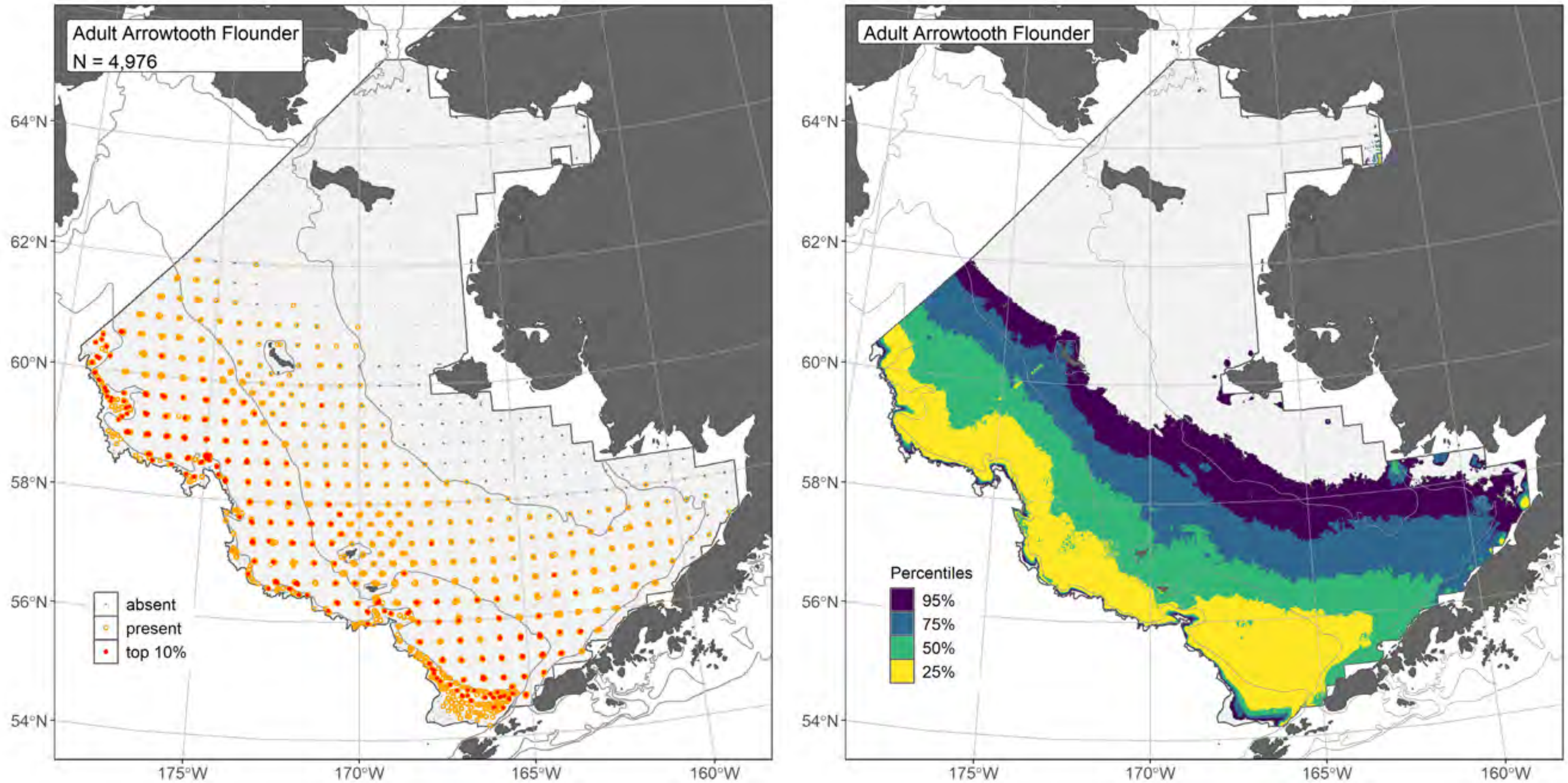

Figure G8. Distribution of adult arrowtooth flounder (ATF) catches (N = 4,976) in AFSC RACE-GAP EBS summer bottom trawl surveys of the EBS Shelf (1982–2019), EBS Slope (2002, 2004, 2008, 2012, 2016), and Northern Bering Sea (2010, 2017, 2019), with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station (left panel). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult ATF distribution and abundance from AFSC RACE-GAP EBS summer bottom trawl surveys (1982–2019), with 50 m, 100 m, and 200 m isobaths indicated; colors indicate the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of habitat-related, ensemble-predicted numerical abundance (right panel).

G.3.2 Giant octopus in the Bering Sea

The habitat disturbance threshold (≥ 10% CEA disturbed) was exceeded for EBS giant (Pacific) octopus in the FE analysis (13.5%) and was attributed to changes in the SDM EFH map CEA between 2017 and 2023. The CEA was reduced by 38.0% from the 2017 CEA (Figure G9). The 2017 SDM for giant octopus in the EBS was a presence-only MaxEnt model. The 2023 SDM ensemble included the GAM_P, hGAM, paGAM, and MaxEnt models. Overall, the ensemble fit to observed octopus distribution and abundance was fair. The 2017 AUC (0.87) was very similar to the 2023 AUC (0.88) (i.e., the only performance metric available for comparison with the 2017 presence-only MaxEnt model) (Table D2). The ensemble was fair at predicting catches of high and low octopus abundance (ρ = 0.28), at explaining deviance (PDE = 0.31), and good at discriminating presence-absence (AUC = 0.88). Habitat-related ensemble-predicted numerical abundance of giant octopus life stages collected in RACE-GAP summer bottom trawl surveys of the EBS (1992–2019) was translated into EFH areas and additional habitat-related subareas (Figure G10). The EFH area of giant octopus was mapped primarily to the outer shelf domain and extended onto the upper continental slope. CEA and EFH hotspots for giant octopus were located progressively further offshore within the larger EFH area.

Comparing the 2017 SDMs and 2023 ensembles demonstrated that the type of model used in 2017 had a large effect on the performance metrics and calculated EFH area. Approximately 18% of ensembles resulted in EFH areas that were smaller by at least half; in each of these cases the 2017 SDM was a MaxEnt model. The relatively large decrease in CEA observed in the 2023 EBS giant octopus map compared to the 2017 map was largely attributed to moving from the single use of a presence-only MaxEnt model in 2017 to an SDM ensemble in 2023. Mapping EFH using SDM ensembles rather than single SDMs helped mitigate the influence of any one SDM method on the EFH area and should reduce the magnitude of the change in EFH area attributable to modeling methods in future EFH mapping, making it easier to detect changes in species distribution or habitat impacts.

The reviewing stock author reported *medium concern* with the SDM EFH map for giant octopus in the EBS and commented “Giant octopus are not well sampled by bottom trawl gear. Thus SDM based on summer survey data are not likely to be good representations of octopus habitat.” They were unable to recommend other existing data sources that could augment the RACE-GAP bottom trawl survey data in the SDM ensemble to improve the EFH map for this species. They reported *medium concern* with the FE model and commented “I question whether the SDM for giant octopus is useful given that they are not well sampled by bottom trawl gear. Thus the FE may not be appropriate.” The stock author provided a qualitative assessment of the effects of fishing on giant octopus EFH. Based on their assessment, they reported **no further action and recommended that fishing has not had an impact on EBS giant octopus habitat that is more than minimal and not temporary.**

Data availability issues for giant octopus are ongoing in the AI, EBS, and GOA. Mapping requirements for EFH component 1 are some or all portions of the geographic range of the species (50 CFR 600.815(a)(1)(iii)(1)). **EFH mapping requirements have been met for giant octopus in the EBS. The 2023 SDM ensemble EFH map provides the best available science for mapping EFH for this species at this time and represents an improvement over the 2017 SDM EFH map.** If possible, EFH component 1 may be improved for this species through research leading up to a future EFH 5-year Review, which are by design an iterative process and occurring at least every five years (50 CFR 600.815(a)(10)).

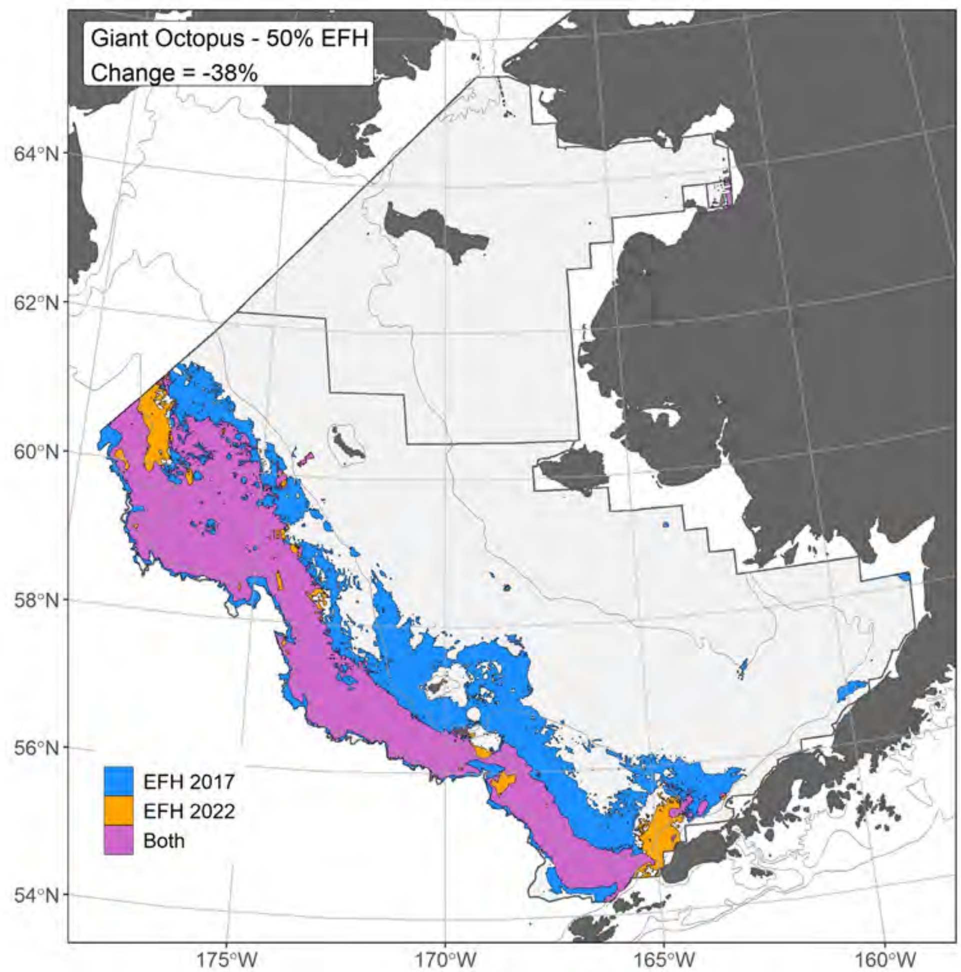

Figure G9. Change from 2017 to 2022 (2023) in EBS giant octopus core EFH area (CEA, top 50% of EFH area); colors represent CEA in 2017, 2022 (2023), or both.

