10. Assessment of the Northern Rockfish stock in the Gulf of Alaska

by

Curry J. Cunningham, Peter-John F. Hulson, Chris R. Lunsford, Dana H. Hanselman

November 2018

Executive Summary

Gulf of Alaska (GOA) rockfish are assessed on a biennial stock assessment schedule. In 2017, the scheduled frequency for some stock assessments was changed in response to the National Stock Assessment Prioritization effort. Prior to 2017, Gulf of Alaska (GOA) rockfish were assessed on a biennial stock assessment schedule to coincide with the availability of new trawl survey data. Under the new schedule, full assessments for northern rockfish will be conducted in even years and partial assessments will be presented in odd years, resulting in the same frequency of assessment but age compositions from the most recent survey being available to each full assessment. For 2018, we present a full stock assessment document with updated assessment and projection model results. In this full assessment, we update the 2015 assessment model with new data available since 2015 and present a new model fitting to a model-based index of abundance from the NOAA GOA bottom trawl survey created using a Vector Autoregressive Spatio-temporal (VAST) model.

As in 2015, the general model structure for GOA northern rockfish is a separable age-structured model, and this same model structure is used for Gulf of Alaska Pacific ocean perch, dusky rockfish, and rougheye/blackspotted rockfish. This consists of an assessment model, which uses survey and fishery data to generate a historical time series of population estimates, and a projection model, which uses results from the assessment model to predict future population estimates and recommended harvest levels.

Summary of Changes in Assessment Inputs

Changes in input data: The input data were updated to include survey biomass estimates for 2017, survey age compositions for 2015 and 2017, final catch for 2015, 2016 and 2017, preliminary catch for 2018, fishery age compositions from 2014 and 2016, and fishery size compositions for 2015 and 2017.

Changes in the assessment methodology: The assessment methodology has changed since the 2015 assessment and incorporates the following changes:

1. **Fitting to VAST model-based survey biomass index.** In the past a design-based stratified-random biomass index from the GOA bottom trawl survey was fit by the assessment model. Vector Autoregressive Spatio-temporal (VAST) models generate survey indices from the same data, but account for the spatial correlation among survey hauls and years and separate the likelihood of a given survey observation between the probability of encountering a species and the probability of the catch (biomass) given that a species was observed in a specific location and year. Directly accounting for the spatial correlation of GOA northern rockfish may result in survey indices that are more robust to changes in the allocation of survey effort among strata over time.
2. **Rescaling survey index likelihood weight to account for change in index precision.** The new VAST model-based survey biomass index has higher estimated precision (lower estimated CV) than the previous design-based survey index. In order to maintain more consistent contributions from all assessment model data sources to the total likelihood, the weight on the negative log-likelihood for the survey index was adjusted from 1.0 to 0.25, proportional to the average ratio of the variances from the alternative indices.

Summary of Results

The 2019 projected age 2+ total biomass is 87,409 t. The recommended ABC for 2019 is **4,529** t, the maximum allowable ABC under Tier 3a. This ABC is a 23% increase compared to the 2018 ABC of 3,685 t and a 35% increase from the projected 2019 ABC from last year. The OFL is **5,402** t. The corresponding reference values for northern rockfish recommended for this year and the following year are summarized in the table below along with corresponding values from last year's SAFE. Overfishing is not occurring, the stock is not overfished, and it is not approaching an overfished condition.

Apportionment is based on the random effects model developed by Plan Team survey averaging working group, which was fit to area-specific design-based biomass indices through 2017 from the bottom trawl survey. The 2019 ABC apportionment to the WGOA increases to 26.3% from the 2016-18 apportionment percentage of 11.4%, and apportionment to the CGOA decreases from 88.5% to 73.7%. However, these proportions are consistent with 2014-2015 apportionments adopted following the 2013 survey. Similar to other rockfish species, the proportion of survey biomass can often change across management regions due to large influential survey hauls impacting the biomass estimates across space.

Quantity	As estimated or specified *last* year for: 2018	2019	As estimated or recommended *this* year for: 2019*	2020*
M (natural mortality)	0.059	0.059	0.059	0.059
Tier	3a	3b	3a	3a
Projected total (age 2+) biomass (t)	74,748	73,814	87,409	84,326
Projected Female spawning biomass	28,017	26,512	36,365	34,046
$B_{100\%}$	69,957	69,957	76,199	76,199
$B_{40\%}$	27,983	27,983	30,480	30,480
$B_{35\%}$	24,485	24,485	26,670	26,670
F_{OFL}	0.074	0.070	0.073	0.073
$maxF_{ABC}$	0.062	0.058	0.061	0.061
F_{ABC}	0.062	0.058	0.061	0.061
OFL (t)	4,380	3,984	**5,402**	5,093
maxABC (t)	3,685	3,350	4,529	4,270
ABC (t)	3,685	3,350	**4,529**	4,270
Status	As determined *last* year for: 2016	2017	As determined *this* year for: 2017	2018
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches of 3,219 t and 2,983 t used in place of maximum permissible ABC for 2019 and 2020.

The following table shows the recommended apportionment for 2019 and 2020.

Area Apportionment	Western 26.28%	Central 73.70%	Eastern 0.02%	Total 100%
2019 Area ABC (t)	**1,190**	**3,338**	**1**	**4,529**
2019 OFL (t)				**5,402**
2020 Area ABC (t)	**1,122**	**3,147**	**1**	**4,270**
2020 OFL (t)				**5,093**

*For management purposes the small ABC in the Eastern area is combined with other rockfish.

Further summaries for recommendations are provided below:

Species	Year	Biomass[1]	OFL	ABC*	TAC	Catch[2]
	2017	75,028	4,522	3,786	3,786	1,836
Northern	2018	74,748	4,380	3,685	3,685	2,288
rockfish	2019	87,409	5,402	4,529		
	2020	84,326	5,093	4,270		

Stock/		2018				2019		2020	
Assemblage	Area	OFL	ABC	TAC	Catch[2]	OFL	ABC	OFL	ABC
	W		420	420	297		1,190		1,122
Northern	C		3,261	3,261	1,991		3,338		3,147
rockfish	E*		4	4			1		1
	Total	4,380	3,685	3,685	2,288	5,402	4,529	5,093	4,270

[1]Total biomass estimates from the age structured model.
[2]Current as of October 6, 2018 Source: NMFS Alaska Regional Office via the Alaska Fisheries Information Network (AKFIN).
* For management purposes, the small ABC for northern rockfish in the Eastern Gulf of Alaska is combined with other slope rockfish and is why this total differs from above.

SSC and Plan Team Comments on Assessments in General

There are four general SSC requests from 2017 that warrant a coordinated response. Earlier this year, the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams proposed a process for coordinating individual assessment authors' responses to these requests, with the dual goals of: A) ensuring that all authors are made aware of the requests in a timely fashion, and B) making it possible for the authors' responses to be at least roughly consistent across assessments. The proposed process has since been approved by SSMA and MESA leadership. As part of the process, the SSC subsequently clarified two of the requests (#1 and Part 2 of #4 below) at its June 2018 meeting.

Specifically, in 2017 the SSC requested:

1. *...that authors balance the desire to improve model fit with increased risk of model misspecification.*

   This request was recently clarified by the SSC as follows (emphasis added):

   > *"The tradeoff between model complexity and parsimony, and therefore between bias and precision of estimates, represents a basic and fundamental ecological modelling challenge. In the context of fisheries stock assessment, we are frequently faced with the choice of assigning lack of fit to process error (actual changes in the mechanisms generating the data) and observation error (our imprecise ability to measure the underlying processes). In the former case, it is often appropriate to add model complexity in order to reduce bias, in the latter, adding parameters will decrease model precision and could add bias. There are no completely objective criteria that can be employed in the search for a model that is complex enough, without being overly parameterized, making final model formulation the result of a subjective analysis informed by the author's training and professional experience."*

   > *"The SSC would prefer that new assessments should start as simple as practicable, and additional model complexity should be evaluated using all diagnostic tools available to*

authors. Even existing assessments should be periodically evaluated for "complexity creep" and consistency with similar assessments. Diagnostic tools can include evaluation of: residual patterns, consistency with biological hypotheses, plausibility of estimated values, model stability, retrospective patterns, consistency with modelling of similar species (or the same species in other areas), model predictive skill, and even expert judgment. It is essential that analysts utilize a comprehensive evaluation and not rely on a single model selection criterion. The SSC notes that simple parameter counts may not always be appropriate when parameter values are constrained via informative prior probabilities, or distributional assumptions (recruitment and other constrained deviations). Further, likelihood-based model complexity criteria (e.g., AIC, likelihood ratios, DIC) can be very sensitive to data-weighting and penalized likelihoods, and are therefore not sufficient to justify or discourage additional model complexity."

*"**In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases**."*

2. *...that the metric (or metrics) used to describe fish condition be consistent among assessments and the Ecosystem Status Report where possible.*

   To help coordinate author responses to this request, a committee was established earlier this year, consisting of all Ecosystem Status Report (ESR) and assessment authors who currently report fish condition. The committee agreed that the "weight-length residual" method currently used in the ESR should be the standard. Chris Rooper has offered to share his R code for doing the necessary calculations and making plots. Of course, assessment authors are *not* required to report fish condition, but if they choose to do so, conforming to the weight-length residual method will ensure that this SSC request is satisfied.

3. *...that authors investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations, with consideration of a two-step approach including a projection using F to find the catch associated with that F and then a second projection using that fixed catch. More specifically: step 1 would consist of using the target F for each forecast year to obtain a distribution of catch levels due to parameter and model uncertainty; and step 2 would consist of running a new set of projections conditional on each year's catch being fixed at the mean or median of the corresponding distribution computed in step 1, so as to obtain a distribution of F for each forecast year.*

   SSMA and MESA leadership will facilitate coordinated responses to this request by issuing specific guidance and individual tasking.

   It is our understanding that some AFSC-produced standardized software will be developed to conduct these requested projections. We look forward to that product to implement this recommendation.

4. Part 1: *...that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC along with an integrated analysis of the indices. These integrated analyses are to be produced by the respective assessment author(s) and presented at the October Council meeting.*

   The co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from SSMA and MESA leadership, suggest that authors address this request as follows:

No later than the summer of each year, the lead author of each assessment will review the previous year's ESR and determine whether any factor or set of factors described in that ESR implies an impending severe decline in stock/complex biomass, where "severe decline" means a decline of at least 20% (or any alternative value that may be established by the SSC), and where biomass is measured as spawning biomass for Tiers 1-3 and survey biomass as smoothed by the standard Tier 5 random effects model for Tiers 4-5. If an author determines that an impending severe decline is likely and if that decline was not anticipated in the most recent stock assessment, he or she will summarize that evidence in a document that will be reviewed by the respective Team in September of that year and by the SSC in October of that year, including a description of at least one plausible mechanism linking the factor or set of factors to an impending severe decline in biomass, and also including an estimate or range of estimates regarding likely impacts on ABC. In the event that new survey or relevant ESR data become available after the document is produced but prior to the October Council meeting of that year, the document will be amended to include those data prior to its review by the SSC, and the degree to which they corroborate or refute the predicted severe decline should be noted, with the estimate or range of estimates regarding likely impacts on ABC modified in light of the new data as necessary.

The ESR was examined for details pertaining to GOA northern rockfish during the summer of 2018. No indications of a severe decline in stock biomass were found.

Part 2: *...explicit consideration and documentation of ecosystem and stock assessment status for each stock, to be presented at the December Council meeting.*

This request was recently clarified by the SSC by replacing the terms "ecosystem status" and "stock assessment status" with "Ecosystem Status Report information" and "Stock Assessment Information," where the potential determinations for each will consist of "Okay" and "Not Okay," and by issuing the following guidance (emphasis added):

- The SSC clarifies that "stock assessment status" is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.
- Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the "Okay" or "Not Okay" determinations.
- **The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes**.
- **Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC.**
- In consideration of this request to examine stock status information and ecosystem status report information, the leadership of the joint Teams recommended that a group be formed to work with the editors of the ecosystem status report to develop these ecosystem thresholds for action. Moreover, they asked the SSC to assign members to participate in this effort. If the workgroup is formed, the SSC nominates the following SSC members to participate in this workgroup: Franz Mueter and George Hunt.
- Finally, one SSC member indicated that there were multiple groups doing this or a very similar exercise (i.e., trying to explicitly use ecosystem data to anticipate changes in stock status) at present, with several products in the pipeline. The SSC requests that the Alaska

Fisheries Science Center coordinate these efforts so as to avoid duplication of efforts, and determine whether a new group is necessary.

"The SSC recognized that because formal criteria for these categorizations have not been developed by the PT, they will not be presented in December 2018." (SSC October 2018)

The iterative process described in the final bullet above was scheduled to begin at this year's September meeting of the Joint BSAI and GOA Plan Teams. However, no formal criteria for these categorizations were developed by the Plan Teams. We will provide determinations for rougheye and blackspotted rockfish when these formal criteria are established.

"In an effort improve record keeping as assessment authors formulate various stock status evaluation models, the Plan Team has recommended a systematic cataloging convention. Any new model that diverges substantial from the currently accepted model will be marked with the two-digit year and a "0" version designation (e.g., 16.0 for a model from 2016). Variants that incorporate major changes are then distinguished by incremental increases in the version integer (e.g., 16.1 then 16.2), and minor changes are identified by the addition of a letter designation (e.g., 16.1a). The SSC recommends this method of model naming and notes that it should reduce confusion and simplify issues associated with tracking model development over time." (SSC December 2016)

The northern rockfish assessment has used this notation for describe model alternatives in the 2018 full assessment.

"The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock, perhaps following the framework suggested below, during the December Council meeting to aid in identifying areas of concern." (SSC October 2017)

A newly proposed framework for considering ecosystem and socioeconomic factors has been submitted as an appendix in some assessments this year. This is an attempt to document these factors with respect to stock status and also provide indicators for continued monitoring to identify areas of concern. These reports are currently submitted as an appendix and in future years it is anticipated that they would be available for all stocks as the framework is adaptable for data-limited to data-rich stocks. We plan to evaluate and potentially incorporate this new ecosystem/socioeconomic report as an appendix if and when it becomes available for Gulf of Alaska northern rockfish stock.

The SSC supports the GOA PT recommendation to form a study group to explore the criteria necessary for adopting the geostatistical generalized linear mixed model approach in assessments. If this study group is formed, the SSC requests that the group be expanded to include BSAI assessment authors and members from the AFSC survey program. Among the many questions this group could address, the SSC suggests including the following questions:

1. Is the stratified random survey design used for the surveys correctly configured for application of the geostatistical approach?
2. Should the geostatistical approach be applied to all species or a select suite of species that exhibit aggregated spatial distributions and rockfish-like life histories? If application of this approach is recommended for only a subset of managed species, what life history characteristics or biological criteria would qualify a species for this approach?
3. What level of aggregation is necessary for application of the geostatistical approach?
4. If the geostatistical approach is adopted should results also be used for area apportionments?" (SSC, December 2015)

"The SSC strongly encourages further development of these approaches, which could be extended to include covariates such as depth or other habitat features to increase precision.

Care should be taken to estimate biomass over the same area when comparing results between the design-based and geostatistical approach. The SSC also suggested that, when considering anisotropy in the model, that the most appropriate approach for the Gulf of Alaska may be to allow for differences in spatial correlation scales in the along-shelf and cross-shelf directions, respectively, rather than by latitude and longitude. It was suggested that modeling survey data could be a topic for the workshop in February 2018 to discuss options for moving from design-based estimators to geostatistical estimators across stocks." (SSC, October 2017)

"The SSC encourages further exploration to determine the utility of the Vector-autoregressive spatiotemporal (VAST) model estimation methods as an alternative to design-based estimates of survey biomass. ***The SSC supports the PT recommendation to make the use of model-based survey estimates at the individual author's discretion for 2018.*** *The SSC did note that model-based indices may not be appropriate for application to all species/stocks, but encourages further exploration and use of this method where possible and warranted. The SSC noted that in some cases the variance estimates associated with model-based indices may differ from design-based estimates, and that this may have important implications for use in stock assessments, which should be considered along with the alternative indices. It is the SSC's understanding that analysts at the AFSC are developing simulation models to explore this issue.* ***The SSC encourages authors to consider the outcome of these simulations when considering whether or not to apply the method for their stock."*** (SSC, October 2017)

We have grouped these three comments together as they deal with the same topic. A working group is currently in the process of investigating the criteria for use of the geostatistical generalized linear mixed model (delta-GLMM) within assessments performed by the AFSC. Evaluation of the geostatistical delta-GLMM approach has focused on a range of species with different life histories and spatial distribution, and addressed: 1) How do geostatistical delta-GLMM indices compare with design-based estimates?, 2) Are the scale or trend in geostatistical delta-GLMM indices sensitive to the level of spatial complexity specified?, 3) How does alternative specifications for temporal autocorrelation in intercepts and spatio-temporal random effects for encounter probability and positive catch rate components of the geostatistical delta-GLMM influence index estimates, and 4) How do apportionment estimates from the geostatistical delta-GLMM compare with estimates from the current random effects model? Results from these initial evaluations were presented by C. Cunningham at the September 2017 PT meeting and at an AFSC workshop in January 2018. Further investigations into the geostatistical delta-GLMM will continue with the intention of providing stock assessment authors with guidance on which trawl survey biomass index would be appropriate for their stock.

In addition, several simulation analyses to investigate uncertainty in design and model-based indices are under way, led by various AFSC researchers from RACE, ABL, and SSMA.

SSC and Plan Team Comments Specific to this Assessment

"The SSC agrees with the GOA PT recommendation that the author should bring forward models using design based survey estimates and an alternative with survey biomass estimates from the VAST model, for consideration in December." (SSC, October 2018)

"The Team recommends that the existing model (with the design-based survey estimates), and an alternative with survey biomass estimates from the VAST model, be presented in November." (Plan Team, September 2018)

We have done so in this document, describing three models: M15.4 (2018) the 2015 accepted model with updated data through 2018, M18.1 (2018) which fits to a model-based survey biomass index estimated by a Vector Autoregressive Spatio-temporal (VAST) model in place of the traditional design-based survey index, and M18.2 (2018) which also fits the VAST model-based survey index but rescales the log-likelihood weight for the survey index to account for the relative precision in the two indices so as to maintain more consistent total log-likelihood contributions from each data type. Of these, we recommend M18.2 (2018) given the consistency in catchability and mean recruitment estimates to M15.4 (2018), and consideration of the value in balancing total likelihood contributions across input data types.

"The Team recommends that Curry and an AFSC workgroup focused on design-based model estimates conduct the following analyses recommended by the Joint Plan Team in their September 2017 meeting: …" (Plan Team, September 2018)

A formal workgroup is being formed to address some of the outstanding questions. Following the September 2017 Plan Team meeting, C. Cunningham addressed several of these requests.

- Point #2: "Evaluate a VAST model with the spatial-temporal components turned off (i.e., a typical delta-lognormal model) to determine the effect of the delta component vs. the spatiotemporal component."
    - Comparison of VAST model-based indices when the spatial and/or spatio-temporal random effects were not estimated confirmed that the majority of differences between the scale and trend of model-based and design-based indices were not due to the spatial and spatio-temporal correlation structure. This suggested that the delta component of the model (partitioning uncertainty between encounter probability and positive catch rate) might be responsible for majority of differences between design and model-based indices.
- Point #4: "Look at the anisotropy and the variogram to better understand the spatial correlation. This may provide some insight into the behaviors when the coastline is not linear along latitude or longitude."
    - The spatial correlation for GOA northern rockfish based on the variogram is generally SW to NE, consistent with the distribution of this species along the shelf break in the Western and Central GOA. Visual inspection of VAST model residuals for encounter probability and positive catch rate across space did not indicate large residuals, nor any spatial pattern in residuals that would indicate the spatial correlation assumption under geometric anisotropy was incorrectly estimated for this species.

"The Team recommends evaluating how the definition of the length composition plus group, and alternative data-weighting methods, affect model performance." (Plan Team, November 2015)

"The Team recommends continuing to evaluate geostatistical estimators of survey biomass for this stock" (Plan Team, November 2015)

"Based on the model changes made for 2015, the PT recommended further examination of how the definition of the length composition plus group and alternative data-weighting methods affect model performance. They also expressed concern about the high inter-annual variation for survey biomass, and recommended the authors continue to evaluate geostatistical estimators of survey biomass for future assessments. Length bins for fishery length compositions have not been examined, but the authors plan to continue exploring this for the next full assessment. A past recommendation from the SSC and assessment authors was to investigate maturity and the potential for time-dependent changes in maturity, and the authors note that they are working on a sampling project proposal that would collect the data necessary to evaluate this research priority. The SSC agrees that these remaining issues are still applicable and recommend that the authors continue investigations into these issues, particularly the explorations of geostatistical GLMM for the survey biomass estimates, given the high variability in the survey biomass estimates". (SSC, December 2015)

Investigation of an alternative plus-group designation and bin structure for length composition data are ongoing, but were not complete for the 2018 assessment. As such no changes to length bin structure are proposed for the 2018 GOA northern rockfish assessment. Pertaining to different data weighting methods and use of a Vector Autoregressive Spatio-temporal (VAST) model-based index of survey biomass, we have explored the impact of several scaling the log-likelihood weight for the survey index proportional to the average ratio of estimated uncertainty from the two indices (M18.2) and found that preferable to the inclusion of the spatio-temporal model-based index without accounting for the change in index precision.

The sampling project proposal that is referred to in the above comments was not funded. Additional data is needed to investigate time-dependent maturity, because the 2 years of data currently available are insufficient for in-depth investigations. An AFSC Regional Work Plan proposal lead by Christina Conrath (RACE) and Sandi Neidetcher (REFM), in collaboration with Curry Cunningham (ABL), Pete Hulson (ABL), and Steve Barbeaux (REFM), proposed to collect contemporary reproductive samples for a range of species including northern rockfish in the GOA and investigate time-varying maturity schedules and their association with oceanographic conditions. Unfortunately, this proposal was not funded and this continues to be a data gap and research priority for this stock.

"The SSC also looks forward to an update of weight-at-age, length and age transition matrices, ageing error matrix, and length bins for fishery length compositions during the next assessment cycle." (SSC, December 2011)

In September, 2015, updates to the ageing error matrix and length-stratified methodology for growth estimation (including weight-at-age and the length and age transition matrices) were presented and are included in this year's recommended assessment model. No changes have been made to the fishery length bins structure are proposed for the 2018 assessment cycle, however given the dramatic increase in the proportion of northern rockfish in the fishery length composition plus-group this remains a high priority research topic.

Introduction

Biology and distribution

The northern rockfish, *Sebastes polyspinis*, is a locally abundant and commercially valuable member of its genus in Alaskan waters. As implied by its common name, northern rockfish has one of the most northerly distributions among the 60+ species of *Sebastes* in the North Pacific Ocean. It ranges from extreme northern British Columbia around the northern Pacific Rim to eastern Kamchatka and the northern Kuril Islands and also north into the eastern Bering Sea (Allen and Smith 1988). Within this range, northern rockfish are most abundant in Alaska waters, from the western end of the Aleutian Islands to Portlock Bank in the central Gulf of Alaska (Clausen and Heifetz 2002).

Little is known about the life history of northern rockfish. Like other *Sebastes* species, northern rockfish are presumed to be ovoviviparous with internal fertilization. There have been no studies on fecundity of northern rockfish. Observations during research surveys in the Gulf of Alaska indicate that parturition (larval release) occurs in the spring and is completed by summer. Larval northern rockfish cannot be unequivocally identified to species at this time, even using genetic techniques, so information on larval distribution and length of the larval stage is unknown. The larvae metamorphose to a pelagic juvenile stage, but there is no information on when these juveniles become demersal.

Little information is available on the habitat of juvenile northern rockfish. Studies in the eastern Gulf of Alaska and Southeast Alaska using trawls and submersibles have indicated that several species of juvenile (< 20 cm) red rockfish (*Sebastes spp.*) associate with benthic nearshore living and non-living structure and appear to use the structure as a refuge (Carlson and Straty 1981; Kreiger 1993). Freese and Wing

(2003) also identified juvenile (5 to 10 cm) red rockfish (*Sebastes spp.*) associated with sponges (primarily *Aphrocallistes spp.*) attached to boulders 50 km offshore in the GOA at 148 m depth over a substrate that was primarily a sand and silt mixture. Only boulders with sponges harbored juvenile rockfish, and the juvenile red rockfish appeared to be using the sponges as shelter (Freese and Wing 2003). Although these studies did not specifically observe northern rockfish, it is likely that juvenile northern rockfish also utilize similar habitats. Length frequencies of northern rockfish captured in NMFS bottom trawl surveys and observed in commercial fishery bottom trawl catches indicate that older juveniles (>20 cm) are found on the continental shelf, generally at locations inshore of the adult habitat (Pers. comm. Dave Clausen).

Northern rockfish are generally planktivorous. They eat mainly euphausiids and calanoid copepods in both the GOA and the Aleutian Islands (Yang 1993; Yang 1996; Yang and Nelson 2000). There is no indication of a shift in diet over time or a difference in diet between the GOA and AI (Yang 1996, Yang and Nelson 2000). In the Aleutian Islands, calanoid copepods were the most important food of smaller-sized northern rockfish (< 25 cm), while euphausiids were the main food of larger sized fish (> 25 cm) (Yang 1996). The largest size group also consumed myctophids and squids (Yang 2003). Arrow worms, hermit crabs, and shrimp have also been noted as prey items in much smaller quantities (Yang 1993, 1996). Large offshore euphausiids are not directly associated with the bottom, but rather, are thought to be advected onshore near bottom at the upstream ends of underwater canyons where they become easy prey for planktivorous fishes (Brodeur 2001). Predators of northern rockfish are not well documented, but likely include larger fish, such as Pacific halibut, that are known to prey on other rockfish species.

Trawl surveys and commercial fishing data indicate that the preferred habitat of adult northern rockfish in the Gulf of Alaska is relatively shallow rises or banks on the outer continental shelf at depths of about 75-150 m (Clausen and Heifetz 2002). The highest concentrations of northern rockfish from NMFS trawl survey catches appear to be associated with relatively rough (variously defined as hard, steep, rocky or uneven) bottom on these banks (Clausen and Heifetz 2002). Heifetz (2002) identified rockfish as among the most common commercial fish captured with gorgonian corals (primarily *Callogorgia, Primnoa, Paragorgia, Fanellia, Thouarella*, and *Arthrogorgia*) in NMFS trawl surveys of Gulf of Alaska and Aleutian waters. Krieger and Wing (2002) identified six rockfish species associated with gorgonian coral (*Primnoa spp.*) from a manned submersible in the eastern Gulf of Alaska. Research focusing on non-trawlable habitats found rockfish species often associate with biogenic structure (Du Preez et al., 2011, Laman et al., 2015). However, most of these studies did not specifically observe northern rockfish, and more research is required to determine if northern rockfish are associated with living structure, including corals, in the Gulf of Alaska, and the nature of those associations if they exist.

Recent work on black rockfish (*Sebastes melanops*) has shown that larval survival may be higher from older female spawners (Berkeley et al. 2004). The black rockfish population has shown a distinct reduction in the proportion of older fish in recent fishery samples off the West Coast of North America, raising concerns if larval survival diminishes with spawner age. De Bruin et al. (2004) examined Pacific ocean perch (*S. alutus*) and rougheye rockfish (*S. aleutianus*) for senescence in reproductive activity of older fish and found that oogenesis continues at advanced ages. Leaman (1991) showed that older individuals have slightly higher egg dry weight than their middle-aged counterparts. Some literature suggests that environmental factors may affect the condition of female rockfish that contributes to reproductive success (Hannah and Parker, 2007; Rodgveller et al. 2012; Beyer et al. 2015). However, relationships on fecundity or larval survival at age have not yet been evaluated for northern rockfish or other rockfish in Alaska. Stock assessments for Alaska groundfish have assumed that the reproductive success of mature fish is independent of age.

Evidence of stock structure

Gulf of Alaska northern rockfish grow significantly faster and reach a larger maximum length than Aleutian Islands northern rockfish (Clausen and Heifetz 2002). Also, Aleutian Islands northern rockfish are slightly older (maximum age 72) than Gulf of Alaska northern rockfish (maximum age 67), the difference in age could be due to sampling variability. There have been two studies on the genetic stock structure of northern rockfish. One study of northern rockfish provided no evidence for genetically distinct stock structure when comparing samples from near the western Aleutian Islands, the western Gulf of Alaska, and Kodiak Island (Gharrett et al. 2003). The results from that study were considered preliminary, and sample sizes were small. Consequently, the lack of evidence for stock structure did not necessarily confirm stock homogeneity. A more recent study did find spatial structure on a relatively small scale for northern rockfish sampled from several locations in the Aleutian Islands and Bering Sea (Gharrett et al. 2012).

Results of an analysis of localized depletion based on Leslie depletion estimators on targeted rockfish catches detected relatively few localized depletions for northern rockfish (Hanselman et al. 2007). Several significant depletions occurred in the early 1990s for northern rockfish, but were not detected again by the depletion analysis. However, when fishery and survey CPUEs were plotted over time for a geographic block of high rockfish fishing intensity that contained the “Snakehead” area, the results indicated there were year-after-year drops in both fishery and survey CPUE for northern rockfish. The significance of these observations depends on the migratory and stock structure patterns of northern rockfish. If fine-scale stock structure is determined in northern rockfish, or if the area is essential to northern rockfish reproductive success, then these results would suggest that current apportionment of ABC may not be sufficient to protect northern rockfish from localized depletion. Provisions to guard against serial depletion in northern rockfish should be examined in the Gulf of Alaska rockfish rationalization plan. The extension of the fishing season that has been implemented may spread out the fishery in time and space and reduce the risk of localized serial depletion on the “Snakehead” and other relatively shallow (75 – 150 m) offshore banks on the outer continental shelf where northern rockfish are concentrated.

If there is relatively small scale stock structure (120 km) in Gulf of Alaska northern rockfish, then recovery from localized depletion, as indicated above for a region known as the “Snakehead,” could be slow. Analysis of otolith microchemistry may provide a useful tool, in addition to genetic analysis, for identifying small scale (120 km) stock structure of northern rockfish relative to their overall range. Berkeley et al. (2004) suggests that, in addition to the maintenance of age structure, the maintenance of spatial distribution of recruitment is essential for long-term sustainability of exploited rockfish populations. In particular, Berkeley et al. (2004) outline Hedgecock's “sweepstakes hypothesis” to explain small-scale genetic heterogeneity observed in some widely distributed marine populations. According to Berkeley et al. (2004), “most spawners fail to produce surviving offspring because their reproductive activity is not matched in space and time to favorable oceanographic conditions for larval survival during a given season. As a result of this mismatch the surviving year class of new recruits is produced by only a small minority of adults that spawned within those restricted temporal and spatial oceanographic windows that offered good conditions for larval survival and subsequent recruitment”. However, Miller and Shanks (2004) found limited larval dispersal (120 km) in black rockfish off the Pacific coast with an analysis of otolith microchemistry. In particular, these results suggest that black rockfish exhibit some degree of stock structure at very small scales (120 km) relative to their overall range. Localized genetic stocks of Pacific ocean perch have also been found in northern B.C. (Withler et al. 2001), and Kamin et al. (2013) concluded that fine-scale genetic heterogeneity for Pacific ocean perch in Alaska was not the influence of a sweepstakes effect. Limited larval dispersal contradicts Hedgecock's hypothesis and suggests that genetic heterogeneity in rockfish may be the result of stock structure rather than the result of the sweepstakes hypothesis.

Description of management units/measures

From 1988-1993, the North Pacific Fishery Management Council (NPFMC) managed northern rockfish in the Gulf of Alaska as part of the slope rockfish assemblage. In 1991, the NPFMC divided the slope rockfish assemblage in the Gulf of Alaska into three management subgroups: Pacific ocean perch, shortraker/rougheye rockfish, and a complex of all other species of slope rockfish, including northern rockfish. In 1993, a fourth management subgroup, northern rockfish, was also created. In 2004, rougheye rockfish and shortraker rockfish were also split and managed separately. These subgroups were established to protect Pacific ocean perch, shortraker/rougheye, and northern rockfish (the four most sought-after commercial species in the assemblage) from possible overfishing. Each subgroup is now assigned an individual ABC (acceptable biological catch) and TAC (total allowable catch). Prior to 1991, an ABC and TAC were assigned to the entire assemblage. In the assessments after 1991 and until this year's assessment, ABC and TAC for each subgroup, including northern rockfish, is apportioned to the three management areas of the Gulf of Alaska (Western, Central, and Eastern) based on a weighted average of the proportion of biomass by area from the three most recent Gulf of Alaska trawl surveys. In this year's assessment ABC and TAC is apportioned to the three management areas in the Gulf of Alaska with the random effects model developed by the Plan Team survey averaging working group. Northern rockfish are scarce in the eastern Gulf of Alaska, and the ABC apportioned to the Eastern Gulf management area is small. This translates to a TAC that is too difficult to be managed effectively as a directed fishery. Since 1999, the ABC for northern rockfish apportioned to the Eastern Gulf management area is included in the West Yakutat ABC for "other slope rockfish."

