12. Assessment of the Dusky Rockfish stock in the Gulf of Alaska

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Executive Summary

In 2017, the scheduled frequency for some stock assessments was changed in response to the National Stock Assessment Prioritization effort (Methot 2015, Hollowed et al. 2016). Prior to 2017, Gulf of Alaska (GOA) rockfish were assessed on a biennial stock assessment schedule to coincide with the availability of new survey data. The new schedule sets full assessments for dusky rockfish in the 'off' survey years (even years) and partial assessments for the 'on' survey years (odd years). For 2018, we present a full stock assessment document with updated assessment and projection model results.

We use a statistical age-structured model as the primary assessment tool for GOA dusky rockfish, which qualifies as a Tier 3 stock. This assessment consists of a population 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 population model to predict future population estimates and recommended harvest levels. For this assessment year, we update the assessment model accepted in 2015 with new data collected since the last full assessment and propose no model changes.

Summary of Changes in Assessment Inputs

Relative to the last full assessment, we made the following substantive changes in the current assessment.

Changes in input data:

The input data were updated to include survey age compositions for 2015 and 2017, final catch for 2015, 2016, and 2017 and preliminary catch for 2018, fishery age compositions from 2014 and 2016, and fishery size compositions for 2015 and 2017. Additionally, geostatistical model-based trawl survey biomass estimates for 2017 are updated and included.

Changes in the assessment methodology:

The assessment methodology has not changed from the accepted 2015 assessment. Please refer to Lunsford et al. (2015) for more details on the last full assessment methodology (available online at https://www.afsc.noaa.gov/REFM/Docs/2015/GOAdusky.pdf).

Summary of Results

The model for this assessment is model 15.5 (2018), which is the 2015 model with updated data through 2018. This model is identical to the model accepted in 2015, except for inclusion of additional years of data. The model generally produces good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivity. For this year's assessment, we recommend using the 2015 base model updated with data through 2018.

The following results are based on the author recommended model. The maximum allowable ABC for 2019 is **3,700** t based on the Tier 3 harvest control rule for dusky rockfish. This ABC is 6.5% less than last year's ABC of 3,957 t.

The 2019 Gulf-wide OFL for dusky rockfish is **4,521** t. Area apportionments of ABC are based on the recommended random effects smoothing model applied to the design-based survey biomass estimates. The 2019 recommended area apportionments of ABC are 781 t for the Western area, 2,764 t for the Central area, 95 t for the West Yakutat area, and 60 t for the Southeast/Outside area. This represents a shift in ABC from the Central and Eastern (West Yakutat and Southeast/Outside) regions to the Western region. This shift in apportionment is attributable to the trawl survey encountering the second highest biomass ever recorded in the Shumagin area in 2017, resulting in an increase to the Western area apportionment. The corresponding reference values for dusky rockfish are summarized in the following table, with the recommended ABC and OFL values in bold.

The stock is not being subjected to overfishing, is not currently overfished, nor is it approaching a condition of being overfished.

Quantity	As estimated or specified *last* year for:		As estimated or recommended *this* year for:	
	2018	2019	2019*	2020*
M (natural mortality rate)	0.07	0.07	0.07	0.07
Tier	3a	3a	3a	3a
Projected total (age 4+) biomass (t)	56,103	55,704	55,247	54,551
Female spawning biomass (t)	21,559	20,151	20,342	20,106
$B_{100\%}$	49,268	49,268	46,337	46,337
$B_{40\%}$	19,707	19,707	18,535	18,535
$B_{35\%}$	17,244	17,244	16,218	16,218
F_{OFL}	0.121	0.121	0.118	0.118
$maxF_{ABC}$	0.098	0.098	0.095	0.095
F_{ABC}	0.098	0.098	0.095	0.095
OFL (t)	4,841	4,488	**4,521**	4,484
maxABC (t)	3,957	3,668	**3,700**	3,670
ABC (t)	3,957	3,668	**3,700**	3,670
Status	As determined *last* year for:		As determined *this* year for:	
	2016	2017	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 an estimated catch of 2,946 t for 2018, and estimates of 2,303 t and 2,211 t used in place of maximum permissible ABC for 2019 and 2020.

Area Apportionment

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

	Western	Central	Eastern	Total
Area Apportionment	21.1%	74.7%	4.2%	100%
2019 Area ABC (t)	**781**	**2,764**	**155**	**3,700**
2019 OFL (t)				**4,521**
2020 Area ABC (t)	**774**	**2,742**	**154**	**3,670**
2020 OFL (t)				**4,484**

Amendment 41 prohibited trawling in the Eastern area east of 140° W longitude. The ratio of biomass still obtainable in the W. Yakutat area (between 147° W and 140° W) is 0.61. This results in the following apportionment to the W. Yakutat area:

	W. Yakutat	E. Yakutat/Southeast
2019 Area ABC (t)	**95**	**60**
2020 Area ABC (t)	**94**	**60**

Tables for Plan Team Summary is provided here:

Stock	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
	2017	57,307	5,233	4,278	4,278	2,623
Dusky Rockfish	2018	56,103	4,841	3,957	3,957	2,854[2]
	2019	55,247	4,521	3,700		
	2020	54,551	4,484	3,670		

Stock	Area	2018			Catch[2]	2019		2020	
		OFL	ABC	TAC		OFL	ABC	OFL	ABC
	W		146	146	50		781		774
Dusky Rockfish	C		3,502	3,502	2,785		2,764		2,742
	WYAK		232	232	12		95		94
	EYAK/SEO		77	77	7		60		60
	Total	4,841	3,957	3,957	2,854	4,521	3,700	4,484	3,670

[1]Total biomass (age 4+) estimates from age-structured model

[2]Current as of October 6, 2018. Source: NMFS Alaska Regional Office Catch Accounting System via the AKFIN database (http://www.akfin.org).

Responses to SSC and Plan Team Comments on Assessments in General

1) "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 dusky rockfish assessment began using this naming convention for this year's assessment.

2) "...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."

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.

3) "...that authors balance the desire to improve model fit with increased risk of model misspecification." (SSC December 2017)

"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." (SSC June 2018)

No model changes are proposed for this year's assessment. Future model changes will be proposed with the above guidance in mind.

4) "The SSC recommends 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,

with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity." (SSC October 2017)

To facilitate a coordinated response to this request, the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from stock assessment program leadership at the AFSC, have suggested that authors address it by using the previous year's Ecosystem Status Report (ESR) as follows:

> "No later than the summer of each year, the lead author of each assessment should 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 should 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 should 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."

5) "Stock assessment authors are encouraged to work with ESR analysts to identify a small subset of indicators prior to analysis, and preferably based on mechanistic hypotheses." (SSC October 2018)

The ESR was examined for details pertaining to dusky rockfish during the summer of 2018. No indications of a severe decline in stock biomass were identified. Additional indicators regarding rockfish in general concerned an analysis of fish condition using GOA bottom trawl survey data and young-of-the-year (YOY) rockfish abundance in the Eastern GOA surface trawl survey. 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. However, we do not anticipate an impending severe decline in biomass for dusky rockfish in the GOA.

"The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock ... during the December Council meeting to aid in identifying stocks of concern." (SSC October 2017)

> Clarification was given during the December 2017 SSC meeting and then re-clarified during the June 2018 SSC meeting. In the interest of efficiency, the clarification from the December 2017 minutes is not included here. The relevant portion of the clarification from the June 2018 minutes reads as follows:

"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:

- *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."*

"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 dusky rockfish when these formal criteria are established.

SSC and Plan Team Comments Specific to this Assessment
1) "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)

A working group is currently investigating the criteria for use of the geostatistical generalized linear mixed model within assessments performed by the AFSC. The dusky model is the only current assessment using these methods (unless others come forth in 2018), and the recommendations from the working group will be important for us to consider when they become available.

Introduction

Biology and Distribution

Dusky rockfish (*Sebastes variabilis*) have one of the most northerly distributions of all rockfish species in the Pacific. They range from southern British Columbia north to the Bering Sea and west to Hokkaido Island, Japan, but appear to be abundant only in the Gulf of Alaska (GOA). Previously, two forms of dusky rockfish, were recognized; "light dusky rockfish" and "dark dusky rockfish". However, they are now officially distinguished as two separate species (Orr and Blackburn 2004). *Sebastes ciliatus* applies to the dark, shallow-water species with the common name dark rockfish, and *S. variabilis* applies to variably colored, usually deeper-water species, with the common name dusky rockfish. This assessment applies only to *S. variabilis*.

Adult dusky rockfish are concentrated on offshore banks and near gullies on the outer continental shelf at depths of 100 to 200 m (Reuter 1999). Anecdotal evidence from fishermen and from biologists on trawl surveys suggests that dusky rockfish are often caught in association with hard, rocky bottom on these banks or gullies. Also, during submersible dives on the outer shelf of the Eastern GOA, dusky rockfish were observed in association with rocky habitats and in areas with extensive sponge beds, where adults were seen resting in large vase sponges[1]. Another study using a submersible in the Eastern GOA observed small dusky rockfish associated with *Primnoa* spp. corals (Krieger and Wing 2002). Research focusing on untrawlable habitats found rockfish species often associate with biogenic structure (Du Preez and Tunnicliffe 2011, Laman et al. 2015), and that dusky rockfish in particular are often found in both trawlable and untrawlable habitats (Rooper and Martin 2012, Rooper et al. 2012). Several of these studies are notable as results indicate further research is needed to address if there are differences in adult dusky rockfish density between trawlable and untrawlable habitats because currently survey catch estimates are extrapolated to untrawlable habitat (Jones et al. 2012, Rooper et al. 2012).