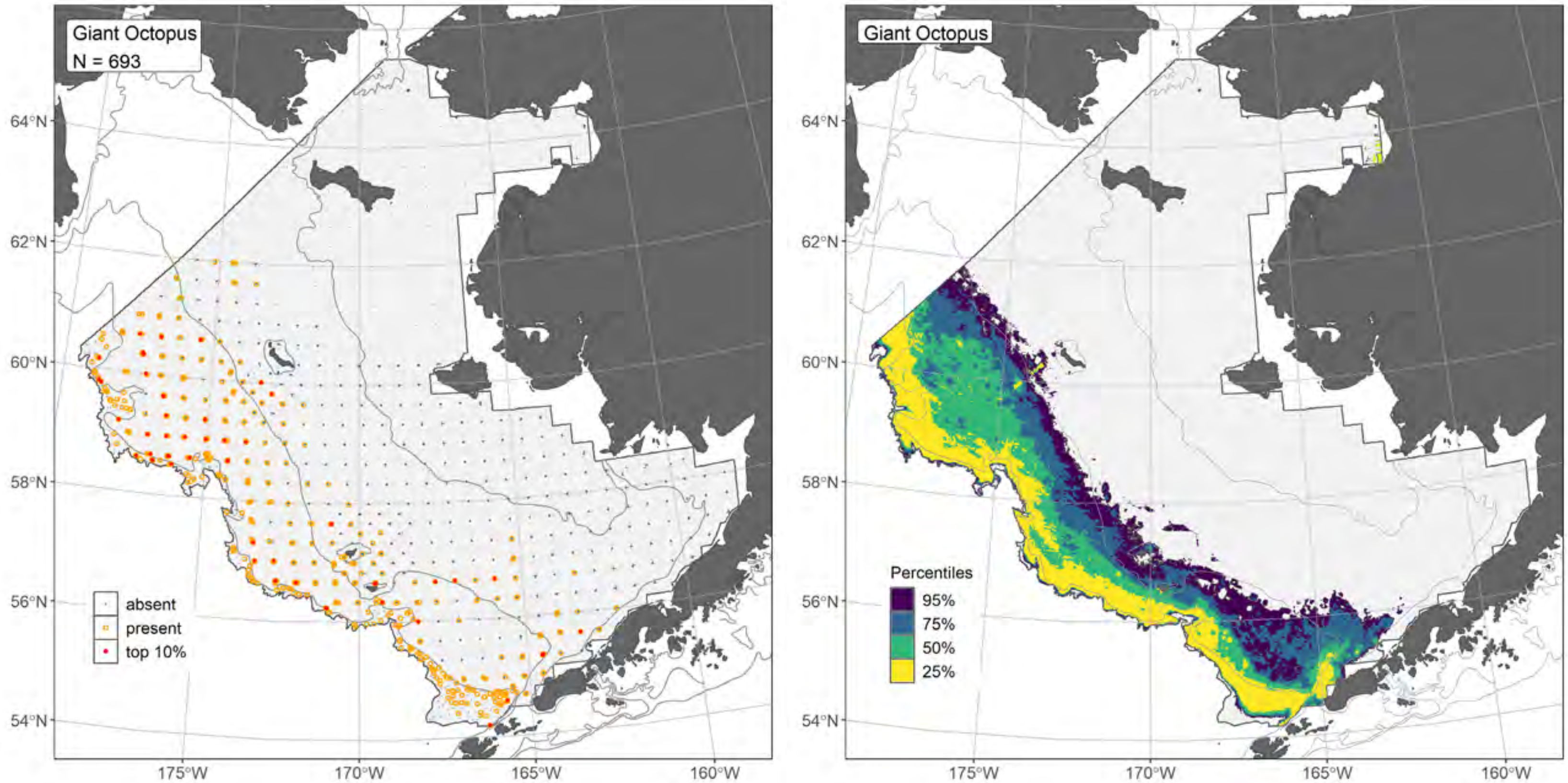

Figure G10. Distribution of giant octopus catches (N = 693) in AFSC RACE-GAP EBS summer bottom trawl surveys of the EBS Shelf (1982–2019), EBS Slope (2002, 2004, 2008, 2012, 2016), and Northern Bering Sea (2010, 2017, 2019), with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station (left panel). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to giant octopus distribution and abundance from AFSC RACE-GAP EBS summer bottom trawl surveys (1982–2019), with 50 m, 100 m, and 200 m isobaths indicated; colors indicate the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of habitat-related, ensemble-predicted numerical abundance (right panel).

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G.5 EFH Summary Table Supporting the 2023 Component 2 Fishing Effects Evaluation

Table G3. EFH Summary Table of the summer distribution of adults or all life stages of groundfishes and crabs provided to stock authors (SAs) for the 2023 EFH component 2 fishing effects (FE) evaluation (* indicates all life stages). SDM Performance Metric Rubric (ρ: < 0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (good), 0.61–0.99 (excellent); AUC: < 0.70 (poor), 0.71–0.90 (good), 0.90–0.99 (excellent); PDE: < 0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (good), 0.61–0.99 (excellent)). CEA (core EFH area) was applied to the FE model output to determine the percent CEA disturbed by fishing, based on the SSC's threshold of ≥ 10%; species where that threshold was reached are indicated (Y). If the reviewing SA reported an SDM EFH map concern or future recommendation in their 2021 EFH component 1 review (Appendix F 11), this is noted to indicates where additional communication occurred between EFH analysts and SAs to address concerns to the extent possible at this time leading up the SSC's February 2022 review. SSC requested in February 2022, that SAs restate their concerns for clarity in a questionnaire; their response is provided in Table 3 and in the EFH Component 2 FE Discussion Paper[90].

Region	Species	N	SDM Performance Metrics				SDM Performance Metrics Overall Score	CEA (upper 50% of EFH area km^2)	≥ 10% CEA Disturbed	SA 2021 EFH Component 1 Review concern and/or recommendation (Appendix F)
			RMSE	ρ	AUC	PDE				
AI	arrowtooth flounder	3,118	42.90	0.49	0.75	0.29	good	40,900		Y
AI	flathead sole	1,374	13.50	0.56	0.86	0.48	good	35,700		
AI	Greenland turbot	359	11.60	0.41	0.96	0.70	excellent	14,000		
AI	Kamchatka flounder	918	19.40	0.54	0.90	0.75	excellent	27,300		
AI	northern rock sole	2,923	58.80	0.72	0.88	0.47	good	39,300		
AI	*other flatfish complex*	-	-	-	-	-	-	40,900		
AI	Dover sole	232	0.87	0.27	0.88	0.43	good	15,400		
AI	English sole	50	1.45	0.23	0.98	0.82	good	5,500		
AI	rex sole	1,891	22.60	0.56	0.82	0.43	good	40,600		
AI	southern rock sole	763	11	0.63	0.97	0.81	excellent	22,200		
AI	Atka mackerel	2,030	1190	0.52	0.65	0.36	fair	40,900		Y
AI	Pacific cod	3,084	40.40	0.50	0.76	0.37	good	40,800		
AI	sablefish	368	8.11	0.40	0.95	0.67	good	17,400		Y
AI	walleye pollock	2,773	447	0.50	0.71	0.28	good	40,900		
AI	northern rockfish	2,063	779	0.56	0.68	0.42	fair	40,900		
AI	Pacific ocean perch	2,908	1570	0.72	0.68	0.46	good	40,900		
AI	rougheye/blackspotted rockfish complex	711	19.40	0.52	0.94	0.76	excellent	18,300		
AI	shortraker rockfish	514	6.14	0.48	0.96	0.76	excellent	14,400		Y
AI	*Other Rockfish complex*	-	-	-	-	-	-	40,900		
AI	dusky rockfish	380	9.17	0.27	0.78	0.45	fair	34,100		
AI	harlequin rockfish	111	23.40	0.18	0.86	0.40	fair	32,600		

[90] EFH Component 2 Fishing Effects Discussion Paper (revised January 2023) available on Council agenda for this meeting.

Region	Species	N	SDM Performance Metrics				SDM Performance Metrics Overall Score	CEA (upper 50% of EFH area km^2)	≥ 10% CEA Disturbed	SA 2021 EFH Component 1 Review concern and/or recommendation (Appendix F)
			RMSE	ρ	AUC	PDE				
AI	shortspine thornyhead	1,051	26.10	0.61	0.93	0.74	excellent	28,900		Y
AI	*skate complex*	-	-	-	-	-	-	40,800		
AI	Alaska skate	149	0.65	0.25	0.82	0.27	fair	25,600		
AI	Aleutian skate	221	0.35	0.21	0.76	0.18	fair	12,300		
AI	mud skate	290	0.42	0.28	0.82	0.26	fair	19,200		
AI	whiteblotched skate	544	2.05	0.49	0.92	0.72	excellent	19,500		
AI	giant octopus*	682	0.81	0.20	0.67	0.09	poor	37,900		
AI	golden king crab*	1,148	6.13	0.56	0.89	0.48	good	27,100		Y
AI	red king crab*	83	1.55	0.15	0.85	0.27	fair	15,800		Y
EBS	Alaska plaice	8,684	111	0.81	0.92	0.56	excellent	347,600		
EBS	arrowtooth flounder	4,976	26.60	0.81	0.96	0.64	excellent	224,400	Y	Y
EBS	Greenland turbot	1,974	4.20	0.53	0.95	0.70	excellent	127,300		
EBS	Kamchatka flounder	1,752	2.14	0.51	0.91	0.63	excellent	145,400		
EBS	northern rock sole	7,790	472.0	0.82	0.89	0.49	good	354,100		
EBS	yellowfin sole	9,480	476.0	0.89	0.96	0.62	excellent	326,500		
EBS	*flathead sole Bering flounder complex*	-	-	-	-	-	-	359,700		
EBS	flathead sole	9,702	143.0	0.72	0.88	0.33	good	358,900		
EBS	Bering flounder	2,966	29.60	0.64	0.97	0.67	excellent	241,300		
EBS	*other flatfish complex*	-	-	-	-	-	-	360,100		
EBS	butter sole	177	13.70	0.20	0.98	0.60	good	65,200		
EBS	deepsea sole*	110	0.30	0.45	0.99	0.87	excellent	5,700		
EBS	Dover sole	91	0.37	0.30	0.99	0.73	good	7,000	Y	
EBS	longhead dab*	2,307	54.0	0.61	0.97	0.68	excellent	203,300		
EBS	rex sole	2,171	9.76	0.56	0.95	0.77	excellent	122,700	Y	
EBS	Sakhalin sole	225	2.10	0.22	0.97	0.68	good	105,200		
EBS	starry flounder	1,619	19.20	0.51	0.96	0.58	good	187,900		
EBS	Atka mackerel	72	0.69	0.09	0.85	0.28	fair	13,800	Y	Y
EBS	Pacific cod	11,853	20.50	0.48	0.79	0.15	good	355,600		
EBS	sablefish	544	1.77	0.39	0.99	0.77	good	35,700	Y	Y
EBS	walleye pollock	13,506	1020	0.63	0.63	0.24	fair	362,900		
EBS	northern rockfish	89	9.08	0.15	0.97	0.71	good	44,100	Y	
EBS	Pacific ocean perch	561	308	0.34	0.99	0.39	fair	101,000	Y	
EBS	rougheye/blackspotted rockfish complex	105	0.15	0.36	0.99	0.75	good	7,000		
EBS	shortspine thornyhead	696	16	0.55	0.99	0.92	excellent	25,100	Y	Y