Amendment 41, which took effect in 2000, prohibited trawling east of 140 degrees W. longitude in the Eastern GOA. However, trawling did not occur in this area starting in 1998. Since most slope rockfish, especially Pacific ocean perch, are caught exclusively with trawl gear, this amendment could have concentrated fishing effort for slope rockfish in the Eastern area in the relatively small area between 140 degrees and 147 degrees W. longitude that remained open to trawling. This probably does not have a major effect on northern rockfish populations because their abundance in the Eastern area is low.

In November, 2006, NMFS issued a final rule to implement Amendment 68 of the GOA groundfish Fishery Management Plan for 2007 through 2011. This action implemented the Central GOA Rockfish Pilot Program (RPP). The intention of this Program was to enhance resource conservation and improve economic efficiency for harvesters and processors in the rockfish fishery. An additional objective was to spread out the fishery in time and space, allowing for enhanced market conditions for product and reducing the pressure of what was an approximately two-week fishery in July. The primary rockfish management groups in this program are northern rockfish, Pacific ocean perch, and pelagic shelf rockfish. Potential effects of this program on northern rockfish include: 1) Extended fishing season lasting from May 1 – November 15, 2) changes in spatial distribution of fishing effort within the Central GOA, 3) improved at-sea and plant observer coverage for vessels participating in the rockfish fishery, and 4) a higher potential to harvest 100% of the TAC in the Central GOA region. In a comparison of catches in the four years before the RPP to the four years after, it appears that average catches have increased overall (although, this may be due to increased observer coverage) and have spread out spatially in the western and central Gulf (see Figure 10.1in Hulson et al. 2013). The authors will pay close attention to the benefits and consequences of this action. A summary of key management measures and a time series of catch, ABC and TAC are provided in Table 10.1.

Fishery

Description of the directed fishery

In the Gulf of Alaska, northern rockfish are generally caught with bottom trawls identical to those used in the Pacific ocean perch fishery. Many of these nets are equipped with so-called "tire gear," in which automobile tires are attached to the footrope to facilitate towing over rough substrates. Most of the catch has been taken during July, as the directed rockfish trawl fishery in the Gulf of Alaska has traditionally opened around July 1. Rockfish trawlers usually direct their efforts first toward Pacific ocean perch because of its higher value relative to other rockfish species. After the TAC for Pacific ocean perch has been reached and NMFS closes directed fishing for this species, trawlers switch and target northern rockfish. With implementation of the Central Gulf Rockfish Pilot Project in 2007, catches have been spread out more throughout the year.

Historically, bottom trawls have accounted for nearly all the commercial harvest of northern rockfish in the Gulf of Alaska. In the years 1990-98, bottom trawls took over 99% of the catch (Clausen and Heifetz 2002). Before 1996, most of the slope rockfish trawl catch (>90%) was taken by large factory-trawlers that processed the fish at sea. A significant change occurred in 1996, however, when smaller shore-based trawlers began taking a sizeable portion of the catch in the Central Gulf for delivery to processing plants in Kodiak. Factory trawlers continued to take nearly all the northern rockfish catch in the Western area during this period.

A study of the northern rockfish fishery for the period 1990-98 showed that 89% of northern rockfish catch was taken from just five relatively small fishing grounds: Portlock Bank, Albatross Bank, an unnamed bank south of Kodiak Island that fishermen commonly refer to as the "Snakehead," Shumagin Bank, and Davidson Bank (Clausen and Heifetz 2002). The Snakehead accounted for 46% of the northern rockfish catch during these years. All of these grounds can be characterized as relatively shallow (75–150 m) offshore banks on the outer continental shelf.

Data from the observer program for 1990-98 indicated that 82% of the northern rockfish catch during that period came from directed fishing for northern rockfish and 18% was taken as incidental catch in fisheries for other species (Clausen and Heifetz 2002).

Description of the catch time series

Total commercial catch (t) of northern rockfish in the GOA for the years 1961-2018 is summarized by foreign, joint venture, and domestic fisheries (Table 10.2 and Figure 10.1).

Catches of GOA northern rockfish during the years 1961-1976 were estimated as 5% of the foreign GOA Pacific ocean perch catch in the same years. A Pacific ocean perch trawl fishery by the U.S.S.R. and Japan began in the Gulf of Alaska in the early 1960's. This fishery developed rapidly with massive efforts by the Soviet and Japanese fleets. Catches peaked in 1965 when a total of nearly 350,000 metric tons (t) were caught, but declined to 45,500 t by 1976 (Ito 1982). Some northern rockfish were likely taken in this fishery, but there are no available summaries of northern rockfish catches for this period. Foreign catches of all rockfish were often reported simply as "Pacific ocean perch" with no attempt to differentiate species. The only detailed analysis of bycatch in slope rockfish fisheries of the Gulf of Alaska is that of Ackley and Heifetz (2001) who examined data from the observer program for the years 1993-95. Consequently, our best estimate of northern rockfish catch from 1961-1976 comes from analysis of the ratio of northern rockfish catch to Pacific ocean perch catch in the years 1993-1995. For hauls targeting on Pacific ocean perch, northern rockfish composed 5% of the catch (Ackley and Heifetz 2001).

Catches of GOA northern rockfish during the years 1977-1983 were available from NMFS foreign and joint venture fisheries observer data. With the advent of a NMFS observer program aboard foreign fishing vessels in 1977, enough information on species composition of rockfish catches was collected so that estimates of the northern rockfish catch were made for 1977-83 from extrapolation of catch compositions from the foreign observer program (Clausen and Heifetz 2002). The relatively large catch estimates for the foreign fishery in 1982-83 are an indication that at least some directed fishing for northern rockfish probably occurred in those years. Joint venture catches of northern rockfish, however, appear to have been relatively modest.

Catches of GOA northern rockfish during the years 1984-1989 were estimated as 8% of the domestic slope rockfish catch during the same years. A completely domestic trawl fishery for rockfish in the Gulf of Alaska began in 1984 but a domestic observer program was not implemented until 1990. Domestic catches of GOA northern rockfish during the years 1984-1989 were estimated from the ratio of domestic northern rockfish catch to domestic slope rockfish catch (8%) reported by the 1990 NMFS observer program:

$$\text{northern rockfish catch}_i = \frac{\text{northern rockfish catch}_{1990}}{\text{slope rockfish assemblage catch}_{1990}} * \text{ slope rockfish assemblage catch}_i$$

Catches of GOA northern rockfish during the years 1990-1992 were estimated from extrapolation of catch compositions from the domestic observer program (Clausen and Heifetz 2002). Catch estimates of northern rockfish increased greatly from about 1,700 t in 1990 to nearly 7,800 t in 1992. The increases for 1991 and 1992 can be explained by the removal of Pacific ocean perch and shortraker/rougheye rockfish from the slope rockfish management group. As a result of this removal, relatively low TAC's were adopted for these three species, and the rockfish fleet redirected more of its effort to northern rockfish in 1991 and 1992.

Catches of GOA northern rockfish during the years 1993-present were available directly from NMFS domestic fisheries observer data. Northern rockfish were removed from the slope rockfish assemblage and managed with an individual TAC beginning in 1993. As a consequence, directly reported catch for northern rockfish has been available since 1993. Catch of northern rockfish was reduced after the implementation of a northern specific TAC in 1993. Most of the catch since 1993 has been taken in the Central area, where the majority of the northern rockfish exploitable biomass is located. Gulfwide catches for the years 1993-2018 have ranged from 1,836 t to 5,966 t. Annual ABCs and TACs have been relatively consistent during this period and have varied between 3,685 t and 5,760 t. In 2001, catch of northern rockfish was below TAC because the maximum allowable bycatch of Pacific halibut was reached in the central Gulf of Alaska for "deep water trawl species," which includes northern rockfish. Catches of northern rockfish were near their TAC's in 2003 – 2016, however in 2017 catch was 48% of the TAC and 2018 projected catch is likely to reach only 66% of the TAC for this year. Consultation with industry representatives suggested the low catch to TAC ratio in 2017 was largely driven by the fleet targeting alternative higher value species. Research catches of northern rockfish have been relatively small and are listed in Table 10A.1 in Appendix 10A.

Bycatch and discards

The only detailed analysis of incidental catch in slope rockfish fisheries of the Gulf of Alaska is that of Ackley and Heifetz (2001) who examined data from the observer program for the years 1993-95. For hauls targeting on northern rockfish, the predominant incidental species were dusky rockfish, distantly followed by "other slope rockfish," Pacific ocean perch, and arrowtooth flounder.

Total FMP groundfish catch estimates in the GOA rockfish fishery from 2013-2018 are shown in Table 10.3. For the GOA rockfish fishery during 2013-2018, the largest non-rockfish bycatch groups are arrowtooth flounder (1,197 t/year), walleye pollock (1,004 t/year), Atka mackerel (742 t/year), sablefish (530 t/year) and Pacific cod (480 t/year). Non-FMP species catch in the rockfish target fisheries is dominated by giant grenadier and miscellaneous fish (Table 10.4). However, the amounts from hauls targeting northern rockfish are likely much lower as this includes all rockfish target hauls.

Prohibited species catch in the GOA rockfish fishery is generally low for most species. Catch of prohibitted and non-target species generally decreased with implementation of the Central GOA Rockfish Program (Hulson et al. 2013). The only increase of prohbited species catch observed in 2018 was in Golden King crab and Opilio crab catch (Table 10.5). Chinook salmon catch has been lower than the five year average since 2016.

Gulfwide discard rates (% discarded) for northern rockfish in the commercial fishery for 1993-2018 are as follows:

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001
% Discarded	26.5	17.7	12.7	16.6	28	18.4	11.3	10.0	17.7
Year	2002	2003	2004	2005	2006	2007	2008	2009	2010
% Discarded	10.0	9.4	7.9	4.3	9.2	2.6	4.9	3.1	1.5
Year	2011	2012	2013	2014	2015	2016	2017	2018	
% Discarded	3.9	2.5	4.2	3.9	4.6	5.7	8.0	1.7	

These discard rates are generally similar to those in the Gulf of Alaska for Pacific ocean perch and dusky rockfish. Discard mortality is assumed to be 100% for GOA northern rockfish.

Data

The following table summarizes the data used in the stock assessment model for northern rockfish (bold denotes new data for this assessment):

Source	Data	Years
Fisheries	Catch	1961-**2018**
NMFS bottom trawl surveys	Biomass index	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, **2017**
NMFS bottom trawl surveys	Age	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, **2015, 2017**
U.S. trawl fisheries	Age	1998, 1999, 2000, 2001, 2002, 2004, 2005, 2006, 2008, 2010, 2012, **2014, 2016**
U.S. trawl fisheries	Length	1990,1991,1992, 1993, 1994, 1995, 1996, 1997, 2003, 2007, 2009, 2011, 2013, **2015, 2017**

Fishery data

Catch

Catch of northern rockfish range from 185 t to 17,430 t during 1961 to 2018. Detailed description of catch is provided above (within the "*Description of the catch time series*" section) and in Table 10.2 and Figure 10.1.

Age and Size composition

Observers aboard fishing vessels and at onshore processing facilities have provided data on length and age compositions of the commercial catch of northern rockfish. Length compositions are presented in Table 10.6 and Figure 10.2 and age compositions are presented in Table 10.7 and Figure 10.3; these tables also include associated annual sample sizes and number of hauls sampled for the age and length compositions. The fishery age compositions indicate that stronger than average year-classes occurred around the year 1976 and 1984. The fishery age compositions from 2004 and 2006 also indicate that the 1996-1998 year-classes were strong. The clustering of several large year-classes in each period is most likely due to aging error. Recent fishery length compositions (2003-present) indicate that a large proportion of the northern rockfish catch are found to be larger than 38 cm, which is the current plus length bin.

Survey Data

Biomass Estimates from Trawl Surveys

Bottom trawl surveys were conducted in the Gulf of Alaska triennially from 1984 – 1999 and biennially from 1999 – 2015. The surveys provide an index of biomass, size and age composition data, and growth characteristics. The trawl surveys have used a stratified random design to sample fishing stations that cover all areas of the Gulf of Alaska out to a depth of 1,000 m (in some surveys only to 500 m). Generally, attempts have been made through the years to standardize the survey design and the fishing nets used, but there have been some exceptions to this standardization. In particular, much of the survey effort in 1984 and 1987 was by Japanese vessels that used a very different net design than what has been the standard used by U.S. vessels throughout the surveys. To deal with this problem, fishing power comparisons of rockfish catches have been done for the various vessels used in the surveys (for a discussion see Heifetz et al. 1994). Results of these comparisons have been incorporated into the biomass estimates listed in this report, and the estimates are believed to be the best available. Even so, the use of Japanese vessels in 1984 and 1987 introduced an element of uncertainty as to the standardization of these two surveys. Also, a different survey design was used in the eastern Gulf of Alaska in 1984, and the eastern Gulf of Alaska was not covered by the 2001 survey. These data inconsistencies for the eastern Gulf of Alaska have had little effect on the survey results for northern rockfish, as relative abundance of northern rockfish is very low in the eastern Gulf of Alaska.

The *design-based* trawl survey indices of biomass for northern rockfish have been highly variable from survey to survey (Table 10.8). In particular, the 2011 biomass estimate (173,641 t) was 93% larger than the 2009 estimate (89,896 t), while the 2009 biomass estimate was 60% smaller than the 2007 estimate (227,069 t). The 2007 biomass estimate was 36% smaller than the 2005 estimate (358,998 t), which was over 440% larger than the 2003 estimate (66,310 t). The 2013 biomass estimate (370,454 t) was the highest estimated biomass on record and was similar to the 2005 estimate. This increase is largely explained by a three-fold increase in the Chirikof region. The 2017 *design-based* trawl survey biomass index (150,325 t) represented an increase of 207% from the 2015 index 48,933 t), but is 59% below the high 2013 index (Table 10.8). The 2017 *design-based* trawl survey index is 12% lower than the long-term average (170,158 t). Such large fluctuations in biomass do not seem reasonable given the long life, slow growth, low natural mortality, late maturity, and relatively modest level of commercial catch of northern rockfish, hence our proposal to inform the 2018 GOA northern rockfish assessment with an alternative Vector Autoregressive Spatio-temporal (VAST) *model-based* index from these same survey data.

The precision of some of the biomass estimates has been low and is reflected in the high CVs associated with some survey biomass estimates of northern rockfish, that are the result of few very large catches during the survey (Table 10.8). In both 1999 and 2001, a single very large survey haul of northern rockfish greatly increased the biomass estimates and resulted in wide confidence bounds. The haul in 2001 was the largest individual catch (14 t) of northern rockfish ever taken during a Gulf of Alaska survey; this tow accounted for 58.7% of total survey catch by mass in that year. In contrast, the 2005 and 2007 survey had several large hauls of northern rockfish in the Central Gulf and confidence bounds were narrower (Table 10.8). The 2009 survey did not have any very large hauls and the biomass estimate was lower and more precise than the 2005 and 2007 estimates. The 2011 survey had several large hauls and the confidence bounds are comparable to 2007. The 2013 survey had several large catches in the Chirikof region but relatively low catches in other areas resulting in a CV of 60% (Figure 10.5). The 2015 biomass estimate was much more precise and had a CV of 34%, similar to other low biomass estimates from past surveys, while the 2017 biomass estimate was over three times as large as 2015 with a CV of 45%. The highly variable biomass estimates for northern rockfish suggest that an alternative to the design-based estimators may be useful to reduce the variability in biomass estimates, which is why in this assessment we recommend a *model-based* index of bottom trawl survey biomass.

Age and Size composition
Ages for northern rockfish were determined from the break-and-burn method (Chilton and Beamish 1982). These age compositions (Table 10.9 and Figure 10.6) indicate that recruitment of northern rockfish is highly variable. Several surveys (1984, 1987, 1990, and 1996) show especially strong year-classes from the period around 1975-77; although they differ as to which specific years were greatest, likely due to age determination errors. The 1993, 1996, and 1999 age compositions also indicate that the 1983-85 year-classes may be stronger than average. Recent age compositions (2005, 2007, 2009, and 2011) indicate that the 1996-98 year-classes may also be stronger than average, which is in agreement with recent age compositions obtained from the commercial fishery described above. Trawl surveys provide size composition data for northern rockfish but are not used directly in the current age structured assessment model (Table 10.10 and Figure 10.7). In years with age readings, trawl survey size composition data are multiplied by an age-length key (computed from length-stratified otolith collections) to obtain survey age compositions. Similar to the fishery length compositions discussed above, a large proportion of northern rockfish lengths are greater than the current plus length bin (38 cm); especially in recent years. Also similar to the fishery age compositions, the proportion of older fish older has been increasing since the mid to early 2000s.

Maturity Data
In previous stock assessments for northern rockfish, age at maturity was been based on a logistic curve fit to ovarian samples collected from female northern rockfish in the central Gulf of Alaska (GOA) in the spring of 1996 (*n*=75, C. Lunsford pers. comm. July 1997, Heifetz et al. 2009). A more recent study reevaluating maturity of northern rockfish (Chilton 2007, *n*=157) has been published, providing additional information for maturity-at-age. This study collected ovarian samples from female northern rockfish throughout the year in both 2000 and 2001. In a report submitted to the GOA Groundfish Plan Team in September 2010, the two studies were compared and the advantages and disadvantages of the different approaches for studying maturity (histology versus visual inspection) were discussed (Rodgveller et al. 2010). In this year's assessment, as in the 2011 assessment, we combine the data from both studies to estimate maturity of northern rockfish. Due to the relatively small sample sizes for each study, the close proximity in time for each study (4 years apart compared to the 51 year time series used in this assessment), and the large difference in the age at 50% maturity (12.8 years used in previous assessments compared to 8 years obtained by Chilton 2007), we combine these data and estimate an intermediate maturity-at-age rather than consider time-dependent changes in maturity (Figure 10.8). There could be time-dependent changes in maturity-at-age for northern rockfish, although, additional data would be necessary to evaluate this hypothesis.

Analytic Approach

General Model Structure
The basic model for Gulf of Alaska northern rockfish is described as a separable age-structured model (Box 1) and was implemented using AD Model Builder software (Fournier et al. 2012). The assessment model is based on a generic rockfish model developed in a workshop held in February 2001 (Courtney et al. 2007) and follows closely the GOA Pacific ocean perch model. The northern rockfish model is fit to time series extending from 1961-2018. As with other rockfish age-structured models, this model does not attempt to fit a stock-recruitment relationship but estimates a mean recruitment, which is adjusted by estimated recruitment deviations for each year. The parameters, population dynamics, and equations of the model are shown in Box 1.

Description of Alternative Models
In total, two changes were made to input data and model configuration in this year's (2018) assessment compared to the 2015 assessment. We present these changes in a step-wise manner, building upon each previous model change to arrive at the preferred model for this year's assessment. Model M15.4 (2018) is

equivalent in structure to the 2015 accepted model, M15.4 (2015), but with updated catch, survey, and composition data. M18.1 (2018) has the same model structure but fits to a Vector Autoregressive Spatio-temporal (VAST) model-based bottom trawl survey biomass index, in place of the design-based index. Model 18.2 (2018) also fits the model-based index, but rescales the negative log-likelihood weight for the index to account for the difference in precision among indices, with the purpose of maintaining consistency in the relative likelihood contributions from all data types. The following table provides the model case name and description of the changes made to the model.

Model case	Description
M15.4 (2015)	2015 accepted model
M15.4 (2018)	Same model as 2015, but with updated data through 2018
M18.1	Model M15.4 with new data through 2018, but fitting to a VAST model-based biomass index for the GOA bottom trawl survey
M18.2	Model M18.1, but with the negative log-likelihood weight on the survey biomass index reduced from 1 to 0.25 to account for the ratio of index variances

Note, each additional model case includes the changes made to the model in the previous model case. For example, model case M18.1 would also include the updated data through 2018 from model case M15.4 (2018), in addition to the inclusion of the model-based index. A brief description of each model changed is provided below.

M15.4 (2018) – 2015 model with updated data through 2018

In 2018, five additions to the data inputs for the GOA northern rockfish assessment model are available. These include bottom trawl survey data for 2017, fishery catch data from 2016 and 2017, finalized catch data from 2015, and projected 2018 catch. New data also include fishery length compositions from 2015 and 2017 (Table 10.6), fishery age compositions from 2014 and 2016 (Table 10.7), and survey age compositions for 2015 and 2017 (Table 10.9). Model 15.4 (2018) has the same model structure as the accepted 2015 model, M15.4 (2015), but fits to these expanded datasets. Relative to subsequent models (M18.1 and M18.2), this model fits to the design-based biomass index from the GOA bottom trawl survey. All data weights in this model are equivalent to the 2015 accepted model, M15.4 (2015).

M18.1 - Alternative VAST model-based survey biomass index

Model 18.1 fits to a model-based biomass index from the GOA bottom trawl survey estimated using a Vector Autoregressive Spatio-temporal (VAST) model, but in all other respects is equivalent to Model 15.4 (2018).

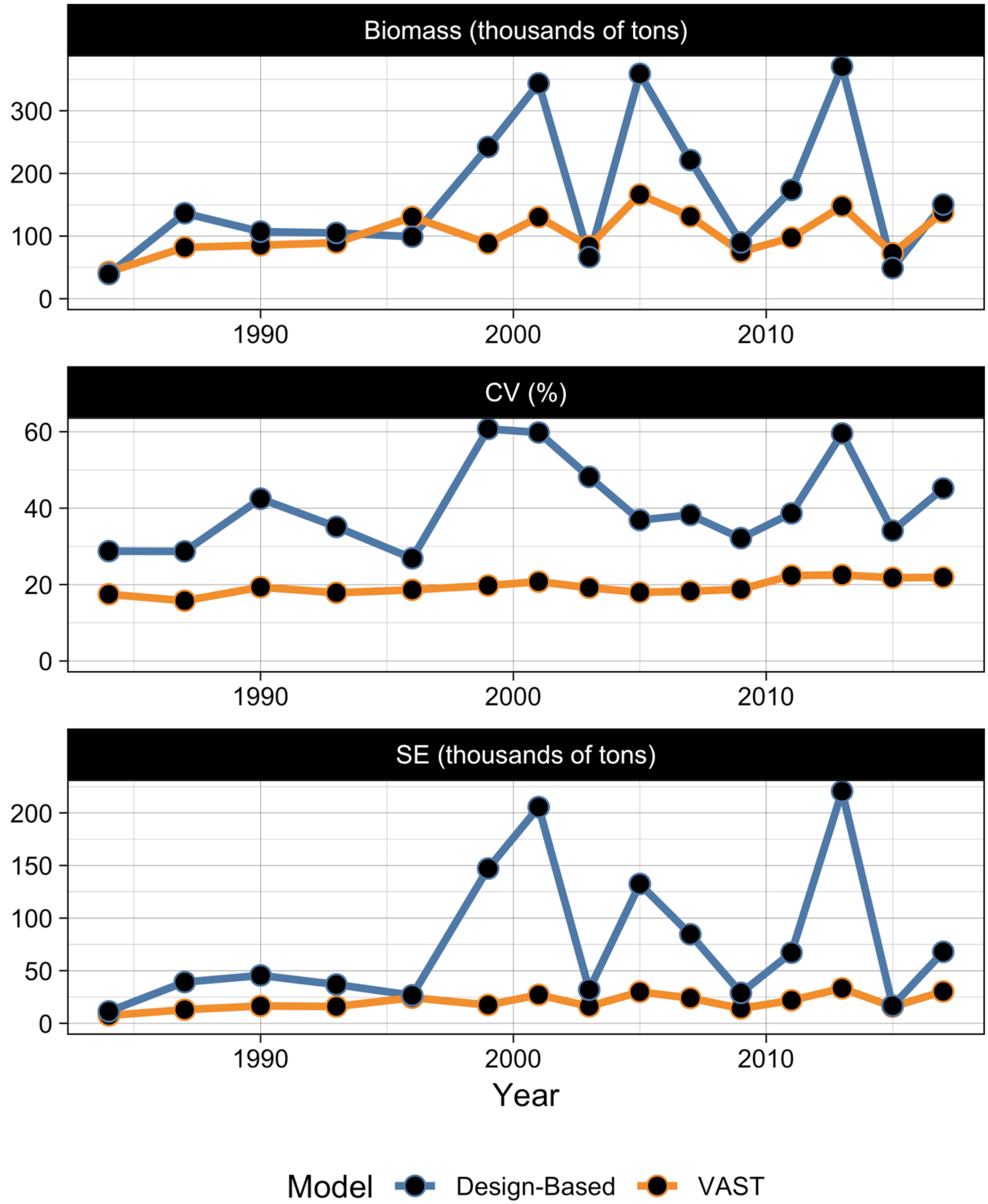
VAST models (Thorson and Barnett 2017) have been proposed as an alternative to the design-based estimators for generating biomass indices from survey data. The NOAA-AFSC Groundfish Assessment Program conducts biennial bottom trawl surveys in the Gulf of Alaska and Aleutian Islands regions using a stratified random sample design, with effort allocated among strata based on observed catch rates, value, stratum variances, and stratum areas (von Szalay and Raring 2016). While design-based methods provide unbiased estimates of biomass for stratified random sample designs, a positive skew, wide tails, or a large number of zero observations (tows) can lead to unbiased but imprecise estimates of biomass (Thorson et al. 2011, Shelton et al. 2014). This is particularly problematic for patchily-distributed species whose non-uniform distributions in space, like GOA northern rockfish, result in large proportions of zero observations. Furthermore, design-based estimators assume uniform density within strata, ignoring information provided by the spatial correlation structure across sample locations.

Two alternative approaches to index standardization present potential opportunities to reduce uncertainty in biomass indices from GOA bottom trawl survey data for species such as northern rockfish. The first is to model biomass observations as the joint probability of encounter probability and positive catch rates. Known within the fisheries literature as delta generalized linear mixed models (Stefansson 1996, Maunder and Punt 2004) and more generally as hurdle models (Ver Hoef and Jansen 2007), methods that model these two components of catch observations have been found to better partition variance and reduce uncertainty in survey indices. Delta generalized mixed models have found increased use for standardization of zero-inflated survey data in recent years, especially for US West Coast groundfish (Thorson and Ward 2014, Thorson et al. 2015a).

The second are geostatistical methods for modeling the correlation structure in biomass observations across space. Design-based estimators of biomass calculate average density within sampling strata, based on observed catches given area swept, and compute an estimate of absolute biomass by stratum by multiplying stratum density times stratum area. As a result, variance among samples within a stratum result in an increase in the variance estimated for species biomass. However, Shelton et al. (2014) illustrated that for darkblotched rockfish (*Sebastes cramerai*) much of the variation in survey catches could be explained by spatially-correlated variability in habitat quality, and that accounting for the location of samples resulted in significant reductions in uncertainty for biomass indices derived from trawl survey data. In addition to increased precision of abundance indices for darkblotched rockfish, geostatistical model estimates did not have the spikes in abundance which had been deemed implausible for such a long-lived species (Gertseva and Thorson 2013).

Thorson et al. (2015a) developed a generalized maximum likelihood estimator for geostatistical index standardization, which approximate spatial and spatio-temporal variation in catch rates as Gaussian Markov random fields, which have subsequently been implemented using the Vector Autoregressive Spatio-temporal (VAST) modelling software (Thorson 2018). When this model was applied to 28 groundfish species encountered in the U.S. West Coast trawl survey, estimation intervals from the conventional design-based approach were 60% larger on average than those derived from the geostatistical model-based estimator, but the trend and scale of resulting indices were generally consistent between methods (Thorson et al. 2015a). When applied to simulated data, Thorson et al. (2015a) found the geostatistical delta-glmm provided unbiased estimates of abundance, with well-calibrated confidence intervals that indicated greater precision than design-based estimators. Overall, the current body of research suggests that by modeling both encounter probability and positive catch rate probabilities together, and estimating spatial and spatiotemporal correlation, VAST models are able to explain more of the variability in catch rate data, produce indices of abundance with greater precision than conventional design-based estimators, and may be able to use trawl survey data more efficiently.

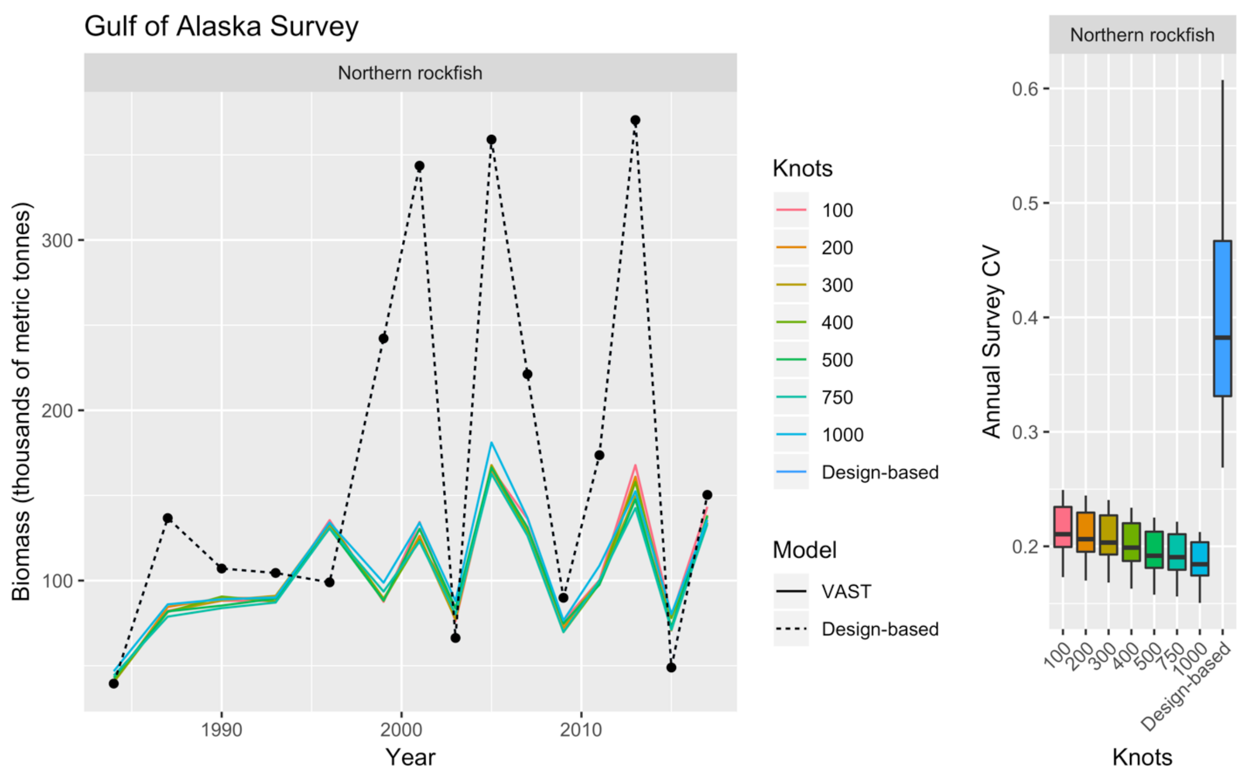
Given the potential benefits of VAST models for generating biomass indices with greater precision from GOA bottom trawl survey data, we have proposed this model-based index of biomass for inclusion in the assessment of GOA northern rockfish. The figure below shows a comparison of the design-based and model-based biomass indices generated from the same GOA bottom trawl survey data for northern rockfish, along with the estimated uncertainty (CV and SE) for both indices across time.