Management Units

Dusky rockfish are managed as a separate stock in the GOA Federal Management Plan (FMP). There are three management areas in the GOA: Western, Central, and Eastern. The Eastern area is further divided into West Yakutat and East Yakutat/Southeast Outside management units. This is done to account for the trawl prohibition in the East Yakutat/Southeast Outside area (east of 140 degree W. longitude) created by Amendment 41.

Stock structure

A review of dusky rockfish stock structure was presented to the GOA Plan Team in September 2011, and was presented as an Appendix to the 2012 assessment document. In summary, available data suggests lack of significant stock structure, therefore the current resolution of spatial management is likely adequate and consistent with management goals (Lunsford et al. 2012). It is evident from this evaluation that life history focused research is warranted and will help in evaluating dusky rockfish stock structure in the GOA.

Life history

Parturition is believed to occur in the spring, based on observation of ripe females sampled on a research cruise in April 2001 in the Central GOA. Similar to all other species of *Sebastes*, dusky rockfish are ovoviviparous with fertilization, embryonic development, and larval hatching occurring inside the mother. After extrusion, larvae are pelagic, but larval studies are hindered because they can only be positively

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[1]V.M. O'Connell, Alaska Dept. of Fish and Game, 304 Lake St., Sitka, AK 99835. Pers. comm. July 1997.

identified by genetic analysis. Post-larval dusky rockfish have not been identified; however, the post-larval stage for other *Sebastes* is pelagic, so it is also likely to be pelagic for dusky rockfish. The habitat of young juveniles is completely unknown. At some point they are assumed to migrate to the bottom and take up a demersal existence; juveniles less than 25 cm fork length are infrequently caught in bottom trawl surveys (Clausen et al. 2002) or with other sampling gear. Older juveniles have been taken only infrequently in trawl surveys, but when caught are often found at more inshore and shallower locations that adults. Laman et al. (2015) found juvenile Pacific ocean perch (*S. alutus*) utilize the vertical habitat that biogenic structures provide in otherwise low-relief, trawlable habitats, indicating these biogenic structures may represent refugia to juvenile rockfish. The major prey of adult dusky rockfish appears to be euphausiids, based on the limited food information available for this species (Yang 1993). In a more recent study, Yang et al. (2006) found that Pacific sand lance along with euphausiids were the most common prey item of dusky rockfish, comprising 82% and 17% , respectively, of total stomach contents by weight.

The evolutionary strategy of spreading reproductive output over many years is a way of ensuring some reproductive success through long periods of poor larval survival (Leaman and Beamish 1984). Fishing generally selectively removes the older and faster-growing portion of the population. If there is a distinct evolutionary advantage of retaining the oldest fish in the population, either because of higher fecundity or because of different spawning times, age-truncation could be deleterious to a population with highly episodic recruitment like rockfish (Longhurst 2002). Work on black rockfish (*S. melanops*) has shown that larval survival may be dramatically higher from older female spawners (Berkeley et al. 2004, Bobko and Berkeley 2004). De Bruin et al. (2004) examined Pacific ocean perch 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. Such relationships have not yet been determined to exist for dusky rockfish in Alaska but maternal age effects on reproduction are an important consideration for assessing population status. Some literature suggests that environmental factors may affect the condition of female rockfish that contribute to reproductive success (Hannah and Parker 2007, Rodgveller et al. 2012, Beyer et al. 2015). No specific studies have addressed if abortive maturation occurs in dusky rockfish in Alaska or if spawning success is variable over time. Stock assessments for Alaska groundfish have assumed that the reproductive success of mature fish is independent of age and that all mature females will spawn annually.

Fishery

Description of Directed Fishery

Dusky rockfish are caught almost exclusively with bottom trawls in the Central and Western areas of the GOA. Catches of dusky rockfish are concentrated at a number of relatively shallow, offshore banks of the outer continental shelf, especially the "W" grounds west of Yakutat, Portlock Bank northeast of Kodiak Island, and around Albatross Bank south of Kodiak Island. Highest catch-per-unit-effort in the commercial fishery is generally at depths of 100-149 m (Reuter 1999). During the period 1988-95, almost all the catch of dusky rockfish (>95%) was taken by large factory trawlers that processed the fish at sea. This changed starting in 1996, when smaller shore-based trawlers also began taking a sizeable portion of the catch in the Central GOA area for delivery to processing plants in Kodiak.

The Rockfish Program in the Central GOA initiated in 2007 allocated the rockfish quota by sector so the percentage of 2007-present catches by shore-based catcher vessels differs in comparison to previous years. One benefit realized from the Rockfish Program is increased observer coverage and sampled catch for trips that target dusky rockfish (Lunsford et al. 2009). Since the majority of dusky rockfish catch comes from the Central GOA, the effects of the Rockfish Program has implications on the spatial distribution of dusky rockfish catch. In a study on localized depletion of Alaskan rockfish, Hanselman et

al. (2007b) found that dusky rockfish were rarely depleted in areas 5,000-10,000 km^2, except during 1994 in one area known as the "Snakehead" outside Kodiak Island in the GOA. This area was heavily fished for northern (*S. polyspinis*) and dusky rockfish in the 1990s and both fishery and survey catch-per-unit-effort have consistently declined in this area since 1994. Comparison of spatial distribution of the dusky rockfish catch before and after the Rockfish Program began did not show major changes in catch distribution (Lunsford et al. 2013). Interpreting this data is confounded, however, as it's unclear if results are attributable to changes in effort or observer coverage. To further complicate data interpretation, in 2013 the North Pacific Groundfish and Halibut Observer Program was restructured with the objective to create a more rigorous scientific method for deploying observers onto more vessels in Federal fisheries. Because many of the vessels targeting rockfish fall in the partial coverage category, we expect this restructuring effort will change the extent of data collected from the rockfish fishery and data should be monitored.

Catch History

Catch reconstruction for dusky rockfish is difficult because in past years dusky rockfish were managed as part of the pelagic shelf rockfish assemblage (Table 12-1). Fishery catch statistics specific to dusky rockfish in the Gulf of Alaska are available for the years 1977-2018 (Table 12-2). Generally, annual catches increased from 1988 to 1992, and have fluctuated in the years following. This pattern is largely explained by management actions that have affected rockfish during this period. In the years before 1991, TACs were relatively large for more abundant slope rockfish species such as Pacific ocean perch, and there was less reason for fishermen to target dusky rockfish. However, as TACs for slope rockfish became more restrictive in the early 1990's and markets changed, there was a greater economic incentive for taking dusky rockfish. As a result, catches of the pelagic shelf assemblage increased, reaching 3,532 t Gulf-wide in 1992. However, a substantial amount of unharvested TAC generally remains each year in this fishery. This is largely due to in-season management regulations which close the rockfish fishery to ensure other species such as Pacific ocean perch do not exceed TAC, or to prevent excess bycatch of Pacific halibut (*Hippoglossus stenolepis*).

In response to Annual Catch Limit (ACL) requirements, assessments now document all removals including catch that is not associated with a directed fishery and reported in the Catch Accounting System. These types of removals may include sport fishery harvest, research catches, or subsistence catch. Research catches of pelagic shelf rockfish have been reported in previous stock assessments (Lunsford et al. 2009). For this year, estimates of all removals through 2017 not associated with a directed fishery including research catches are available and are presented in Appendix 12.A. In summary, research removals have typically been less than 10 t and some harvest occurs in the recreational fishery. These levels likely do not pose a significant risk to the dusky rockfish stock in the GOA.

Bycatch

Bycatch of other species caught in dusky rockfish targeted hauls has historically been dominated by northern rockfish and Pacific ocean perch (Ackley and Heifetz 2001). Similarly, dusky rockfish was the major bycatch species for hauls targeting northern rockfish. These observations are supported by another study in which catch data from the observer program showed dusky rockfish were most commonly associated with northern rockfish, Pacific ocean perch, and harlequin rockfish (Reuter 1999).

Total FMP groundfish catch estimates in the GOA rockfish fishery from 2014-2018 are shown in Table 12-3. As an average for the GOA rockfish fishery during 2014-2018, the largest non-rockfish bycatch groups are arrowtooth flounder (*Atheresthes stomias*) (1,197 t/year), walleye pollock (*Gadus chalcogrammus*) (1,004 t/year), Atka mackerel (*Pleurogrammus monopterygius*) (742 t/year), sablefish (*Anoplopoma fimbria*) (530 t/year), and Pacific cod (*Gadus macrocephalus*) (480 t/year). Non-FMP species catch in the rockfish target fisheries is dominated by giant grenadier (*Albatrossia pectoralis*) and

miscellaneous fish (Table 12-4). However, the amounts from dusky only targeted hauls 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 (Lunsford et al. 2013). The only increase of prohibited species catch observed in 2018 was for golden (Brown) king crab and opilio crab (Table 12-5). Chinook salmon (*Oncorhynchus tshawytscha*) catch has been lower than the five year average since 2016.

In summary, dusky rockfish are most likely to be associated with other rockfish fisheries and the bycatch of non-rockfish species in the dusky fishery are likely low but the only data available is for all rockfish-targeted hauls. Bycatch estimates decreased for the majority of species in the Central GOA following the implementation of the Rockfish Pilot Program. The significant prohibited species that are encountered are Pacific halibut and chinook salmon.