Region	Species	N	SDM Performance Metrics				SDM Performance Metrics Overall Score	CEA (upper 50% of EFH area km²)	≥ 10% CEA Disturbed	SA 2021 EFH Component 1 Review concern and/or recommendation (Appendix F)
			RMSE	ρ	AUC	PDE				
EBS	shortraker rockfish	142	1.65	0.33	0.99	0.85	good	7,200	Y	Y
EBS	*skate complex*	-	-	-	-	-	-	362,100		
EBS	Alaska skate	5,162	5	0.55	0.78	0.29	good	354,600		
EBS	Aleutian skate	207	0.44	0.30	0.96	0.57	good	31,000	Y	
EBS	Bering skate	1,429	0.88	0.51	0.90	0.48	good	140,700	Y	
EBS	mud skate	147	0.43	0.28	0.98	0.69	good	13,500	Y	
EBS	whiteblotched skate	201	0.34	0.33	0.99	0.70	good	16,200	Y	
EBS	giant octopus*	693	0.69	0.28	0.88	0.31	fair	109,200	Y	
EBS	blue king crab*	1,650	8.04	0.47	0.93	0.52	good	248,700		
EBS	red king crab*	3,376	74.60	0.67	0.95	0.52	good	191,500		Y
EBS	snow crab*	10,628	1930	0.84	0.85	0.41	good	362,600		Y
EBS	Tanner crab*	9,244	140	0.80	0.93	0.35	good	284,400	Y	Y
GOA	arrowtooth flounder	7,043	189	0.55	0.76	0.29	good	148,300		Y
GOA	flathead sole	4,201	63.30	0.72	0.88	0.54	good	135,700		
GOA	rex sole	4,455	36.30	0.59	0.80	0.37	good	147,400		
GOA	Dover sole	2,973	11	0.62	0.87	0.42	good	143,600		
GOA	*shallow water flatfish complex*	-	-	-	-	-	-	142,900		
GOA	Alaska plaice	442	3.60	0.38	0.97	0.71	good	46,100		
GOA	butter sole*	881	30.10	0.46	0.93	0.54	good	107,900		
GOA	English sole	746	13.30	0.34	0.84	0.52	good	127,200		
GOA	northern rock sole	1,980	25	0.69	0.95	0.58	excellent	100,400		
GOA	Pacific sanddab*	77	2.15	0.19	0.98	0.74	good	16,900		
GOA	Petrale sole	271	1.32	0.29	0.96	0.65	good	34,000		
GOA	sand sole	109	4.44	0.22	0.97	0.60	good	26,600		
GOA	slender sole*	751	4.99	0.44	0.94	0.68	excellent	66,900		
GOA	southern rock sole	2,772	22.10	0.76	0.94	0.65	excellent	111,700		
GOA	starry flounder	604	13.30	0.43	0.97	0.59	good	60,700		
GOA	yellowfin sole	491	58	0.40	0.98	0.79	good	62,600		
GOA	Atka mackerel	700	143	0.33	0.85	0.35	fair	123,100		Y
GOA	Pacific cod	4,476	70.20	0.48	0.75	0.25	good	139,300		
GOA	sablefish	2,011	18.90	0.65	0.94	0.61	excellent	114,100		Y
GOA	walleye pollock	4,351	237	0.49	0.74	0.23	good	148,300		
GOA	dusky rockfish	1,061	53.10	0.40	0.83	0.29	fair	138,900		Y
GOA	northern rockfish	1,141	276	0.46	0.89	0.32	good	137,400		

Region	**Species**	**N**	**SDM Performance Metrics**				**SDM Performance Metrics Overall Score**	**CEA (upper 50% of EFH area km^2)**	**≥ 10% CEA Disturbed**	**SA 2021 EFH Component 1 Review concern and/or recommendation (Appendix F)**
			RMSE	**ρ**	**AUC**	**PDE**				
GOA	Pacific ocean perch	2,992	692	0.65	0.81	0.39	good	148,100		
GOA	rougheye/blackspotted rockfish complex	878	9.94	0.46	0.93	0.70	excellent	67,700		Y
GOA	shortraker rockfish	679	7.62	0.47	0.97	0.73	excellent	34,300		Y
GOA	shortspine thornyhead	1,998	44.40	0.70	0.97	0.82	excellent	120,600		Y
GOA	*Other Rockfish complex demersal sub-group*	-	-	-	-	-	-	59,000		Y
GOA	quillback rockfish	73	0.44	0.17	0.96	0.51	fair	9,300		Y
GOA	rosethorn rockfish	186	2.48	0.40	0.99	0.83	good	15,600		Y
GOA	yelloweye rockfish	186	0.46	0.22	0.91	0.43	fair	33,900		Y
GOA	*Other Rockfish complex slope sub-group*	-	-	-	-	-	-	144,200		Y
GOA	greenstriped rockfish	120	1.41	0.30	0.99	0.86	good	10,200		Y
GOA	harlequin rockfish	514	71.30	0.31	0.88	0.45	good	134,100		Y
GOA	pygmy rockfish*	63	3.02	0.14	0.96	0.41	fair	39,400		Y
GOA	redbanded rockfish	321	1.61	0.29	0.93	0.49	good	52,000		Y
GOA	redstripe rockfish	234	47.90	0.25	0.94	0.65	good	112,900		Y
GOA	sharpchin rockfish	425	97.90	0.34	0.95	0.54	good	115,100		
GOA	silvergray rockfish	557	33.30	0.37	0.93	0.63	good	97,000		Y
GOA	spiny dogfish	1,291	10	0.42	0.84	0.48	good	141,800		Y
GOA	*skate complex*	-	-	-	-	-	-	138,400		
GOA	Alaska skate	78	0.15	0.13	0.85	0.25	fair	7,000		
GOA	Aleutian skate	147	0.19	0.17	0.84	0.25	fair	16,100		
GOA	Bering skate	407	0.32	0.28	0.84	0.31	fair	49,800		
GOA	big skate	195	0.21	0.19	0.86	0.27	fair	19,600		
GOA	longnose skate	845	0.46	0.25	0.74	0.15	fair	110,000		
GOA	giant octopus*	459	0.33	0.20	0.75	0.15	fair	71,000		

G.6 2023 EFH Maps with AFSC Longline Survey Station Historic Haul Location Overlay

The following collection of figures shows the 2023 EFH maps of the summer distribution of groundfishes in the BSAI and GOA FMPs with overlay of the AFSC longline survey station historic haul locations (without attribution to species catch locations) for species where the reviewing stock author recommended that longline survey data be included in future EFH mapping efforts in their review of the new SDM ensemble 2023 EFH maps. The longline survey station locations were provided to NMFS AKR by the AFSC Marine Ecology and Stock Assessment program. As an interim step to understanding the recommendation to add longline survey data for this subset of species, these figures demonstrate that new 2023 EFH areas presently include, either entirely or partially, the AFSC longline survey stations. Including longline survey data in the SDMs for these species may enhance the EFH maps.

Figures

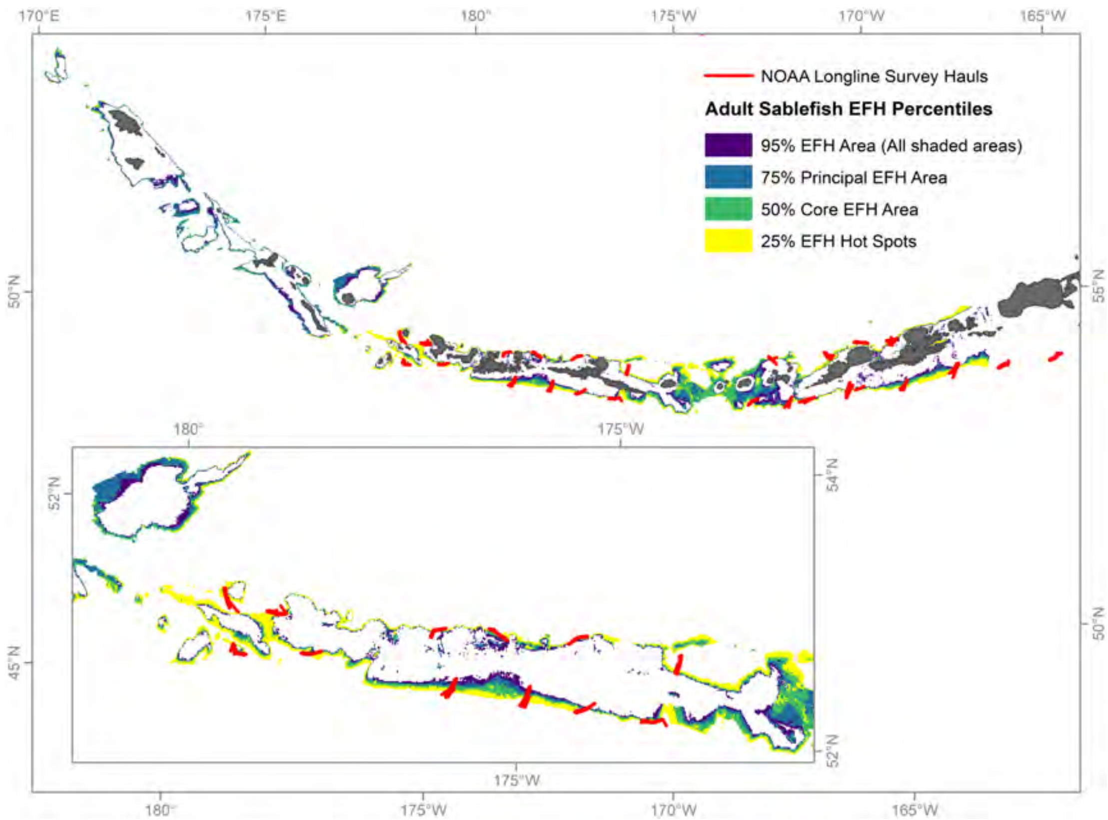

Figure G11. EFH map of adult sablefish in the AI with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to sablefish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult sablefish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1991–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

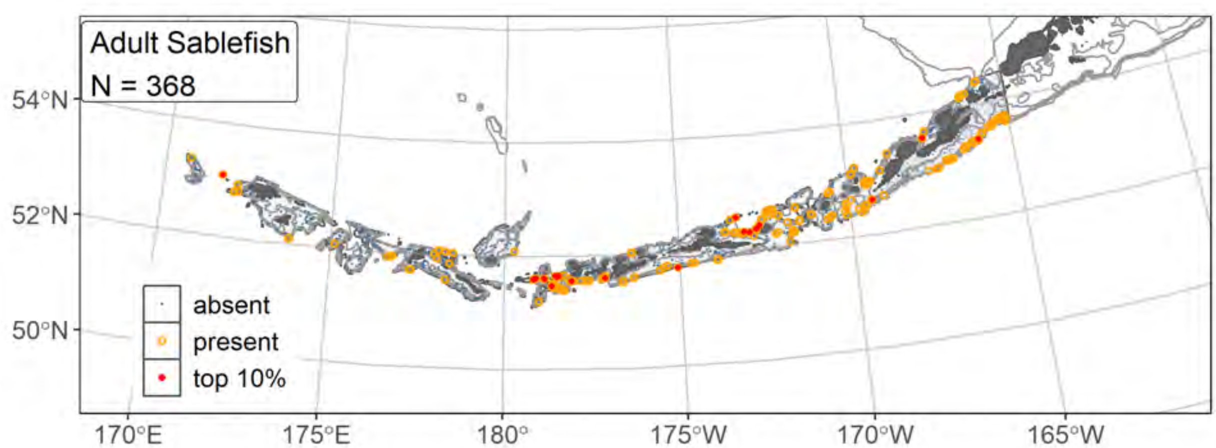

Figure G12. Distribution of adult sablefish catches (N = 368) in 1991–2019 AFSC RACE-GAP summer bottom trawl surveys of the AI with the 100 m, 300 m, and 500 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