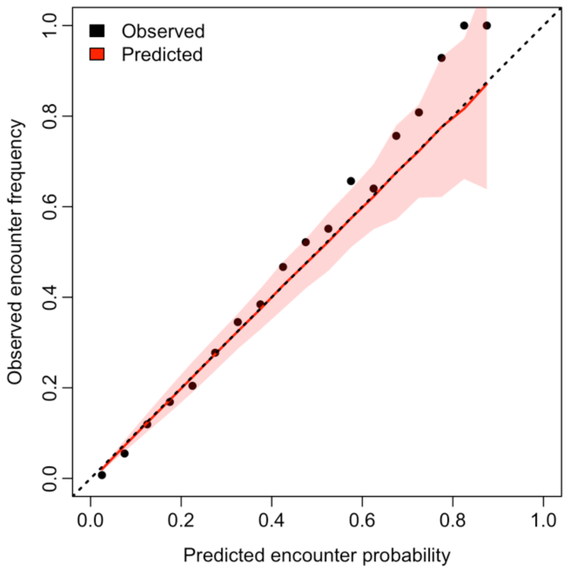
Relative to the design-based index, the VAST index for GOA northern rockfish is both lower in magnitude across the time series and exhibits less interannual variation. In addition to differences in the trend and scale of the two indices, estimated uncertainty in the VAST model-based biomass index is substantially lower (mean CV: 19.5%) than of the design-based index (mean CV: 41.0%). While both design-based and model-based indices are fairly similar through 1996, the large design-based biomass estimates in 2003, 2005, and 2013 are still present in the model-based index, but the increases are much less dramatic. These three high design-based biomass estimates are associated with the highest uncertainty of any estimates in the time series, suggesting they are likely driven by the presence of infrequent high abundance northern rockfish hauls within specific strata in these years.

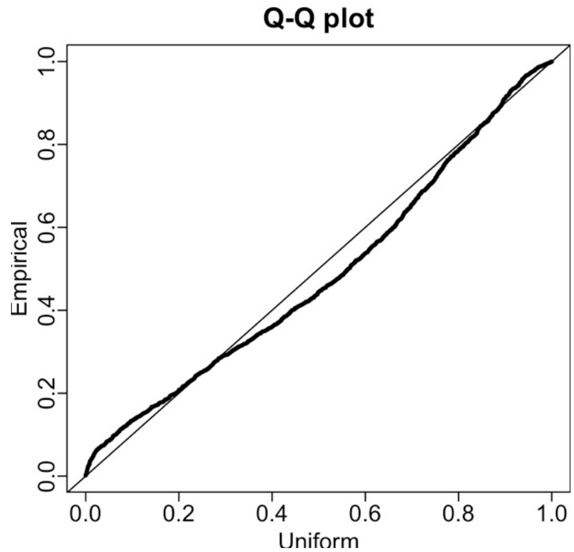
The design-based estimates are highly uncertain and the longevity of northern rockfish make such interannual changes in biomass biologically implausible. Altogether this suggest the model-based index may be appropriate. From a statistical perspective the non-uniform distribution of northern rockfish across space may inherently lend itself better to separate estimation of the encounter probability and positive catch rate components of the sampling process. The separate treatment of these two probability components likely drives part of the observed reduction in uncertainty.

The model-based index was calculated by fitting a VAST model to bottom trawl survey data (1984-2017), approximating spatially continuous variation in density as being piecewise constant in the proximity of 500 knots and a log-normal error distribution for positive catch rates. This level of spatial resolution was selected based on previous analyses presented at the September 2017 Joint Groundfish Plan Team suggesting that changes in the scale of model-based indices for some species with increasing spatial complexity are diminishing, and 500 knots provides a good balance between precision and computational efficiency. The estimated biomass index was corrected for small but persistent bias associated with the estimation and transformation of spatial and spatio-temporal random effects (Thorson and Kristensen 2016). Comparison of indices and index uncertainty (CV) generated across a range of candidate levels of spatial complexity (assumed knots), highlights that while the model-based index is somewhat insensitive to the level of spatial complexity assumed, the precision of the index increases with knot number.



General diagnostics for the fit of VAST models include the comparison of the model predicted and observed encounter probabilities (below), quantile-quantile (Q-Q) plots of positive catch rates (below), and visual inspection of model residuals for both encounter probability and positive catch rate, and value of the maximum gradient component of the model to ensure convergence. The following figure shows predicted vs. observed encounter probabilities and the Q-Q plot for the VAST model used to generate model-based indices of abundance for GOA northern rockfish.





Comparison of observed and predicted encounter probabilities indicate the VAST model is fitting this component of bottom trawl survey data adequately and the Q-Q plot indicates that the positive catch rate data conform to the assumed log-normal error distribution. Visual inspection of Pearson residuals for both encounter probability and positive catch rate components of the model indicate no high value residuals or spatial pattern in the residuals that would suggest an inappropriate approximation of the spatial correlation structure across latitude and longitude. The maximum gradient component of the model was 6.22e-11 indicating the model is likely to have successfully converged.

M18.2 – Alternative VAST model-based survey biomass index, with log-likelihood weight rescaled from 1.0 to 0.25 to account for difference in index precision

As highlighted above the VAST model-based survey index exhibits an increase in precision (lower CV) relative to design-based index. The result of this increase in estimated precision is an increased contribution of the survey data to the total likelihood, and the potential for the assessment model to preferentially fit to the survey abundance index over other data types. The 2015 assessment of GOA dusky rockfish (Lunsford et al. 2015) accounted for this change in index precision when switching from fitting the design-based index to fitting the VAST model-based index, by rescaling the weighting of the negative log-likelihood for these data proportional to the ratio of the mean weighted inverse variance between the two trawl survey biomass estimates. This ensured that the overall contribution to the total likelihood from the new model-based index was similar to that from the previously-used design-based index.

In Model 18.2 we follow a similar procedure to rescale the relative weighting for the survey biomass index to account for the change in survey precision (CV) and ensure that the contribution to the total likelihood from the new model-based index is similar to that of the previous design-based survey index. For GOA northern rockfish the average ratio of CVs across the survey time series is 0.5 (0.33-0.69), so the weight placed on the negative log-likelihood for the survey was scaled proportional to the squared ratio of the CVs across the time series (0.25) from a weight of 1.0 to a weight of 0.25.

Model 18.2 is equivalent in all respects to Model 18.1 except for the reduction in weight on the negative log-likelihood for the survey index from 1.0 to 0.25.

Future research could explore alternative ways to re-weight the index for illustrative purposes, and we specifically recommend exploring the impact of using the estimated CV from the design-based index (or its mean across years) as the CV for the model-based index.

Parameters Estimated Outside the Assessment Model

A von Bertalanffy growth curve was fitted to survey size at age data from 1984-2017 using length-stratified methods (Quinn and Deriso 1999, Bettoli and Miranda 2001). Sexes were combined. An age to size conversion matrix was then constructed by adding normal error with a standard deviation equal to the survey data for the probability of different sizes for each age class. Previous parameters are available from Heifetz and Clausen (1991), Courtney et al. (1999), and Malecha et al. (2007). The estimated parameters for the growth curve from length-stratified methods are shown below:

L_∞=41.34 cm κ=0.17 t_0=-0.22

The previous assessments growth curve parameters were:

L_∞=41.72 cm κ=0.16 t_0=-0.34

Weight-at-age was constructed with weight at age data from the same data set as the length at age. Mean weight-at-age is approximated by the equation: $W_a = W_\infty\left(1 - e^{-k(a-t_0)}\right)^b$. The estimated growth parameters from length-stratified methods are shown below.

W_∞=1056 g k=0.18 t_0=-0.04 b=3.01

The previous assessments growth parameters for weight were:

W_∞=1064 g k=0.18 t_0=0.01 b=3.04

Aging error matrices were constructed by assuming that the break-and-burn ages were unbiased but had a given amount of normal error around each age based on between-reader percent agreement tests conducted at the AFSC Age and Growth lab. We fix the variability of recruitment deviations (σ_r) at 1.5 which allows highly variable recruitment.

Parameters Estimated Inside the Assessment Model

The estimates of natural mortality (*M*) and catchability (*q*) are estimated with the use of lognormal prior distributions as penalties that are added to the overall objective function in order to constrain parameter estimates to reasonable values and to speed model convergence. Arithmetic means and standard errors (μ, σ) for the lognormal distributions were provided as input to the model. The standard errors for selected model parameters were estimated based on multivariate normal approximation of the covariance matrix. The prior mean for natural mortality of 0.06 is based on the estimate provided by Heifetz and Clausen (1991) using the method of Alverson and Carney (1975). Natural mortality is notoriously a difficult parameter to estimate within the model so we assign a “tight” prior CV of 5%. Catchability is a parameter that is somewhat unknown for rockfish, so while we assign it a prior mean of 1 (assuming all fish in the area swept are captured and there is no herding of fish from outside the area swept, and that there is no effect of untrawlable grounds), we assign it a less precise CV of 45%. This allows the parameter more freedom than that allowed to natural mortality. This is identical to that used in the Gulf of Alaska Pacific ocean perch and dusky rockfish assessments. Maturity-at-age is modeled with the logistic function, similar to selectivity-at-age for the survey and fishery. The fit to the two studies that have provided maturity data for northern rockfish from the model is shown in Figure 10.8. The numbers of estimated parameters from the model are shown below. Other derived parameters are described in Box 1.

Given that we are using Bayesian estimation, there is no need to implement any recruitment bias-correction algorithm (e.g., using Methot and Taylor 2011).

Parameter name	Symbol	Number
Natural mortality	M	1
Catchability	q	1
Log-mean-recruitment	μ_r	1
Recruitment deviations	τ_y	105
Spawners-per-recruit levels	$F_{35\%}, F_{40\%}, F_{50\%}$	3
Average fishing mortality	μ_f	1
Fishing mortality deviations	ϕ_y	58
Logistic fishery selectivity	$a_{f50\%}, \delta_f$	2
Logistic survey selectivity	$a_{s50\%}, \delta_s$	2
Logistic maturity-at-age	$a_{m50\%}, \delta_m$	2
Total		176

Uncertainty approach

Evaluation of model uncertainty has recently become an integral part of the "precautionary approach" in fisheries management. In complex stock assessment models such as this model, evaluating the level of uncertainty is difficult. One way is to examine the standard errors of parameter estimates from the Maximum Likelihood (ML) approach derived from the Hessian matrix. While these standard errors give some measure of variability of individual parameters, they often underestimate their variance and assume that the joint distribution is multivariate normal. An alternative approach is to examine parameter distributions through Markov Chain Monte Carlo (MCMC) methods (Gelman et al. 1995). When treated this way, our stock assessment is a large Bayesian model, which includes informative (e.g., lognormal natural mortality with a small CV) and noninformative (or nearly so, such as a parameter bounded between 0 and 10) prior distributions. In the model presented in this SAFE report, the number of parameters estimated is 170. In a low-dimensional model, an analytical solution might be possible, but in one with this many parameters an analytical solution is intractable. Therefore, we use MCMC methods to estimate the Bayesian posterior distribution for these parameters. The basic premise is to use a Markov chain to simulate a random walk through the parameter space (i.e., Metropolis MCMC algorithm), which will eventually converge to a stationary distribution which approximates the posterior distribution. Determining whether a particular chain has converged to this stationary distribution can be complicated, but generally if allowed to run long enough, the chain will converge (Jones and Hobert 2001). The "burn-in" is a set of iterations removed at the beginning of the chain. This method is not strictly necessary but we use it as a precautionary measure. In our simulations we removed the first 1,000,000 iterations out of 10,000,000 and "thinned" the chain to one value out of every 2,000, leaving a sample distribution of 4,500. Further assurance that the chain had converged was to compare the mean of the first half of the chain with the second half after removing the "burn-in" and "thinning". Because these two values were similar we concluded that convergence had been attained. We use these MCMC methods to provide further evaluation of uncertainty in the results below including 95% confidence intervals for some parameters.

Data weighting

Multinomial sample sizes are calculated as the square root of the number of hauls multiplied by the number of composition samples in each year, and scaled to a maximum of 100 across years. Sample sizes were calculated in the same way for fishery age and length compositions, and survey age compositions.

Effective sample sizes were assumed equal to the input sample sizes and not estimated or iteratively adjusted within the model.

Data weights are used to rescale the total likelihood contribution from select log-likelihoods for the different data sources. The log-likelihood weight on the three composition data types (fishery age, fishery length, and survey age) is 0.5. The log-likelihood weight on the (VAST) model-based bottom trawl survey biomass index is 0.25 in the recommended model.

BOX 1. AD Model Builder Model Description

Parameter definitions	
y	Year
a	Age classes
l	Length classes
w_a	Vector of estimated weight at age, $a_0 \rightarrow a_+$
m_a	Vector of estimated maturity at age, $a_0 \rightarrow a_+$
a_0	Age at first recruitment
a_+	Age when age classes are pooled
μ_r	Average annual recruitment, log-scale estimation
μ_f	Average fishing mortality
σ_r	Annual recruitment deviation
ϕ_y	Annual fishing mortality deviation
fs_a	Vector of selectivities at age for fishery, $a_0 \rightarrow a_+$
ss_a	Vector of selectivities at age for survey, $a_0 \rightarrow a_+$
M	Natural mortality
$F_{y,a}$	Fishing mortality for year y and age class a ($fs_a \mu_f e^{\varepsilon}$)
$Z_{y,a}$	Total mortality for year y and age class a ($=F_{y,a}+M$)
$\varepsilon_{y,a}$	Residuals from year to year mortality fluctuations
$T_{a,a'}$	Aging error matrix
$T_{a,l}$	Age to length transition matrix
q	Survey catchability coefficient
SB_y	Spawning biomass in year y, ($=m_a\, w_a\, N_{y,a}$)
q_{prior}	Prior mean for catchability coefficient
$\sigma_{r(prior)}$	Prior mean for recruitment deviations
σ_q^2	Prior CV for catchability coefficient
$\sigma_{\sigma_r}^2$	Prior CV for recruitment deviations

BOX 1 (Continued)

Equations describing the observed data

$$\hat{C}_y = \sum_a \frac{N_{y,a} * F_{y,a} * \left(1 - e^{-Z_{y,a}}\right)}{Z_{y,a}} * w_a$$

Catch equation

$$\hat{I}_y = q * \sum_a N_{y,a} * \frac{s_a}{\max\left(s_a\right)} * w_a$$

Survey biomass index (t)

$$\hat{P}_{y,a'} = \sum_a \left(\frac{N_{y,a} * s_a}{\sum_a N_{y,a} * s_a} \right) * T_{a,a'}$$

Survey age distribution
Proportion at age

$$\hat{P}_{y,l} = \sum_a \left(\frac{N_{y,a} * s_a}{\sum_a N_{y,a} * s_a} \right) * T_{a,l}$$

Survey length distribution
Proportion at length

$$\hat{P}_{y,a'} = \sum_a \left(\frac{\hat{C}_{y,a}}{\sum_a \hat{C}_{y,a}} \right) * T_{a,a'}$$

Fishery age composition
Proportion at age

$$\hat{P}_{y,l} = \sum_a \left(\frac{\hat{C}_{y,a}}{\sum_a \hat{C}_{y,a}} \right) * T_{a,l}$$

Fishery length composition
Proportion at length

Equations describing population dynamics

Start year

$$N_a = \begin{cases} e^{\left(\mu_r + \tau_{styr - a_o - a - 1}\right)}, & a = a_0 \\ e^{\left(\mu_r + \tau_{styr - a_o - a - 1}\right)} e^{-(a - a_0)M}, & a_0 < a < a_+ \\ \dfrac{e^{\left(\mu_r\right)} e^{-(a - a_0)M}}{\left(1 - e^{-M}\right)}, & a = a_+ \end{cases}$$

Number at age of recruitment

Number at ages between recruitment and pooled age class

Number in pooled age class

Subsequent years

$$N_{y,a} = \begin{cases} e^{\left(\mu_r + \tau_y\right)}, & a = a_0 \\ N_{y-1,a-1} * e^{-Z_{y-1,a-1}}, & a_0 < a < a_+ \\ N_{y-1,a-1} * e^{-Z_{y-1,a-1}} + N_{y-1,a} * e^{-Z_{y-1,a}}, & a = a_+ \end{cases}$$

Number at age of recruitment

Number at ages between recruitment and pooled age class

Number in pooled age class

Formulae for likelihood components **BOX 1 (Continued)**

$L_1 = \lambda_1 \sum_y \left(\ln \left[\frac{C_y + 0.01}{\hat{C}_y + 0.01} \right] \right)^2$	Catch likelihood
$L_2 = \lambda_2 \sum_y \frac{\left(I_y - \hat{I}_y \right)^2}{2 * \hat{\sigma}^2 \left(I_y \right)}$	Survey biomass index likelihood
$L_3 = \lambda_3 \sum_{styr}^{endyr} -n^*{}_y \sum_a^{a+} \left(P_{y,a} + 0.001 \right) * \ln \left(\hat{P}_{y,a} + 0.001 \right)$	Fishery age composition likelihood
$L_4 = \lambda_4 \sum_{styr}^{endyr} -n^*{}_y \sum_l^{l+} \left(P_{y,l} + 0.001 \right) * \ln \left(\hat{P}_{y,l} + 0.001 \right)$	Fishery length composition likelihood
$L_5 = \lambda_5 \sum_{styr}^{endyr} -n^*{}_y \sum_a^{a+} \left(P_{y,a} + 0.001 \right) * \ln \left(\hat{P}_{y,a} + 0.001 \right)$	Survey age composition likelihood
$L_6 = \lambda_6 \sum_{styr}^{endyr} -n^*{}_y \sum_l^{l+} \left(P_{y,l} + 0.001 \right) * \ln \left(\hat{P}_{y,l} + 0.001 \right)$	Survey size composition likelihood
$L_7 = \frac{1}{2\sigma_q^2} \left(\ln {q}/{q_{prior}} \right)^2$	Penalty on deviation from prior distribution of catchability coefficient
$L_8 = \frac{1}{2\sigma_{\sigma_r}^2} \left(\ln {\sigma_r}/{\sigma_{r(prior)}} \right)^2$	Penalty on deviation from prior distribution of recruitment deviations
$L_9 = \lambda_9 \left[\frac{1}{2 * \sigma_r^2} \sum_y \tau_y^2 + n_y * \ln \left(\sigma_r \right) \right]$	Penalty on recruitment deviations
$L_{10} = \lambda_{10} \sum_y \phi_y^2$	Fishing mortality regularity penalty
$L_{11} = \lambda_{11} \bar{s}^2$	Average selectivity penalty (attempts to keep average selectivity near 1)
$L_{12} = \lambda_{12} \sum_{a_0}^{a_+} \left(s_i - s_{i+1} \right)^2$	Selectivity dome-shapedness penalty – only penalizes when the next age's selectivity is lower than the previous (penalizes a downward selectivity curve at older ages)
$L_{13} = \lambda_{13} \sum_{a_0}^{a_+} \left(FD(FD(s_i - s_{i+1}) \right)^2$	Selectivity regularity penalty (penalizes large deviations from adjacent selectivities by adding the square of second differences)
$L_{total} = \sum_{i=1}^{13} L_i$	Total objective function value

Results

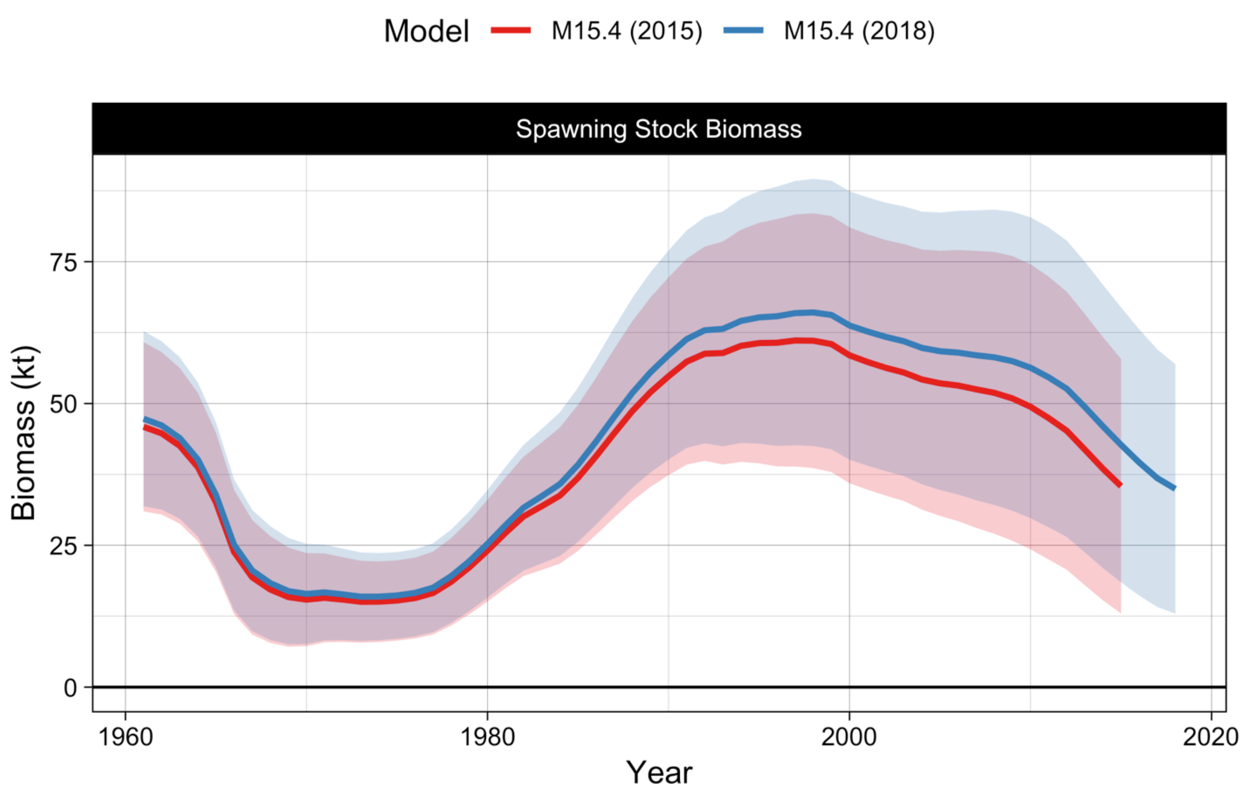
Model Evaluation

Before presenting the standard model results, in this section we will present the results of each of the alternative model cases in a stepwise manner, ultimately arriving at the recommended assessment model for this year. Results investigated include the changes in model results for each model case as well as the model output uncertainty and objective function values.

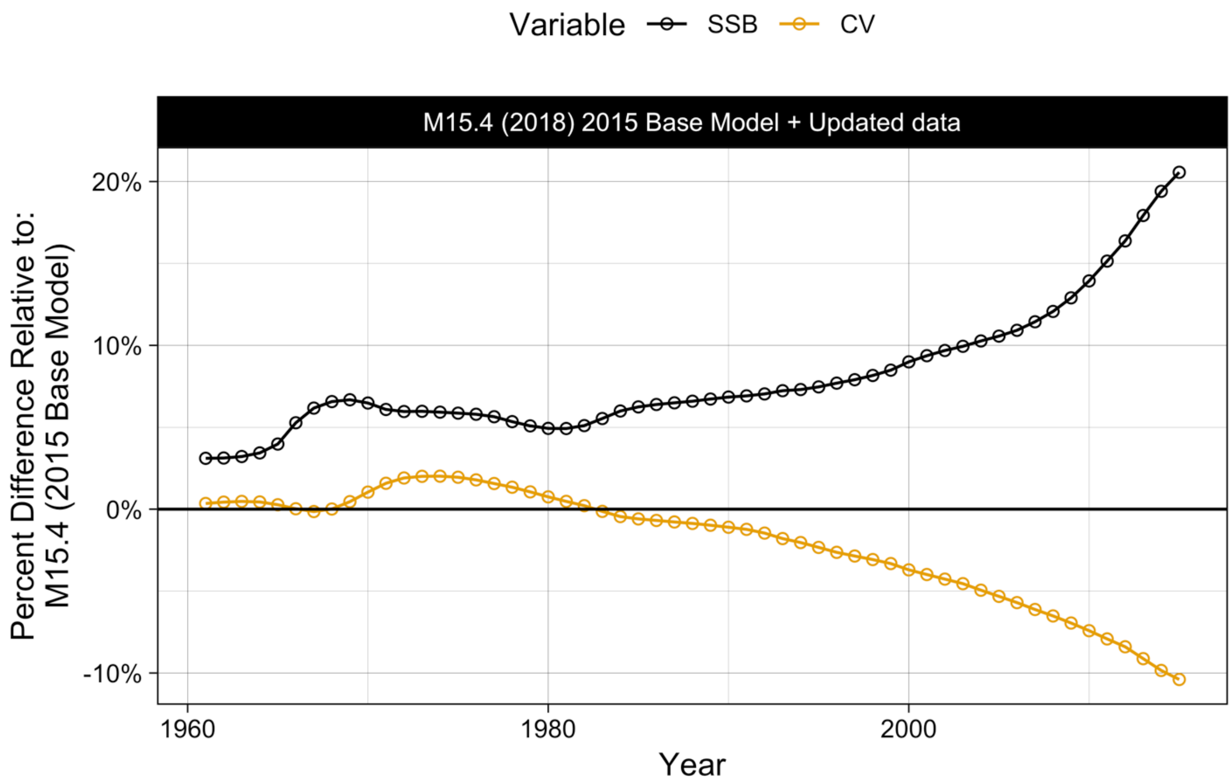
M15.4 (2018) – 2015 model with updated data through 2018

With the update of data to 2018 the overall objective value function increases, as would be expected with the addition of new data fit by the model (Table 10.11). The catchability (q) parameter decreases from the 2015 value of 0.71 to 0.68 with the addition of the 2017 design-based survey biomass estimate and survey age compositions from 2015 and 2017. Mean recruitment increases from 13.81 million in 2015 to 15.28 million in 2018, while natural mortality remains relatively constant with the addition of these new data (Table 10.11).

The following figure compares the estimated trend in spawning stock biomass (kt) between the 2015 final model, M15.4 (2015), and the same model structure with data updated through 2018 – M15.4 (2018). The shaded regions describe the approximate 95% confidence intervals for the prediction. The addition of the new catch, survey, and composition data result in an increase in estimated spawning stock biomass across the time series. The 2015 estimated spawning stock biomass from M15.4 (2015) was 35,426 kt, while the same 2015 biomass estimate from M15.4 (2018) was 42,711 kt.



The figure below depicts the percent difference in spawning stock biomass (SSB) and the coefficient of variation (CV) in spawning stock biomass estimated by M15.4 (2018) fitting updated data, relative to the 2015 final model – M15.4 (2015).

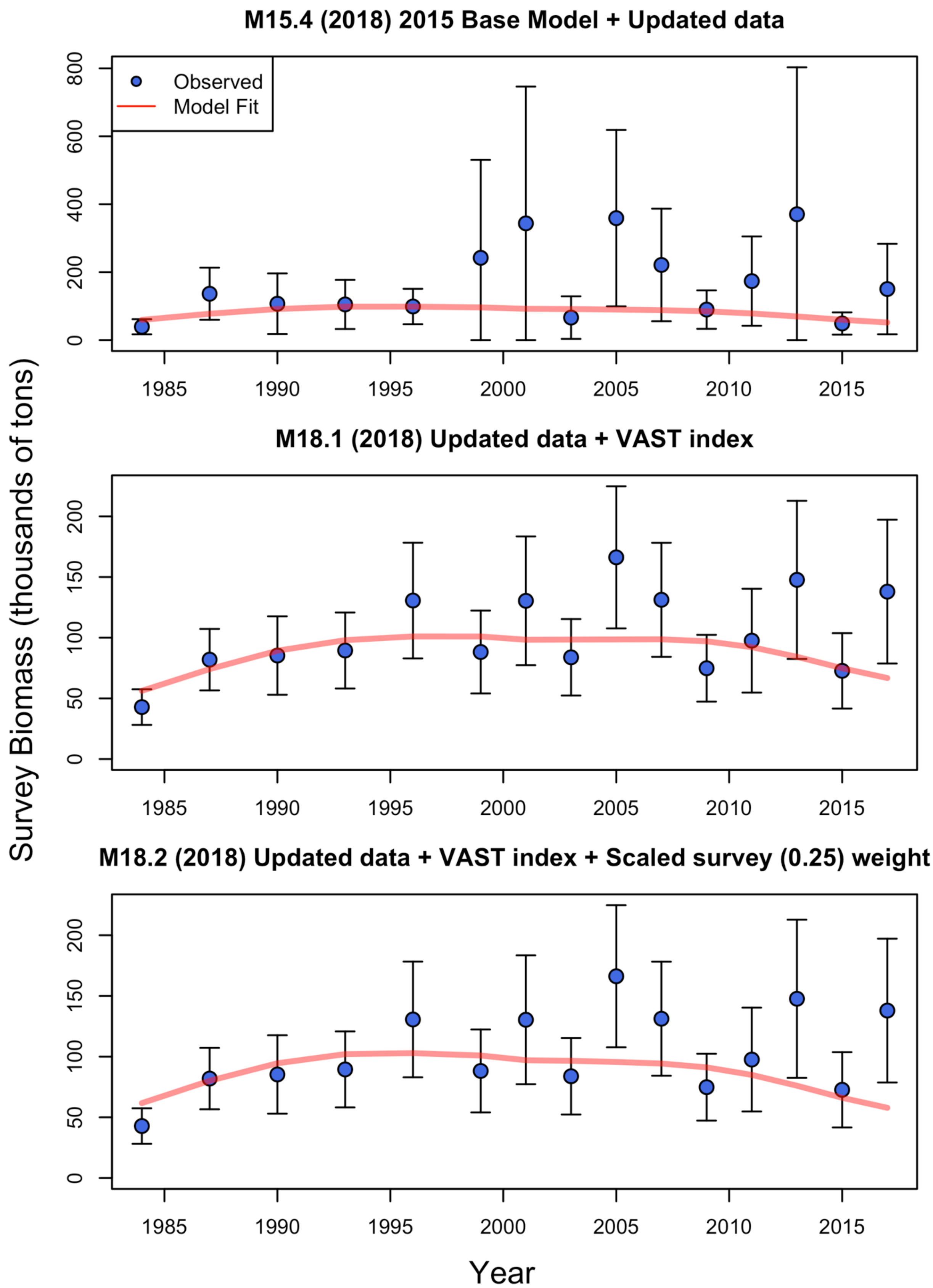


On average across the time series (1961-2015), spawning stock biomass is estimated 8.1% higher when new data are introduced. The magnitude of the difference in biomass estimates between models increases after 1980. In addition to an increase in estimated spawning stock biomass when new data is introduced, the precision of the biomass estimate also increases after 1980 with the CV in spawning stock biomass lower for the M15.4 (2018) compared with M15.4 (2015), suggesting that the inclusion of the new data successfully reduced uncertainty in SSB predictions.

M18.1 - Alternative VAST model-based survey biomass index

Model 18.1 replaces the design-based biomass index from the GOA bottom trawl survey with the VAST model-based index that accounts for the spatial and spatial-temporal correlation structure among survey hauls. With the exception of fitting this alternative biomass index, M18.1 and M15.4 (2018) are equivalent in structure and data inputs.

The figure below illustrates the assessment model fits to the design-based survey index (top panel) and model-based index (bottom panels). As previously described, compared with the design-based index fit by M15.5 (2018) the model-based index fit by M18.1 exhibits much less inter-survey variation and lower uncertainty throughout the time series.