Discards

Gulf-wide discard rates (percent of the total catch discarded within management categories) of dusky rockfish are available from 1991-2018. Rates are listed in the following table and have ranged from less than 1% to 10% of the total dusky catch over time. The significant drop in discard rates in 1998-current can be attributed to a change in management category. The lowest rates were near 1% during 2007-2011 and have since fluctuated from 1-8% in recent years. These rates are considered to be low and are consistent with other GOA rockfish species.

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
% Discard	9.8	5.6	10.5	9.2	6.1	5.0	6.1	1.8	1.3	0.9
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
% Discard	1.7	4.3	1.7	1.8	0.9	5.0	0.7	0.7	1.5	1.0
Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**		
% Discard	1.8	3.9	5.2	3.2	5.3	4.2	7.7	1.3		

Management History

Rockfish (*Sebastes* spp.) species in Federal waters of the GOA were first split into three broad management assemblages by the North Pacific Fishery Management Council (NPFMC) in 1988: slope rockfish, pelagic shelf rockfish, and demersal shelf rockfish. Species in each group were thought to share somewhat similar habitats as adults, and separate "Stock Assessment and Fishery Evaluation" (SAFE) reports were prepared for each assemblage. Dusky rockfish were included in the pelagic shelf rockfish complex, defined as those species of *Sebastes* that inhabit waters of the continental shelf of the GOA, and that typically exhibit midwater, schooling behavior. In 1998 a GOA FMP amendment went into effect that removed black rockfish (*S. melanops*) and blue rockfish (*S. mystinus*) from the assemblage. In 2009 a similar amendment removed dark rockfish from the assemblage. Management authority of these three species was transferred to the State of Alaska.

Beginning in 2009 the pelagic shelf rockfish assemblage consisted of just three species, dusky, widow, and yellowtail rockfish. The validity of this management group became questionable as the group was dominated by dusky rockfish, which has a large biomass in the GOA and supports a valuable directed fishery, especially in the Central GOA. In contrast, yellowtail and widow rockfish have a relatively low abundance in the GOA and are only taken commercially in very small amounts as bycatch. Moreover, since 2003, dusky rockfish has been assessed by an age-structured model and is considered a "Tier 3"

species in the NPFMC harvest policy definitions, while yellowtail and widow rockfish remained "Tier 5" species in which the assessment is based on simple estimates of biomass and natural mortality.

Following recommendations by the authors, the GOA Groundfish Plan Team, and the NPFMC's Science and Statistical Committee, dusky rockfish were assessed separately starting in 2012 and are now presented as a stand-alone species in this document; widow and yellowtail rockfish have been included in the *Other Rockfish* stock assessment (see Appendix 12B, Lunsford et al. 2011). Beginning in 2012, ABCs, TACs, and OFLs specific to dusky rockfish have been assigned.

Management Measures

In 1998, trawling in the Eastern GOA east of 140 degrees W. longitude was prohibited through Amendment 41 (officially recognized in 2000). This had important management concerns for most rockfish species, including the pelagic shelf management assemblage, because the majority of the quota is caught by the trawl fishery. In response to this action, since 1999 the NPFMC has divided the Eastern GOA management area into two smaller areas: West Yakutat (area between 140 and 147 degrees W. longitude) and East Yakutat/Southeast Outside (area east of 140 degrees W. longitude). ABC and TAC recommendations for dusky rockfish are generated for both West Yakutat and East Yakutat/Southeast Outside areas to account for the trawling ban in the Eastern area.

In 2007 the Central GOA Rockfish Program was implemented to enhance resource conservation and improve economic efficiency for harvesters and processors who participate in the Central GOA rockfish fishery. This rationalization program establishes cooperatives among trawl vessels and processors which receive exclusive harvest privileges for rockfish species. The primary rockfish management groups are northern, Pacific ocean perch, and pelagic shelf rockfish (changed to dusky rockfish only in 2012). Potential effects of this program on the dusky rockfish fishery 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. We continue to monitor available fishery data to help understand effects the Rockfish Project may have on the dusky rockfish stock in the Central GOA.

Within the GOA, separate ABCs and TACs for dusky rockfish are assigned to smaller geographical areas that correspond to NMFS management areas. These include the Western GOA, Central GOA, and Eastern GOA (comprised of West Yakutat, and East Yakutat/Southeast Outside sub-areas). OFLs for dusky rockfish are defined on a GOA-wide basis.

A summary of key management measures, a time series of catch, ABC, and TAC are provided in Table 12-1.

Data

Data Summary

The following table summarizes the data available for this assessment (**bold** denotes new data for this assessment):

Source	Data	Years
Fisheries	Catch	1977-2015, 2016, **2017, 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	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2010, 2012, **2014, 2016**
U.S. trawl fisheries	Length	1990-1999, 2007, 2009, 2011, 2013, **2015, 2017**

Fishery Data

Catch

Catch estimates are a combination of foreign observer data, joint venture catch data, and NMFS Regional Office blend data. Catch estimates for dusky rockfish are available from 1977 to 2018 (Table 12-2, Figure 12-1). Catches range from 17 t in 1986 to 4,535 t in 1999. We are skeptical of the low catches that occurred prior to 1988 and believe the catches for years 1985-1987 are likely underestimated. These catches occurred during the end of the joint venture years and prior to accurate catch accounting of the newly formed domestic fishery.

Age and Size Composition

Length frequency data for dusky rockfish in the commercial fishery are available for the years 1991-2017 but are only used in the model when age compositions are not expected to be available for that year (Table 12-6). These data are the raw length frequencies for all dusky rockfish measured by observers in a given year. Generally, these lengths were taken from hauls in which dusky rockfish were either the target or a dominant species, and they provide an indication of the trend in size composition for the fishery. Some years (1995, 1996) had relatively small sample sizes and should be treated with caution as all years, regardless of sample size, are included. Size of fish taken by the fishery generally appears to have increased after 1992; in particular, the mode increased from 42 cm in 1991-92 to 44-45 cm in 1993-96. The mode then decreased to 43 cm in 1997, and rose back to 44-46 cm in 1999 to present. Fish smaller than 40 cm are seen in moderate numbers in certain years (1991-92, 1997, and 2017, Figure 12-8), but it is unknown if this is an artifact of observer sampling patterns, or if it shows true influxes of younger fish or a decrease in older fish.

Age samples for dusky rockfish have been collected by observers in the 1999-2018 commercial fisheries. Aging has been completed for the 2000-2016 samples (Table 12-7). Similar to the fishery length data discussed in the preceding paragraph, the data in Table 12-7 depicts the raw age distribution of the samples, and we did not attempt any further analysis to estimate a more comprehensive age composition. However, the samples were randomly collected from fish in over 100 hauls that had large catches of dusky rockfish, so the raw distribution is probably representative of the true age composition of the fishery. Fish ranged in age from 4 to 66 years. The mode has increased recently from 15 years old in 2000-2006 to 18 years old in 2014-2016. Several large and relatively steady year classes are evident through the time series including 1986, 1992, 1995, and 1999 (Figure 12-2).

Survey Data

Trawl Survey Biomass Estimates

Comprehensive trawl surveys were conducted on a triennial basis in the GOA in 1984, 1987, 1990, 1993, 1996, and 1999, and biennially in 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015 and 2017 (Table 12-8). Dusky rockfish were separated into "light" and "dark" varieties in surveys since 1996 and starting in 2004 labeled as dusky and dark rockfish. Each of these surveys has shown that dusky rockfish (light dusky) overwhelmingly predominate and that dark rockfish (dark dusky) are caught in only small quantities. Presumably, the dusky rockfish biomass in surveys previous to 1996 consisted of nearly all dusky rockfish.

The 1984 and 1987 survey results should be treated with some caution. A different survey design was used in the Eastern GOA in 1984; furthermore, much of the survey effort in the Western and Central GOA 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. Also, the 2001 survey biomass is a weighted average of 1993-1999 biomass estimates, since the Eastern GOA was not surveyed in 2001.

The spatial distribution of the catches of dusky rockfish in the 2013, 2015, and 2017 surveys are shown in Figure 12-3. The magnitude of catch varies greatly with several large tows typically occurring in each survey. It is unknown whether these fluctuations indicate true changes in abundance, temporal changes in the availability of dusky rockfish to the survey gear, or are an artifact of the imprecision of the survey for this species. An increase in trawl survey catches in the west and the lack of large trawl catches of dusky rockfish in the east is evident in Figure 12-3; these values support the shift in apportionment from east to west.

A trawl survey biomass estimator based on a geostatistical generalized linear mixed model (GLMM; Thorson et al. 2015) has been used for this assessment since 2015. Details on the application of this biomass estimator for five GOA rockfish species are available in the 2015 GOA dusky rockfish assessment (Lunsford et al. 2015, Appendix 12B). We believe this estimator is preferred to the design-based estimator for estimating dusky rockfish biomass. The geostatistical GLMM appears to work well in smoothing out the dramatic and unlikely swings in abundance that occur in some of the more patchily distributed GOA rockfish. The model also increases the precision relative to the design-based estimators by incorporating spatial and temporal covariation. For dusky rockfish, these biomass estimates are much smoother than the design-based estimates and have a realistic trend not discernable in the design-based estimates (Tables 12-9A & 12-9B, Figure 12-4). Variance estimates for the geostatistical estimator are lower and CVs are relatively stable over the time series ranging from 14-25 percent.