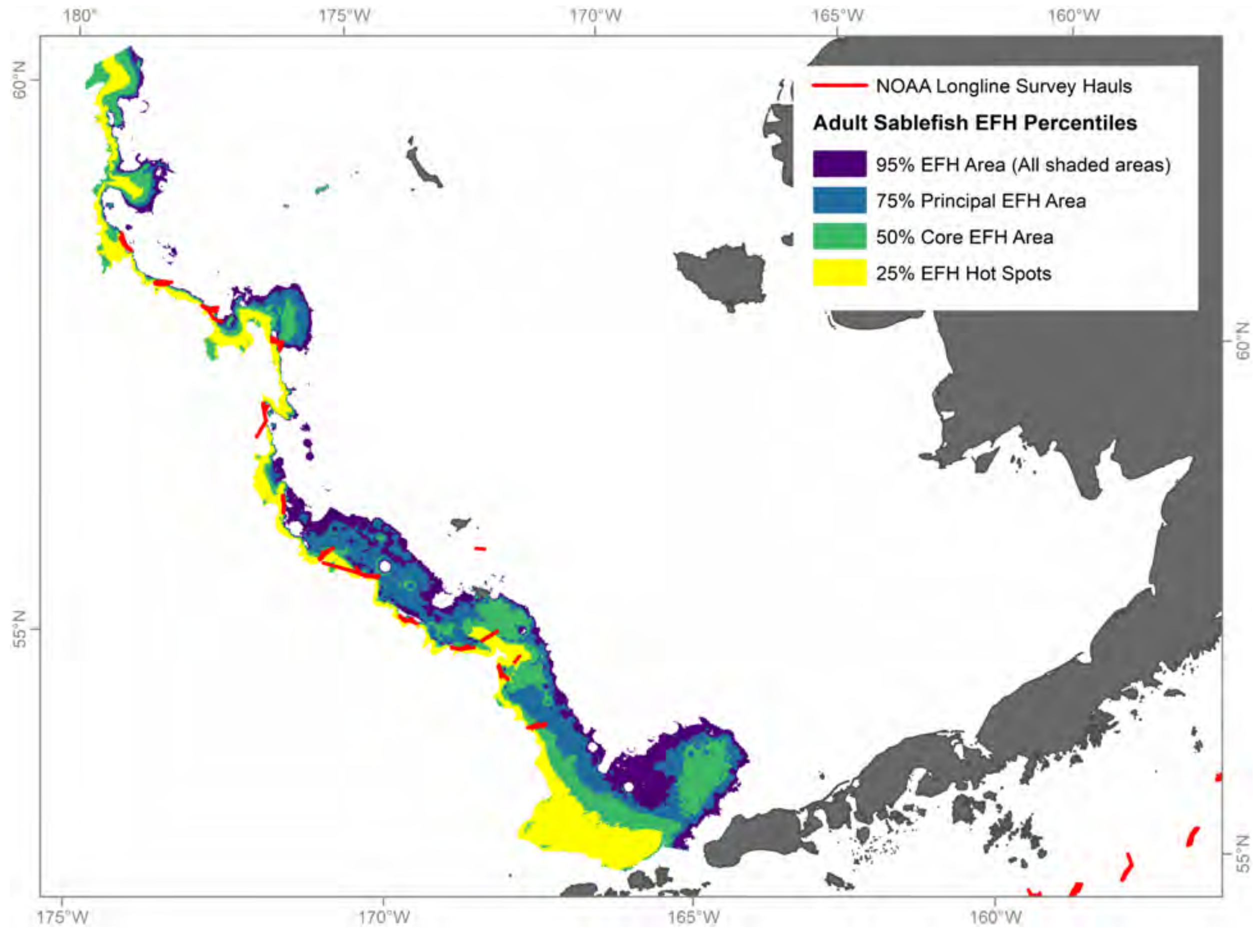

Figure G13. EFH map of adult sablefish in the EBS with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to adult sablefish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult sablefish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1992–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

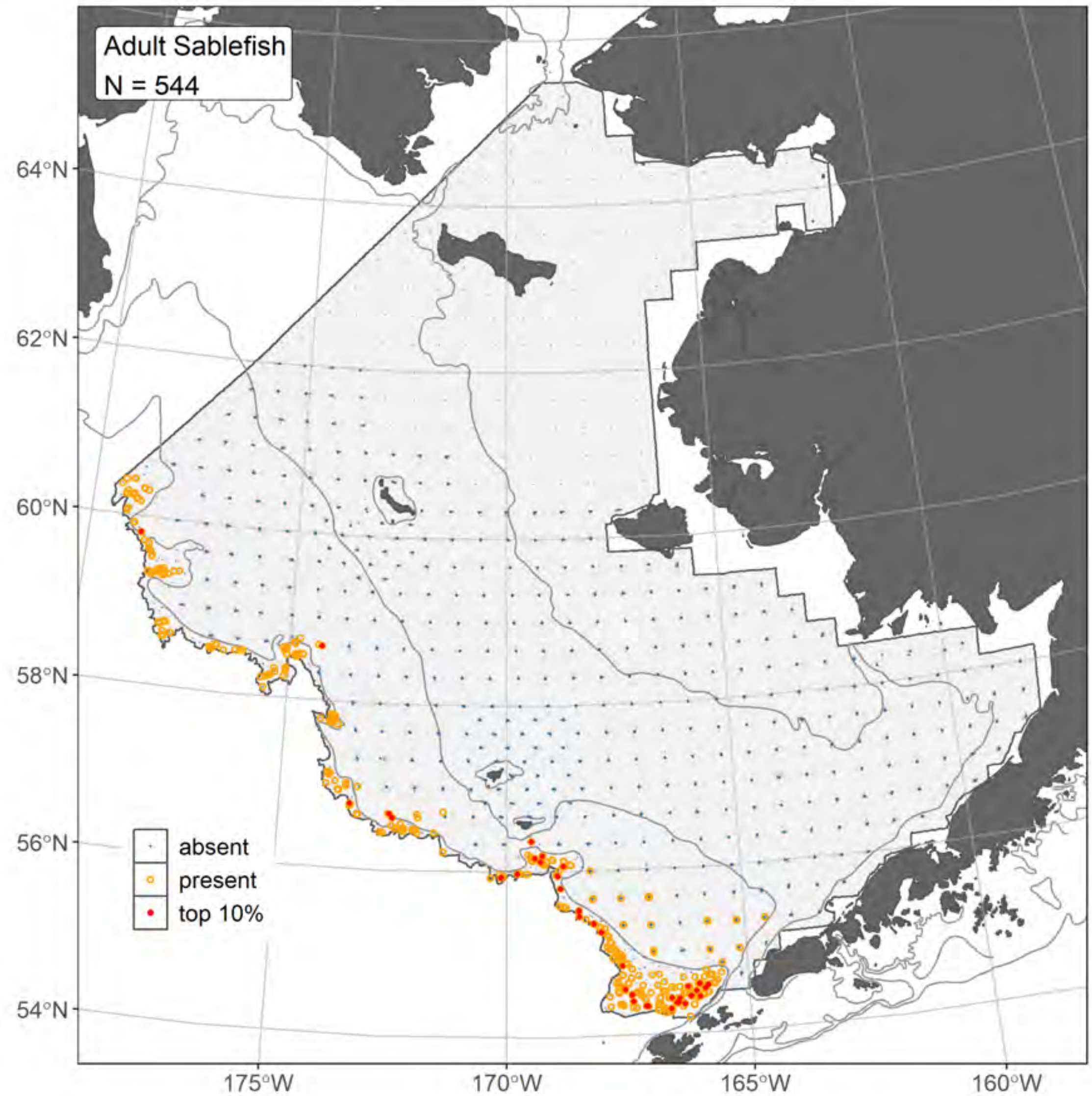

Figure G14. Distribution of adult sablefish catches (N = 544) in 1982–2019 AFSC RACE-GAP summer bottom trawl surveys of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

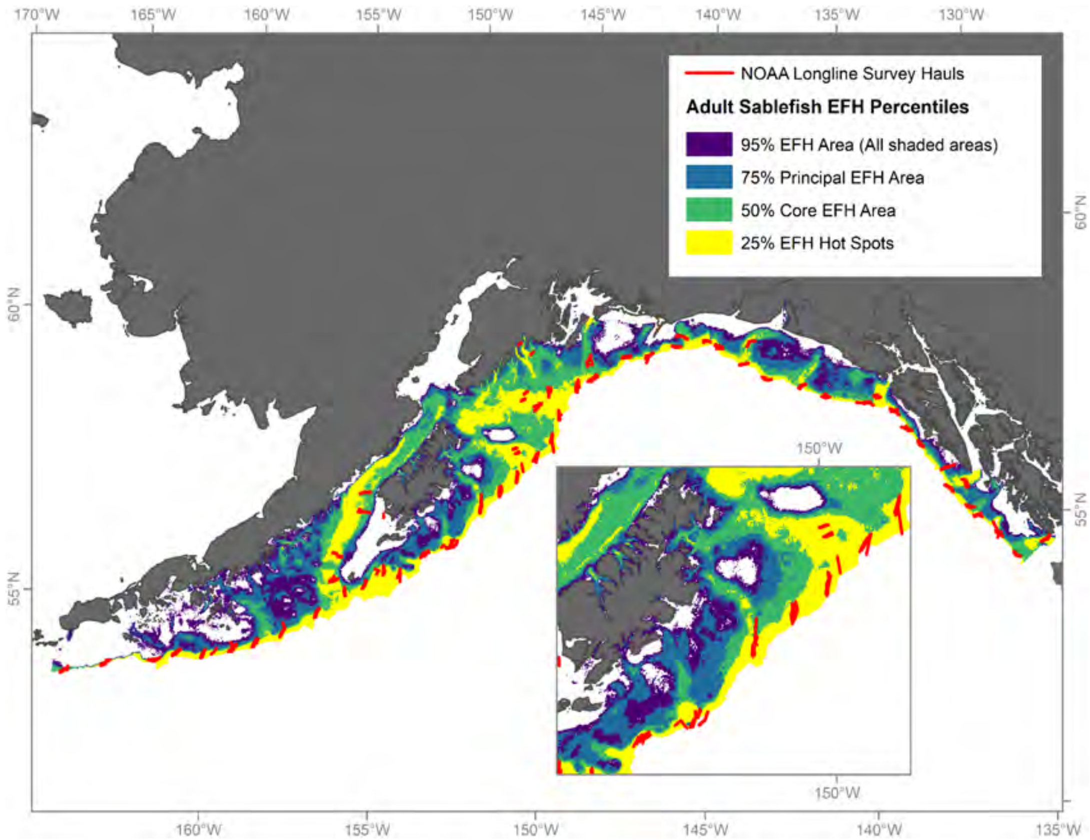

Figure G15. EFH map of adult sablefish in the Gulf of Alaska with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to sablefish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult sablefish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1993–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

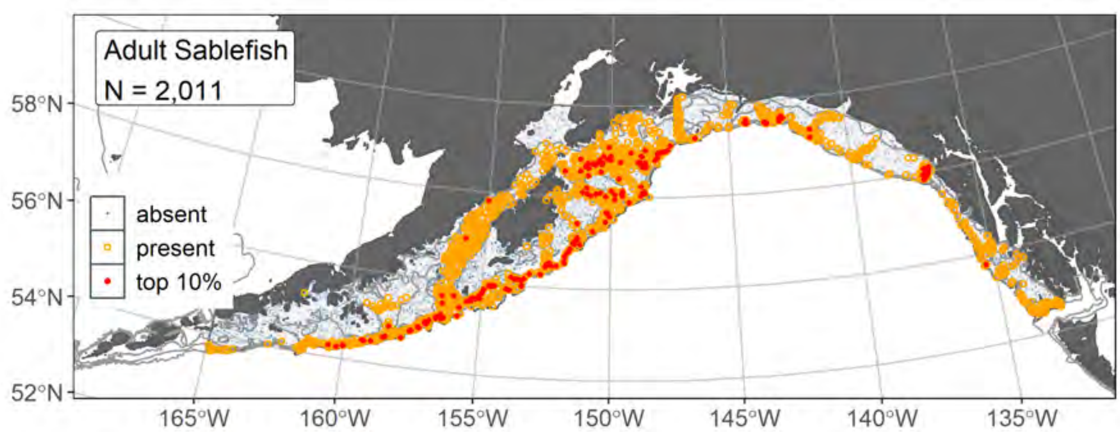

Figure G16. Distribution of adult sablefish catches (N = 2,011) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