M15.4 (2018) 2015 Base Model + Updated data
Observed
Model Fit
M18.1 (2018) Updated data + VAST index
M18.2 (2018) Updated data + VAST index + Scaled survey (0.25) weight
Survey Biomass (thousands of tons)
Year
0
200
400
600
800
50
100
150
1985
1990
1995
2000
2005
2010
2015

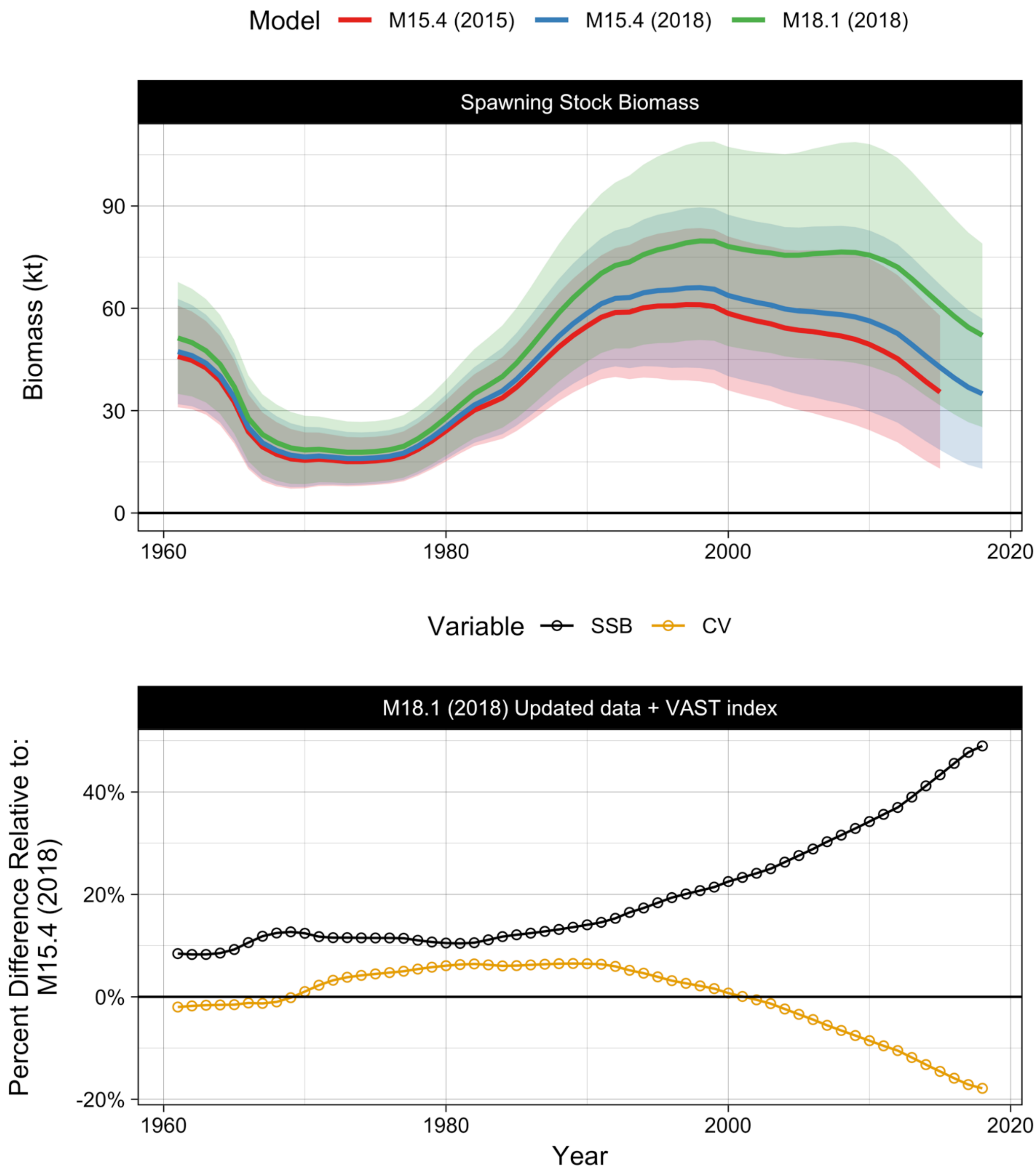
Relative to M15.4 (2018) fitting the design based index, M18.1 appears to better track the trend in point estimates from the model-based index. While still not capturing the majority of inter-survey variation, visually M18.1 appears to be obtaining a better overall fit to the model-based index than is achieved by M15.4 (2018) where the model functionally ignores much of the recent variation in design-based survey indices. Despite less variation in the model-based index, M18.1 is still not capturing the high indices in 2005, 2013, and 2017.

The inclusion of the VAST model-based index in M18.1 results in a drop in the estimated value of the catchability (q) parameter from 0.68 (M15.4 2018) to 0.60 (Table 10.11). Informing the assessment model with the model-based index in place of the design-based index also results in a substantial increase in mean recruitment from 15.28 million (M15.4 2018) to 18.79 million (M18.1). The change in index results in an increase in the objective function value from 238.7 to 242.9.

The figure below illustrates the spawning stock biomass and uncertainty estimates for the 2015 accepted model M15.4 (2015), the same model structure with updated data M15.4 (2018), and the model fitting to the VAST model-based index M18.1. This figure also shows the percent difference in spawning stock biomass and the estimated CV in spawning stock biomass between M18.1 and M15.4 (2018), both incorporating data through 2018 although fitting different survey indices.

Spawning stock biomass estimates are substantially higher when fitting to the model-based index (M18.1), 19.8% higher on average across the time series. From 1961-1980 spawning stock biomass estimates from M18.1 are 10.8% higher on average, after which time the difference between the two estimates increases appreciably with the spawning stock biomass for 2018 49.0% higher from the assessment model fitting the VAST model-based index.

Estimates of uncertainty in spawning stock biomass also differ between assessment models fitting the alternative survey biomass indices. Between 1961 and 2000, the CV of spawning stock biomass from the model fitting the VAST survey index (M18.1) is between 2% below and 6.5% above the CV from the model fitting the design-based index. However, after 2000 the model estimated CV in spawning stock biomass from M18.1 begins to decrease relative to M15.4 (2018) with the CV for 2018 spawning stock biomass from the model fitting the VAST survey index 17.9% lower than the CV in the estimate for this same year from the model fitting the design-based index.

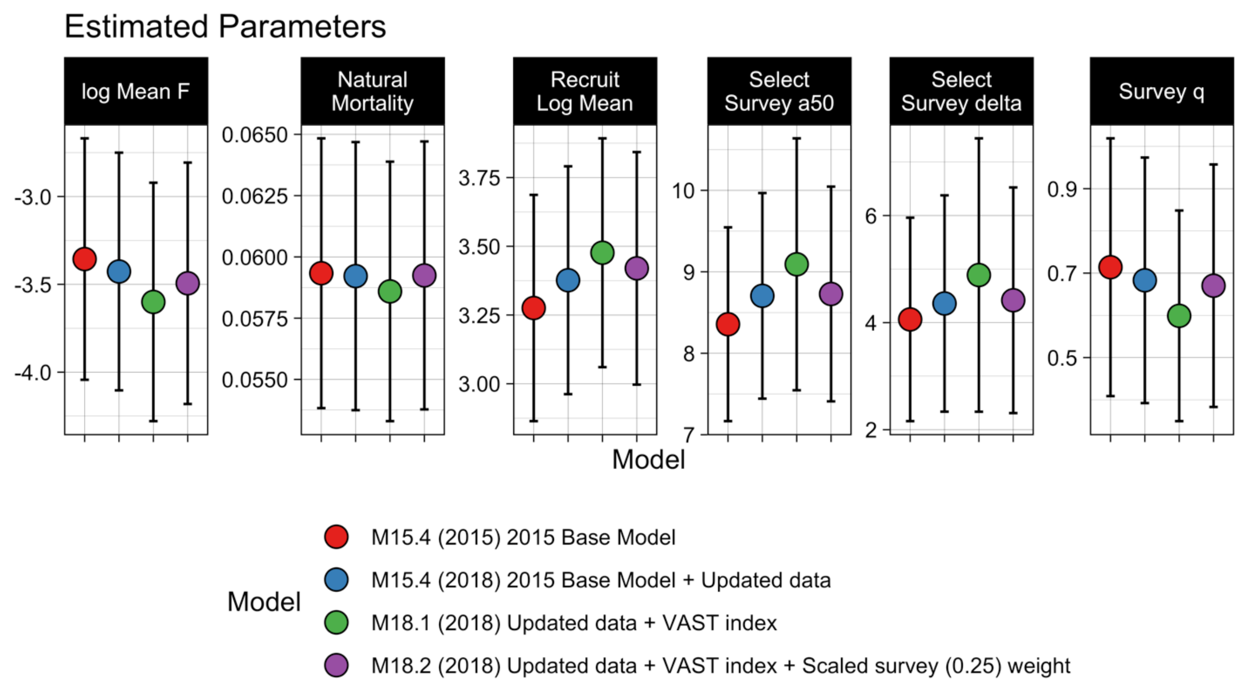


M18.2 – Alternative VAST model-based survey biomass index, with log-likelihood weight rescaled from 1.0 to 0.25 to account for difference in index precision

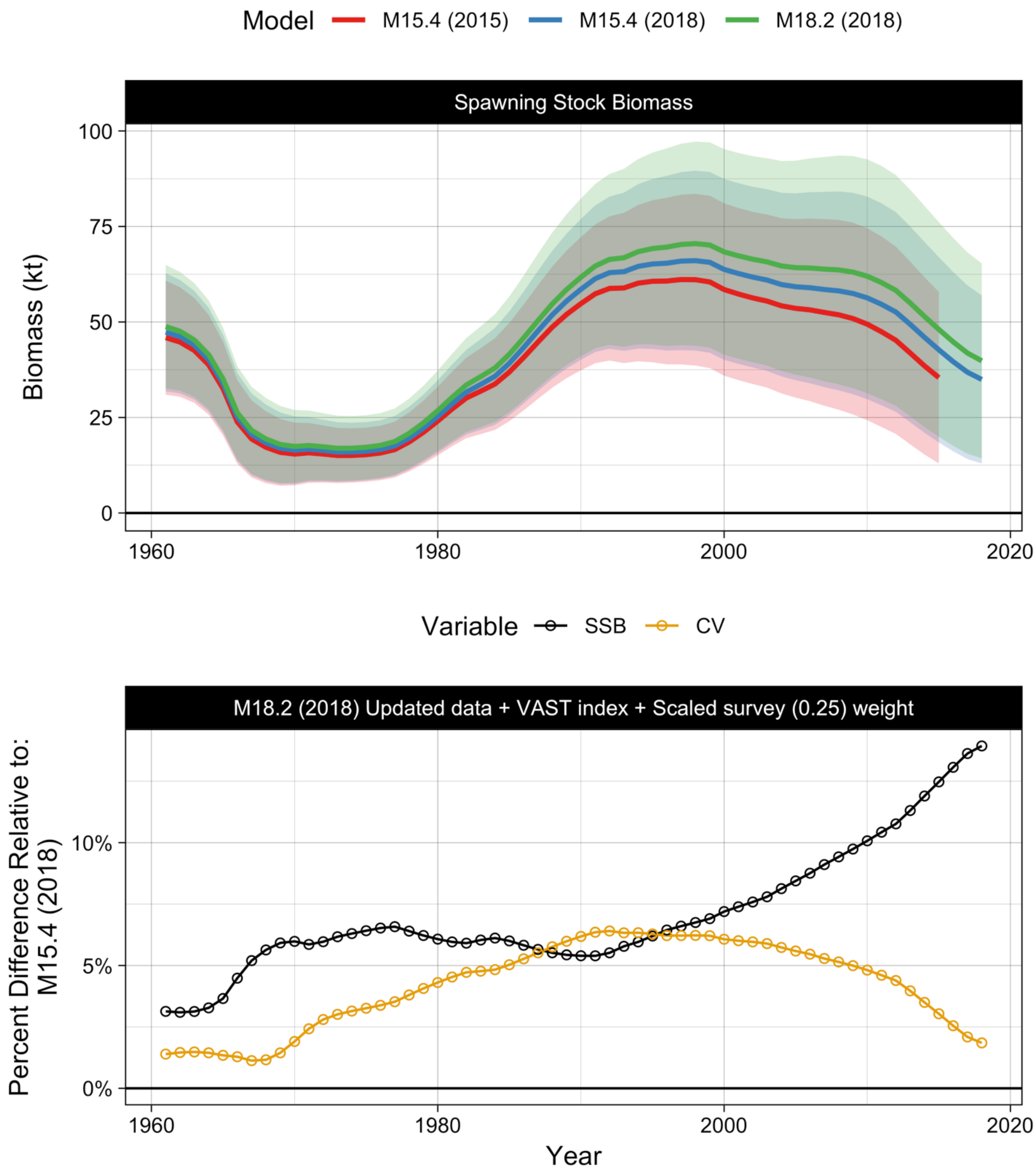
Model 18.2 attempts to account for the increased contribution from the likelihood for the survey index to the total negative log-likelihood resulting from the higher estimated precision of the VAST model-based index relative to the design-based index, by scaling the likelihood weight for this data source proportional to the average ratio of index variances.

As expected with the reduction in weight on the negative log-likelihood for the survey index, the total objective function value decreases from M18.1 to M18.2, driven by a reduction in the negative log-likelihood for the survey biomass but also for the survey age composition data (Table 10.11). This suggests M18.2 provides a superior fit to the survey age composition data.

The figure below shows a comparison of point estimates and approximate 95% confidence intervals for assessment model parameters of interest. The estimate of survey catchability (q) from M18.2 of 0.67 is substantially higher than the estimate of 0.60 from M18.1, and more consistent with the estimate from the model fitting the design-based index with updated data M15.4 (2018) of 0.68. The substantially lower estimated survey catchability from M18.1 is a consequence of the distinctly higher scale of spawning stock biomass estimates from M18.1 (see below) relative to M18.2. The estimate of mean recruitment from M18.2 of 16.33 million is 13% lower than the estimate from M18.1 of 18.79 million and more consistent with the M15.4 (2018) estimate of 15.28 million. Interestingly, while the A_{50} and δ survey selectivity parameters were estimated substantially higher by M18.1 indicating older age at capture for the survey, estimates from M18.2 with the rescaled survey log-likelihood weight are more consistent with M15.4 (2015).



The following figure compares spawning stock biomass estimates between the 2015 final model M15.4 (2015), with that of the same model with data updated through 2018 (M15.4 2018) and the model fitting the VAST model-based survey index with rescaled weight on log-likelihood for the survey index (M18.2).



Model 18.2 estimates higher spawning stock biomass than either of the models fitting the design-based index throughout the time series, but below estimates from M18.1 that did not include the rescaled log-likelihood weight for survey data. Spawning stock biomass is estimated to be 5.5% higher 1961-1990 for M18.2 relative to M15.4 (2018), with progressively higher relative spawning stock biomass estimates after that point. The 2018 spawning stock biomass estimate from M18.2 is 13.9% higher than the model fitting the design-based index (M15.4 2018). Estimated uncertainty in the spawning stock biomass is

slightly higher from M18.2 relative to M15.4 (2018), with CVs 4.2% higher on average across the time series, but becoming more similar for spawning stock biomass estimates in years approaching 2018.

Overall, we contend that the VAST model-based estimator is likely providing more reasonable estimates of GOA northern rockfish biomass from bottom trawl survey data, because it: (1) partitions variance between the encounter probability and positive catch rate components of the survey process, and (2) accounts for the observed spatial correlation in northern rockfish survey observations, both of which provide potential benefits for this patchily-distributed species with infrequent encounter rates in the trawl survey. While we believe the inclusion of the model-based survey index in place of the design-based index is warranted, it is our opinion that the weight on the log-likelihood for the survey data be rescaled to account for the relative precision of the model and design-based survey indices, so as to provide consistency in the relative contribution of all data types to the overall assessment model objective function. Furthermore, relative to M18.1 the model fitting the new VAST model-based survey index but with rescaled data weighting (M18.2) produces estimates of model parameters (catchability, mean recruitment, and those describing survey selectivity) that are more consistent with the 2015 accepted model with updated data, M15.4 (2018). Therefore, we recommend the use of Model 18.2 which fits to the VAST model-based survey index but rescales the log-likelihood weight proportional to the difference in precision of the indices for the 2018 assessment of GOA northern rockfish.

Uncertainty results

From the MCMC chains described in the *Uncertainty Approach* section, we summarize the posterior densities of key parameters for the recommended model using histograms (Figure 10.14). We also use these posterior distributions to show uncertainty around time series estimates such as spawning biomass (Table 10.14 and Figures 10.9 and 10.15). Table 10.15 shows the maximum likelihood estimate (MLE) of key parameters with their corresponding standard deviations derived from the Hessian matrix compared to the standard deviations derived from MCMC methods. The Hessian and MCMC standard deviations are similar for q and M, but the MCMC standard deviations are larger for the estimates of $F_{40\%}$, ABC, and female spawning biomass. These larger standard deviations indicate that these parameters are more uncertain than indicated by the standard estimates. The distributions of $F_{40\%}$, *ABC*, total biomass, and spawning biomass are skewed, indicating there is a possibility of biomass being higher than model estimates.

Retrospective analysis

A within-model retrospective analysis of the recommended model was conducted for the last 10 years of the time-series by dropping data one year at a time. The revised Mohn's "rho" statistic (Hanselman et al. 2013) in female spawning biomass was -0.20, indicating that the model increases the estimate of female spawning biomass in recent years as data is added to the assessment. The retrospective female spawning biomass and the relative difference in female spawning biomass from the model in the terminal year are shown in Figure 10.16 (with 95% credible intervals from MCMC). In general, the relative difference in female spawning biomass in recent ranged from around -27% to around -3%, but there are some large changes (upwards of 100%) in the mid- to late-1970s.

When we present alternative model configurations, our usual criteria for choosing a superior model are: (1) the best overall fit to the data (in terms of negative log-likelihood), (2) biologically reasonable patterns of estimated recruitment, catchabilities, and selectivities, and (3) a good visual fit to length and age compositions, and (4) parsimony.

Model 18.2 generally produces good visual fits to the data survey data, a slight improvement in the fit to survey age composition data, and biologically reasonable patterns of recruitment, abundance, and selectivities. The 2018 model shows recent recruitment is low but increasing, and there was a decrease in spawning and total biomass from previous projections. Therefore the, 2019 recommended model is utilizing the new information effectively, and we use it to recommend 2019 ABC and OFL.

Time Series Results

Key results have been summarized in Tables 10.11 to 10.15. Model predictions fitted the data well (Figures 10.1 to 10.4 and 10.6) and most parameter estimates have remained similar to the last assessment's results, with the exception of small decreases in estimated in survey catchability and small increases in mean recruitment and parameters describing survey selectivity.

Definitions

Spawning biomass is the biomass estimate of mature females. Total biomass is the biomass estimate of all northern rockfish age two and greater. Recruitment is measured as the number of age two northern rockfish. Fishing mortality is fully-selected F, meaning the mortality at the age the fishery has fully selected the fish.

Biomass and exploitation trends

The estimates of current population abundance indicate that it is dominated by older fish from the 1970 and 1976 year-classes, and the above average 1984 and 1994 year-classes (Table 10.12). Since the early 1990s the total biomass estimated in the model has been decreasing from a high of over 189,000 t in 1992. Similarly, the spawning biomass estimated in the model has also been decreasing since 1998. However, the fit to the VAST model-based survey biomass index fails to capture the apparent increase in northern rockfish abundance indicated by point estimates of the 2005, 2007, 2013, and 2017 trawl surveys (Figure 10.4). Higher survey indices in these years may represent significant abundances of northern rockfish that are not fully accounted for in assessed biomass, but may also simply represent variation in survey catchability.

Goodman et al. (2002) suggested that stock assessment authors use a "management path" graph as a way to evaluate management and assessment performance over time. In the management path we plot the ratio of fishing mortality to F_{OFL} ($F_{35\%}$) and the estimated spawning biomass relative to $B_{35\%}$. Harvest control rules based on $F_{35\%}$ and $F_{40\%}$ and the tier 3b adjustment are provided for reference. The historical management path for northern rockfish has been above the F_{OFL} adjusted limit for only a few years in the 1960s. In recent years, northern rockfish have been above $B_{35\%}$ and below $F_{35\%}$ (Figure 10.10).

Parameter estimates from this year's model were similar to the previous northern rockfish assessment (Table 10.11). The trajectory of fishing mortality has remained below the $F_{40\%}$ level most of the time and below $F_{35\%}$ in all years except 1964-66 during the period of intense fishing for Pacific ocean perch (Figure 10.10). Selectivity estimates for the fishery and the survey are similar, but with the survey selectivity increasing somewhat more gradually with age. Compared to the maturity at age curve that is estimated, selectivity occurs at slightly younger ages than the age of maturity (Table 10.12 and Figure 10.11).

Recruitment

Recruitment estimates show a high degree of uncertainty, but indicate several large year-classes in the early and late 1970's, early 1980's and mid 1990's (Table 10.13 and 10.14 and Figure 10.12). Recent recruitment since 2005 has been considerably lower than the 1970 – 2005. Fits to the fishery and survey age compositions were reasonable with this year's recommended model (Figures 10.3 and 10.6). Increasing proportions of GOA northern rockfish in the plus age or length groups for both survey and fishery composition indicate a substantial number of individuals are successfully surviving natural and fishing mortality to attain old age and large size.

Harvest Recommendations

Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan defines the "overfishing level"

(OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Northern rockfish in the GOA are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$,,equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing.

Estimation of the $B_{40\%}$ reference point requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the average of age-2 recruitments between 1979 and 2016. Because of uncertainty in very recent recruitment estimates, we lag 2 years behind model estimates in our projection. Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. The 2018 estimates of these reference points are:

$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	$F_{40\%}$	$F_{35\%}$
76,199	30,480	26,670	0.061	0.073

Specification of OFL and Maximum Permissible ABC

Female spawning biomass for 2019 is estimated at 36,365 t. This is above the $B_{40\%}$ value of 30,480 t. Under Amendment 56, Tier 3, the maximum permissible fishing mortality for ABC is $F_{40\%}$ and fishing mortality for OFL is $F_{35\%}$. Applying these fishing mortality rates for 2019, yields the following ABC and OFL:

$F_{40\%}$	0.061
ABC	4,529
$F_{35\%}$	0.073
OFL	5,402

Projections and Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2018 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2019 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2018. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch after 2018 is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2019, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In 2019 and 2020, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the realized catches in 2015-2017 to the ABC recommended in the assessment for each of those years. For the remainder of the future years, maximum permissible ABC is used. (Rationale: In many fisheries the ABC is routinely not fully utilized, so assuming an average ratio catch to ABC will yield more realistic projections.)
>
> *Scenario 3*: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 4*: In all future years, F is set equal to the 2013-2017 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2018 or 2) above ½ of its MSY level in 2018 and above its MSY level in 2028 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2019 and 2020, F is set equal to *max* F_{ABC}, and in all subsequent years F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2020 or 2) above 1/2 of its MSY level in 2020 and expected to be above its MSY level in 2030 under this scenario, then the stock is not approaching an overfished condition.)

Spawning biomass, fishing mortality, and yield are tabulated for the seven standard projection scenarios (Table 10.16). The difference for this assessment for projections is in Scenario 2 (Author's F); we use pre-specified catches to increase accuracy of short-term projections in fisheries where the catch is usually less than the ABC. This was suggested to help management with setting preliminary ABCs and OFLs for two-year ahead specifications.

Status determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2019, it does not provide the best estimate of OFL for 2020, because the mean 2019 catch under Scenario 6 is predicated on the 2019 catch being equal to the 2019 OFL, whereas the actual 2019 catch will likely be less than the 2019 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2017) is 1,836 t. This is less than the 2017 OFL of 4,522 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2018:

a. If spawning biomass for 2018 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2018 is estimated to be above $B_{35\%}$ the stock is above its MSST.

c. If spawning biomass for 2018 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 10.16). If the mean spawning biomass for 2028 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:

a. If the mean spawning biomass for 2020 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2020 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2020 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2030. If the mean spawning biomass for 2030 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Table 10.16, the stock is not overfished and is not approaching an overfished condition.

Specified catch estimation

In response to Gulf of Alaska Plan Team minutes in 2010, we have established a consistent methodology for estimating current-year and future-year catches in order to provide more accurate two-year projections of ABC and OFL to management. In the past, two standard approaches in rockfish models have been employed; assume the full TAC will be taken, or use a certain date prior to publication of assessments as a final estimate of catch for that year. Both methods have disadvantages. If the author assumes the full TAC is taken every year, but it rarely is, the ABC will consistently be underestimated. Conversely, if the author assumes that the catch taken by around October is the final catch, and substantial catch is taken thereafter, ABC will consistently be overestimated. Therefore, going forward in the Gulf of Alaska rockfish assessments, for current year catch, we are applying an expansion factor to the official catch on or near October 1 by the 3-year average of catch taken between October 1 and December 31 in the last three complete catch years (e.g. 2015-2017 for this year). For northern rockfish, the expansion factor for 2018 catch is 1.07.

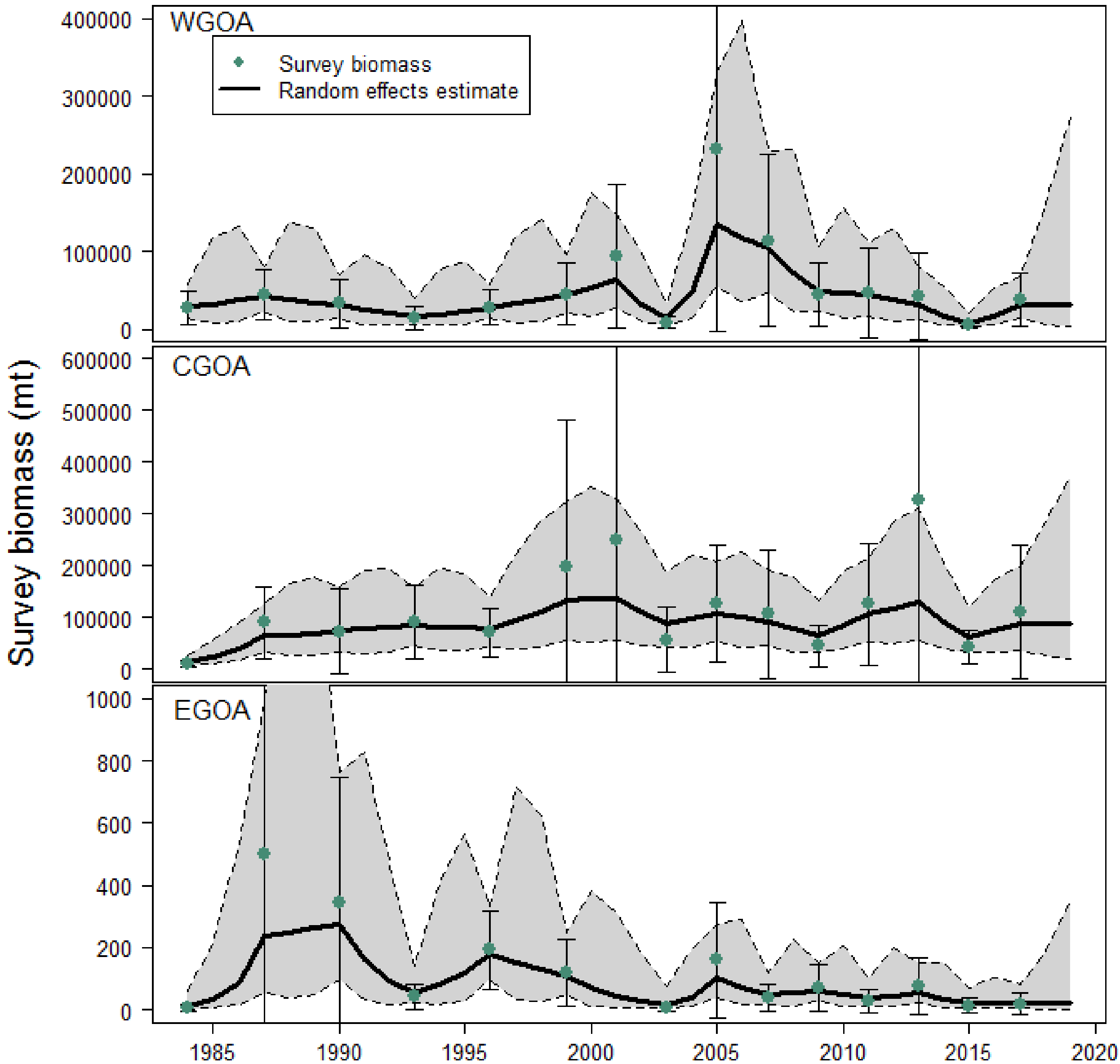
For catch projections into the next two years, we are using the ratio of the last three official catches to the last three TACs multiplied against the future two years' ABCs (if TAC is normally the same as ABC). This method results in slightly higher ABCs in each of the future two years of the projection, based on both the lower catch in the first year out, and based on the amount of catch taken before spawning in the projection two years out.

Alternative Projection

During the 2006 rockfish CIE review, it was suggested that projections should account for uncertainty in the entire assessment, not just recruitment from the endpoint of the assessment. We continue to present an alternative projection scenario using the uncertainty of the full assessment model, harvesting at the same estimated yield ratio (0.71) as Scenario 2, except for all years instead of the next two. This projection propagates uncertainty throughout the entire assessment procedure and is based on an MCMC chain of 10,000,000. The projection shows wide credibility intervals on future spawning biomass (Figure 10.15). The $B_{35\%}$ and $B_{40\%}$ reference points are based on the 1977-2016 year classes, and this projection predicts that the median spawning biomass will eventually dip to $B_{35\%}$ harvesting at maxABC in future years.

Apportionment of ABC

For this assessment the Plan Team and SSC requested that the random effects model proposed by the survey averaging working group be utilized for apportionment. The random effects model was fit to the survey biomass estimates (with associated variance) for the Western, Central, and Eastern Gulf of Alaska. The random effects model estimates a process error parameter (constraining the variability of the modeled estimates among years) and random effects parameters in each year modeled. The fit of the random effects model to survey biomass in each area is shown in the following figure. For illustration the 95% confidence intervals are shown for the survey biomass (error bars) and the random effects estimates of survey biomass (dashed lines).



In general the random effects model fits the area-specific design-based survey biomass estimates reasonably well. Based on the random effects estimates the area apportionments for Gulf of Alaska northern rockfish are 26.28% for the Western area (up from 11.4% in 2015), 73.7% for the Central area (down from 88.5% in 2015), and 0.02% for the Eastern area (same as in 2015). Overall, the trawl survey biomass increased in all three areas in 2017 compared to 2015. Applying the random effect model apportionments to the recommended ABC for northern rockfish results in 1,190 t for the Western area, 3,338 t for the Central area, and 1 t for the Eastern area. For management purposes, the small ABC of northern rockfish in the Eastern area is combined with other rockfish.

Ecosystem Considerations

In general, a determination of ecosystem considerations for northern rockfish is hampered by the lack of biological and habitat information. A summary of the ecosystem considerations presented in this section is listed in Table 10.17.

Ecosystem Effects on the Stock

Recent Observations: Two indicators presented in the GOA 2017 Ecosystem Status Report concerned the status of GOA northern rockfish. Rooper et al. (2017) analyzed GOA bottom trawl survey data for several species of adult rockfish and compared the CPUE along environmental gradients of depth, bottom temperature and position. No significant trends were observed across any rockfish species, suggesting that rockfish are not responding to temperature fluctuations by adjusting depth or distribution to maintain constant temperature. Additional indicators regarding rockfish in general concerned an analysis of fish condition using GOA bottom trawl survey data (Boldt et al., 2017) and young-of-the-year (YOY) rockfish abundance in the eastern GOA surface trawl survey (Strasburger et al., 2017). Fish condition for northern rockfish was the lowest on record and second lowest on record for Pacific ocean perch in 2017 (Boldt et al., 2017). YOY rockfish abundance was low in 2017 compared to previous years with a potentially northerly distribution shift based on the center of gravity estimates as well as some range expansion (Strasburger et al., 2017).

Prey availability/abundance trends: Similar to many other rockfish species, stock biomass of northern rockfish appears to be influenced by periodic abundant year-classes. Availability of suitable zooplankton prey items in sufficient quantity for larval or post-larval northern rockfish may be an important determining factor of year-class strength. Unfortunately, there is no information on the food habits of larval or post-larval rockfish to help determine possible relationships between prey availability and year-class strength. Moreover, identification to the species level for field collected larval slope rockfish is difficult. Visual identification is not possible, though genetic techniques allow identification to species level for larval slope rockfish (Gharrett et al. 2001). Some juvenile rockfish found in inshore habitat feed on shrimp, amphipods, and other crustaceans, as well as some mollusk and fish (Byerly 2001). Adult slope rockfish such as Pacific ocean perch and northern rockfish feed on euphausiids. Adult rockfish such as shortraker and rougheye are probably opportunistic feeders with more mollusks and fish in their diet. Little if anything is known about abundance trends of likely rockfish prey items. Euphausiids are also a major item in the diet of walleye pollock. Changes in the abundance of walleye pollock could lead to a corollary change in the availability of euphausiids, which would then have an impact on Pacific ocean perch and northern rockfish.

Predator population trends: Rockfish are preyed on by a variety of other fish at all life stages and to some extent by marine mammals during late juvenile and adult stages. Whether or not the impact of any particular predator is significant or dominant is unknown. Predator effects would likely be more important on larval, post-larval, and small juvenile slope rockfish, but information on these life stages and their predators is nil.

Changes in physical environment: Strong year-classes corresponding to the period around 1977 have been reported for many species of groundfish in the Gulf of Alaska, including Pacific ocean perch, northern rockfish, sablefish, and Pacific cod. Therefore, it appears that environmental conditions may have changed during this period in such a way that survival of young-of-the-year fish increased for many groundfish species, including slope rockfish. Pacific ocean perch appear to have had a strong 1986 or 1987 year-class, and northern rockfish appear to have had a strong 1984 year-class. There may be other years when environmental conditions were especially favorable for rockfish species. The environmental mechanism for this increased survival remains unknown. Changes in water temperature and currents could have effects on prey item abundance and success of transition of rockfish from pelagic to demersal stage. Rockfish in early juvenile stage have been found in floating kelp patches which are subject to ocean currents.