The GLMM estimator has evolved over time. In 2015, the 'spatialdeltaGLMM' R package was used as the GLMM estimator, and that has now evolved into the R package 'VAST'. While the estimator results are very similar, the VAST package used for 2017 produces slightly different results than the version used for 2015 (figure below). The largest difference in results between the two estimators occurs in 1990. The 2017 GLMM specifications in VAST include 1) no bias correction, 2) 1000 knots, 3) estimating spatial and spatiotemporal random effects, 4) no autocorrelation, 5) lognormal error distribution with logit link for encounter probability and log link for positive catch rate.

Biomass estimates from the 2017 VAST GLMM range from a minimum 20,435 t in 1984 to a maximum of 65,575 t in 2005 (Table 12-9B). Overall, biomass estimates show some inter-annual variability and a moderate increase over time. The 2017 biomass estimate of 53,842 t is a three percent increase from the 2015 estimate and fairly close to the 2017 design-based estimate (51,270 t; Table 12-9A).

Survey Size Compositions

Gulf-wide survey size compositions are available for 1984-2017 (Table 12-10; Figure 12-17). Survey size compositions suggest that strong recruitment of dusky rockfish is a relatively infrequent event, as only three surveys, 1993, 2001, and 2003, showed evidence of substantial recruitment. Mean population length increased from 39.4 cm in 1987 to 43.1 cm in 1990. In 1993, however, a large number of small fish (~27-35 cm long) appeared which formed a sizeable percentage of the population, and this recruitment decreased the mean length to 38.3 cm. In the 1996 and 1999 surveys, the length frequency distribution was similar to that of 1990, with very few small fish, and both years had a mean population length of 43.9 cm. The 2001 size composition, although not directly comparable to previous years because the Eastern GOA was not sampled, shows modest recruitment of fish <40 cm. In 2003, a distinct mode of fish is seen at ~30 cm that suggests relatively strong recruitment may have occurred, and this is supported again in 2005 with a distinct mode at ~37 cm. No evidence of recruitment of small fish has been seen in recent surveys. Average length has increased each survey year since 2009 and is more comparable to fishery lengths in recent years (Tables 12-6, Table 12-10). The exception may be in 2017 where the mode of lengths has decreased to 42.4 cm. Sample sizes have remained stable varying from 1,113 lengths taken in 1990 to 3,383 in 2005. Survey length compositions are used in estimating the length-age conversion matrix and in estimating the population age composition, but are not used as an additional compositional time series because survey ages are available from those same years and are used in the model except for the most recent year.

Gulf-wide age composition data for dusky rockfish are available for the 1984 through 2017 trawl surveys (Table 12-11). The mode of the age data has been steadily increasing from 10 years in 1984 to 18 years in 2015 and recently decreased to 15 years in 2017. Similar to the length data, these age data also indicate that strong recruitment is infrequent. For each survey, ages were determined using the "break-and-burn" method of aging otoliths, and a Gulf-wide age-length key was developed. The key was then used to estimate age composition of the dusky rockfish population in the GOA. The 1976 year class appeared to be abundant in the early surveys, especially 1984 (Figure 12-5). The 1986 year class appeared strong in the 1993, 1996, and perhaps the 1999 surveys. Because rockfish are difficult to age, especially as the fish grow older, one possibility is that some of the fish aged 12 in 1999 were actually age 13 (members of the 1986 year class), which would agree more with the 1993 and 1996 age results. Little recruitment occurred in the years following until the 1992 and 1995 year classes appeared. The only prominent year class until the most recent survey was the 1998 year class, which had the highest proportion of ages sampled in the 2013 survey. In 2017, there appears to be some evidence for two potentially stronger year classes in 2007 and 2010.

Analytic Approach

General Model Structure

We present model results for dusky rockfish based on an age-structured model 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 and northern rockfish models (Hanselman et al. 2007a, Courtney et al. 1999). In 2003, biomass estimates from an age-structured assessment model were first accepted as an alternative to trawl survey biomass estimates. 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. We do this because there does not appear to be an obvious stock-recruitment relationship in the model estimates, and there have been very high recruitments at low stock size (Figure 12-6). The parameters, population dynamics, and equations of the model are in Box 1.

Model Selection

No changes were made to input data and model configuration in this year's assessment compared to the 2015 assessment. The 2015 assessment made several changes in the size-age conversion matrix, the aging error matrix, the plus group age, and implemented the geospatial GLMM for the survey biomass index; no additional changes were deemed necessary.

Model case	Description
15.5 (2015)	2015 accepted model (Model case M5 in 2015)
15.5 (2018)	Same model as 2015, but with updated data through 2018

Parameters Estimated Outside the Assessment Model

Parameters fit outside the assessment model include the life-history parameters for weight-at-age, age error matrices, and natural mortality. For dusky rockfish, these values were previously taken from the 2001 Pelagic Shelf Rockfish SAFE Document (Clausen and Heifetz 2001). Length-weight information for dusky rockfish is derived from data collected from GOA trawl surveys from 1990-2017, with a total sample size of 5,345. The length weight relationship for combined sexes, using the formula $W = aL^b$, where W is weight in grams and L is fork length in mm, $a = 7.19 \times 10^{-6}$ and $b = 3.14$.

The size-age conversion matrix was constructed from the Von Bertalanffy growth curve fit to length and age data collected from GOA trawl surveys from 1990-2017. The conversion matrix was constructed by adding normal error with a standard deviation equal to the standard deviation of survey lengths for each age class. Estimated parameters are: $L_\infty = 48.4$ cm, $\kappa = 0.18$, and $t_0 = 0.39$.

Ageing 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 for dusky rockfish. In past assessments the ageing error matrix was constructed by assuming the same age determination error used for northern rockfish (Courtney et al. 1999).

Prior to 2007, the natural mortality rate used for dusky rockfish was 0.09. Questions about the validity of the high natural mortality rate of dusky rockfish versus other similarly aged rockfish were raised in previous stock assessments (Lunsford et al. 2007). In 2007, the natural mortality rate was changed to 0.07 based on an estimate calculated by Malecha et al. (2004) using updated data. This method used the Hoenig (1983) empirical estimator for natural mortality based on maximum lifespan. Based on the highest age recorded in the trawl survey of 59 this estimate is 0.08. The highest recorded age in the fishery ages was 76, which equates to a Hoenig estimate of 0.06. The current natural mortality estimate used in this assessment (0.07) is comparable to other similarly aged rockfish in the GOA.

Parameters Estimated Inside the Assessment Model

Maturity-at-age is modeled with the logistic function which estimates parameters for maturity-at-age conditionally. Parameter estimates for maturity-at-age are obtained by combining data collected on female dusky rockfish maturity from Lunsford (pers. comm. July 1997) and Chilton (2010). The binomial likelihood is used in the assessment model as an additional component to the joint likelihood function to fit the combined observations of female dusky rockfish maturity (e.g., Quinn and Deriso, 1999). The binomial likelihood was selected because (1) the sample sizes for maturity are small and assuming convergence to the normal distribution may not be appropriate in this case, (2) the binomial likelihood inherently includes sample size as a weighting component, and, (3) resulting maturity-at-age from the normal likelihood (weighted by sample size) was very similar to maturity-at-age obtained with the binomial likelihood.

The fit to the combined observations of maturity-at-age obtained in the preferred assessment model is shown in Figure 12-7. Parameters for the logistic function describing maturity-at-age estimated conditionally in the model, as well as all other parameters estimated conditionally, were identical to estimating maturity-at-age independently. Estimating maturity-at-age parameters conditionally influences the model only through the evaluation of uncertainty, as the MCMC procedure includes variability in the maturity parameters in conjunction with variability in all other parameters, rather than assuming the maturity parameters are fixed. Thus, estimation of maturity-at-age within the assessment model allows for uncertainty in maturation to be incorporated into uncertainty for key model results (e.g., ABC; described below in the *Uncertainty approach* section). The age at 50% maturity is estimated to be 10.3. Using the parameters from the vonBertalanffy growth model (see 'Parameters estimated outside the model' section, above), the size at 50% maturity is 40.3 cm.

Other parameters estimated conditionally in the current model include, but are not limited to: logistic parameters for selectivity for survey and fishery, mean recruitment, fishing mortality, spawner per recruit levels, and logistic parameters for maturity. The numbers of estimated parameters are shown below. Other derived parameters are described in Box 1.

Parameter name	Symbol	Number
Catchability	q	1
Log-mean-recruitment	μ_r	1
Recruitment variability	σ_r	1
Spawners-per-recruit levels	$F_{35\%}, F_{40\%}, F_{50\%}$	3
Recruitment deviations	τ_y	65
Average fishing mortality	μ_f	1
Fishing mortality deviations	ϕ_y	42
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		120

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 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 non-informative (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 120. In a low-dimensional model, an analytical solution might be possible, but in a model 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 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 100,000 iterations out of 1,000,000 and "thinned" the chain to one value out of every two hundred, leaving a sample distribution of 4,500. Further assurance that the chain had converged was attained by comparing 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 of the parameters presented here, including 95% credible intervals for some parameters.