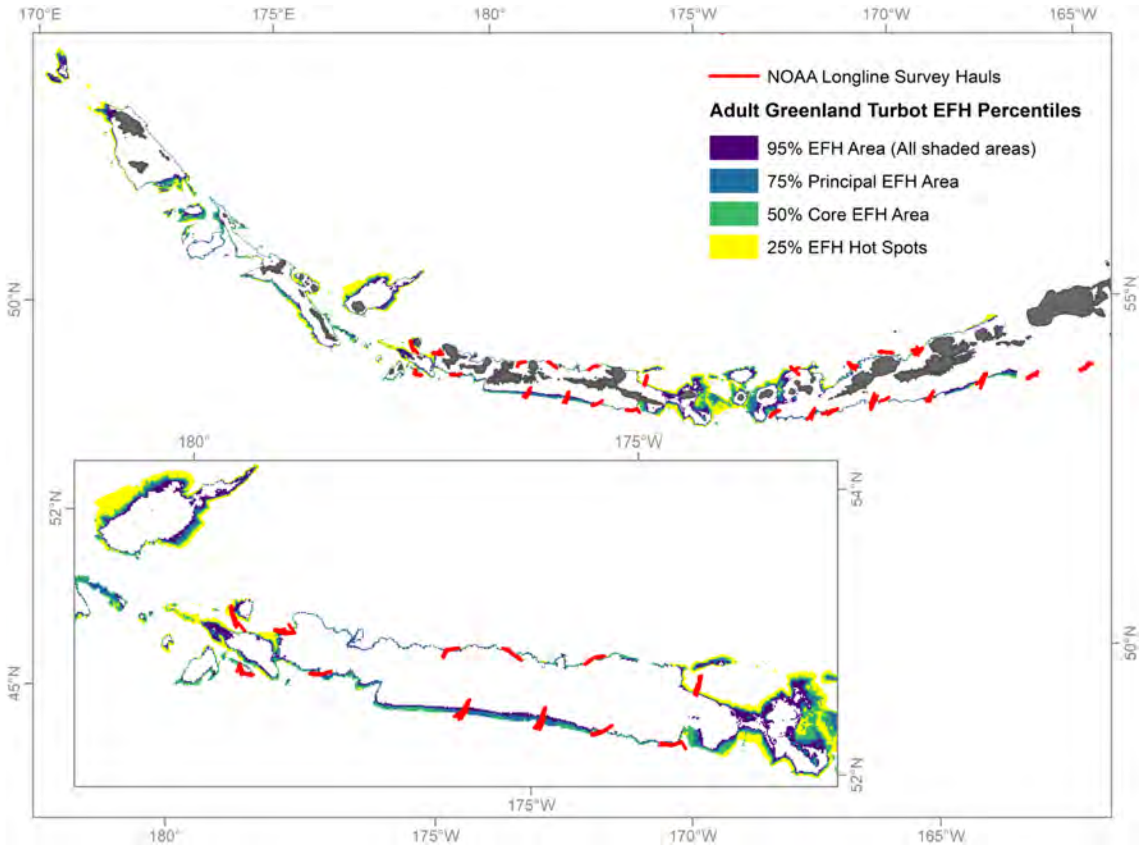

Figure G17. EFH map of adult Greenland turbot in the AI with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to Greenland turbot catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult Greenland turbot distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1991–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

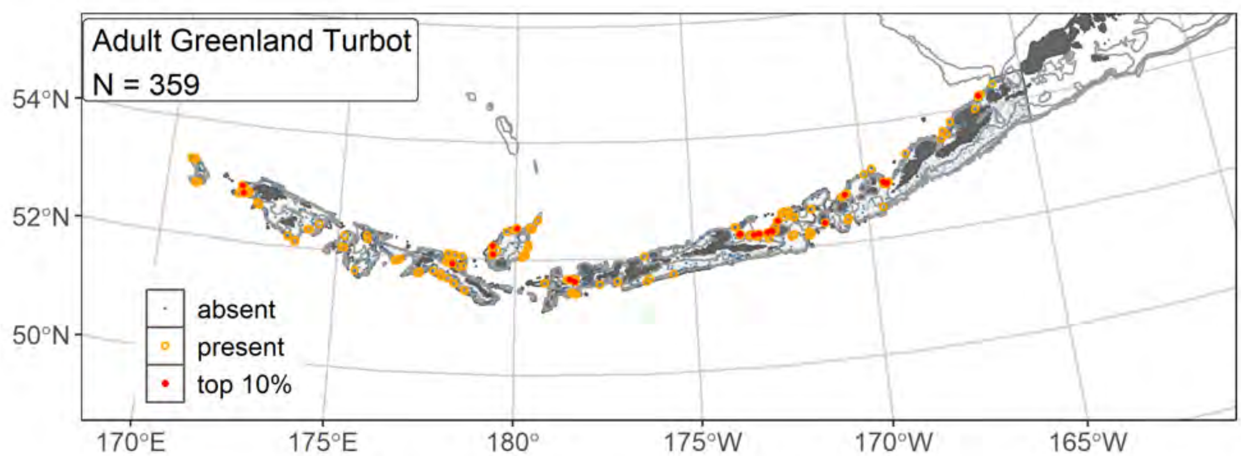

Figure G18. Distribution of adult Greenland turbot catches (N = 359) in 1991–2019 AFSC RACE-GAP summer bottom trawl surveys of the AI with the 100 m, 300 m, and 500 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and small blue dots indicate absence, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

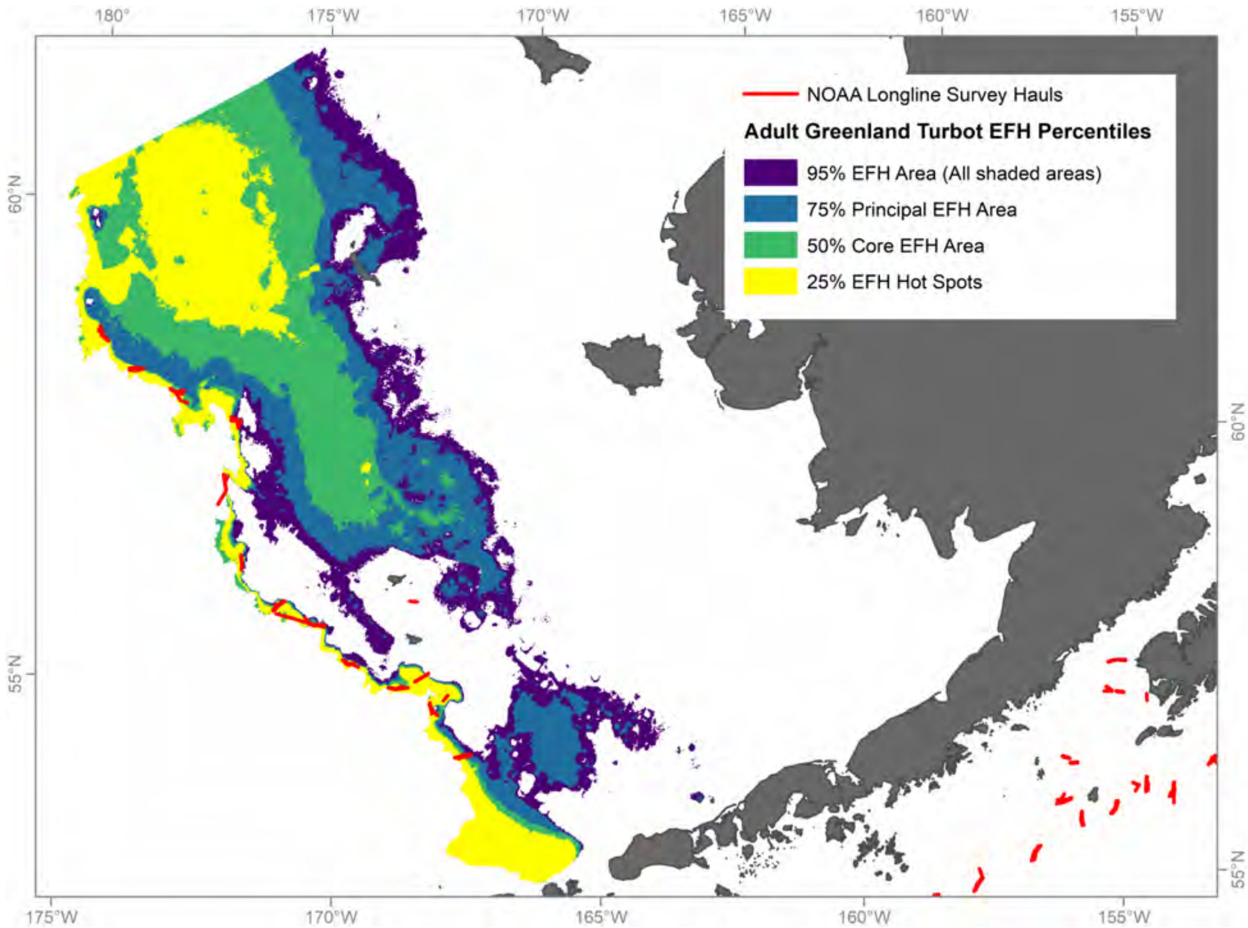

Figure G19. EFH map of adult Greenland turbot in the EBS with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to adult Greenland turbot catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult Greenland turbot distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1992–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

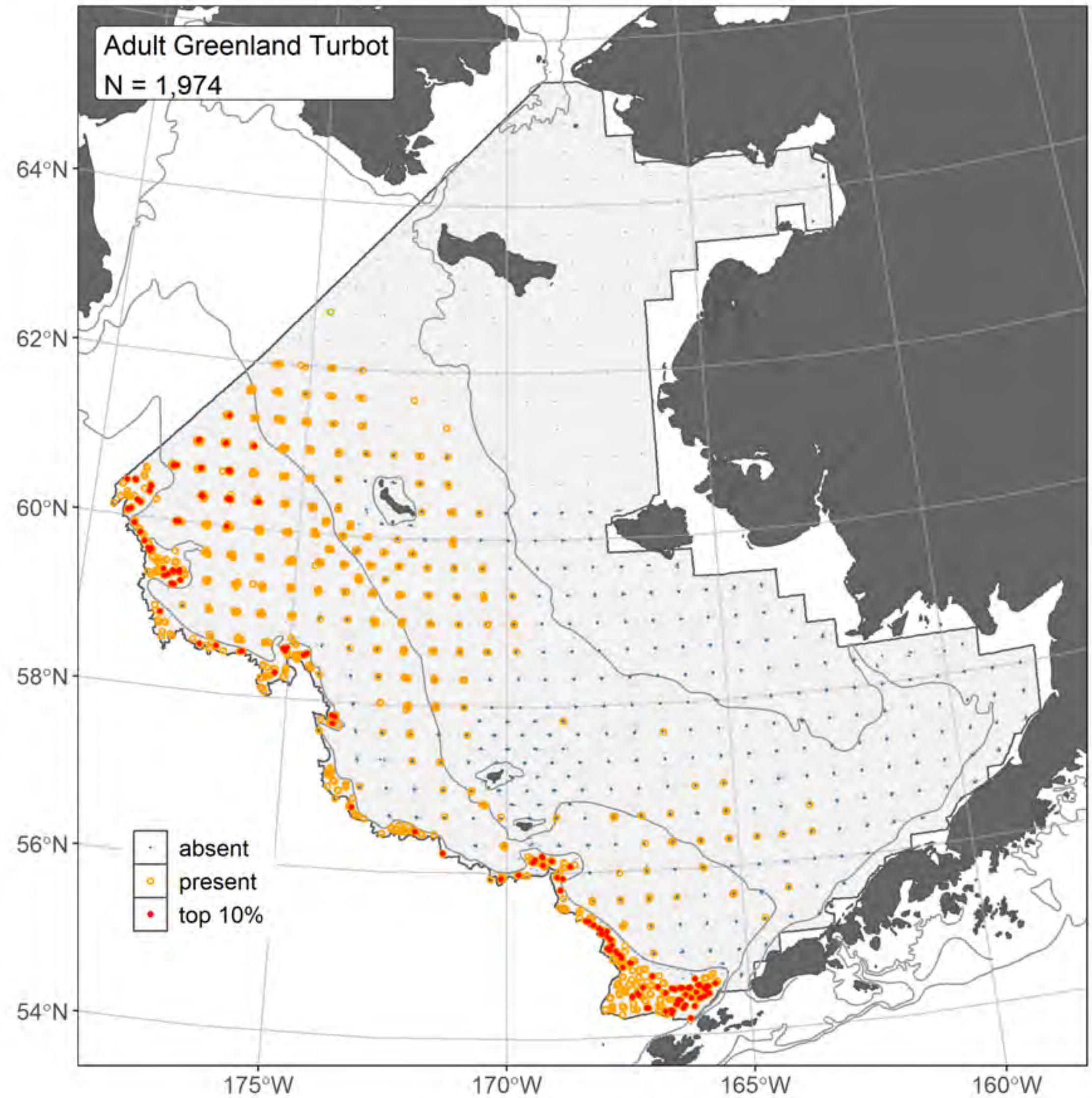

Figure G20. Distribution of adult Greenland turbot catches (N = 1,974) in 1982–2019 AFSC RACE-GAP summer bottom trawl surveys of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