Changes in bottom habitat due to natural or anthropogenic causes could alter survival rates by altering available shelter, prey, or other functions. Submersible studies on the GOA shelf observed juvenile red rockfish closely associated with sponges that were growing on boulders (Freese and Wing 2003). The Essential Fish Habitat Environmental Impact Statement (EFH EIS) (NMFS 2005) concluded that the effects of commercial fishing on the habitat of groundfish is minimal or temporary based largely on the criterion that groundfish stocks were above Minimum Stock Size Threshold (MSST). However, such criteria are inadequate to make such a conclusion (Drinkwater 2004). While proof of adverse effects on habitat would be difficult to obtain, the lack of an increasing trend in stock abundance and relatively low levels of recent recruitment are not supportive of the EIS conclusions.

Rockfish fishery effects on the ecosystem

Fishery-specific contribution to bycatch of HAPC biota: In the Gulf of Alaska, bottom trawl fisheries for pollock, deepwater flatfish, and Pacific ocean perch account for most of the observed bycatch of coral, while rockfish fisheries account for little of the bycatch of sea anemones, sea whips, and sea pens. The bottom trawl fisheries for Pacific ocean perch and Pacific cod and the pot fishery for Pacific cod account for most of the observed bycatch of sponges (Table 10.4).

Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components: The directed slope rockfish trawl fishery that begins in July is concentrated in known areas of abundance and typically lasts only a few weeks. The annual exploitation rates on rockfish are thought to be quite low. Insemination is likely in the fall or winter, and parturition is likely mostly in the spring. Hence, reproductive activities are probably not directly affected by the commercial fishery.

Fishery-specific effects on amount of large size target fish: No evidence for targeting large fish.

Fishery contribution to discards and offal production: Fishery discard rates of northern rockfish during 2009-2018 have been 1.5 – 5.0%.

Fishery-specific effects on age-at-maturity and fecundity of the target fishery: Unknown.

Fishery-specific effects on EFH living and non-living substrate: Unknown, but the heavy-duty "rockhopper" trawl gear commonly used in the fishery can disturb seafloor habitat. Table 10.4 shows the estimated bycatch of living structure such as benthic urochordates, corals, sponges, sea pens, and sea anemones by the GOA rockfish fisheries. The average bycatch of corals/bryozoans (1.09 t), and sponges (5.59 t) by rockfish fisheries are a large proportion of the catch of those species taken by all Gulfwide fisheries.

Data Gaps and Research Priorities

Life history and habitat utilization

There is little information on larval, post-larval, or early life history stages of northern rockfish. Habitat requirements for larval, post-larval, and early stages are mostly unknown. Habitat requirements for later stage juvenile and adult fish are anecdotal or conjectural. Research needs to be done on the bottom habitat of the major fishing grounds, on what HAPC biota are found on these grounds, and on what impact bottom trawling may have on these biota.

Assessment Data

The highly variable design-based biomass estimates for northern rockfish from bottom trawl survey suggest that the stratified random design of the surveys does a relatively poor job of assessing stock condition of northern rockfish and that a different survey approach may be needed to reduce the variability in biomass estimates. In particular, the CIE review report recommended that assumptions about extending area-swept estimates of biomass in trawlable versus untrawlable grounds may impact catchability assumptions. The AFSC is currently undertaking a study on habitat classifications so that assumptions about catchability, in particular, time-dependent changes in catchability, can be more rigorously established.

To address this issue, we have evaluated and proposed a model-based trawl survey biomass index as an alternative the design-based index that informed previous GOA northern rockfish assessments. The model-based survey biomass index is generated by a Vector Autoregressive Spatio-Temporal (VAST) model. The benefits of the VAST model-based approach to survey index standardization are that as a delta-model it partitions the likelihood of trawl survey observations between encounter probability and positive catch rate components, and accounts for spatial and spatio-temporal correlations in survey catch rates.

Given the substantial influence of maturity-at-age on management quantities (i.e., ABC) we strongly suggest that continued research be devoted to collecting maturity-at-age data for northern and other Gulf of Alaska rockfish. A proposal is currently in the process of being developed that would collect a larger sample size for northern rockfish and compare maturity at age estimates to previous studies. If funded, additional data collected as part of this study would be used to investigate possible time-dependent maturity.

Literature Cited

Ackley, D. R., and J. Heifetz. 2001. Fishing practices under maximum retainable bycatch rates in Alaska's groundfish fisheries. Alaska Fish. Res. Bull. 8:22-44.

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. NOAA Tech. Rep. NMFS 66, 151 p.

Alverson, D. L., and M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer 36(2): 133-143.

Berkeley, S. A., M. A. Hixon, R. J. Larson, and M. S. Love. 2004. Fisheries Sustainability via Protection of Age Structure and Spatial Distribution of Fish Populations. Fisheries 29:23-32.

Bettoli, P.W., and L.E. Miranda. 2001. Cautionary note about estimating mean length at age with subsampled data. N. Amer. J. Fish. Man. 21:425-428.

Beyer, S. G., S.M. Sogard, C.J. Harvey, and J.C. Field. 2015. Variability in rockfish (Sebastes spp.) fecundity: species contrasts, maternal size effects, and spatial differences. Environmental Biology of Fishes 98(1): 81-100.

Boldt, J. L., and L. J. Haldorson. 2004. Size and condition of wild and hatchery pink salmon juveniles in Prince William Sound, Alaska. Transactions of the American Fisheries Society 133:173.

Brodeur, R. D., 2001 Habitat -specific distribution of Pacific ocean perch (*Sebastes alutus*) in Pribilof Canyon, Bering Sea. Continental Shelf Research 21:207-224.

Byerly, M. M., 2001. The ecology of age 1 Copper Rockfish (*Sebastes caurinus*) in vegetated habitats of Sitka sound, Alaska. M.S. Thesis University of Alaska, Fairbanks.

Carlson, H.R., and R.R. Straty. 1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky, coastal areas of southeastern Alaska. Mar. Fish. Rev. 43(7): 13-19.

Chilton, E., 2007. Maturity of female northern rockfish *Sebastes polyspinis* in the central Gulf of Alaska. Alaska Fish. Res. Bull. 12:264-269.

Chilton, D.E., and R.J. Beamish. 1982. Age determination methods for fishes studied by the groundfish program at the Pacific Biological Station. Can. Spec. Pub. Fish. Aquat. Sci. 60.

Clausen, D., and J. Heifetz. 2002. The Northern rockfish, *Sebastes polyspinis*, in Alaska: commercial fishery, distribution, and biology. Mar. Fish. Rev. 64: 1-28.

Courtney, D.L., J. Heifetz, M. F. Sigler, and D. M. Clausen. 1999. An age structured model of northern rockfish, *Sebastes polyspinis*, recruitment and biomass in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2000. Pp. 361-404. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Courtney, D.L., J. N. Ianelli, D. Hanselman, and J. Heifetz. 2007. Extending statistical age-structured assessment approaches to Gulf of Alaska rockfish (Sebastes spp.). In: Heifetz, J., DiCosimo J., Gharrett, A.J., Love, M.S, O'Connell, V.M, and Stanley, R.D. (eds.). Biology, Assessment, and Management of North Pacific Rockfishes. Alaska Sea Grant, University of Alaska Fairbanks. pp 429–449.

de Bruin, J., R. Gosden, C. Finch, and B. Leaman. 2004. Ovarian aging in two species of long-lived rockfish, *Sebastes aleutianus* and *S. alutus*. Biol. Reprod. 71: 1036-1042.

Drinkwater, K., 2004. Summary Report: Review on evaluation of fishing activities that may adversely affect Essential Fish Habitat (EFH) in Alaska. Center of Independent Experts Review (CIE) June 2004, Alaska Fisheries Science Center, Seattle, Washington.

Du Preez, C. and V. Tunnicliffe. 2011. Shortspine thornyhead and rockfish (Scorpaenidae) distribution in response to substratum, biogenic structures and trawling. Mar. Ecol. Prog. Ser 425: 217-231.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Freese, J.F., and B.L. Wing. 2003. Juvenile red rockfish, *Sebastes* spp., associations with sponges in the Gulf of Alaska. Mar. Fish. Rev. 65(3):38-42.

Gelman, A., J.B. Carlin, H.S. Stern, and D.B. Rubin. 1995. Bayesian data analysis. Chapman and Hall, London. 526 pp.

Gertseva, V., and J. T. Thorson. 2013. Status of the darkblotched rockfish resource off the continental U.S. Pacific Coast in 2013. National Marine Fisheries Service, Northwest Fisheries Science Center, Fisheries Resource and Monitoring Division, Seattle, WA.

Gharrett, A. J., A.K. Gray, and J. Heifetz. 2001. Identification of rockfish (*Sebastes* spp.) from restriction site analysis of the mitochondrial NM-3/ND-4 and 12S/16S rRNA gene regions. Fish. Bull. Fish. Bull. 99:49-62.

Gharrett, A. J., A. K. Gray, D. Clausen and J. Heifetz. 2003. Preliminary study of the population structure in Alaskan northern rockfish, *Sebastes polyspinis*, based on microsatellite and tDNA variation. Fisheries Division, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Juneau AK 99801 Unpublished contract report. 16 p.

Gharrett, A. J., R. J. Riley, and P. D. Spencer. 2012. Genetic analysis reveals restricted dispersal of northern rockfish along the continental margin of the Bering Sea and Aleutian Islands. Trans. Am. Fish. Soc. 141:370-382.

Goodman, D., M. Mangel, G. Parkes, T.J. Quinn II, V. Restrepo, T. Smith, and K. Stokes. 2002. Scientific Review of the Harvest Strategy Currently Used in the BSAI and GOA Groundfish Fishery Management Plans. Draft report. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hannah, R. W., and S. J. Parker. 2007. Age-modulated variation in reproductive development of female Pacific Ocean Perch (*Sebastes alutus*) in waters off Oregon. Pages 1–20 *in* J. Heifetz, J. DiCosimo, A. J. Gharrett, M. S. Love, V. M. O'Connell, and R. D. Stanley, editors. Biology, assessment, and management of North Pacific rockfishes. University of Fairbanks, Alaska Sea Grant Program, Report AK-SG-07-01, Fairbanks.

Hanselman, D., P. Spencer, S.K. Shotwell, and R. Reuter. 2007. Localized depletion of three Alaska rockfish species, p. 493-511. In J. Heifetz, J. DiCosimo, A. J. Gharrett, M. S. Love, V. M. O'Connell, and R. D. Stanley (editors), Biology, Assessment, and Management of North Pacific Rockfishes. University of Alaska Sea Grant Program Report No. AK-SG-07-01, University of Alaska, Fairbanks.

Hanselman, D.H., B. Clark, and M. Sigler. 2013. Report of the groundfish plan team retrospective investigations group, part II: the compilation. Presented at September 2013 Plan Team, 12 pp. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/Retrospectives_2013_final3.pdf

Heifetz, J., 2002. Coral in Alaska: distribution, abundance, and species associations. Hydrobiologia. 471:19-28.

Heifetz, J., D. Hanselman, J. Ianelli, S.K. Shotwell, and C. Tribuzio. 2009. Assessment of the Northern Rockfish Stock in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the 2010 Gulf of Alaska groundfish fishery, p. 817-874. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Heifetz, J., and D. M. Clausen. 1991. Slope rockfish. In Stock assessment and fishery evaluation report for the 1992 Gulf of Alaska groundfish fishery, p. 5-1 - 5-30. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Heifetz, J., D. M. Clausen, and J. N. Ianelli. 1994. Slope rockfish. In Stock assessment and fishery evaluation report for the 1995 Gulf of Alaska groundfish fishery, p. 5-1 - 5-24. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hulson, P.-J. F., D. H. Hanselman, S. K. Shotwell, and J. N. Ianelli, 2011. Assessment of the northern rockfish stock in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 893-970. North Pacific Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99501.

Ito, D. H., 1982. A cohort analysis of Pacific ocean perch stocks from the Gulf of Alaska and Bering Sea regions. U.S. Dept. Commer., NWAFC Processed Rept. 82-15.

Jones, G.L., and J.P. Hobert. 2001. Honest exploration of intractable probability distributions via Markov Chain Monte Carlo. Statistical Science 16(4):312-334.

Kamin, L. M., K. J. Palof, J. Heifetz, and A.J. Gharrett, A. J. 2013. Interannual and spatial variation in the population genetic composition of young-of-the-year Pacific ocean perch (Sebastes alutus) in the Gulf of Alaska. Fisheries Oceanography. doi: 10.1111/fog.12038

Krieger, K. J., 1993. Distribution and abundance of rockfish determined from a submersible and by bottom trawling. Fish. Bull. 91: 87-96.

Krieger, K.J., and B. L. Wing .2002. Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. Hydrobiologica 471: 83-90.

Laman, E.A., S. Kotwicki, and C.N. Rooper. 2015. Correlating environmental and biogenic factors with abundance and distribution of Pacific ocean perch (Sebastes alutus) in the Aleutian Islands, Alaska. Fishery Bulletin 113(3).

Leaman, B. M., 1991. Reproductive styles and life history variables relative to exploitation and management of *Sebastes* stocks. Environmental Biology of Fishes 30: 253-271.

Malecha, P.W., D.H. Hanselman, and J. Heifetz. 2007. Growth and mortality of rockfishes (*Scorpaenidae*) from Alaska waters. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-172, 61 p.

Maunder, M. N., and A. E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70:141-159.

Methot, R. D., and I. G. Taylor. 2011. Adjusting for bias due to variability of estimated recruitments in fishery assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68:1744-1760.

Miller, J.A., and A L. Shanks. 2004. Evidence for limited larval dispersal in black rockfish (*Sebastes melanops*): implications for population structure and marine-reserve design Canadian Journal of Fisheries and Aquatic Sciences, 61(9) pp. 1723-1735.

National Marine Fisheries Service. 2005. Final Environmental Impact Statement for Essential Fish Habitat Identification and Conservation in Alaska. http://www.fakr.noaa.gov/habitat/seis/efheis.htm.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York, 542 p.

Rodgveller, C., J. Heifetz, and C. Lunsford. 2010. Maturity estimates for Pacific ocean perch (*Sebastes alutus*), dusky (*S. ciliatus*), northern (*S. polyspinus*), rougheye (*S. aleutianus*), and blackspotted (*S. melanostictus*) rockfish. Report submitted to the Gulf of Alaska Groundfish Plan Team.

Rodgveller, C.J., C.R. Lunsford, and J.T. Fujioka. 2012. Effects of maternal age and size on embryonic energy reserves, developmental timing, and fecundity in quillback rockfish (*Sebastes maliger*). Fishery Bulletin 110(1): 36-45.

Shelton, A. O., J. T. Thorson, E. J. Ward, and B. E. Feist. 2014. Spatial semiparametric models improve estimates of species abundance and distribution. Canadian Journal of Fisheries and Aquatic Sciences 71:1655-1666.

Spencer, P.D., and J.N. Ianelli. 2012. Assessment of the Pacific ocean perch stock in the Bering Sea/Aleutian Islands. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands, p. 1291-1348. North Pacific Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99501.

Stefansson, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES Journal of Marine Science 53:577-588.

Thorson, J. T. 2018. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. Fisheries Research. 210: 143-161.

Thorson, J. T., and K. Kristensen. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fisheries Research 175: 66-74.

Thorson, J. T., A. O. Shelton, E. J. Ward, and H. Skaug. 2015a. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES Journal of Marine Science. Doi: 10.1093/icesjms/fsu243.

Thorson, J. T., H. J. Skaug, K. Kristensen, A. O. Shelton, E. J. Ward, J. H. Harms, and J. A. Benante. 2015b. The importance of spatial models for estimating the strength of density dependence. Ecology 96:1202-1212.

Thorson, J. T., I. J. Stewart, and A. E. Punt. 2011. Accounting for fish shoals in single- and multi-species survey data using mixture distribution models. Canadian Journal of Fisheries and Aquatic Sciences 68:1681-1693.

Thorson, J. T., and E. J. Ward. 2014. Accounting for vessel effects when standardizing catch rates among cooperative surveys. Fisheries Research 155:168-176.

Ver Hoef, J. M., and J. K. Jansen. 2007. Space—time zero-inflated count models of Harbor seals. Environmetrics 18:697-712.

von Szalay, P. G., and N. W. Raring. 2016. Data report: 2015 Gulf of Alaska bottom trawl survey., U.S. Dep. of Commer.

Withler, R.E., T.D. Beacham, A.D. Schulze, L.J. Richards, and K.M. Miller. 2001. Co-existing populations of Pacific ocean perch, *Sebastes alutus*, in Queen Charlotte Sound, British Columbia. Mar. Bio. 139: 1-12.

Yang, M-S., 1993. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-22, 150 p.

Yang, M-S., 1996. Diets of the important groundfishes in the Aleutian Islands in summer 1991. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-60, 105 p.

Yang, M-S., and M. W. Nelson. 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-112, 174 p.

Tables

Table 10.1. A summary of key management measures and the time series of catch, ABC and TAC for northern rockfish in the Gulf of Alaska.

Year	Catch (t)	ABC	TAC		Management Measures
1988*	1,107				The slope rockfish assemblage, including northern rockfish, was one of three management groups for *Sebastes* implemented by the North Pacific Management Council. Previously, *Sebastes* in Alaska were managed as “Pacific ocean perch complex” or “other rockfish”
1989*	1,527				
1990*	1,716				
1991*	4,528				Slope assemblage split into three management subgroups with separate ABCs and TACs: Pacific ocean perch, shortraker/rougheye rockfish, and all other slope species
1992*	7,770				
1993	4,820	5,760	5,760		Northern rockfish designated as a subgroup of slope rockfish with separate ABC and TAC
1994	5,966	5,760	5,760		
1995	5,635	5,270	5,270		
1996	3,340	5,720	5,270		
1997	2,935	5,000	5,000		
1998	3,055	5,000	5,000		
1999	5,409	4,990	4,990		Eastern GOA divided into West Yakutat and East Yakutat/Southeast Outside in response to trawl closure in Eastern GOA. Because northern rockfish are scarce in Eastern GOA, the ABC and TAC for northern rockfish in Eastern GOA allocated to West Yakutat ABC as part of "other slope rockfish".
2000	3,333	5,120	5,120		Amendment 41 became effective which prohibited trawling in the Eastern Gulf east of 140 degrees W. Preliminary age-structured model results presented for northern rockfish.
2001	3,133	4,880	4,880		Assessment and harvest recommendations now based on using an age structured model constructed with AD Model Builder software.
2002	3,339	4,770	4,770		
2003	5,256	5,530	5,530		
2004	4,811	4,870	4,870		
2005	4,522	5,091	5,091		
2006	4,958	5,091	5,091		
2007	4,187	4,938	4,938		Amendment 68 created the Central Gulf Rockfish Pilot Project

* Northern rockfish managed as part of the slope rockfish assemblage and not assigned separate ABC/TAC

Table 10.1. (continued) A summary of key management measures and the time series of catch, ABC and TAC for northern rockfish in the Gulf of Alaska.

Year	Catch (t)	ABC	TAC		Management Measures
2008	4,052	4,549	4,549		
2009	3,952	4,362	4,362		
2010	3,902	5,098	5,098		
2011	3,443	4,854	4,854		NPFMCs Central GOA Rockfish Program goes into effect starting with 2012 fishery
2012	5,077	5,507	5,507		
2013	4,879	5,130	5,130		
2014	4,277	5,324	5,324		
2015	3,944	4,999	4,999		
2016	3,437	4,004	4,004		
2017	1,836	3,786	3,786		
2018	2,288	3,685	3,685		

Table 10.2. Commercial catch (t) and management action for northern rockfish in the Gulf of Alaska, 1961-present. The *Description of the catch time series* Section describes procedures used to estimate catch during 1961-1993. Catch estimates for 1993-2017 are from NMFS Observer Program and Alaska Regional Office updated through October 9, 2018.

Year	Foreign	Joint venture	Domestic	Total	TAC	%TAC
1961	800	-	-	800	-	-
1962	3,250	-	-	3,250	-	-
1963	6,815	-	-	6,815	-	-
1964	12,170	-	-	12,170	-	-
1965	17,430	-	-	17,430	-	-
1966	10,040	-	-	10,040	-	-
1967	6,000	-	-	6,000	-	-
1968	5,010	-	-	5,010	-	-
1969	3,630	-	-	3,630	-	-
1970	2,245	-	-	2,245	-	-
1971	3,875	-	-	3,875	-	-
1972	3,880	-	-	3,880	-	-
1973	2,820	-	-	2,820	-	-
1974	2,550	-	-	2,550	-	-
1975	2,520	-	-	2,520	-	-
1976	2,275	-	-	2,275	-	-
1977	622	-	-	622	-	-
1978	553	-	-	554	-	-
1979	666	3	-	670	-	-
1980	809	tr	-	810	-	-
1981	1,469	-	-	1,477	-	-
1982	3,914	-	-	3,920	-	-
1983	2,705	911	-	3,618	-	-
1984	494	497	10	1,002	-	-
1985	tr	115	70	185	-	-
1986	tr	11	237	248	-	-

Table 10.2 (continued). Commercial catch (t) and management action for northern rockfish in the Gulf of Alaska, 1961-present. The *Description of the catch time series* Section describes procedures used to estimate catch during 1961-1993. Catch estimates for 1993-2017 are from NMFS Observer Program and Alaska Regional Office updated through October 9, 2018.

Year	Foreign	Joint venture	Domestic	Total	TAC	%TAC
1987	-	56	427	483	-	-
1988[1]	-	tr	1,107	1,107	-	-
1989	-	-	1,527	1,527	-	-
1990	-	-	1,697	1,716	-	-
1991[2]	-	-	4,528	4,528	-	-
1992	-	-	7,770	7,770	-	-
1993[3]	-	-	4,820	4,820	5,760	84%
1994	-	-	5,966	5,966	5,760	104%
1995	-	-	5,635	5,635	5,270	107%
1996	-	-	3,340	3,340	5,270	63%
1997	-	-	2,935	2,935	5,000	59%
1998	-	-	3,055	3,055	5,000	61%
1999	-	-	5,409	5,409	4,990	108%
2000	-	-	3,333	3,333	5,120	65%
2001	-	-	3,133	3,133	4,880	64%
2002	-	-	3,339	3,339	4,770	70%
2003	-	-	5,256	5,256	5,530	95%
2004	-	-	4,811	4,811	4,870	99%
2005	-	-	4,522	4,522	5,091	89%
2006	-	-	4,958	4,958	5,091	97%
2007[4]	-	-	4,187	4,187	4,938	85%
2008	-	-	4,052	4,052	4,549	89%
2009	-	-	3,952	3,952	4,362	91%
2010	-	-	3,902	3,902	5,098	77%
2011	-	-	3,443	3,440	4,854	71%
2012	-	-	5,077	5,063	5,507	92%
2013	-	-	4,879	4,569	5,130	89%
2014	-	-	4,277	4,277	5,324	80%
2015	-	-	3,944	3,944	4,999	79%
2016	-	-	3,437	3,437	4,004	86%
2017	-	-	1,836	1,836	3,786	48%
2018*	-	-	2,440	2,440	3,685	66%

[1] 1988 - Slope rockfish assemblage management implemented by NPFMC.

[2] 1991 - Slope rockfish divided into 3 management subgroups: Pacific ocean perch, shortraker/ rougheye, and other slope rockfish.

[3] 1993 – A fourth management subgroup, northern rockfish, was created

[4] 2007 – Central Gulf Rockfish Pilot Project implemented for rockfish fishery.

* Catch as of 10/9/2018.

Table 10.3. Incidental catch of FMP groundfish species caught in rockfish targeted fisheries in the Gulf of Alaska from 2014 - 2018. Conf. = Confidential data since # vessels or # processors is fewer than or equal to 2. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/07/2018.

Group Name	2014	2015	2016	2017	2018	Average
Pacific Ocean Perch	15,283	17,566	20,402	19,077	20,709	18,607
Northern Rockfish	3,647	3,632	3,155	1,602	2,146	2,836
GOA Dusky Rockfish	2,752	2,492	3,004	2,192	2,679	2,624
Arrowtooth Flounder	1,425	1,397	1,200	1,404	557	1,197
Pollock	1,339	1,329	572	1,056	721	1,004
Other Rockfish	735	849	972	748	987	858
Atka Mackerel	446	988	595	543	1,138	742
Sablefish	527	434	481	585	622	530
Pacific Cod	625	785	365	253	372	480
GOA Rougheye Rockfish	359	225	351	269	314	303
GOA Thornyhead Rockfish	243	220	336	360	347	301
GOA Shortraker Rockfish	243	238	291	253	262	257
GOA Rex Sole	84	116	140	112	119	114
GOA Deep Water Flatfish	68	44	64	58	58	59
Sculpin	33	44	43	45	61	45
Flathead Sole	30	46	26	81	36	44
GOA Demersal Shelf Rockfish	38	39	40	40	57	43
GOA Skate, Longnose	26	33	46	42	21	34
GOA Skate, Other	45	21	18	22	21	25
Squid	19	24	12	22	28	21
GOA Shallow Water Flatfish	28	27	15	11	18	20
Shark	2	6	12	40	15	15
GOA Skate, Big	4	7	5	6	3	5
Octopus	7	11	2	1	2	5
Halibut	1	0	1	6	2	2

Table 10.4. Non-FMP species bycatch estimates in tons for Gulf of Alaska rockfish targeted fisheries 2014 - 2018. Conf. = Confidential data since # vessels or # processors is fewer than or equal to 2. Note that Birds are estimated in numbers rather than tons. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/07/2018.

Group Name	2014	2015	2016	2017	2018
Benthic urochordata	Conf.	0.28	0.50	0.20	0.01
Birds - Northern Fulmar	Conf.	-	-	Conf.	50
Bivalves	0.01	Conf.	Conf.	0.01	0.003
Brittle star unidentified	0.05	0.05	0.03	0.60	0.01
Capelin	-	-	Conf.	-	-
Corals Bryozoans - Corals Bryozoans Unidentified	1.92	0.70	0.85	0.47	1.53
Corals Bryozoans - Red Tree Coral	Conf.	Conf.	-	-	-
Deep sea smelts (bathylagidae)	-	-	-	-	Conf.
Eelpouts	0.13	0.01	0.02	0.13	0.22
Eulachon	0.02	0.03	0.04	0.13	0.12
Giant Grenadier	513	786	438	1,006	427
Greenlings	4	8	6	4	4
Grenadier - Rattail Grenadier Unidentified	Conf.	44	3	Conf.	22
Gunnels	-	Conf.	-	-	-
Hermit crab unidentified	0.04	0.03	0.01	0.03	0.01
Invertebrate unidentified	Conf.	0.19	0.09	0.07	0.54
Lanternfishes (myctophidae)	-	0.04	0.14	0.003	0.003
Misc crabs	0.08	0.16	0.35	1.14	0.58
Misc crustaceans	Conf.	Conf.	0.03	0.01	0.13
Misc deep fish	-	-	Conf.	Conf.	-
Misc fish	125	143	102	115	137
Misc inverts (worms etc)	-	-	Conf.	-	-
Other osmerids	Conf.	Conf.	0.03	Conf.	-
Pacific Hake	-	Conf.	0.04	Conf.	0.06
Pandalid shrimp	0.10	0.05	0.22	0.14	0.07
Polychaete unidentified	-	-	-	0.02	-
Scypho jellies	5.13	1.63	8.05	0.54	0.67
Sea anemone unidentified	2.15	1.14	1.27	0.79	0.40
Sea pens whips	0.06	Conf.	0.02	0.03	0.002
Sea star	1.60	3.48	1.72	3.64	4.45
Snails	0.10	0.26	0.18	0.18	6.19
Sponge unidentified	1.81	5.45	2.88	3.20	14.63
State-managed Rockfish	50	47	13	24	50
Stichaeidae	Conf.	Conf.	-	Conf.	1.53
Urchins dollars cucumbers	0.21	0.99	0.34	0.43	0.24

Table 10.5. Prohibited Species Catch (PSC) estimates reported in tons for halibut and herring, and thousands of animals for crab and salmon, by year, for the GOA rockfish fishery 2014 - 2018. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/07/2018.

Group Name	2014	2015	2016	2017	2018	Average
Bairdi Tanner Crab	0.19	0.05	0.01	0.76	0.20	0.24
Blue King Crab	0	0	0	0	0	0
Chinook Salmon	1.25	1.91	0.38	0.52	0.29	0.87
Golden (Brown) King Crab	0.03	0.02	0.02	0.21	0.32	0.12
Halibut	127	157	124	126	52	117
Herring	0	0	0	0	0	0
Non-Chinook Salmon	0.56	0.34	0.22	0.64	0.30	0.41
Opilio Tanner (Snow) Crab	0	0	0	0	0.12	0.02
Red King Crab	0	0	0	0	0	0

Table 10.6. Fishery length (cm) compositions used in the assessment model for northern rockfish in the Gulf of Alaska (at-sea and port samples combined).

Length class (cm)	Year									
	1991	1992	1993	1994	1995	1996	1997	2003	2007	2009
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
24	0.001	0.000	0.000	0.000	0.002	0.000	0.002	0.000	0.000	0.000
25	0.002	0.000	0.000	0.000	0.004	0.000	0.006	0.001	0.000	0.000
26	0.003	0.000	0.001	0.000	0.007	0.000	0.014	0.001	0.000	0.000
27	0.004	0.000	0.001	0.001	0.009	0.001	0.020	0.002	0.001	0.001
28	0.007	0.001	0.002	0.002	0.008	0.002	0.021	0.002	0.002	0.001
29	0.010	0.003	0.005	0.004	0.010	0.003	0.021	0.007	0.002	0.001
30	0.023	0.006	0.010	0.007	0.013	0.007	0.019	0.012	0.007	0.004
31	0.041	0.015	0.024	0.017	0.015	0.006	0.014	0.031	0.009	0.009
32	0.072	0.032	0.046	0.030	0.021	0.013	0.015	0.045	0.023	0.010
33	0.123	0.053	0.079	0.070	0.043	0.028	0.029	0.071	0.038	0.020
34	0.180	0.094	0.109	0.116	0.081	0.058	0.054	0.075	0.060	0.038
35	0.196	0.139	0.156	0.175	0.127	0.122	0.115	0.084	0.085	0.077
36	0.145	0.157	0.166	0.199	0.156	0.177	0.159	0.075	0.105	0.098
37	0.091	0.154	0.127	0.171	0.164	0.189	0.173	0.083	0.124	0.111
38+	0.102	0.346	0.273	0.209	0.336	0.393	0.337	0.510	0.542	0.630
Sample size	15,321	15,207	10,732	8,138	11,537	7,942	5,261	6,025	7,101	6,045
# Hauls	147	125	94	90	121	108	73	374	489	456

Table 10.6 (continued) Fishery length (cm) compositions used in the assessment model for northern rockfish in the Gulf of Alaska (at-sea and port samples combined).

Length class (cm)	Year			
	2011	2013	2015	2017
15	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000
24	0.000	0.001	0.000	0.001
25	0.000	0.001	0.001	0.000
26	0.000	0.001	0.001	0.001
27	0.000	0.001	0.001	0.001
28	0.000	0.002	0.002	0.002
29	0.001	0.003	0.004	0.010
30	0.001	0.003	0.005	0.007
31	0.002	0.006	0.009	0.010
32	0.005	0.004	0.010	0.014
33	0.011	0.009	0.011	0.020
34	0.023	0.019	0.018	0.030
35	0.051	0.036	0.033	0.030
36	0.076	0.066	0.054	0.043
37	0.103	0.099	0.110	0.067
38+	0.725	0.751	0.739	0.765
Sample size	5,121	6,418	7176	3529
# Hauls	403	500	554	378

Table 10.7. Fishery age compositions for northern rockfish in the Gulf of Alaska. All age compositions are based on “break and burn” reading of otoliths.