Parameter definitions	**BOX 1. AD Model Builder Model Description**
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, fixed
$F_{y,a}$	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

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

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 (n^*_y =square root of sample size, with the largest set to one hundred)

$$L_4 = \lambda_4 \sum_{styr}^{endyr} -n^*_y \sum_l^{l+} \left(P_{y,l} + 0.001\right) * \ln\left(\hat{P}_{y,l} + 0.001\right)$$

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

$$L_7 = \frac{1}{2\sigma_q^2} \left(\ln \frac{q}{q_{prior}} \right)^2$$

Penalty on deviation from prior distribution of catchability coefficient

$$L_8 = \frac{1}{2\sigma_{\sigma_r}^2} \left(\ln \frac{\sigma_r}{\sigma_{r(prior)}} \right)^2$$

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

The model for this assessment is model 15.5 (2018), which is the 2015 model with updated data through 2018. This model is identical to the model accepted in 2015, except for inclusion of additional years of data. 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, (3) a good visual fit to length and age compositions, and (4) parsimony. Because the 2015 and 2018 models are identical and we are not providing alternative model configurations for comparison with the current model; we will only evaluate the 2018 model based on changes in results from 2015.

The model generally produces good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivities. Therefore, the recommended 2018 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 12-12 – 12-15. In general, model predictions continue to fit the data well (Figures 12-1, 12-2, 12-4, 12-5, 12-8).

Definitions

Spawning biomass is the biomass estimate of mature females. Total biomass is the biomass estimate of all dusky rockfish age four and greater. Recruitment is measured as number of age four dusky 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 model tracks most of the survey biomass estimates well from 1985 to 2003, however the 2005 observed value is not well fit by the model (Figure 12-4) and the model under predicts survey biomass for 2013-2017. In general, the predicted survey biomass is a better fit to the observed data for the 15.5 (2018) model compared to the 15.5 (2015) model.

Total biomass estimates (age 4+) indicate a moderately increasing trend with a peak in 2006, the year following the exceptionally high 2005 survey biomass estimate, and a decreasing trend thereafter. Spawning biomass estimates increase from 1977 to 2010, then decline slightly from 2011 to 2018 (Figure 12-9). MCMC credible intervals indicate that the historic low was more certain than the more recent increases, particularly when looking at the upper credible interval.

The estimated selectivity curve for the fishery and survey data suggested a pattern similar to what we expect for dusky rockfish (Figure 12-10). The commercial fishery should target larger and subsequently older fish and the survey should sample a larger range of ages. Ninety-five percent of dusky rockfish are selected by the fishery and survey by age 13. The age at 50% selection is 8.5 for the survey and 10.4 for the fishery.

The fully-selected fishing mortality time series indicates a rise in fishing mortality from late 1980's through the late 1990's and has been relatively stable from 2003-2018, ranging between 0.05 and 0.08 (Figure 12-11). In 2012, the harvest exceeded TAC in the Western GOA. This occurred in all rockfish fisheries in response to a delayed closing of the fishery. 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. We use a phase-plane plot to show the ratio of fishing mortality to F_{OFL} ($F_{35\%}$) and

the estimated spawning biomass relative to the target level ($B_{35\%}$) for 1977-2018 and projected values for 2019-2020. Harvest control rules based on $F_{35\%}$ and $F_{40\%}$ and the Tier 3b adjustment are provided for reference. The historical management path for dusky rockfish has been above the F_{OFL} adjusted limit for only a few years in the early 1980's and early 1990's. Since 2000, dusky rockfish have been above $B_{40\%}$ and well below $F_{40\%}$ (Figure 12-12).

Recruitment

There is some lack of fit to the plus group in the fishery size compositions for 1991-1993 (Figure 12-8). This may be due to the increase in size of fish taken by the fishery in those years as mentioned in the Fishery data section. The 2017 fishery size composition fits well for all but the plus group, where the model prediction is much higher than what was observed in the fishery. In general, the model fits the fishery age compositions well. The strong year classes from 1992 and 1995 have largely moved into the plus age group and no strong year classes have shown up since (Figure 12-2).

The survey age compositions also track the 1992 year class well and try to fit the 1995 year class, which appeared consistently strong in surveys through 2013 (Figure 12-5); in 2015 the model predicted a smaller proportion of fish to be in the plus age group than what was observed in the survey. Recruitment estimates have not been strong since several above average events in early to mid 1990's, though there is some evidence of new recruits in the survey age compositions from the 2007 and 2010 year classes.

Recruitment (age 4) is highly variable throughout the time series (Figure 12-13), particularly the most recent years, where typically very little information is known about the strength of incoming year classes. There also does not seem to be a clear spawner recruit relationship for dusky rockfish as recruitment appears unrelated to spawning stock biomass (Figure 12-6). MCMC credible intervals for recruitment are fairly narrow in some years; however, the credible intervals nearly contain zero for many years which indicates considerable uncertainty, particularly for the most recent years (Figure 12-13).

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 0.06, indicating that the model decreases the estimate of female spawning biomass in recent years as data is added to the assessment. The Mohn's rho statistic for the 2015 approved model was 0.10. The retrospective female spawning biomass and the relative difference in female spawning biomass from the model in the terminal year are shown in Figure 12-14 (with 95% credible intervals from MCMC). In general, the relative difference in female spawning biomass ranges from around 0% to 50%.

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 12-15) and credible intervals (Table 12-15). We also use these posterior distributions to show uncertainty around time series estimates such as total biomass, recruitment, and spawning biomass (Figures 12-9, 12-13, 12-16).

Table 12-13 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 larger for the estimates of *q*, $F_{40\%}$, ABC, and female spawning biomass. These larger standard deviations indicate that these parameters are more uncertain than indicated by the standard estimates. However, all estimates fall within the Bayesian credible intervals.

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, dusky rockfish in the GOA are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, which is equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing, $F_{35\%}$ which is 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 $F_{40\%}$, which is 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 4 recruits from 1981-2014 (year classes between 1977 and 2010). Because of uncertainty in very recent recruitment estimates, we lag 4 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 estimates of these female spawning biomass reference points for 2019 are:

$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	$F_{40\%}$	$F_{35\%}$
46,337	18,535	16,218	0.095	0.118

Specification of OFL and Maximum Permissible ABC

Female spawning biomass for 2019 is estimated at 20,342 t, which is above the $B_{40\%}$ value of 18,535 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:

$F_{40\%}$	0.095
ABC	3,700
$F_{35\%}$	0.118
OFL	4,521

Population Projections

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 follow (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 above 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 12-16). 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 2,623 t. This is less than the 2017 OFL of 5,233 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 12-16). 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 12-16, the stock is not overfished and is not approaching an overfished condition. The test for determining whether a stock is overfished is based on the 2017 catch compared to OFL. The official total catch for 2017 is 2,623 t which is less than the 2017 OFL of 5,233 t; therefore, the stock is not being subjected to overfishing. The tests for evaluating whether a stock is overfished or approaching a condition of being overfished require examining model projections of spawning biomass relative to $B_{35\%}$ for 2018 and 2020. The estimates of spawning biomass for 2018 and 2020 from the current year (2018) projection model are 21,203 t and 20,106 t, respectively. Both

estimates are above the $B_{35\%}$ estimate of 16,218 t and, therefore, the stock is not currently overfished nor approaching an overfished condition.

Alternative Projection

During the 2006 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 (0.62) 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 1,000,000. The projection shows wide credibility intervals on future spawning biomass (Figure 12-16). The $B_{35\%}$ and $B_{40\%}$ reference points are based on the 1981-2014 age-4 recruitments, and this projection predicts that the median spawning biomass will decrease quickly until average recruitment is attained.

Area Allocation of Harvests

The random effects model was fit to the survey design-based biomass estimates (with associated variance) for the Western, Central, and Eastern GOA. 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).
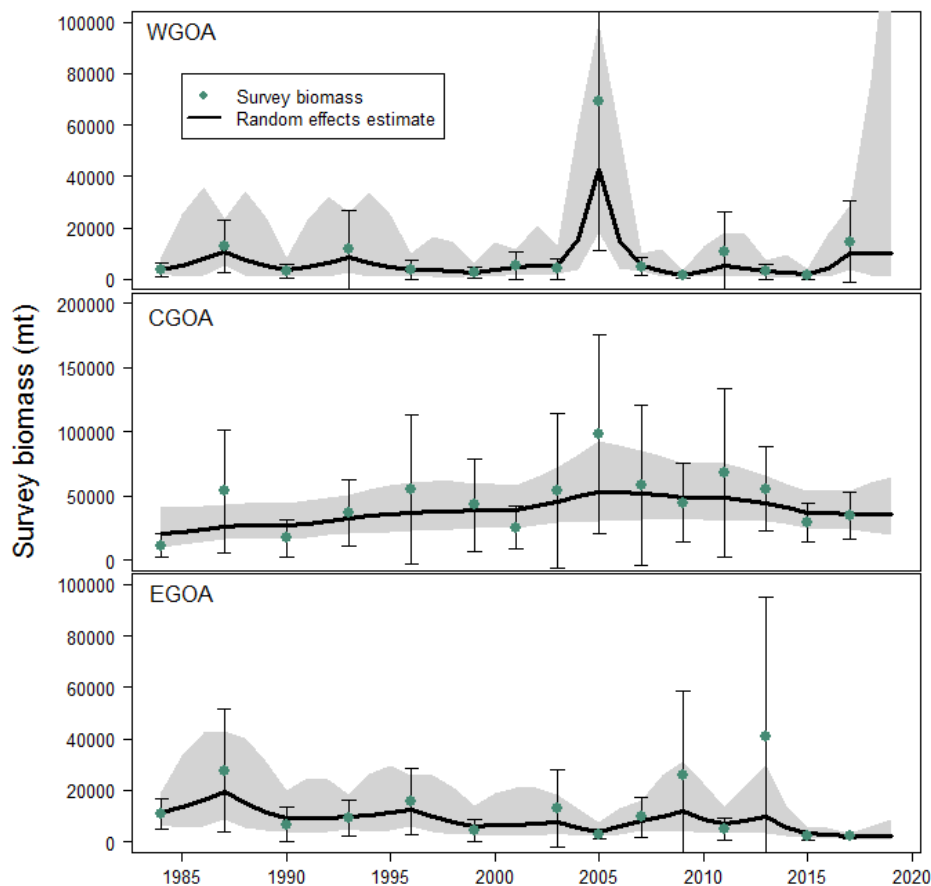
In general the random effects model fits the area-specific survey biomass reasonably well. Using the random effects model estimates of survey biomass, the apportionment results in 21.1% for the Western area (up from 3.7% in 2015), 74.7% for the Central area (down from 88.5% in 2015), and 4.2% for the Eastern area (down from 7.8% in 2015). The changes in apportionment in 2018 compared to 2015 can be attributed to an increase in biomass from the bottom trawl survey biomass in the Western area. This results in recommended ABC's of **781** t for the Western area, **2,764** t for the Central area, and **155** t for the Eastern area.