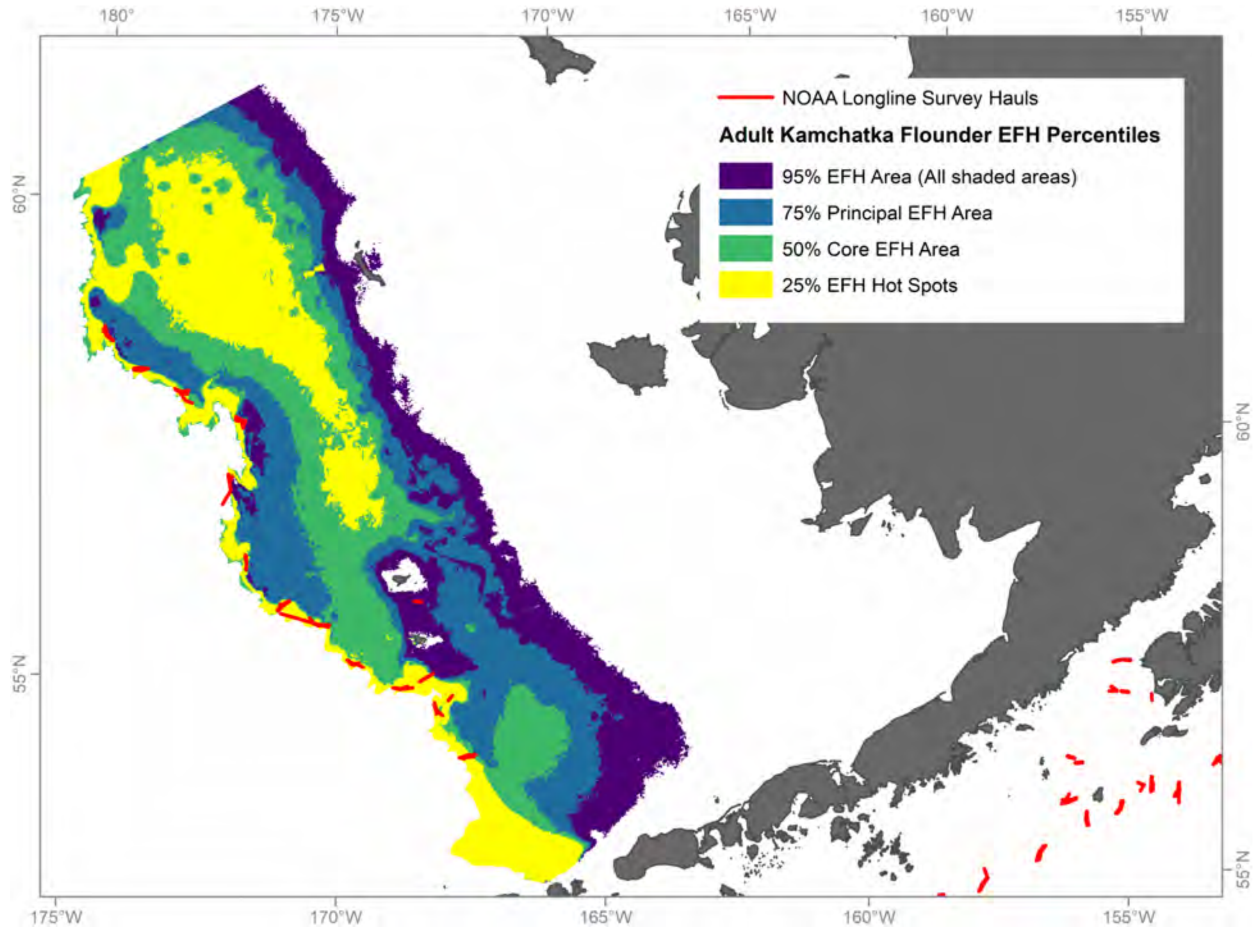

Figure G21. EFH map of adult Kamchatka flounder in the EBS with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to adult Kamchatka flounder catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult Kamchatka flounder distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1992–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

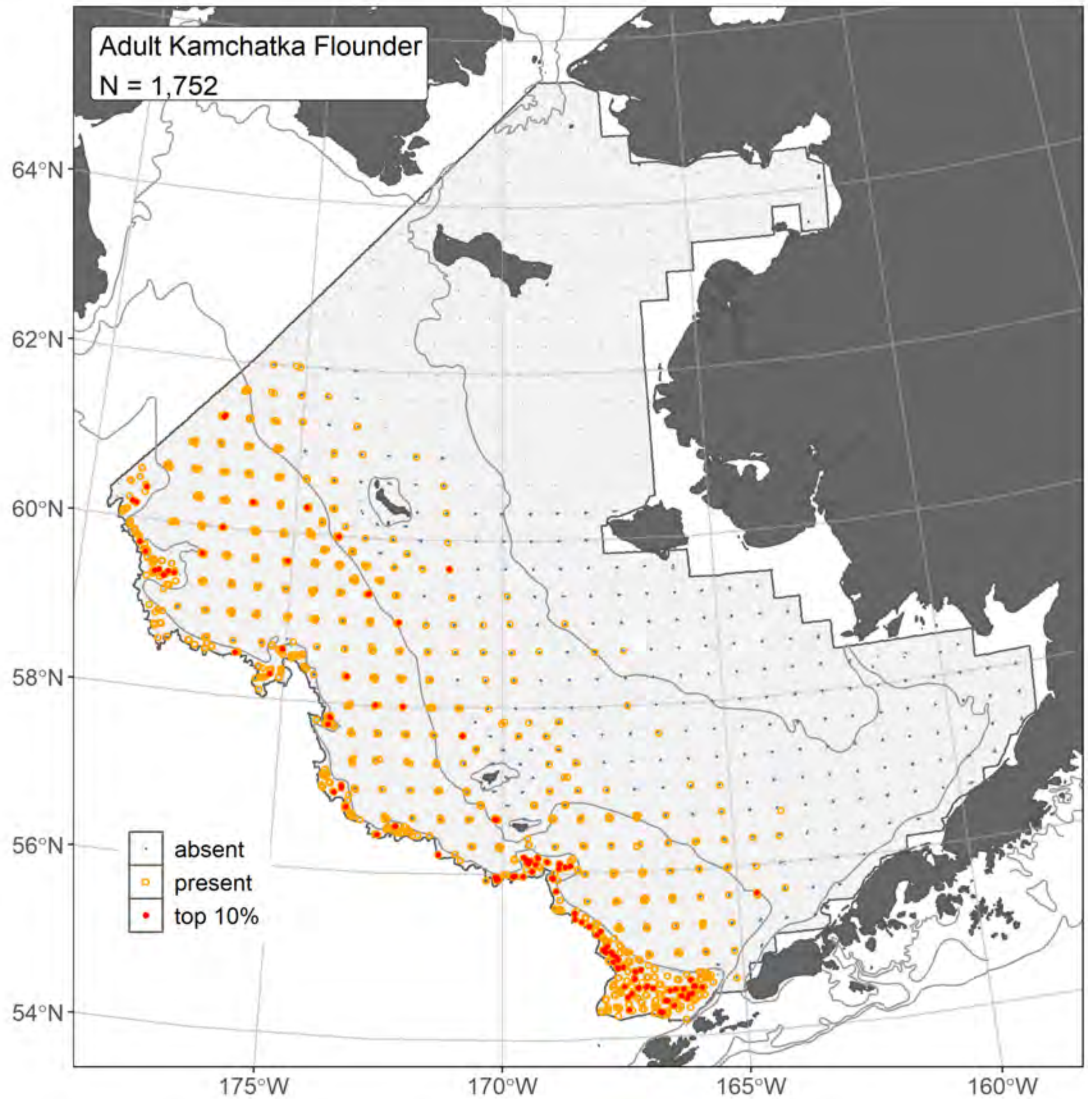

Figure G22. Distribution of adult Kamchatka flounder catches (N = 1,752) in 1982–2019 AFSC RACE-GAP summer bottom trawl surveys of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

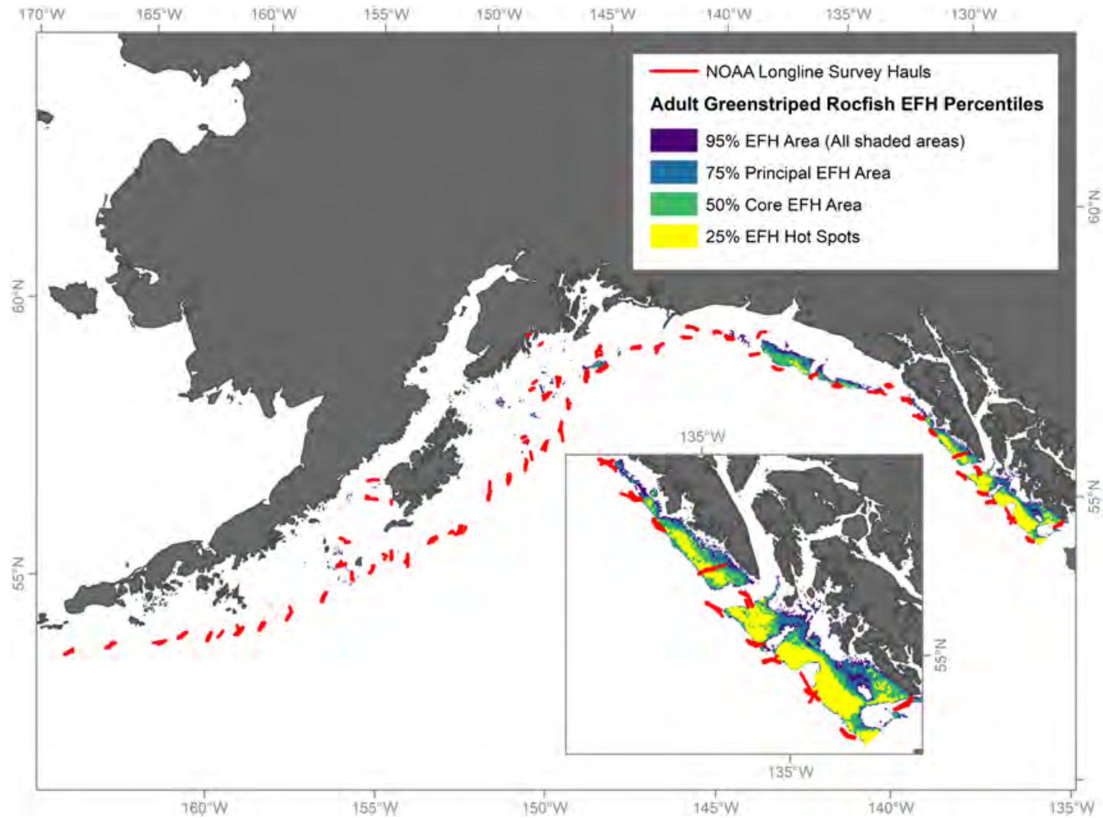

Figure G23. EFH map of adult greenstriped rockfish in the Gulf of Alaska with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to greenstriped rockfish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult greenstriped rockfish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1993–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

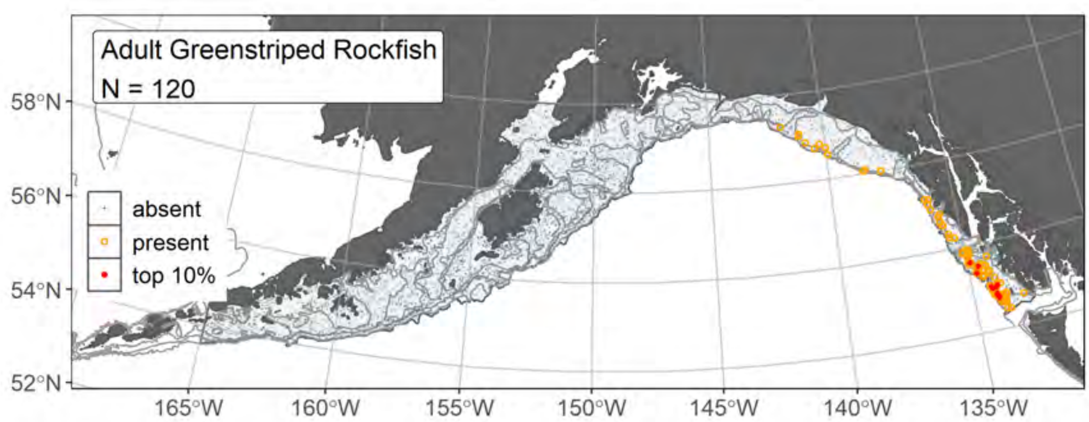

Figure G24. Distribution of adult greenstriped rockfish catches (N = 120) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