Age	Year							
	1998	1999	2000	2001	2002	2004	2005	2006
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.006	0.002	0.000	0.000	0.001	0.000	0.000
6	0.004	0.003	0.024	0.011	0.000	0.015	0.000	0.006
7	0.006	0.006	0.005	0.055	0.032	0.008	0.021	0.002
8	0.034	0.000	0.015	0.024	0.151	0.036	0.045	0.046
9	0.022	0.042	0.019	0.031	0.070	0.111	0.066	0.064
10	0.032	0.013	0.043	0.038	0.055	0.176	0.147	0.070
11	0.058	0.029	0.031	0.049	0.042	0.050	0.164	0.132
12	0.070	0.039	0.058	0.042	0.044	0.035	0.052	0.070
13	0.094	0.049	0.053	0.053	0.047	0.036	0.017	0.048
14	0.094	0.062	0.048	0.051	0.032	0.028	0.031	0.034
15	0.068	0.127	0.074	0.040	0.031	0.027	0.038	0.034
16	0.078	0.065	0.094	0.053	0.047	0.032	0.026	0.020
17	0.034	0.058	0.067	0.084	0.068	0.015	0.019	0.016
18	0.034	0.042	0.060	0.060	0.067	0.025	0.031	0.038
19	0.022	0.019	0.024	0.044	0.032	0.046	0.026	0.028
20	0.026	0.023	0.022	0.027	0.026	0.058	0.033	0.020
21	0.044	0.032	0.010	0.035	0.023	0.035	0.045	0.040
22	0.050	0.029	0.043	0.018	0.021	0.029	0.024	0.050
23	0.036	0.075	0.034	0.033	0.013	0.023	0.026	0.036
24	0.030	0.042	0.046	0.033	0.029	0.011	0.009	0.024
25	0.022	0.010	0.022	0.044	0.044	0.012	0.009	0.010
26	0.024	0.026	0.029	0.042	0.028	0.021	0.005	0.012
27	0.012	0.016	0.014	0.013	0.011	0.039	0.026	0.018
28	0.010	0.042	0.021	0.020	0.008	0.029	0.031	0.018
29	0.026	0.036	0.024	0.009	0.010	0.012	0.024	0.034
30	0.020	0.023	0.041	0.018	0.011	0.017	0.028	0.032
31	0.006	0.029	0.019	0.020	0.011	0.011	0.007	0.022
32	0.010	0.013	0.014	0.013	0.011	0.008	0.002	0.006
33	0.012	0.003	0.010	0.009	0.010	0.009	0.007	0.006
34	0.000	0.006	0.002	0.004	0.005	0.007	0.017	0.012
35	0.002	0.006	0.003	0.002	0.000	0.009	0.005	0.012
36	0.000	0.000	0.003	0.002	0.003	0.009	0.005	0.020
37	0.002	0.006	0.002	0.011	0.005	0.003	0.002	0.008
38	0.006	0.003	0.002	0.007	0.000	0.003	0.002	0.000
39	0.002	0.003	0.005	0.000	0.002	0.001	0.005	0.002
40	0.004	0.003	0.007	0.002	0.005	0.001	0.000	0.002
41	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000
42	0.000	0.006	0.002	0.000	0.000	0.004	0.002	0.002
43	0.002	0.003	0.003	0.000	0.000	0.003	0.002	0.002
44	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.004
45+	0.000	0.000	0.003	0.000	0.003	0.004	0.000	0.000
Sample size	498	308	585	451	616	746	422	500
# Hauls	51	160	187	156	187	270	211	206

Table 10.7 (continued) Fishery age compositions for northern rockfish in the Gulf of Alaska. All age compositions are based on "break and burn" reading of otoliths.

Age	Year				
	2008	2010	2012	2014	2016
2	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.002	0.001	0.000
6	0.000	0.000	0.000	0.003	0.000
7	0.006	0.000	0.007	0.010	0.002
8	0.020	0.012	0.000	0.003	0.034
9	0.026	0.024	0.003	0.010	0.021
10	0.078	0.032	0.022	0.009	0.018
11	0.068	0.060	0.041	0.011	0.020
12	0.048	0.115	0.027	0.041	0.010
13	0.093	0.072	0.094	0.066	0.011
14	0.076	0.052	0.105	0.049	0.028
15	0.030	0.068	0.077	0.077	0.062
16	0.022	0.052	0.057	0.090	0.051
17	0.012	0.028	0.089	0.061	0.075
18	0.006	0.018	0.048	0.071	0.087
19	0.012	0.016	0.022	0.066	0.059
20	0.022	0.024	0.026	0.061	0.067
21	0.020	0.022	0.012	0.025	0.097
22	0.016	0.032	0.010	0.022	0.070
23	0.038	0.014	0.009	0.015	0.028
24	0.050	0.014	0.024	0.028	0.021
25	0.028	0.034	0.021	0.011	0.030
26	0.030	0.030	0.024	0.027	0.013
27	0.022	0.016	0.033	0.027	0.016
28	0.006	0.020	0.038	0.022	0.007
29	0.014	0.014	0.010	0.010	0.008
30	0.026	0.024	0.024	0.032	0.016
31	0.028	0.014	0.012	0.018	0.015
32	0.034	0.024	0.010	0.013	0.021
33	0.032	0.028	0.015	0.018	0.015
34	0.018	0.038	0.015	0.008	0.008
35	0.018	0.020	0.019	0.011	0.010
36	0.006	0.004	0.022	0.014	0.003
37	0.018	0.008	0.014	0.013	0.005
38	0.018	0.010	0.014	0.010	0.008
39	0.012	0.012	0.010	0.009	0.008
40	0.006	0.014	0.012	0.011	0.008
41	0.002	0.010	0.005	0.003	0.011
42	0.008	0.004	0.002	0.005	0.003
43	0.004	0.002	0.003	0.003	0.008
44	0.000	0.010	0.002	0.004	0.005
45+	0.022	0.014	0.019	0.015	0.018
Sample size	497	503	583	789	610
# Hauls	311	311	420	406	394

Table 10.8. Biomass estimates (t), by statistical area, for northern rockfish in the Gulf of Alaska based on triennial and biennial trawl surveys. Gulfwide CV's are also listed. Design-based estimates are presented.

Year	Statistical areas					Total	CV
	Shumagin	Chirikof	Kodiak	Yakutat	South-eastern		
1984	27,716	5,165	6,448	5	0	39,334	29%
1987	45,038	13,794	77,084	500	0	136,417	29%
1990	32,898	5,792	68,044	343	0	107,076	42%
1993	13,995	40,446	49,998	41	0	104,480	35%
1996	28,114	40,447	30,212	192	0	98,965	27%
1999	45,457	29,946	166,665	118	0	242,187	61%
2001	93,291	24,490	225,833	117[a]	0[a]	343,731	60%
2003	9,146	49,793	7,336	5	0	66,310	48%
2005	231,110	102,605	25,123	160	0	358,998	37%
2007	114,222	92,250	20,559	38	0	227,069	38%
2009	44,693	8,842	36,290	70	0	89,896	32%
2011	47,082	91,774	34,757	28	0	173,641	39%
2013	42,936	304,516	22,927	76	0	370,454	60%
2015	5,680	36,356	6,885	12	0	48,933	34%
2017	38,426	107,618	4,262	19	0	150,325	45%

[a]Biomass estimates are not available for the Yakutat and Southeastern areas in 2001 because these areas were not sampled that year. Substitute values are listed in this table and were obtained by averaging the biomass estimates for each of these areas in the 1993, 1996, and 1999 surveys.

Table 10.9. Survey age compositions for northern rockfish in the Gulf of Alaska. All age compositions are based on "break and burn" reading of otoliths.

Age	Year							
	1984	1987	1990	1993	1996	1999	2001	2003
2	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
3	0.000	0.003	0.001	0.003	0.002	0.000	0.005	0.001
4	0.000	0.018	0.002	0.003	0.001	0.002	0.003	0.001
5	0.014	0.055	0.029	0.009	0.002	0.011	0.006	0.035
6	0.040	0.041	0.054	0.011	0.011	0.003	0.013	0.021
7	0.091	0.030	0.027	0.011	0.006	0.009	0.041	0.014
8	0.191	0.003	0.041	0.064	0.021	0.009	0.016	0.096
9	0.112	0.029	0.054	0.120	0.041	0.042	0.038	0.126
10	0.051	0.101	0.045	0.065	0.053	0.028	0.072	0.056
11	0.046	0.112	0.058	0.103	0.085	0.079	0.061	0.036
12	0.026	0.112	0.035	0.044	0.076	0.069	0.040	0.029
13	0.071	0.034	0.054	0.049	0.077	0.054	0.063	0.021
14	0.067	0.043	0.082	0.040	0.040	0.056	0.049	0.051
15	0.063	0.014	0.097	0.024	0.033	0.078	0.050	0.033
16	0.040	0.037	0.051	0.052	0.039	0.092	0.054	0.043
17	0.019	0.103	0.051	0.031	0.017	0.016	0.045	0.000
18	0.019	0.041	0.007	0.040	0.034	0.072	0.058	0.018
19	0.006	0.080	0.011	0.028	0.054	0.019	0.029	0.030
20	0.007	0.027	0.066	0.004	0.088	0.013	0.022	0.061
21	0.003	0.026	0.066	0.023	0.028	0.030	0.017	0.012
22	0.010	0.007	0.046	0.034	0.031	0.022	0.012	0.021
23	0.031	0.007	0.019	0.044	0.030	0.025	0.027	0.011
24	0.021	0.003	0.009	0.044	0.033	0.030	0.045	0.007
25	0.006	0.004	0.010	0.046	0.027	0.020	0.029	0.014
26	0.003	0.017	0.034	0.007	0.052	0.015	0.042	0.025
27	0.010	0.026	0.006	0.017	0.014	0.034	0.012	0.030
28	0.004	0.012	0.012	0.022	0.015	0.025	0.009	0.054
29	0.009	0.003	0.002	0.006	0.028	0.024	0.024	0.035
30	0.000	0.002	0.010	0.000	0.006	0.016	0.021	0.016
31	0.004	0.005	0.010	0.002	0.007	0.024	0.014	0.000
32	0.013	0.000	0.009	0.010	0.004	0.045	0.019	0.000
33	0.003	0.002	0.005	0.005	0.015	0.010	0.011	0.041
34	0.000	0.003	0.000	0.006	0.007	0.008	0.008	0.010
35	0.003	0.000	0.000	0.006	0.005	0.000	0.017	0.012
36	0.000	0.000	0.000	0.009	0.000	0.003	0.004	0.007
37	0.004	0.000	0.000	0.001	0.007	0.000	0.000	0.019
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.014	0.002	0.012	0.002	0.003
40	0.006	0.000	0.000	0.002	0.000	0.002	0.010	0.011
41	0.005	0.000	0.000	0.000	0.000	0.003	0.009	0.000
42	0.000	0.001	0.000	0.000	0.003	0.000	0.000	0.000
43	0.004	0.000	0.000	0.000	0.004	0.000	0.000	0.000
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45+	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000
Sample size	356	497	331	242	462	278	466	216
# Hauls	6	17	12	17	19	27	85	22

Table 10.9 (continued) Survey age compositions for northern rockfish in the Gulf of Alaska. All age compositions are based on "break and burn" reading of otoliths.

Age	Year						
	2005	2007	2009	2011	2013	2015	2017
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.001	0.000	0.000	0.001	0.000	0.000	0.000
5	0.001	0.001	0.003	0.000	0.000	0.000	0.001
6	0.014	0.007	0.000	0.000	0.001	0.001	0.002
7	0.037	0.004	0.007	0.000	0.004	0.006	0.002
8	0.052	0.029	0.015	0.002	0.004	0.006	0.009
9	0.047	0.091	0.022	0.003	0.002	0.006	0.008
10	0.061	0.058	0.051	0.015	0.006	0.023	0.003
11	0.047	0.074	0.071	0.019	0.023	0.011	0.015
12	0.033	0.063	0.053	0.023	0.028	0.007	0.015
13	0.011	0.083	0.060	0.040	0.032	0.012	0.011
14	0.021	0.031	0.062	0.039	0.038	0.020	0.011
15	0.012	0.017	0.038	0.021	0.052	0.050	0.014
16	0.020	0.026	0.034	0.029	0.070	0.055	0.030
17	0.032	0.020	0.021	0.059	0.044	0.073	0.043
18	0.031	0.010	0.033	0.017	0.070	0.055	0.038
19	0.008	0.020	0.033	0.016	0.031	0.030	0.037
20	0.039	0.028	0.027	0.023	0.037	0.045	0.040
21	0.046	0.033	0.016	0.022	0.013	0.066	0.056
22	0.019	0.038	0.010	0.029	0.023	0.022	0.040
23	0.012	0.049	0.027	0.021	0.029	0.027	0.044
24	0.012	0.011	0.041	0.039	0.033	0.014	0.014
25	0.021	0.012	0.046	0.031	0.030	0.025	0.023
26	0.025	0.014	0.026	0.015	0.011	0.020	0.014
27	0.022	0.027	0.017	0.047	0.033	0.023	0.027
28	0.037	0.028	0.014	0.034	0.032	0.024	0.026
29	0.036	0.030	0.030	0.018	0.035	0.017	0.026
30	0.038	0.033	0.013	0.027	0.015	0.027	0.013
31	0.023	0.024	0.012	0.023	0.037	0.021	0.014
32	0.040	0.016	0.025	0.022	0.002	0.029	0.046
33	0.018	0.010	0.022	0.025	0.014	0.025	0.034
34	0.046	0.019	0.011	0.030	0.024	0.014	0.021
35	0.027	0.014	0.012	0.052	0.009	0.020	0.041
36	0.024	0.023	0.021	0.036	0.031	0.018	0.035
37	0.011	0.009	0.019	0.035	0.036	0.035	0.026
38	0.005	0.014	0.028	0.039	0.017	0.010	0.025
39	0.011	0.005	0.013	0.017	0.019	0.020	0.030
40	0.011	0.010	0.010	0.019	0.012	0.035	0.030
41	0.004	0.004	0.008	0.030	0.018	0.018	0.017
42	0.000	0.001	0.007	0.028	0.023	0.012	0.011
43	0.004	0.002	0.005	0.014	0.007	0.009	0.013
44	0.013	0.003	0.007	0.008	0.003	0.016	0.030
45+	0.026	0.010	0.029	0.030	0.052	0.052	0.068
Sample size	417	605	651	430	495	465	462
# Hauls	72	82	69	74	68	56	80

Table 10.10. Survey length (cm) compositions available for northern rockfish in the Gulf of Alaska, 1984-2015. (Note that the number of hauls used for length composition in the current assessment is the number of hauls used to estimate population numbers at length from the NMFS bottom-trawl survey which are limited to good performance survey tows and which may be less than the number of hauls from which specimens were collected for age determination (e.g, 2001).)

Length class	Year										
(cm)	1984	1987	1990	1993	1996	1999	2001	2003	2005	2007	2009
15	0.010	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
16	0.007	0.004	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001
17	0.005	0.005	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
18	0.008	0.004	0.000	0.001	0.001	0.000	0.003	0.000	0.000	0.000	0.001
19	0.006	0.005	0.001	0.001	0.001	0.001	0.002	0.001	0.000	0.000	0.001
20	0.005	0.008	0.001	0.000	0.001	0.001	0.002	0.001	0.000	0.000	0.001
21	0.003	0.009	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.001
22	0.005	0.010	0.003	0.002	0.002	0.002	0.002	0.002	0.000	0.000	0.001
23	0.008	0.012	0.005	0.003	0.002	0.003	0.001	0.004	0.000	0.000	0.001
24	0.017	0.013	0.012	0.003	0.002	0.002	0.002	0.006	0.001	0.000	0.000
25	0.022	0.015	0.011	0.007	0.003	0.002	0.002	0.007	0.000	0.002	0.001
26	0.027	0.015	0.030	0.005	0.007	0.006	0.004	0.018	0.001	0.002	0.001
27	0.045	0.017	0.024	0.007	0.008	0.002	0.005	0.011	0.001	0.006	0.003
28	0.052	0.022	0.017	0.008	0.006	0.006	0.008	0.007	0.001	0.002	0.002
29	0.089	0.044	0.017	0.007	0.008	0.002	0.005	0.010	0.063	0.006	0.002
30	0.095	0.071	0.013	0.012	0.009	0.003	0.010	0.015	0.034	0.003	0.008
31	0.102	0.118	0.022	0.015	0.016	0.002	0.011	0.021	0.012	0.007	0.006
32	0.093	0.140	0.038	0.041	0.020	0.027	0.023	0.040	0.013	0.018	0.013
33	0.074	0.130	0.090	0.055	0.027	0.031	0.017	0.064	0.021	0.038	0.012
34	0.060	0.122	0.126	0.091	0.034	0.035	0.053	0.077	0.025	0.062	0.032
35	0.051	0.087	0.139	0.147	0.059	0.054	0.051	0.063	0.031	0.070	0.040
36	0.058	0.067	0.118	0.161	0.121	0.078	0.121	0.078	0.052	0.084	0.056
37	0.049	0.034	0.102	0.123	0.118	0.128	0.127	0.071	0.055	0.093	0.082
38+	0.110	0.044	0.229	0.310	0.552	0.614	0.549	0.503	0.686	0.606	0.734
Sample size	4,235	9,584	3,091	4,384	4,239	3,471	3,810	2,941	4,556	4,723	2,849
# Hauls	50	82	48	106	131	124	106	126	147	139	132

Table 10.10 (continued) Survey length (cm) compositions available for northern rockfish in the Gulf of Alaska, 1984-2015. (Note that the number of hauls used for length composition in the current assessment is the number of hauls used to estimate population numbers at length from the NMFS bottom-trawl survey which are limited to good performance survey tows and which may be less than the number of hauls from which specimens were collected for age determination (e.g, 2001).)

Length class (cm)	Year			
	2011	2013	2015	2017
15	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000
18	0.000	0.000	0.001	0.000
19	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000
23	0.001	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000
25	0.000	0.001	0.002	0.001
26	0.000	0.001	0.001	0.000
27	0.000	0.001	0.001	0.001
28	0.001	0.001	0.004	0.001
29	0.000	0.001	0.002	0.001
30	0.000	0.004	0.002	0.004
31	0.001	0.002	0.006	0.004
32	0.002	0.004	0.007	0.008
33	0.004	0.005	0.009	0.007
34	0.015	0.012	0.013	0.008
35	0.012	0.013	0.007	0.014
36	0.018	0.034	0.025	0.016
37	0.044	0.040	0.053	0.032
38+	0.900	0.880	0.867	0.899
Sample size	2,460	3,138	2,325	2,570
# Hauls	89	86	95	92

Table 10.11. Summary of results (including likelihood components and key parameter estimates) from the 2018 model cases investigated compared with 2015 results.

	M 15.4 (2015)	M 15.4 (2018)	M 18.1 (2018)	M 18.2 (2018)
Catch	0.09	0.08	0.15	0.10
Survey Biomass	10.14	10.86	13.46	4.10
Fishery Ages	28.52	33.13	32.68	33.10
Survey Ages	55.27	63.30	65.48	63.25
Fishery Sizes	50.59	45.94	45.20	46.10
Maturity Likelihood	70.23	70.23	70.23	70.23
Data-Likelihood	214.85	223.54	227.19	216.88
Penalties/Priors				
Recruitment Devs	8.12	9.27	9.36	9.22
F Regularity	5.55	5.53	5.61	5.54
q prior	0.28	0.36	0.65	0.40
M prior	0.02	0.03	0.11	0.03
Objective Fun Total	228.83	238.74	242.93	232.06
Parameter Estimates				
Active parameters	170	176	176	176
q	0.71	0.68	0.60	0.67
M	0.06	0.06	0.06	0.06
σ_r	1.50	1.50	1.50	1.50
Mean recruitment (millions)	13.81	15.28	18.79	16.33
$F_{40\%}$	0.06	0.06	0.06	0.06
Total Biomass	77,574	77,043	113,230	87,376
Spawning Biomass	31,347	31,801	47,918	36,363
$B_{100\%}$	69,957	71,359	89,262	76,199
$B_{40\%}$	27,983	28,544	35,705	30,480
ABC ($F_{40\%}$)	4,009	3,962	5,924	4,529
$F_{35\%}$	0.07	0.07	0.07	0.07
OFL ($F_{35\%}$)	4,784	4,726	7,068	5,402

Table 10.12. Estimated numbers (thousands) in 2015, fishery selectivity, and survey selectivity of northern rockfish in the Gulf of Alaska based on the preferred model. Also shown are schedules of age specific weight and female maturity.

Age	2018 numbers (thousands)	Percent mature	Weight (g)	Fishery selectivity	Survey selectivity
2	9,922	1	29	0	0.011
3	8,422	1	76	0	0.022
4	7,452	1	140	0.001	0.041
5	6,154	3	217	0.006	0.077
6	5,071	5	299	0.034	0.140
7	3,799	9	381	0.156	0.240
8	2,869	16	462	0.496	0.381
9	2,538	26	537	0.840	0.545
10	3,397	40	606	0.965	0.700
11	2,250	56	668	0.993	0.820
12	1,532	71	723	0.999	0.899
13	1,705	83	771	1	0.945
14	899	90	814	1	0.971
15	740	95	850	1	0.985
16	1,491	97	882	1	0.992
17	3,300	98	908	1	0.996
18	2,426	99	931	1	0.998
19	3,274	100	951	1	0.999
20	7,565	100	967	1	0.999
21	4,317	100	981	1	1
22	3,389	100	993	1	1
23	5,287	100	1,003	1	1
24	7,287	100	1,012	1	1
25	1,278	100	1,019	1	1
26	1,556	100	1,025	1	1
27	1,512	100	1,030	1	1
28	2,031	100	1,034	1	1
29	958	100	1,037	1	1
30	1,953	100	1,040	1	1
31	1,556	100	1,043	1	1
32	1,106	100	1,045	1	1
33	2,100	100	1,047	1	1
34	3,755	100	1,048	1	1
35	1,163	100	1,049	1	1
36	2,344	100	1,050	1	1
37	1,362	100	1,051	1	1
38	1,209	100	1,052	1	1
39	640	100	1,053	1	1
40	860	100	1,053	1	1
41	1,678	100	1,054	1	1
42	1,865	100	1,054	1	1
43	1,113	100	1,054	1	1
44	390	100	1,054	1	1
45	682	100	1,055	1	1
46	332	100	1,055	1	1
47	501	100	1,055	1	1
48	1,147	100	1,055	1	1
49	280	100	1,055	1	1
50+	1,902	100	1,056	1	1

Table 10.13. Comparison of 2018 estimated time series of female spawning biomass, 6+ biomass (age 6 and greater), catch/(6+ biomass), and the number of age two recruits for northern rockfish in the Gulf of Alaska compared with 2015 estimates.

	Spawning Biomass (t)		6+ total biomass (t)		Catch / (6+ total biomass)		Age Two Recruits (millions)	
Year	Current	Previous	Current	Previous	Current	Previous	Current	Previous
1977	18,693	16,602	70,377	64,302	0.009	0.01	32.3	24.8
1978	20,833	18,587	75,759	69,317	0.007	0.008	49.7	41.7
1979	23,579	21,124	83,367	75,968	0.008	0.009	41.7	34.5
1980	26,791	24,070	88,203	80,255	0.009	0.01	20.1	15.9
1981	30,258	27,216	96,982	87,748	0.015	0.017	14.0	11.1
1982	33,519	30,114	109,585	99,383	0.036	0.039	24.8	20.3
1983	35,696	31,899	118,928	107,755	0.030	0.034	26.0	21.5
1984	37,977	33,764	124,003	111,972	0.008	0.009	41.6	34.7
1985	41,549	36,894	129,638	116,858	0.001	0.002	19.0	15.5
1986	45,830	40,707	137,656	124,049	0.002	0.002	55.9	46
1987	50,354	44,754	145,493	131,112	0.003	0.004	28.4	23.1
1988	54,727	48,659	156,425	141,191	0.007	0.008	13.6	11.1
1989	58,497	51,988	161,816	145,933	0.009	0.01	17.4	13.8
1990	61,707	54,798	174,697	157,706	0.010	0.011	20.0	15.6
1991	64,644	57,369	181,971	164,195	0.025	0.027	9.1	7.2
1992	66,384	58,779	182,441	164,135	0.043	0.047	17.7	13.4
1993	66,807	58,897	179,402	160,434	0.027	0.03	12.1	9.2
1994	68,405	60,165	179,192	159,439	0.033	0.037	11.4	8.9
1995	69,222	60,654	174,729	154,530	0.032	0.036	8.6	7.2
1996	69,600	60,715	171,735	150,819	0.019	0.022	45.1	36.3
1997	70,290	61,108	169,436	148,010	0.017	0.02	30.0	22.6
1998	70,508	61,066	166,884	145,096	0.018	0.021	17.5	12.6
1999	70,142	60,479	163,135	141,254	0.033	0.038	20.4	15.9
2000	68,341	58,494	165,220	142,577	0.020	0.023	32.6	23.8
2001	67,316	57,315	167,307	143,808	0.019	0.022	12.9	7.9
2002	66,426	56,291	167,193	143,022	0.020	0.023	8.7	5
2003	65,731	55,463	167,359	142,686	0.031	0.037	10.9	5.5
2004	64,659	54,231	168,431	142,531	0.029	0.034	4.5	2.8
2005	64,219	53,561	165,874	138,991	0.027	0.032	2.0	1.5
2006	64,132	53,164	162,150	134,442	0.031	0.037	2.2	1.7
2007	63,829	52,496	157,873	128,975	0.027	0.032	3.9	2.8
2008	63,622	51,882	152,472	123,140	0.027	0.033	3.1	3.7
2009	63,057	50,895	146,024	116,631	0.027	0.034	4.2	5.1
2010	61,980	49,421	139,161	109,901	0.028	0.035	5.7	5.4
2011	60,306	47,430	132,330	103,295	0.026	0.033	3.9	6.3
2012	58,260	45,197	125,613	97,360	0.040	0.052	4.1	7.4
2013	54,960	41,870	117,427	90,278	0.042	0.054	5.1	7.9
2014	51,433	38,495	109,909	83,786	0.039	0.051	6.4	8.6
2015	48,039	35,426	102,807	78,470	0.038	0.054	7.4	8.6
2016	44,789	-	96,255	-	0.036	-	8.4	-
2017	41,861	-	90,641	-	0.020	-	8.9	-
2018	39,819	-	87,162	-	0.028	-	9.9	-

Table 10.14. Estimated time series of number of age 2 recruits (in thousands), total biomass, and female spawning biomass with 95% confidence bounds for northern rockfish in the Gulf of Alaska, from this year's model MCMC results.

Year	Recruits (Age 2)			Total Biomass			Spawning Biomass		
	Mean	2.50%	97.50%	Mean	2.50%	97.50%	Mean	2.50%	97.50%
1977	32,274	661	77,258	77,427	53,832	110,900	18,693	11,527	29,278
1978	49,732	2,496	120,369	85,361	59,858	120,945	20,833	13,250	31,897
1979	41,714	1,177	95,466	94,403	66,987	132,393	23,579	15,343	35,347
1980	20,060	606	61,950	103,813	74,237	144,352	26,791	17,863	39,402
1981	13,996	486	49,532	113,037	81,191	156,218	30,258	20,553	43,747
1982	24,773	1,048	60,893	121,368	87,496	166,891	33,519	22,932	48,107
1983	26,037	856	75,909	126,835	90,951	175,095	35,696	24,531	51,142
1984	41,620	1,522	84,202	132,697	94,755	183,053	37,976	25,907	54,574
1985	19,004	500	62,723	140,897	100,685	193,965	41,549	28,606	59,025
1986	55,895	15,573	103,742	150,546	108,021	207,017	45,830	31,917	64,526
1987	28,378	1,172	61,596	160,222	115,247	219,610	50,354	35,291	70,318
1988	13,598	625	39,227	169,257	121,959	231,099	54,727	38,685	75,584
1989	17,419	1,311	41,095	176,965	127,878	241,177	58,497	41,634	80,858
1990	20,038	1,982	41,327	183,363	132,406	249,859	61,707	44,001	84,929
1991	9,053	397	26,539	188,301	135,732	256,542	64,644	46,029	88,942
1992	17,673	3,795	35,904	189,257	135,270	258,497	66,384	46,978	91,322
1993	12,085	932	28,483	185,776	130,896	255,982	66,807	46,513	92,536
1994	11,405	1,328	25,259	184,230	128,975	254,520	68,404	47,332	95,320
1995	8,614	480	21,948	180,504	125,114	250,586	69,222	47,437	96,375
1996	45,137	24,200	77,112	177,276	121,614	248,164	69,600	47,312	97,275
1997	29,976	7,608	57,803	176,670	120,390	248,855	70,290	47,479	98,378
1998	17,528	1,484	43,161	176,720	119,855	249,635	70,508	47,291	99,126
1999	20,372	2,193	42,476	176,899	119,129	251,018	70,142	46,864	98,919
2000	32,575	14,009	63,194	175,241	116,349	250,425	68,341	45,033	97,366
2001	12,876	1,216	29,203	175,722	115,770	252,280	67,316	44,024	96,698
2002	8,729	811	22,894	176,119	114,908	253,843	66,426	43,117	95,802
2003	10,867	2,115	24,160	175,810	113,796	254,453	65,731	42,213	95,340
2004	4,492	346	11,573	172,759	110,311	251,774	64,659	40,923	94,723
2005	2,036	159	6,328	169,190	106,595	248,878	64,219	39,943	94,785
2006	2,249	183	6,812	164,891	102,307	244,790	64,132	39,270	95,501
2007	3,861	421	10,069	159,214	97,176	238,225	63,829	38,446	95,920
2008	3,134	264	10,197	153,488	92,038	231,696	63,622	37,804	96,459
2009	4,164	331	12,621	147,258	86,712	224,715	63,057	36,825	96,656
2010	5,712	471	15,929	140,715	81,078	216,482	61,980	35,529	95,669
2011	3,915	229	13,760	133,938	75,531	208,275	60,306	33,757	93,812
2012	4,115	225	16,791	127,479	70,625	199,903	58,260	32,028	91,471
2013	5,114	226	22,791	119,393	63,957	190,234	54,960	29,330	87,600
2014	6,428	270	30,588	111,684	57,713	180,277	51,432	26,523	83,336
2015	7,351	264	41,327	104,863	52,129	171,654	48,039	23,721	78,860
2016	8,390	274	57,263	98,752	47,281	163,853	44,789	21,160	74,782
2017	8,936	290	66,174	93,581	43,249	157,501	41,861	18,898	70,935
2018	9,922	315	113,431	90,466	41,136	154,080	39,819	17,516	67,943
2019	16,326	369	87,719	87,375	38,826	151,304	36,363	15,521	62,584
2020	16,326	408	95,568	84,210	38,294	148,593	34,021	14,631	58,010

Table 10.15. Estimates of key parameters with Hessian estimates of standard deviation (σ), MCMC standard deviations (σ(MCMC)) and 95% Bayesian credible intervals (BCI) derived from MCMC simulations.

Parameter	μ	μ (MCMC)	Median (MCMC)	σ	σ(MCMC)	BCI-Lower	BCI-Upper
q	0.67	0.75	0.72	0.15	0.21	0.46	1.24
M	0.0592	0.0598	0.0598	0.0028	0.0028	0.0544	0.0655
$F_{40\%}$	0.0606	0.0694	0.0663	0.0156	0.0201	0.0396	0.1192
2019 SSB	36,363	34,343	32,842	12,182	12,000	15,521	62,584
2019 ABC	4,529	4,770	4,443	1,902	2,274	1,205	9,973

Table 10.16. Set of projections of spawning biomass and yield for northern rockfish in the Gulf of Alaska. This set of projections encompasses six harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For a description of scenarios see *Projections and Harvest Alternatives*. All units in t. $B_{40\%}$ = 30,480 t, $B_{35\%}$ = 26,670 t, $F_{40\%}$ = 0.061, and $F_{35\%}$ = 0.073.