Because the Eastern area is now divided into two management areas for dusky rockfish, i.e., the West Yakutat area (area between 147 degrees W. longitude and 140 degrees W. longitude) and the East Yakutat/Southeast Outside area (area east of 140 degrees W. longitude), the ABC for this management group in the Eastern area must be further apportioned between these two smaller areas. In an effort to balance uncertainty with associated costs to the fishing industry, the GOA Plan Team has recommended that apportionment to the two smaller areas in the Eastern GOA be based on the upper 95% confidence limit of the weighted average of the estimates of the Eastern GOA biomass proportion that is in the West Yakutat area. The upper 95% confidence interval of this proportion is 0.61 (down from 0.75 in 2015), so that the dusky rockfish ABC for West Yakutat would be 95 t, and the ABC for East Yakutat/Southeast Outside would be 60 t (Table 12-17).

Overfishing Definition
Based on the definitions for overfishing in Amendment 44 in Tier 3a (i.e., $F_{OFL} = F_{35\%}=0.118$), the 2019 overfishing (OFL) is set equal to 4,521 t for dusky rockfish in the GOA (Table 12-17).

Ecosystem Considerations

In general, a determination of ecosystem considerations is hampered by the lack of biological and habitat information for dusky rockfish. However, a review of the most recent (2017) GOA Ecosystem Status Report did not reveal strong evidence of declining trends in indicators which results in strong concern for dusky rockfish. It is noted that the Eastern GOA surface trawls in 2017 caught relatively few YOY rockfish (species not determined) compared to the high numbers seen in 2016 though no connection between these catches and year class strength have been established. How dusky rockfish responded to the marine heat wave of 2014-2015 is unknown at this time.

A summary of the ecosystem considerations presented in this section is listed in Table 12-18. Additionally, we provide information regarding the FMP, non-FMP, and prohibited species caught in rockfish target fisheries to help understand ecosystem impacts by the dusky fishery (Tables 12-3, 12-4, 12-5).

Ecosystem Effects on the Stock

Prey availability/abundance trends: similar to many other rockfish species, stock condition of dusky rockfish appears to be greatly influenced by periodic abundant year classes. Availability of suitable zooplankton prey items in sufficient quantity for larval or post-larval dusky 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, field-collected larval dusky rockfish at present cannot even be visually identified to species. Yang (1993) reported that adult dusky rockfish consume mostly euphausiids. Yang et al. (2006) reports Pacific sandlance *Ammodytes hexapterus* and euphausiids as the most common prey item of dusky rockfish with Pacific sandlance comprising 82% of stomach content weight. Euphausiids are also a major item in the diet of walleye pollock, Pacific ocean perch, and northern rockfish. Changes

in the abundance of these three species could lead to a corollary change in the availability of euphausiids, which would then have an impact on dusky rockfish.

Predator population trends: there is no documentation of predation on dusky rockfish. Larger fish such as Pacific halibut that are known to prey on other rockfish may also prey on adult dusky rockfish, but such predation probably does not have a substantial impact on stock condition. Predator effects would likely be more important on larval, post-larval, and small juvenile dusky rockfish, but information on these life stages and their predators is nil.

Changes in physical environment: strong year classes corresponding to the period 1976-77 have been reported for many species of groundfish in the Gulf of Alaska, including walleye pollock, Pacific ocean perch, northern rockfish, sablefish, and Pacific cod. As discussed in the *survey data* section, age data for dusky rockfish indicates that the 1976 and/or 1977 year classes were also unusually strong for this species. 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 dusky rockfish. The environmental mechanism for this increased survival of dusky rockfish, however, remains unknown. Pacific ocean perch and dusky rockfish both appeared to have strong 1986 year classes, and this may be another year when environmental conditions were especially favorable for rockfish species.

Changes in bottom habitat due to natural or anthropogenic causes could alter survival rates by altering available shelter, prey, or other functions. Associations of juvenile rockfish with biotic and abiotic structure have been noted by Carlson and Straty (1981), Pearcy et al. (1989), and Love et al. (1991). However, the Essential Fish Habitat Environmental Impact Statement (EFH EIS; NMFS 2001) concluded that the effects of commercial fishing on the habitat of groundfish are minimal or temporary. The long-term upward trend in abundance suggests that at current levels of abundance and exploitation, habitat effects from fishing is not limiting this stock.

Fishery Effects on the Ecosystem

Fishery-specific contribution to bycatch of HAPC biota: there is limited habitat information on adult dusky rockfish, especially regarding the habitat of the major fishing grounds for this species in the GOA. Nearly all the catch of dusky rockfish, however, is taken by bottom trawls, so the fishery potentially could affect HAPC biota such as corals or sponges if it occurred in localities inhabited by that biota. Corals and sponges are usually found on hard, rocky substrates, and there is some evidence that dusky rockfish may be found in such habitats. On submersible dives on the outer continental shelf of the Eastern GOA, light dusky rockfish were observed in association with rocky habitats and in areas with extensive sponge beds, where the fish were observed resting in large vase-type sponges.[2] Also, dusky rockfish often co-occur and are caught with northern rockfish in the commercial fishery and in trawl surveys (Reuter 1999) and catches of northern rockfish have been associated with a rocky or rough bottom habitat (Clausen and Heifetz 2002). Based on this indirect evidence, it can be surmised that dusky rockfish are likely also associated with rocky substrates. An analysis of bycatch of HAPC biota in commercial fisheries in the Gulf of Alaska in 1997-99 indicated that the dusky rockfish trawl fishery ranked fourth among all fisheries in the amount of corals taken as bycatch and sixth in the amount of sponges taken (National Marine Fisheries Service 2001). Little is known, however, about the extent of these HAPC biota and whether the bycatch is detrimental.

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 dusky rockfish trawl fishery in the GOA

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[2]V.M. O=Connell, Alaska Dept. of Fish and Game, 304 Lake St., Sitka, AK 99835. Pers. commun. July 1997.

previously started in July and usually lasted only a few weeks. As mentioned previously in the *fishery* section, the fishery is concentrated at a number of offshore banks on the outer continental shelf. Beginning in 2007 the Rockfish Program began which allowed fishing in the Central GOA from May 1 – November 15. There is no published information on time of year of insemination or parturition (larval release), but insemination is likely in the fall or winter, and anecdotal observations indicate parturition is mostly in the spring. Hence, reproductive activities are probably not directly affected by the commercial fishery. However, there may be some interaction in the Central GOA if parturition is delayed until May 1.

Fishery-specific effects on amount of large size target fish: a comparison between Table 12-6 (length frequency in the commercial fishery) and Table 12-10 (size composition in the trawl surveys) suggests that although the fishery does not catch many small fish <40 cm length, the fishery also does not catch a significantly greater percentage of very large fish, relative to trawl survey catches.

Fishery contribution to discards and offal production: fishery discard rates of dusky rockfish have been quite low in recent years, especially after formation of the Rockfish Program. The discard rate in the dusky rockfish fishery is unknown as discards are grouped as rockfish fishery target and are not available for just the dusky fishery.

Fishery-specific effects on age-at-maturity and fecundity of the target fishery: the fishery effects on age-at-maturity and fecundity are unknown, but based on the size of 50% maturity of female dusky rockfish reported in this document (40.3 cm), the fishery length frequency distributions in Figure 12-6 suggest that the fishery may catch some immature fish.

Fishery-specific effects on EFH living and non-living substrate: effects of the dusky rockfish fishery on non-living substrate is unknown, but the heavy-duty rockhopper trawl gear commonly used in the fishery can move around rocks and boulders on the bottom. Table 12-4 shows the estimated bycatch of living structure such as benthic urochordates, corals, sponges, sea pens, and sea anemones by the GOA rockfish fisheries.

Data Gaps and Research Priorities

There is no information on larval, post-larval, or early stage juvenile dusky rockfish. Larval dusky rockfish can only be identified with genetic techniques, which are very high in cost and manpower. Analysis of stock structure through the stock structure template illustrates the need for a large scale genetic study to investigate stock structure of dusky rockfish in the GOA. Habitat requirements for larval, post-larval, and early stage juvenile dusky rockfish are unknown. Habitat requirements for later stage juvenile and adult fish are anecdotal or conjectural. Research needs to be done to identify the HAPC biota on the bottom habitat of the major fishing grounds and what impact bottom trawling has on these biota. Several different techniques are used by stock assessors to weight length and age sample sizes in models. Research is currently being conducted to determine the best technique for weighting sample sizes and results should help us in choosing appropriate rationale for weighting.