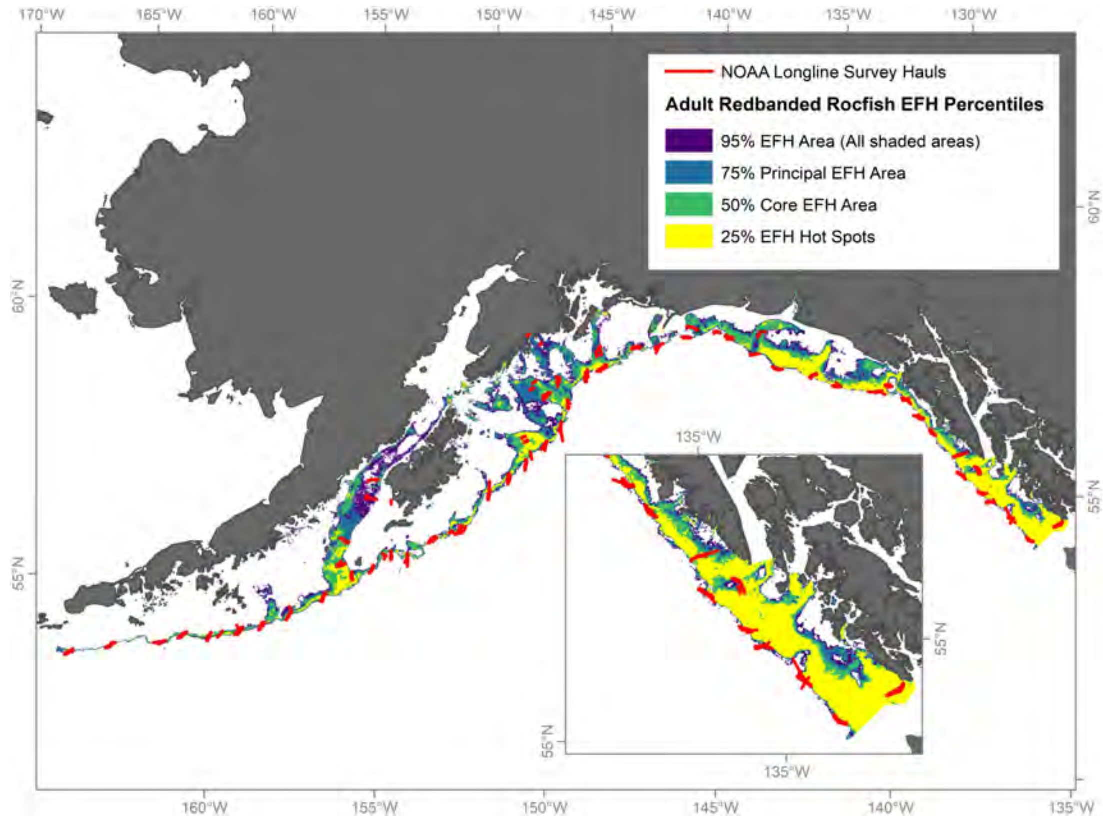

Figure G25. EFH map of adult redbanded rockfish in the Gulf of Alaska with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to redbanded rockfish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult redbanded rockfish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1993–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

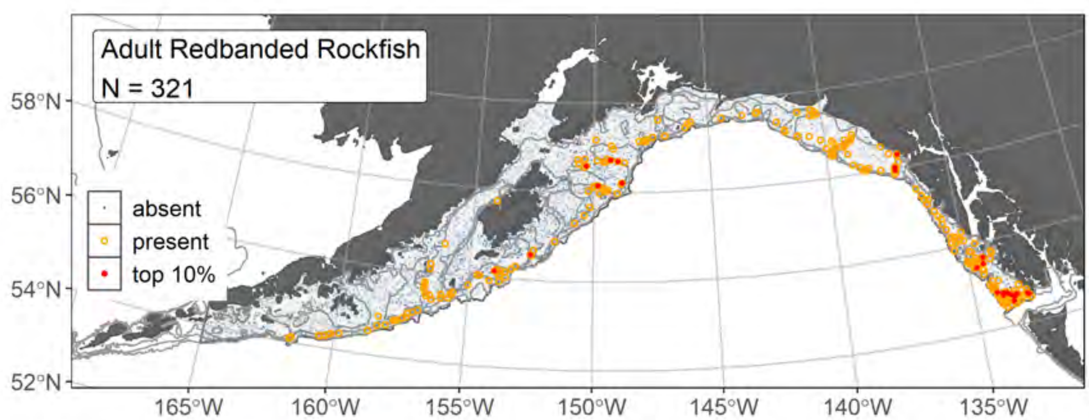

Figure G26. Distribution of adult redbanded rockfish catches (N = 321) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

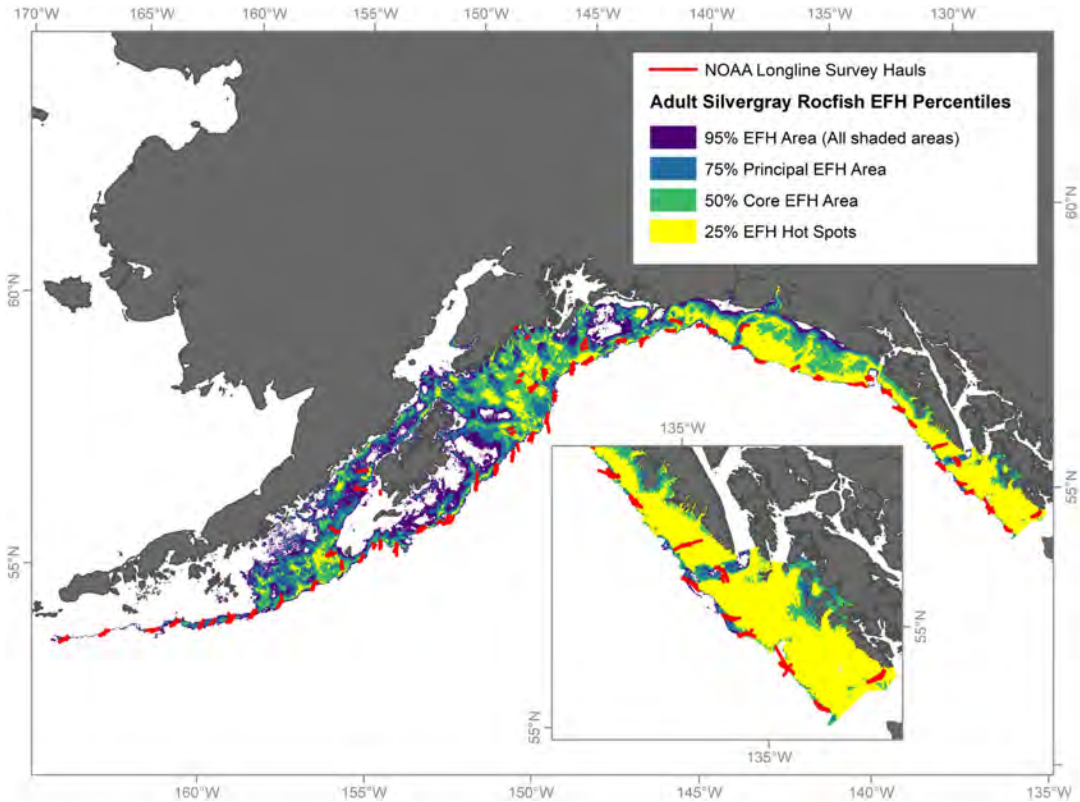

Figure G27. EFH map of adult silvergray rockfish in the Gulf of Alaska with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to silvergray rockfish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult silvergray rockfish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1993–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

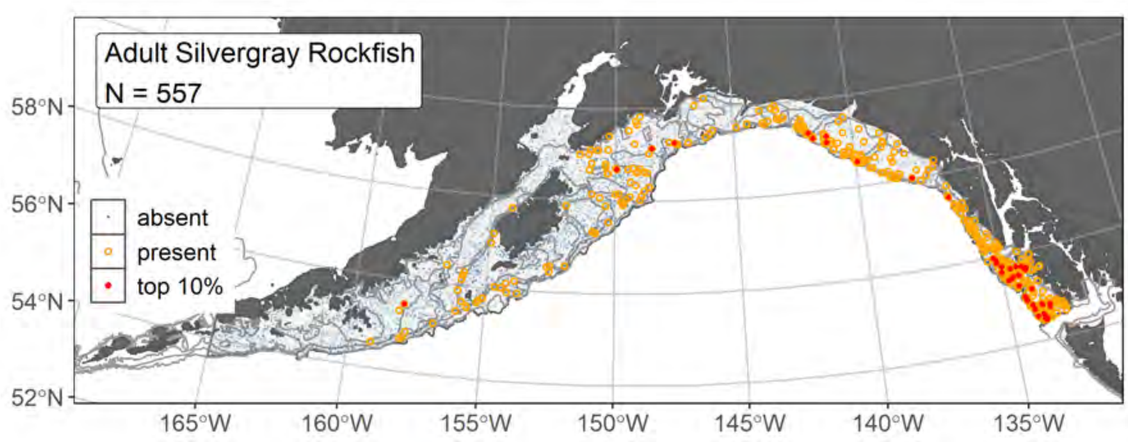

Figure G28. Distribution of adult silvergray rockfish catches (N = 557) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

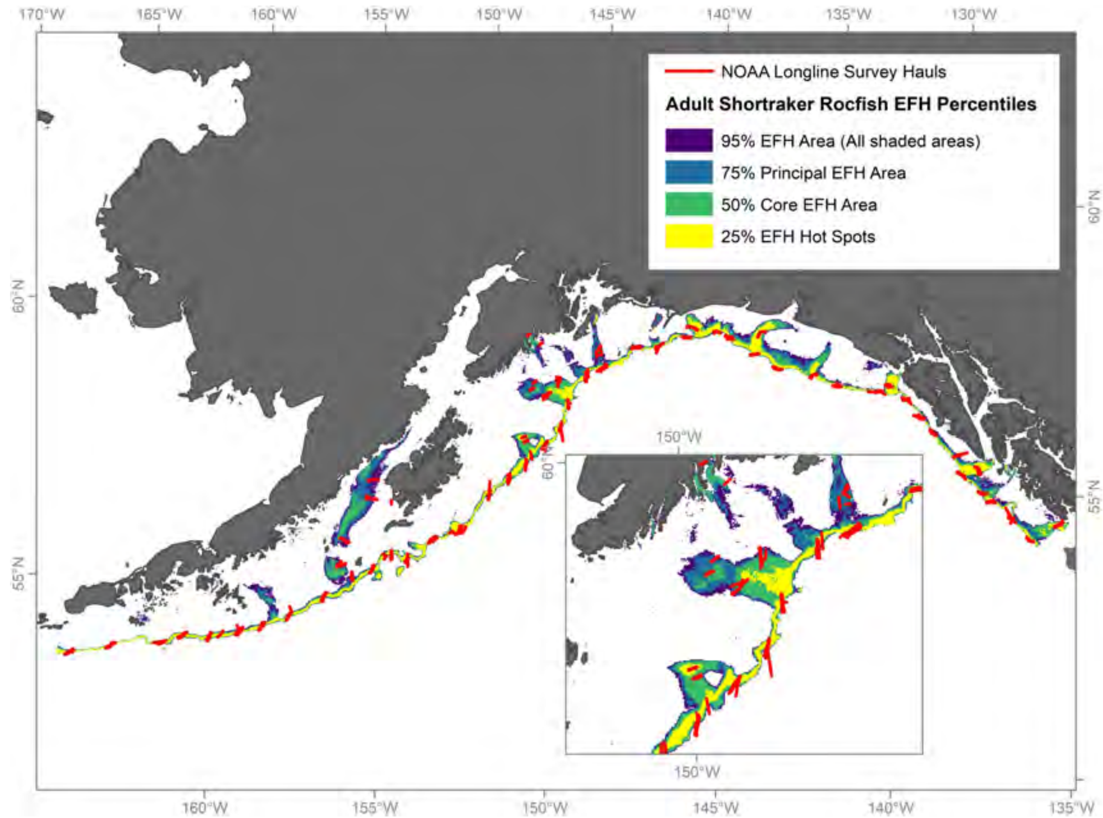

Figure G29. EFH map of adult shortraker rockfish in the Gulf of Alaska with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to shortraker rockfish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult shortraker rockfish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1993–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