Year	Maximum permissible F	Author's F[1] (Estimated catches)	Half maximum F	5-year average F	No fishing	Overfished	Approaching overfished
			Spawning biomass (mt)				
2018	38,647	38,647	38,647	38,647	38,647	38,647	38,647
2019	36,150	36,365	36,515	36,460	36,884	36,006	36,150
2020	33,245	34,046	34,597	34,390	36,008	32,719	33,245
2021	30,702	31,819	32,900	32,560	35,267	29,880	30,580
2022	28,565	29,563	31,447	30,994	34,696	27,543	28,134
2023	26,896	27,752	30,261	29,713	34,330	25,748	26,245
2024	25,666	26,402	29,377	28,737	34,203	24,433	24,854
2025	24,852	25,482	28,796	28,088	34,349	23,560	23,915
2026	24,432	24,971	28,523	27,781	34,803	23,097	23,396
2027	24,378	24,836	28,530	27,819	35,588	23,006	23,256
2028	24,630	25,018	28,802	28,172	36,694	23,221	23,429
2029	25,098	25,423	29,318	28,768	38,062	23,646	23,817
2030	25,679	25,951	30,062	29,517	39,605	24,177	24,316
2031	26,296	26,522	30,960	30,340	41,239	24,734	24,847
			Fishing mortality				
2018	0.031	0.031	0.031	0.031	0.031	0.031	0.031
2019	0.061	0.043	0.030	0.035	-	0.073	0.073
2020	0.061	0.042	0.030	0.035	-	0.073	0.073
2021	0.061	0.061	0.030	0.035	-	0.071	0.071
2022	0.057	0.059	0.030	0.035	-	0.065	0.065
2023	0.053	0.055	0.030	0.035	-	0.061	0.061
2024	0.051	0.052	0.029	0.035	-	0.058	0.058
2025	0.049	0.050	0.028	0.035	-	0.055	0.055
2026	0.048	0.049	0.028	0.035	-	0.054	0.054
2027	0.048	0.049	0.028	0.035	-	0.054	0.054
2028	0.048	0.049	0.028	0.035	-	0.054	0.054
2029	0.049	0.050	0.029	0.035	-	0.055	0.055
2030	0.050	0.051	0.030	0.035	-	0.057	0.057
2031	0.051	0.052	0.030	0.035	-	0.058	0.058
			Yield (mt)				
2018	2,441	2,441	2,441	2,441	2,441	2,441	2,441
2019	4,529	4,529	2,298	2,641	-	5,402	4,529
2020	4,197	4,270	2,193	2,508	-	4,947	4,197
2021	3,921	4,059	2,107	2,400	-	4,479	4,677
2022	3,460	3,705	2,041	2,315	-	3,852	4,018
2023	3,110	3,308	1,959	2,252	-	3,414	3,546
2024	2,881	3,044	1,878	2,215	-	3,131	3,237
2025	2,778	2,914	1,856	2,220	-	2,998	3,085
2026	2,782	2,898	1,888	2,262	-	2,991	3,064
2027	2,852	2,950	1,950	2,319	-	3,062	3,123
2028	2,967	3,051	2,027	2,382	-	3,184	3,235
2029	3,109	3,179	2,107	2,447	-	3,338	3,381
2030	3,254	3,312	2,185	2,510	-	3,499	3,533
2031	3,389	3,436	2,261	2,573	-	3,653	3,681

[1]Projected ABCs and OFLs for 2019 and 2020 are derived using estimated catch of 2,441 for 2018, and projected catches of 3,219 t and 2,983 t for 2019 and 2020 based on realized catches from 2015-2017. This calculation is in response to management requests to obtain more accurate projections.

Table 10.17. Analysis of ecosystem considerations for slope rockfish.

Indicator	*Observation*	*Interpretation*	*Evaluation*
Ecosystem effects on stock			
Prey availability or abundance trends	important for larval and post-larval survival, but no information known	may help to determine year-class strength	possible concern if some information available
Predator population trends	Unknown		little concern for adults
Changes in habitat quality	Variable	variable recruitment	possible concern
Fishery effects on ecosystem			
Fishery contribution to bycatch			
Prohibited species	unknown		
Forage (including herring, Atka mackerel, cod, and pollock)	unknown		
HAPC biota (seapens/whips, corals, sponges, anemones)	fishery disturbing hard-bottom biota, i.e., corals, sponges	could harm the ecosystem by reducing shelter for some species	concern
Marine mammals and birds	probably few taken		little concern
Sensitive non-target species	unknown		
Fishery concentration in space and time	little overlap between fishery and reproductive activities	fishery does not hinder reproduction	little concern
Fishery effects on amount of large size target fish	no evidence for targeting large fish	large fish and small fish are both in population	little concern
Fishery contribution to discards and offal production	discard rates moderate to high for some species of slope rockfish	little unnatural input of food into the ecosystem	some concern
Fishery effects on age-at-maturity and fecundity	fishery is catching some immature fish	could reduce spawning potential and yield	possible concern

Figures

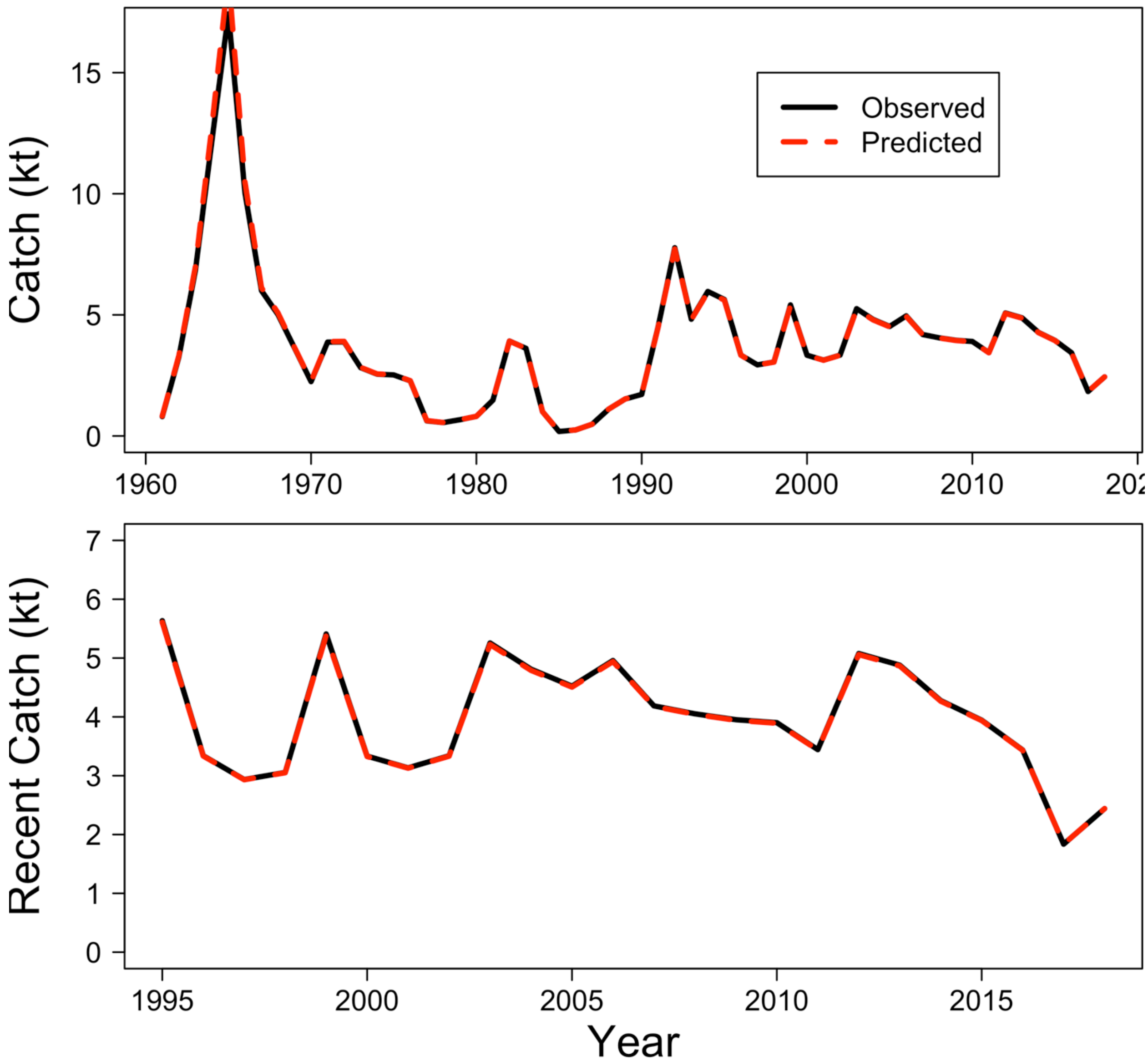


Figure 10.1. Estimated (red dashed lines) and observed (black solid lines) long-term and recent commercial catch of northern rockfish in the Gulf of Alaska. The *Description of the catch time series* section describes the procedures used to estimate catch for the years 1965-1993. Catch for the years 1993-2015 is from NMFS Observer Program and Alaska Regional Office.

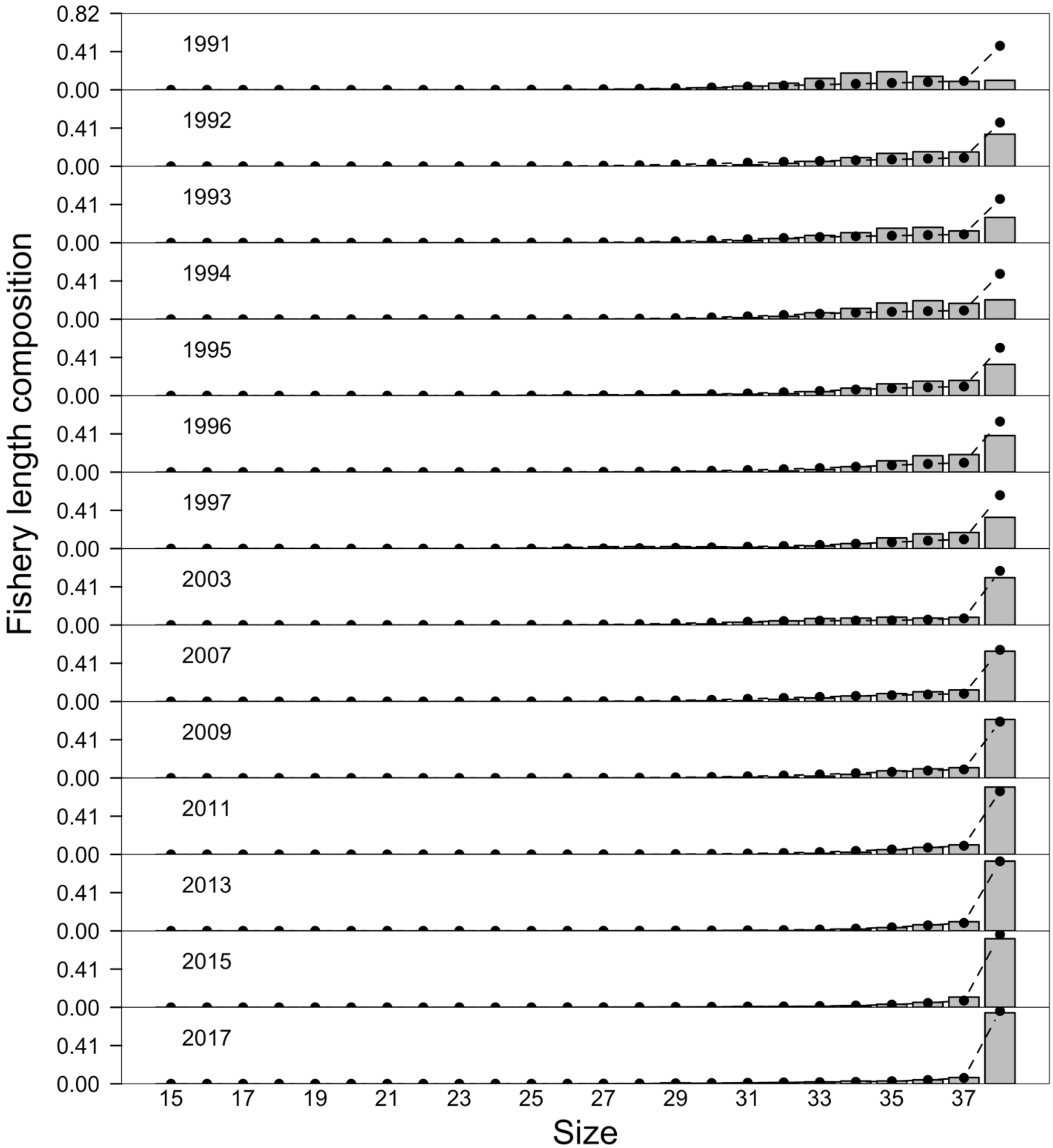


Figure 10.2. Fishery length compositions for GOA northern rockfish. Observed = bars, predicted from author recommended model = line with circles.

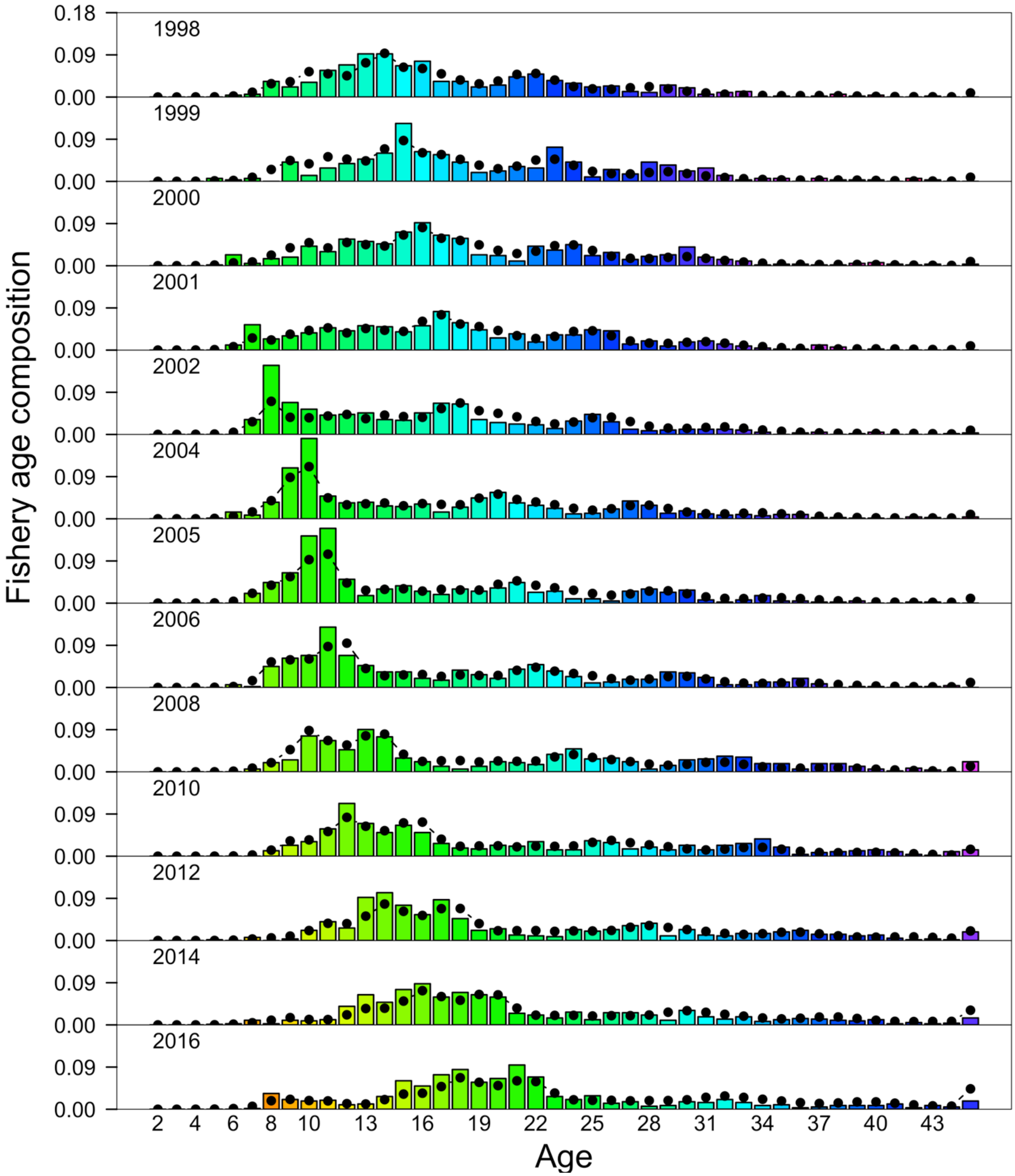


Figure 10.3. Fishery age compositions for GOA northern rockfish. Observed = bars, predicted from author recommended model = line with circles.

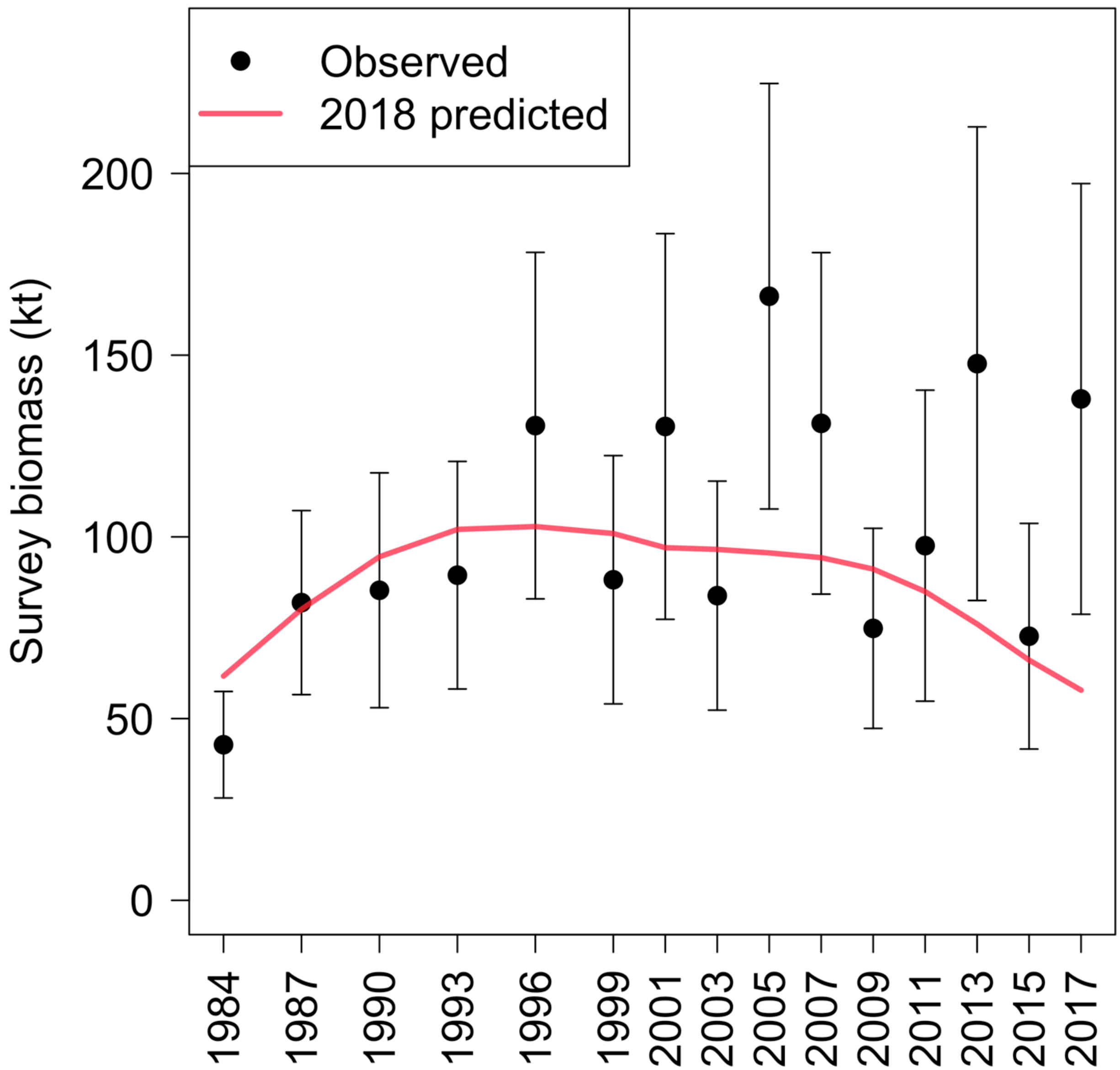


Figure 10.4. Observed and predicted GOA northern rockfish trawl survey VAST model-based index of biomass (shown in units of kilotons). Observed biomass=circles with 95% confidence intervals of sampling error.

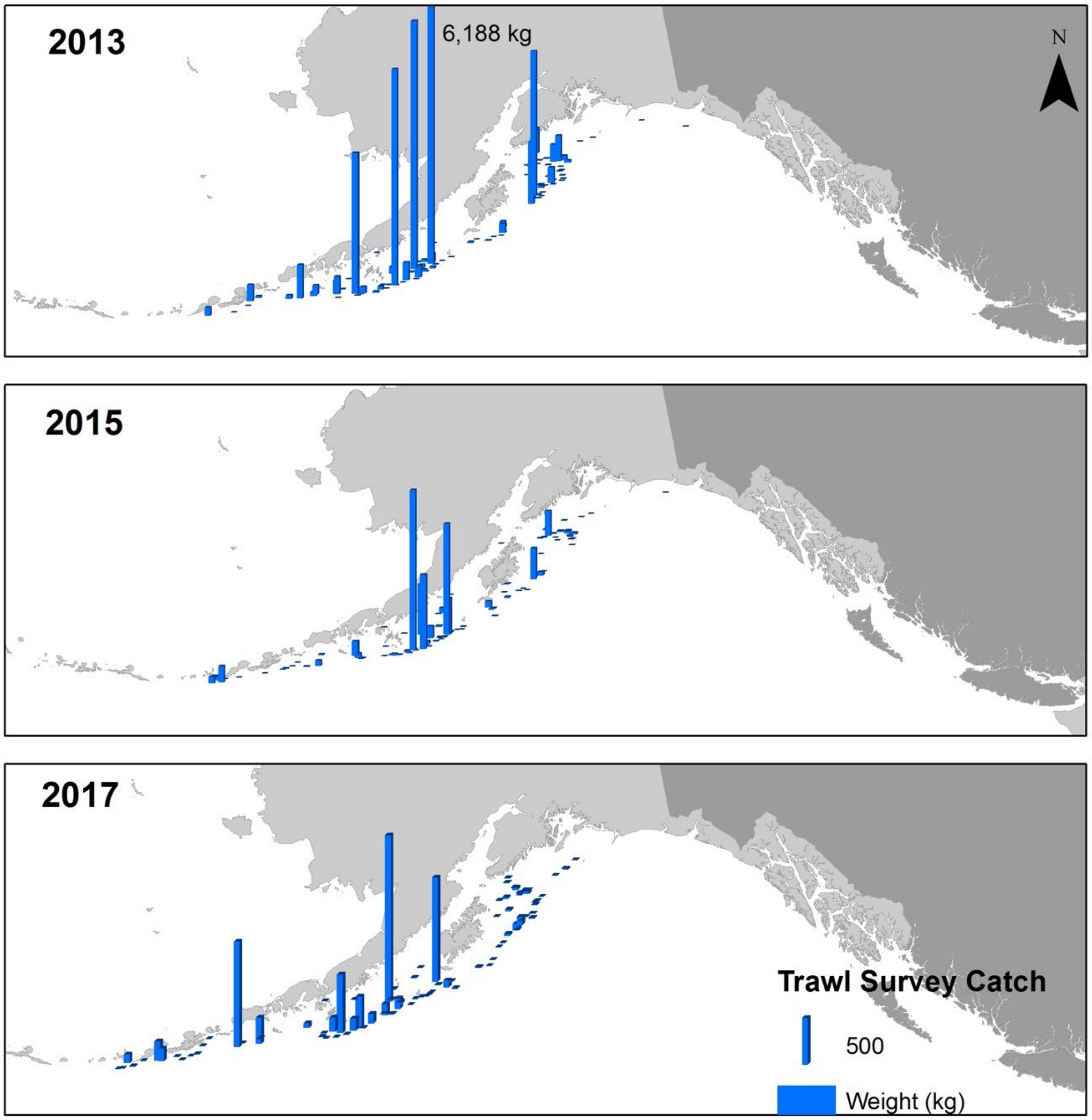


Figure 10.5. Spatial distribution of northern rockfish catch in the Gulf of Alaska during the trawl surveys.

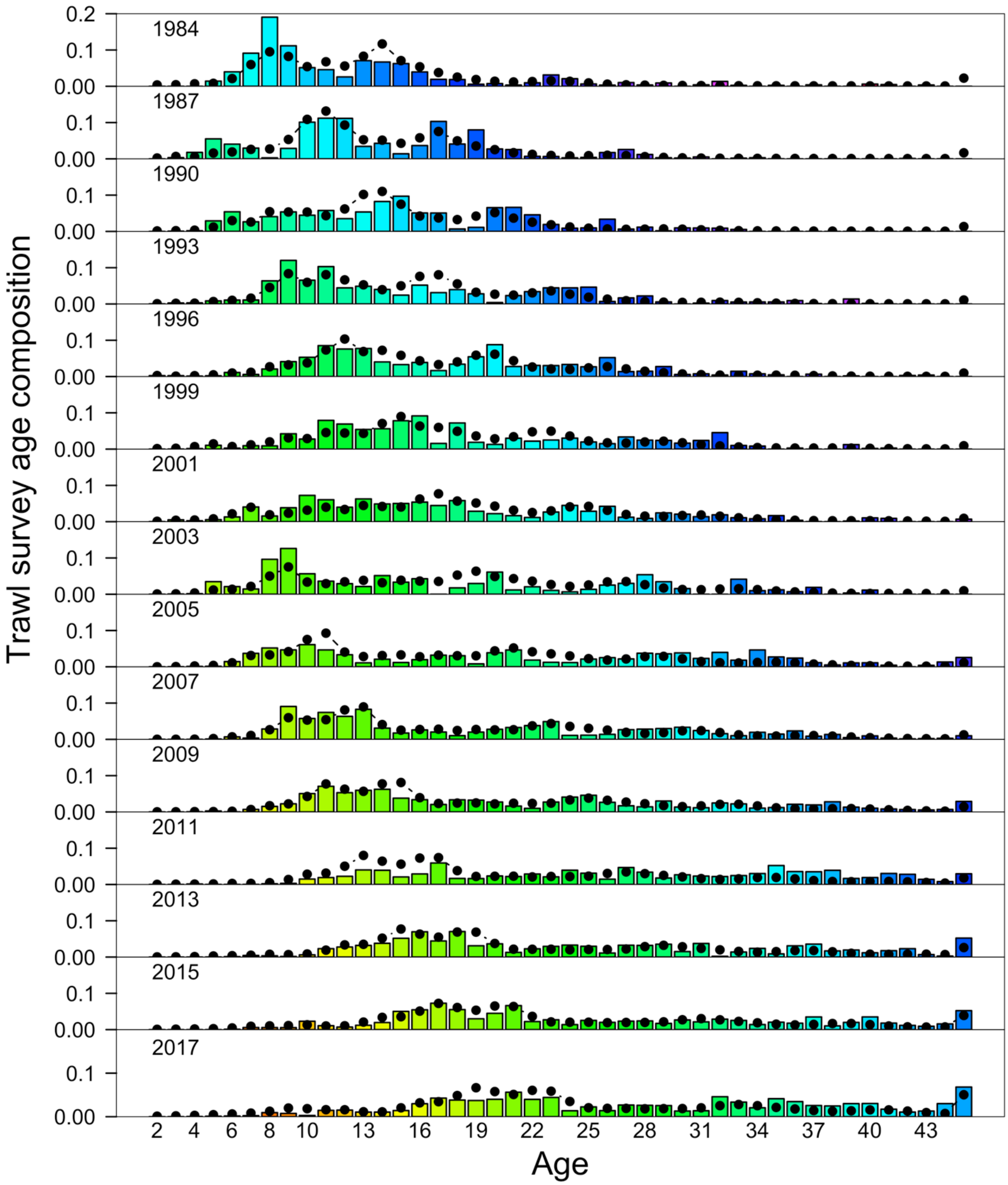


Figure 10.6. Trawl survey age composition by year for GOA northern rockfish. Observed = bars, predicted from author recommended model = line with circles.

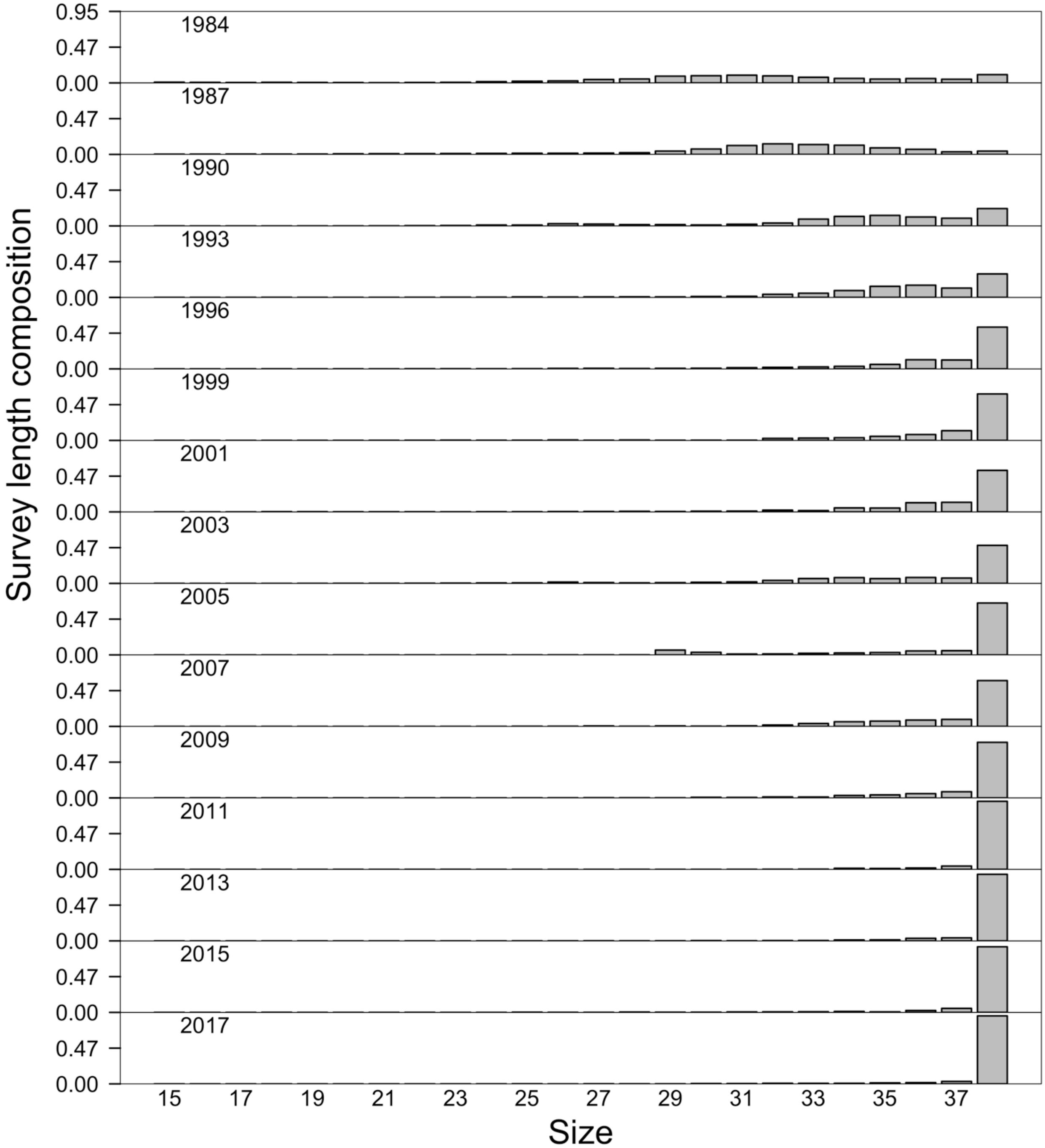


Figure 10.7. Groundfish survey length compositions for GOA northern rockfish. Observed = bars. Survey size distributions not used in the model because survey ages are available for these years.