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Tables

Table 12-1. A summary of key management measures and the time series of catch, ABC and TAC for pelagic shelf rockfish and dusky rockfish in the Gulf of Alaska, units in t.

Year	Catch[1]	ABC	TAC	OFL	Management Measures
1988	1,086	3,300	3,300	n/a	Pelagic shelf rockfish assemblage 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" which included PSR species. Apportionment and biomass determined from average percent biomass of most recent trawl surveys
1989	1,738	6,600	3,300	n/a	No reported foreign or joint venture catches of PSR
1990	1,647	8,200	8,200	n/a	
1991	2,187	4,800	4,800	n/a	
1992	3,532	6,886	6,886	11,360[3]	
1993	3,182	6,740	6,740	11,300[3]	
1994	2,980	6,890	6,890	11,550[3]	
1995	2,882	5,190	5,190	8,704[3]	
1996	2,290	5,190	5,190	8,704[3]	Area apportionment based on 4:6:9 weighting scheme of 3 most recent survey biomass estimates rather than average percent biomass
1997	2,467	5,140	5,140	8,400[3]	
1998	3,109	4,880	4,880	8,040[3]	Black and blue rockfish removed from PSR assemblage and federal management plan Trawling prohibited in Eastern Gulf east of 140 degrees W.
1999	4,658	4,880	4,880	8,190[3]	Eastern Gulf divided into West Yakutat and East Yakutat/Southeast Outside and separate ABCs and TACs assigned
2000	3,728	5,980	5,980	9,040[3]	Amendment 41 became effective which prohibited trawling in the Eastern Gulf east of 140 degrees W.
2001	3,006	5,980	5,980	9,040[3]	Dusky rockfish treated as Tier 4 species whereas dark, widow, and yellowtail broken out as Tier 5 species
2002	3,321	5,490	5,490	8,220[3]	
2003	3,056	5,490	5,490	8,220[3]	Age structured model for dusky rockfish accepted to determine ABC and moved to Tier 3 status
2004	2,688	4,470	4,470	5,570[3]	
2005	2,236	4,553	4,553	5,680[3]	
2006	2,452	5,436	5,436	6,662[3]	
2007	3,383	5,542	5,542	6,458[3]	Amendment 68 created the Central Gulf Rockfish Pilot Project
2008	3,657	5,227	5,227	6,400[3]	
2009	3,075	4,781	4,781	5,803[3]	Dark rockfish removed from PSR assemblage and federal management plan
2010	3,119	5,059	5,509	6,142[3]	
2011	2,538[2]	4,754	4,754	5,570[3]	Dusky rockfish broken out as stand-alone species for 2012. Widow and yellowtail rockfish included in other rockfish assemblage.
2012	4,010[2]	5,118	5,118	6,257	
2013	3,158[2]	4,700	4,700	5,746	
2014	3,062[2]	5,486	5,486	6,708	
2015	2,781[2]	5,109	5,109	6,246	
2016	3,327[2]	4,686	4,686	5,733	
2017	2,623[2]	4,278	4,278	5,233	
2018	2,854[2]	3,957	3,957	4,841	

[1] Catch is for entire pelagic shelf rockfish assemblage,
[2] Catch is for dusky rockfish only, updated through October 6, 2018. Source: AKFIN.
[3] OFL is for entire pelagic shelf rockfish assemblage.

Table 12-2. Commercial catch (t) of dusky rockfish in the Gulf of Alaska, with Gulf-wide values of acceptable biological catch (ABC), total allowable catch (TAC), and percent TAC harvested (% TAC). Values are a combination of foreign observer data, joint venture catch data, and NMFS Regional Office Catch Accounting System data.

Year	Catch	ABC[1]	TAC[1]	% TAC
1977	388	-	-	-
1978	162	-	-	-
1979	224	-	-	-
1980	597	-	-	-
1981	845	-	-	-
1982	852	-	-	-
1983	1,017	-	-	-
1984	540	-	-	-
1985	34	-	-	-
1986	17	-	-	-
1987	19	-	-	-
1988	1,067	3,300	3,300	32%
1989	1,707	6,600	3,300	52%
1990	1,612	8,200	8,200	20%
1991	2,035	4,800	4,800	41%
1992	3,443	6,886	6,886	50%
1993	3,119	6,740	6,740	46%
1994	2,913	6,890	6,890	42%
1995	2,836	5,190	5,190	55%
1996	2,275	5,190	5,190	44%
1997	2,464	5,140	5,140	48%
1998	3,107	4,880	4,880	64%
1999	4,535	4,880	4,880	93%
2000	3,699	5,980	5,980	62%
2001	2,997	5,980	5,980	50%
2002	3,301	5,490	5,490	60%
2003	3,020	5,490	5,490	55%
2004	2,557	4,470	4,470	57%
2005	2,209	4,553	4,553	49%
2006	2,436	5,436	5,436	45%
2007	3,372	5,542	5,542	61%
2008	3,631	5,227	5,227	69%
2009	3,069	4,781	4,781	64%
2010	3,109	5,059	5,059	61%
2011	2,529	4,754	4,754	53%
2012	4,010	5,118	5,118	78%
2013	3,158	4,700	4,700	67%
2014	3,062	5,486	5,486	56%
2015	2,781	5,109	5,109	54%

[1] ABC and TAC are for the pelagic shelf rockfish assemblage which dusky rockfish was a member of until 2011. Individual ABCs and TACs were assigned to dusky rockfish starting in 2012.

Table 12-2. (Continued) Commercial catch (t) of dusky rockfish in the Gulf of Alaska, with Gulf-wide values of acceptable biological catch (ABC), total allowable catch (TAC), and percent TAC harvested (% TAC). Values are a combination of foreign observer data, joint venture catch data, and NMFS Regional Office Catch Accounting System data.

Year	Catch	ABC[1]	TAC[1]	% TAC
2016	3,327	4,686	4,686	71%
2017	2,623	4,278	4,278	61%
2018[a]	2,854	3,957	3,957	72%

[1] ABC and TAC are for the pelagic shelf rockfish assemblage which dusky rockfish was a member of until 2011. Individual ABCs and TACs were assigned to dusky rockfish starting in 2012.
[a] Catch updated through October 6, 2018. Source: AKFIN.

Table 12-3. Incidental catch of FMP groundfish species caught in rockfish targeted fisheries in the Gulf of Alaska from 2014-2018. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/7/2018.

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 12-4. Non-FMP species bycatch estimates in tons for Gulf of Alaska rockfish targeted fisheries 2014-2018. Conf. = Confidential because of less than three vessels. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/7/18.

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 12-5. 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 PSCNQ via AKFIN 10/7/2018.

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 12-6. Fishery size compositions and sample size by year used in the model for dusky rockfish in the Gulf of Alaska. Lengths below 21 are pooled and lengths greater than 47 are pooled.

Length (cm)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2007
≤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	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.002	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
28	0.000	0.002	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.001
29	0.000	0.003	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000
30	0.002	0.005	0.000	0.002	0.000	0.012	0.000	0.000	0.000	0.000
31	0.002	0.011	0.000	0.000	0.001	0.006	0.001	0.000	0.000	0.000
32	0.003	0.012	0.000	0.000	0.000	0.004	0.001	0.000	0.000	0.000
33	0.004	0.015	0.000	0.002	0.000	0.014	0.004	0.001	0.000	0.002
34	0.007	0.019	0.000	0.001	0.001	0.008	0.008	0.001	0.000	0.003
35	0.025	0.019	0.000	0.004	0.002	0.004	0.019	0.000	0.002	0.003
36	0.029	0.015	0.000	0.004	0.005	0.010	0.026	0.001	0.002	0.005
37	0.019	0.017	0.001	0.003	0.004	0.008	0.042	0.003	0.001	0.010
38	0.024	0.027	0.001	0.009	0.007	0.002	0.041	0.006	0.004	0.014
39	0.069	0.036	0.006	0.004	0.020	0.010	0.034	0.012	0.006	0.019
40	0.084	0.108	0.020	0.019	0.028	0.033	0.041	0.027	0.011	0.035
41	0.134	0.117	0.046	0.041	0.045	0.052	0.060	0.059	0.028	0.057
42	0.145	0.125	0.103	0.074	0.059	0.082	0.088	0.099	0.079	0.075
43	0.140	0.114	0.145	0.076	0.084	0.093	0.106	0.147	0.116	0.103
44	0.136	0.117	0.200	0.146	0.098	0.120	0.112	0.170	0.164	0.115
45	0.085	0.100	0.197	0.171	0.124	0.128	0.119	0.163	0.182	0.131
46	0.057	0.073	0.151	0.176	0.126	0.126	0.097	0.126	0.148	0.132
47+	0.034	0.060	0.131	0.266	0.397	0.278	0.199	0.185	0.257	0.295
Sample size	2,012	5,495	3,659	2,117	1,794	515	3,090	2,565	1,684	4,599

Table 12-6. (Continued) Fishery size compositions and sample size by year for dusky rockfish in the Gulf of Alaska. Lengths below 21 are pooled and lengths greater than 47 are pooled.