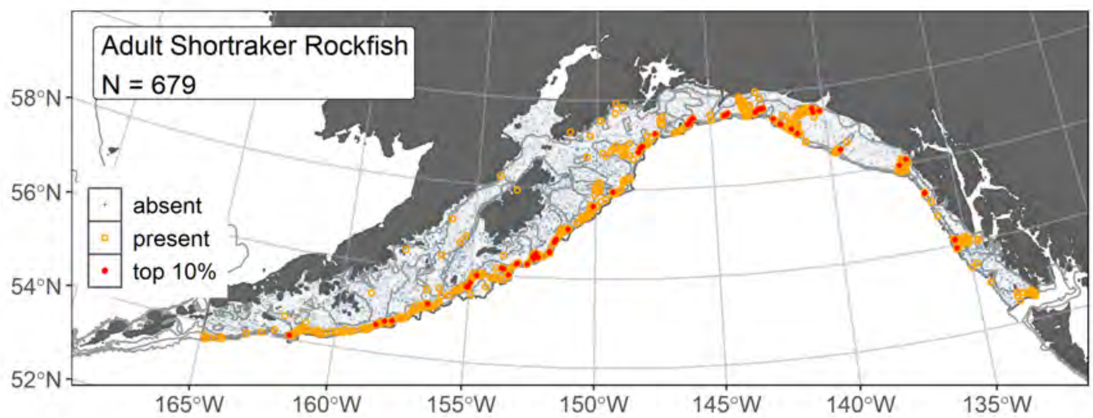

Figure G30. Distribution of adult shortraker rockfish catches (N = 679) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

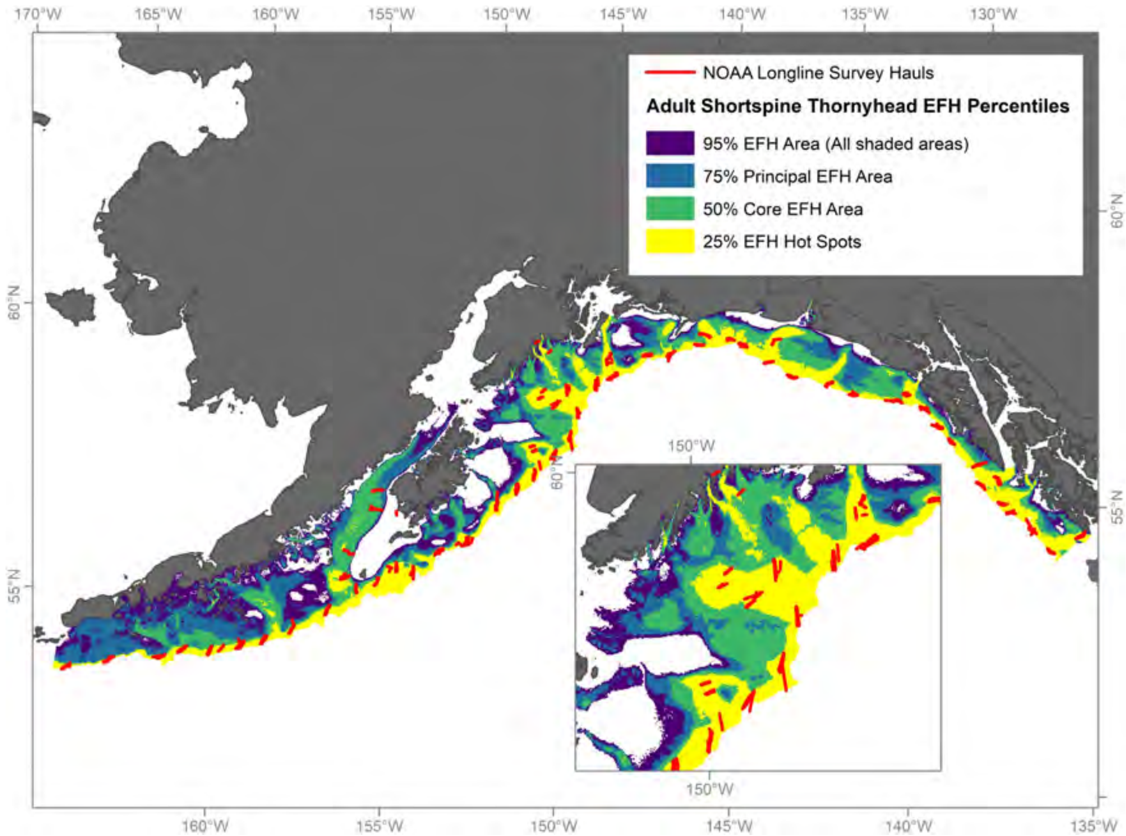

Figure G31. EFH map of adult shortspine thornyhead rockfish (SST) in the Gulf of Alaska with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to SST catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult SST distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1993–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

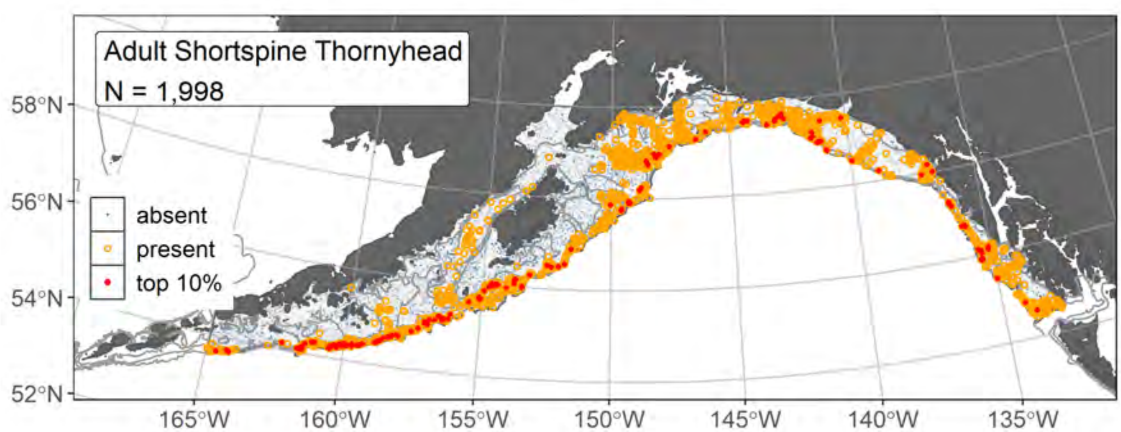

Figure G32. Distribution of adult SST catches (N = 1,998) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.

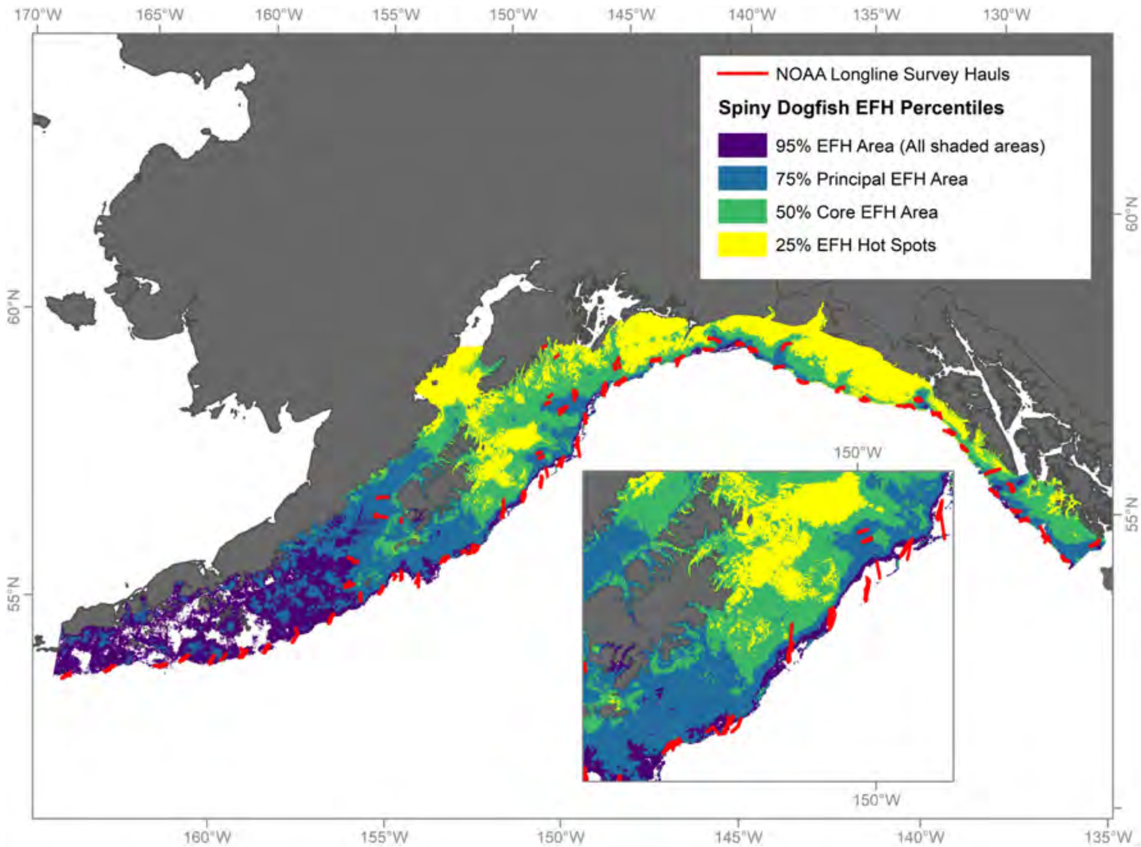

Figure G33. EFH map of spiny dogfish in the Gulf of Alaska with overlay of AFSC longline survey station historic haul locations (red lines) (*without attribution to spiny dogfish catch locations*). EFH is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to spiny dogfish distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1993–2019); within the EFH map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

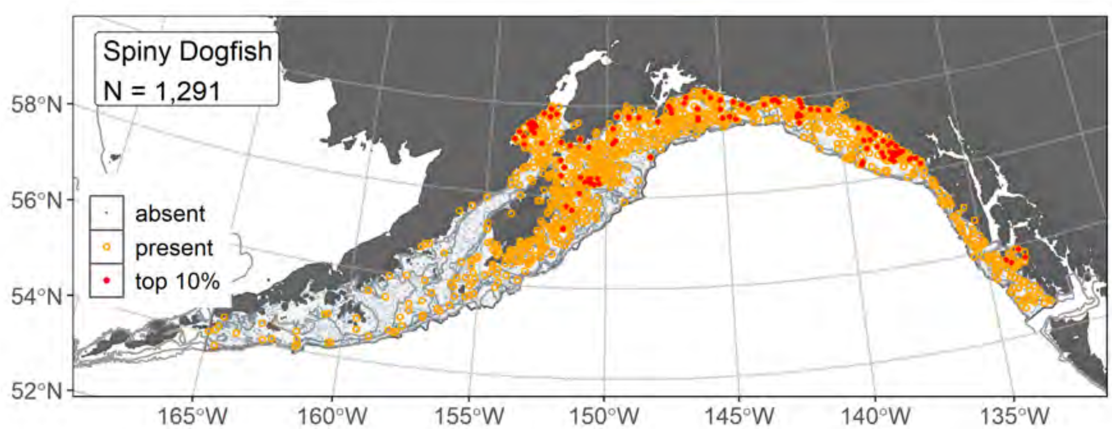

Figure G34. Distribution of spiny dogfish catches (N = 1,291) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the GOA with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present, each datum at a station represents a year of sampling at that location, multiple years are overplotted at each station.