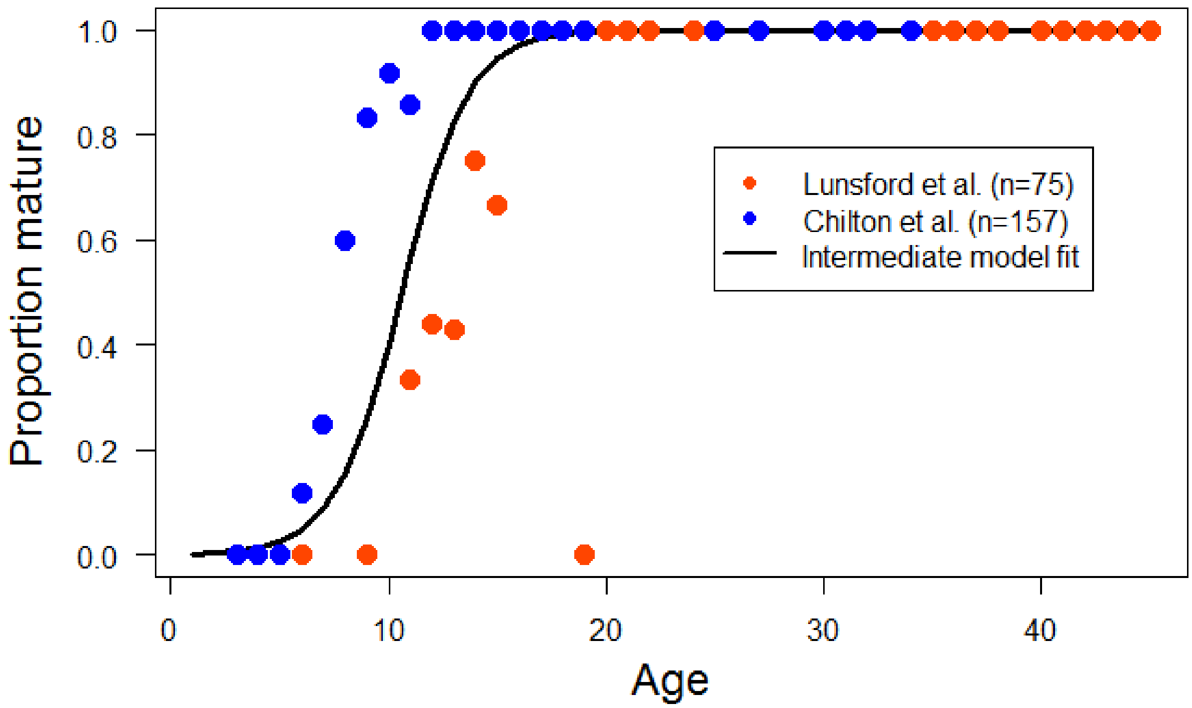


Figure 10.8. Intermediate model fit to combined female northern rockfish maturity data. Also shown are separate model fits to each dataset.

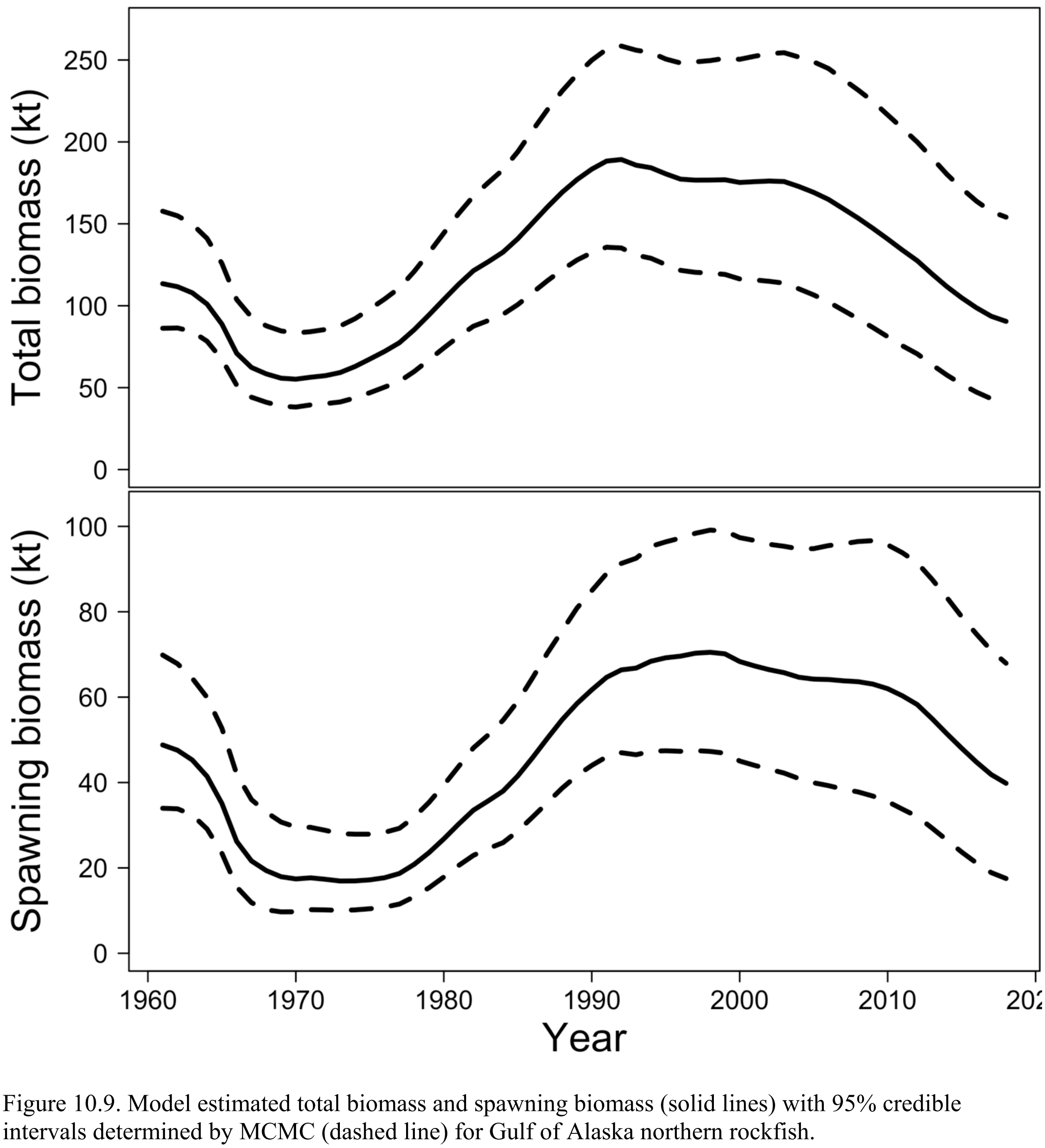


Figure 10.9. Model estimated total biomass and spawning biomass (solid lines) with 95% credible intervals determined by MCMC (dashed line) for Gulf of Alaska northern rockfish.

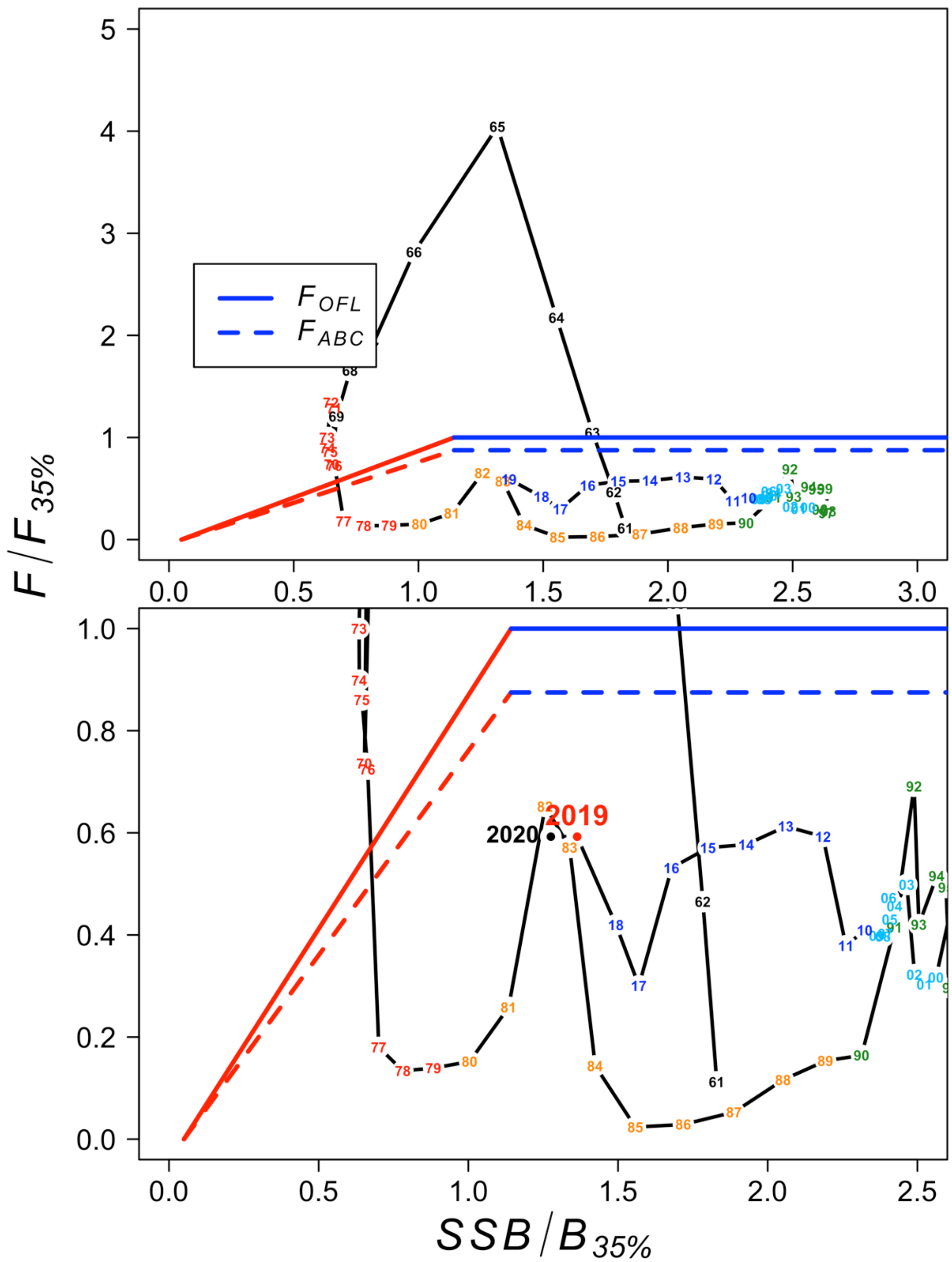


Figure 10.10. Time series of northern rockfish estimated spawning biomass (*SSB*) relative to $B_{35\%}$ and fishing mortality (*F*) relative to $F_{35\%}$ for author recommended model.

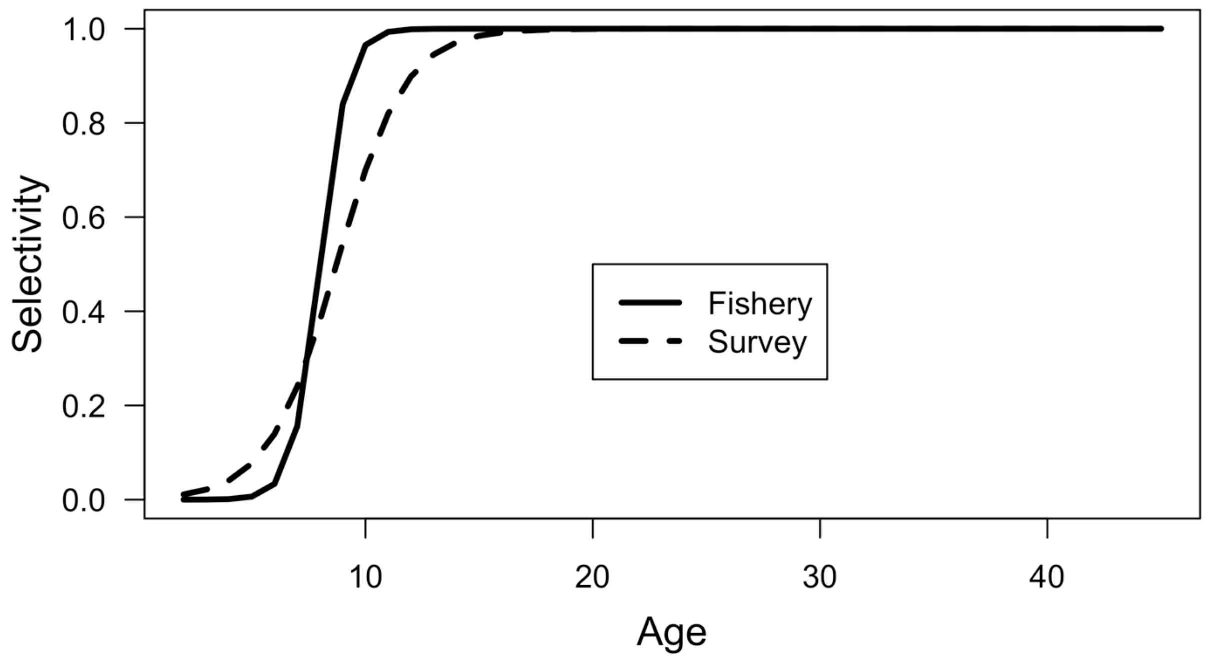


Figure 10.11. Fishery (solid line) and survey (dotted line) estimates of selectivity for GOA northern rockfish based on the authors recommended model.

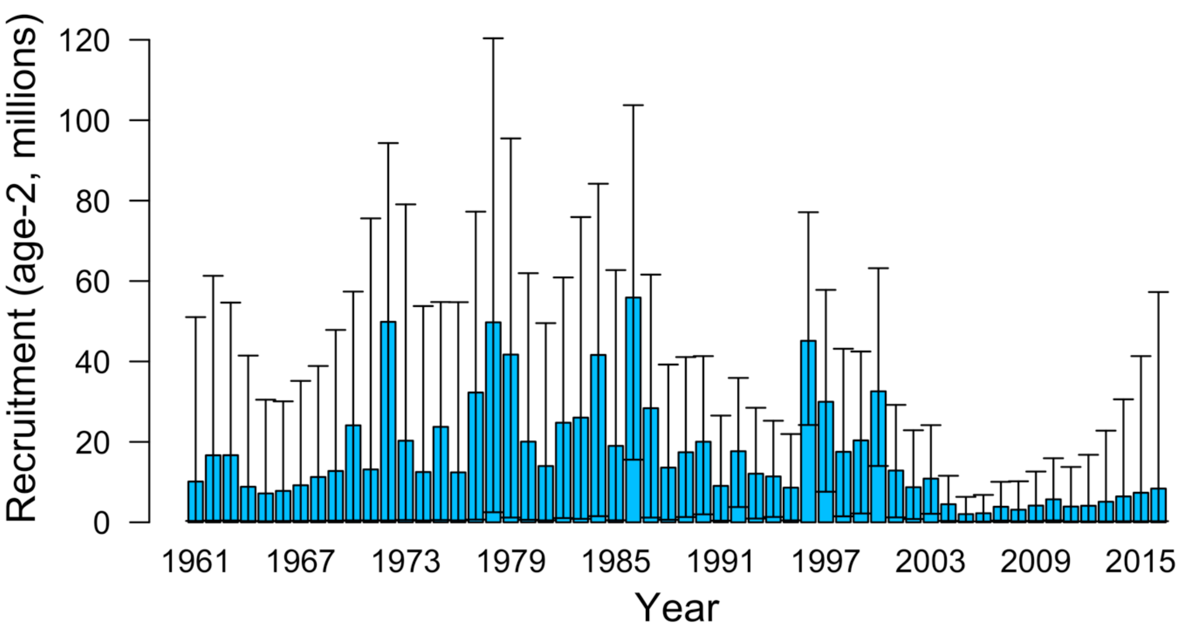


Figure 10.12. Estimates of recruitment (at age-2) and 95% credible intervals for GOA northern rockfish based on the 2015 model.

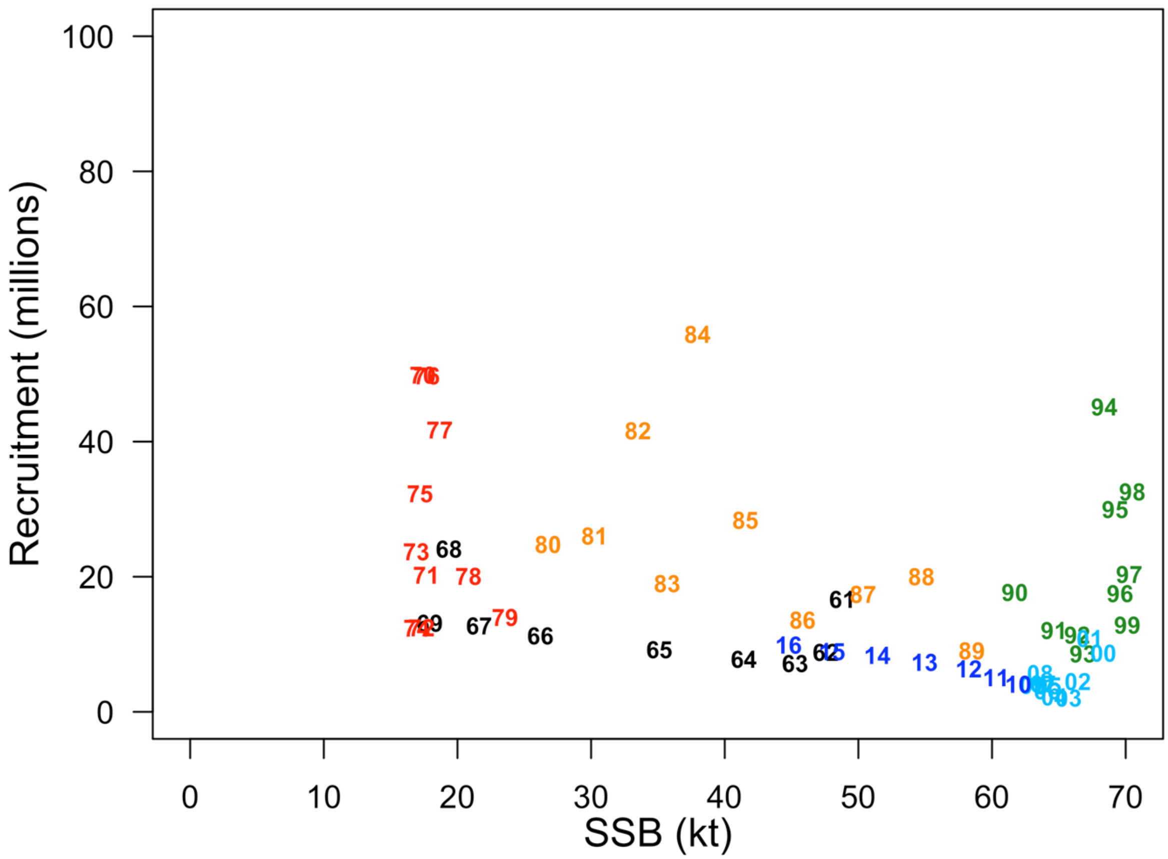


Figure 10.13. Relationship between female spawning stock biomass (SSB) and recruitment (by year class) for GOA northern rockfish based on the 2018 model.

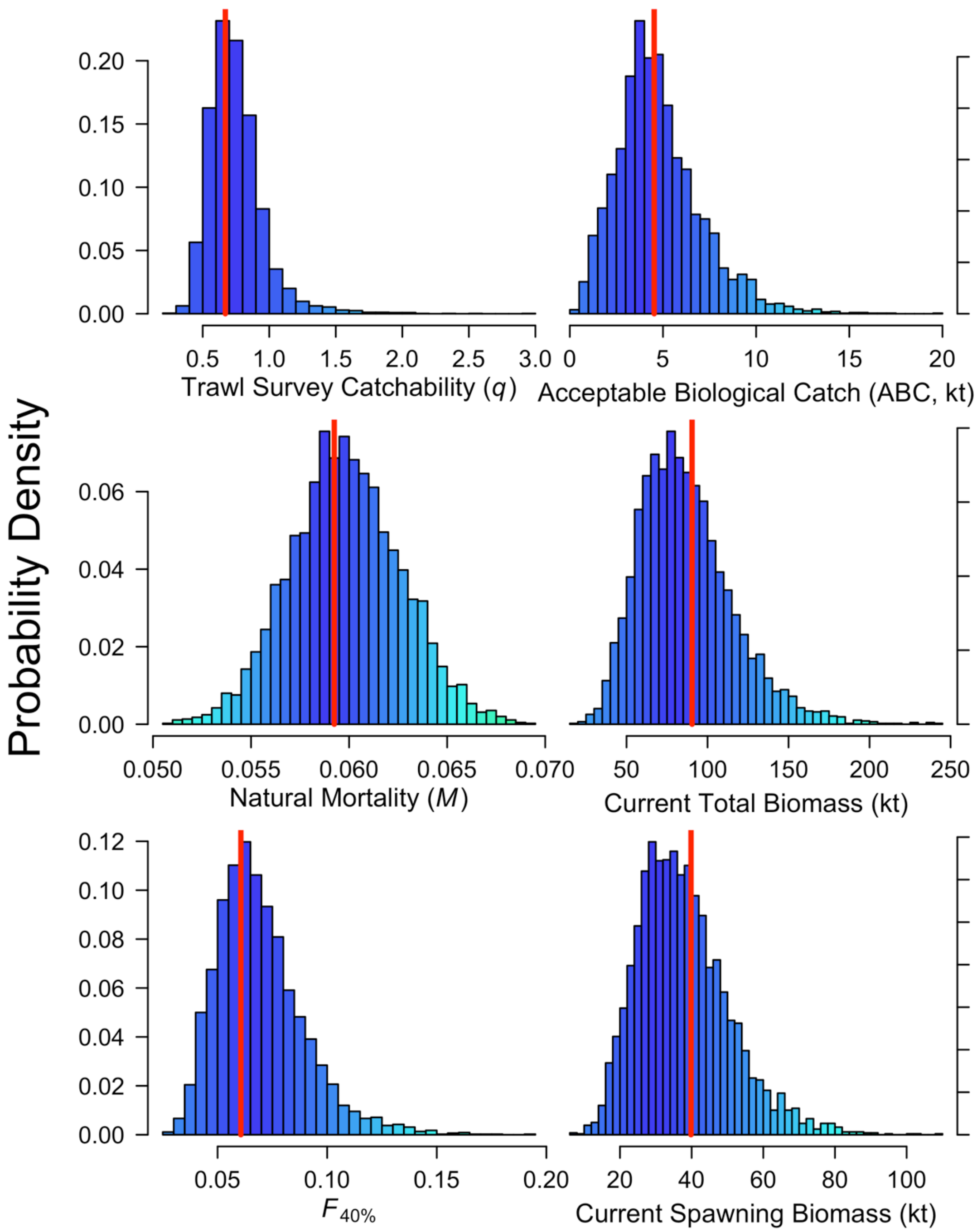


Figure 10.14. Histograms of estimated posterior distributions for key parameters derived from the MCMC for GOA northern rockfish. Vertical white lines represent the maximum likelihood estimate for comparison with the MCMC results.

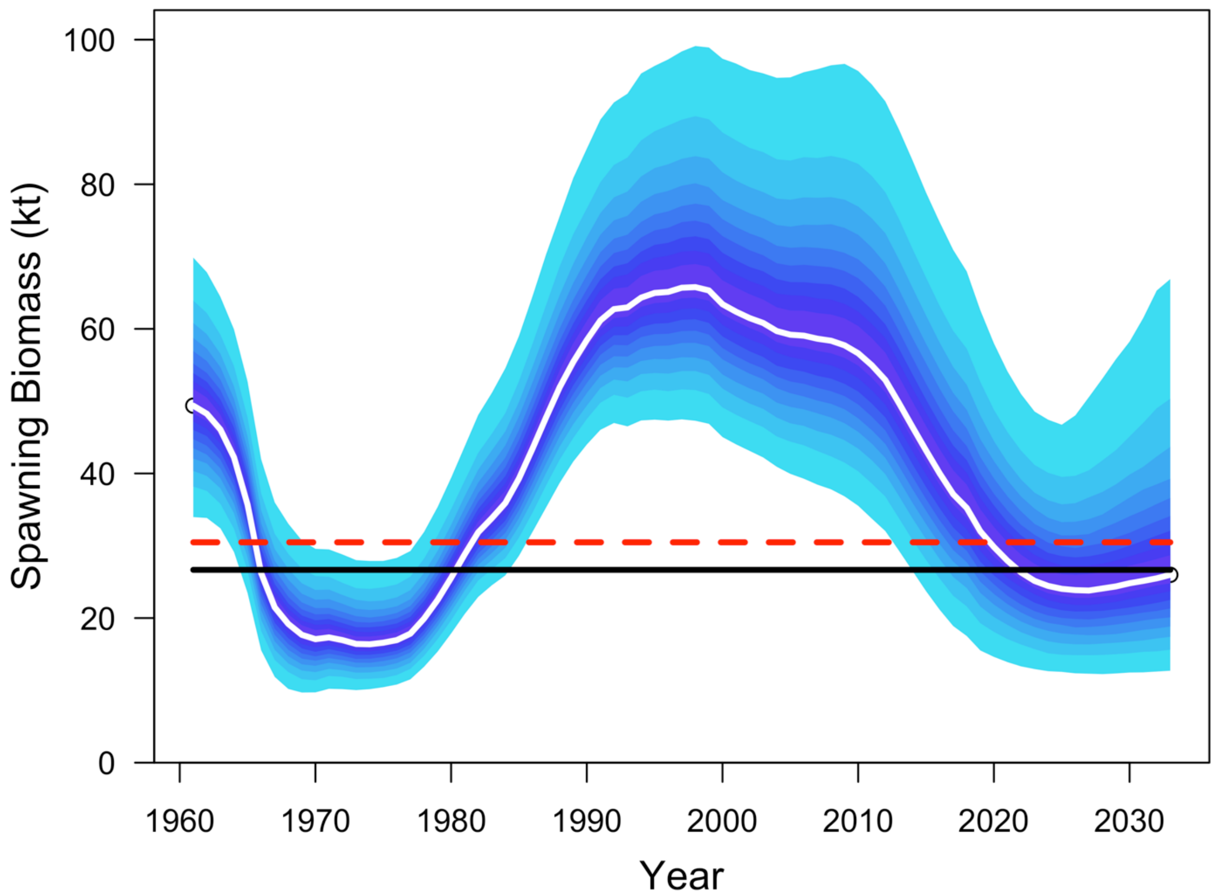


Figure 10.15. Bayesian credible intervals for entire spawning stock biomass series including projections through 2030, when managing under Scenario 2 but assuming the same average yield ratio forward in time. Red dashed line is $B_{40\%}$ and black solid line is $B_{35\%}$ based on recruitments from 1977-2016. The white line is the median of MCMC simulations. Each shade is 5% of the posterior distribution.

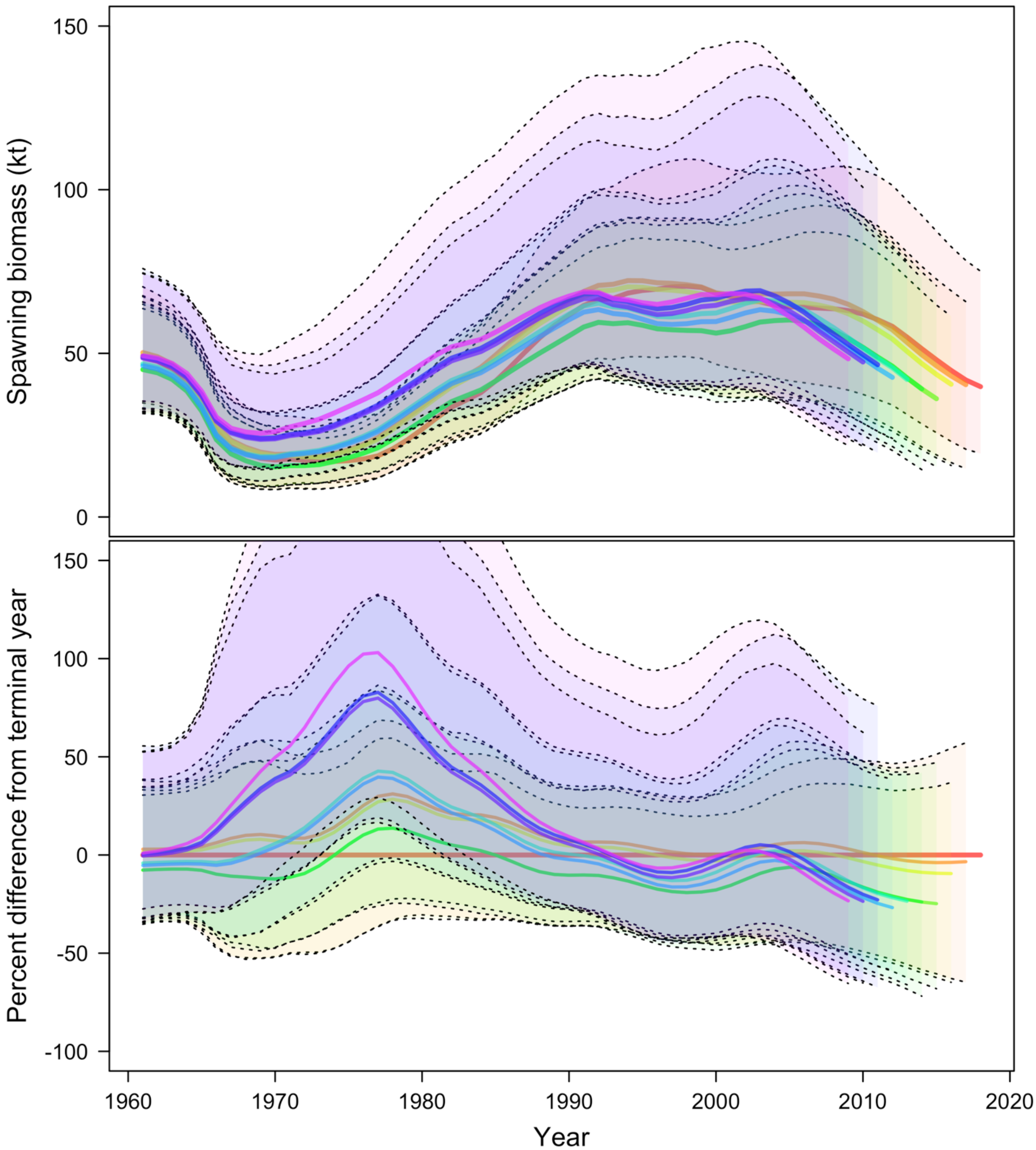


Figure 10.16 Retrospective peels of estimated female spawning biomass for the past 10 years from the recommended model with 95% credible intervals derived from MCMC (top), and the percent difference in female spawning biomass from the recommended model in the terminal year with 95% credible intervals from MCMC.

Appendix 10A.—Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, a dataset has been generated to help estimate total catch and removals from NMFS stocks in Alaska. This dataset estimates total removals that occur during non-directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For Gulf of Alaska (GOA) northern rockfish, these estimates can be compared to the research removals reported in previous assessments (Heifetz et al. 2009; Table 10 A-1). Northern rockfish research removals are minimal relative to the fishery catch and compared to the research removals of other species. The majority of research removals are taken by the Alaska Fisheries Science Center's (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of northern rockfish in the GOA. Other research activities that harvest northern rockfish include longline surveys by the International Pacific Halibut Commission and the AFSC and the State of Alaska's small mesh trawl surveys. Recreational harvest of northern rockfish rarely occurs. Total removals from activities other than a directed fishery have been near 10 t for 2010 - 2017. The 2017 other removals is <1% of the 2018 recommended ABC of 4,529 t and represents a very low risk to the northern rockfish stock. Research harvests from trawl in recent years are higher in odd years due to the biennial cycle of the AFSC bottom trawl survey in the GOA and have been less than 10 t except in 2013 when 18 t were removed. These removals do not pose a significant risk to the northern rockfish stock in the GOA.

Literature Cited

Heifetz, J., D. Hanselman, J. N. Ianelli, S. K. Shotwell, and C. Tribuzio. 2009. Gulf of Alaska northern rockfish. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2010. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501. pp. 817-874.

Table 10A.1. Total removals of Gulf of Alaska northern rockfish (t) from activities not related to directed fishing, since 1977. Trawl survey sources are a combination of the NMFS echo-integration, small-mesh, and GOA bottom trawl surveys, and occasional short-term research projects. Other is longline, personal use, recreational, and subsistence harvest.

Year	Source	Trawl	Other	Total
1977	**Assessment of northern rockfish in the Gulf of Alaska (Heifetz et al. 2009)**	0		0
1978		1		1
1979		1		1
1980		1		1
1981		8		8
1982		6		6
1983		2		2
1984		11		11
1985		11		11
1986		1		1
1987		41		41
1988		0		0
1989		1		1
1990		19		19
1991		0		0
1992		0		0
1993		21		21
1994		0		0
1995		0		0
1996		13		13
1997		1		1
1998		2		2
1999		13		13
2000		0		0
2001		23		23
2002		0		0
2003		7		7
2004		0		0
2005		27		27
2006		0		0
2007		22		22
2008		0		0
2009		7		7
2010	**AKRO**	<1	<1	1
2011		11	<1	11
2012		<1	<1	1
2013		18	<1	18
2014		<1	<1	1
2015		8	<1	8
2016		<1	<1	<1
2017		7	<1	7