Length (cm)	2009	2011	2013	2015	2017
≤21	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.001	0.000
30	0.000	0.000	0.000	0.000	0.001
31	0.001	0.000	0.000	0.001	0.001
32	0.000	0.001	0.001	0.001	0.002
33	0.002	0.001	0.001	0.002	0.003
34	0.004	0.001	0.004	0.006	0.006
35	0.006	0.001	0.004	0.007	0.008
36	0.010	0.001	0.004	0.007	0.011
37	0.013	0.002	0.005	0.014	0.023
38	0.021	0.007	0.009	0.017	0.031
39	0.027	0.014	0.012	0.023	0.044
40	0.043	0.026	0.018	0.035	0.059
41	0.049	0.044	0.031	0.038	0.069
42	0.070	0.077	0.053	0.049	0.070
43	0.086	0.107	0.081	0.078	0.089
44	0.104	0.121	0.120	0.108	0.097
45	0.121	0.137	0.132	0.128	0.113
46	0.123	0.128	0.120	0.122	0.119
47+	0.319	0.332	0.405	0.362	0.251
Sample size	4,843	3,550	4,792	4,784	4,575

Table 12-7. Fishery age compositions for dusky rockfish in the Gulf of Alaska. Pooled age 25+ includes all fish 25 and older.

Age(yr)	2000	2001	2002	2003	2004	2005	2006	2008	2010	2012
4	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.002	0.002	0.000	0.002	0.005	0.000	0.000	0.000	0.000	0.000
7	0.000	0.004	0.007	0.000	0.007	0.002	0.006	0.007	0.000	0.002
8	0.012	0.004	0.009	0.019	0.002	0.005	0.026	0.007	0.006	0.003
9	0.007	0.043	0.011	0.030	0.055	0.014	0.036	0.038	0.033	0.003
10	0.034	0.035	0.104	0.046	0.069	0.092	0.078	0.086	0.054	0.025
11	0.049	0.068	0.109	0.177	0.066	0.104	0.146	0.109	0.069	0.090
12	0.141	0.077	0.095	0.102	0.182	0.079	0.097	0.065	0.151	0.095
13	0.207	0.132	0.063	0.091	0.114	0.191	0.074	0.164	0.105	0.116
14	0.212	0.170	0.154	0.038	0.083	0.099	0.113	0.076	0.048	0.139
15	0.100	0.161	0.134	0.073	0.040	0.061	0.071	0.060	0.133	0.085
16	0.051	0.089	0.120	0.127	0.076	0.038	0.052	0.058	0.066	0.062
17	0.027	0.060	0.052	0.097	0.104	0.061	0.039	0.045	0.027	0.075
18	0.015	0.031	0.025	0.062	0.055	0.061	0.071	0.041	0.045	0.033
19	0.015	0.012	0.011	0.018	0.019	0.063	0.036	0.043	0.042	0.021
20	0.012	0.017	0.007	0.014	0.021	0.038	0.049	0.050	0.018	0.029
21	0.029	0.012	0.016	0.008	0.017	0.023	0.023	0.036	0.009	0.034
22	0.022	0.010	0.005	0.008	0.012	0.023	0.019	0.030	0.051	0.036
23	0.019	0.010	0.007	0.010	0.007	0.002	0.010	0.013	0.051	0.021
24	0.015	0.019	0.014	0.002	0.000	0.000	0.006	0.010	0.021	0.031
25+	0.032	0.046	0.057	0.076	0.064	0.045	0.049	0.063	0.069	0.100
Sample size	411	517	441	628	422	444	309	604	332	612

Table 12-7. (Continued) Fishery age compositions for dusky rockfish in the Gulf of Alaska. Pooled age 25+ includes all fish 25 and older.

Age(yr)	2014	2016
4	0.000	0.000
5	0.000	0.000
6	0.003	0.006
7	0.000	0.002
8	0.019	0.013
9	0.008	0.034
10	0.036	0.058
11	0.022	0.056
12	0.031	0.054
13	0.099	0.064
14	0.065	0.054
15	0.076	0.089
16	0.110	0.062
17	0.088	0.056
18	0.060	0.077
19	0.071	0.056
20	0.048	0.043
21	0.028	0.048
22	0.031	0.034
23	0.032	0.021
24	0.020	0.037
25+	0.155	0.137
Sample size	647	626

Table 12-8. Biomass estimates (t) for dusky rockfish in the Gulf of Alaska by statistical area, based on results of NMFS bottom trawl surveys.

Year	Species[1]	Statistical Areas					Total
		Shumagin	Chirikof	Kodiak	Yakutat	Southeastern	
1984	Dusky Unident.	3,843	7,462	4,329	15,126	307	31,068
1987	Dusky Unident.	12,753	4,222	49,560	26,562	1,115	94,212
1990	Dusky Unident.	2,854	1,189	16,153	5,664	967	26,827
	Dusky	-	-	-	-	68	68
1993	Dusky Unident.	11,450	12,880	23,780	7,481	1,626	57,217
1996	Dusky	3,553	19,217	36,038	14,194	1,480	74,480
1999	Dusky	2,538	9,157	33,729	2,097	2,108	49,628
2001[a]	Dusky	5,352	2,062	23,590	7,924	1,738	40,665
2003	Dusky	4,039	46,729	7,192	11,519	1,377	70,856
2005	Dusky	69,295	38,216	60,097	2,488	418	170,513
2007	Dusky	4,985	38,350	20,303	5,579	3,857	73,074
2009	Dusky	1,404	4,075	40,836	25,082	726	72,123
2011	Dusky	10,473	5,169	62,893	4,103	768	83,407
2013	Dusky	2,950	19,123	36,238	40,685	174	99,170
2015	Dusky	1,395	12,877	16,310	1,682	526	32,790
2017	Dusky	14,437	19,566	15,293	922	1,052	51,270

[a]Note: The Yakutat and Southeastern areas were not sampled in the 2001 survey. Estimates of biomass for these two areas in 2001 were obtained by averaging the corresponding area biomasses in the 1993, 1996, and 1999 surveys.
[1] Dusky rockfish included in dusky unidentified rockfish, which included "light" and "dark" dusky combined, until 1996. In 1990 the first instance of dusky rockfish as a separate species occurred.

Table 12-9A. GOA dusky rockfish biomass estimates, standard errors, lower confidence intervals, and upper confidence intervals, based on results of NMFS bottom trawl surveys.

Year	Biomass	Standard Error	Lower CI	Upper CI	Coefficient of Variation (CV)
1984	31,068	7,147	17,060	45,076	23%
1987	94,212	29,391	36,606	151,818	31%
1990	26,895	8,635	9,970	43,820	32%
1993	57,746	16,835	24,749	90,743	29%
1996	74,480	32,851	10,092	138,868	44%
1999	49,628	19,194	12,008	87,248	39%
2001	40,665	11,628	17,874	63,456	29%
2003	70,856	34,352	3,526	138,186	48%
2005	170,513	51,658	69,263	271,763	30%
2007	73,074	34,498	5,458	140,690	47%
2009	72,123	24,687	23,736	120,510	34%
2011	83,407	36,806	11,267	155,547	44%
2013	99,170	35,767	29,067	169,273	36%
2015	32,790	7,870	17,365	48,215	24%
2017	51,270	12,979	25,831	76,709	25%

Table 12-9B. GOA dusky rockfish biomass estimates, standard errors, lower confidence intervals, and upper confidence intervals, based on results of NMFS bottom trawl surveys using a geostatistical general linear mixed model estimator.

Year	Biomass	Standard Error	Lower CI	Upper CI	Coefficient of Variation (CV)
1984	20,435	3,134	14,292	26,578	15%
1987	34,866	4,795	25,468	44,264	14%
1990	24,353	4,715	15,112	33,594	19%
1993	31,059	5,568	20,147	41,971	18%
1996	32,860	6,495	20,130	45,591	20%
1999	30,917	6,731	17,723	44,110	22%
2001	40,071	9,942	20,584	59,558	25%
2003	44,715	8,515	28,026	61,403	19%
2005	65,575	11,127	43,766	87,384	17%
2007	43,643	7,875	28,208	59,077	18%
2009	36,085	6,876	22,609	49,561	19%
2011	36,510	7,844	21,135	51,885	21%
2013	52,555	10,964	31,066	74,044	21%
2015	52,472	9,934	33,002	71,943	19%
2017	53,842	10,775	32,723	74,962	20%

Table 12-10. NMFS trawl survey length compositions for dusky rockfish in the Gulf of Alaska. Lengths below 22 are pooled and lengths greater than 47 are pooled. Survey size compositions are not used in model.

Length (cm)	1984	1987	1990	1993	1996	1999	2001	2003	2005
≤21	0.000	0.000	0.000	0.001	0.003	0.001	0.003	0.000	0.001
22	0.000	0.001	0.008	0.002	0.001	0.001	0.002	0.004	0.001
23	0.000	0.001	0.004	0.004	0.004	0.001	0.003	0.000	0.001
24	0.000	0.000	0.002	0.007	0.003	0.000	0.005	0.001	0.002
25	0.000	0.000	0.006	0.002	0.003	0.002	0.003	0.000	0.002
26	0.000	0.001	0.000	0.015	0.001	0.000	0.004	0.004	0.001
27	0.000	0.000	0.006	0.018	0.001	0.001	0.006	0.017	0.001
28	0.002	0.000	0.006	0.023	0.001	0.000	0.002	0.024	0.001
29	0.001	0.000	0.007	0.021	0.005	0.001	0.022	0.027	0.004
30	0.004	0.001	0.000	0.030	0.002	0.002	0.024	0.044	0.005
31	0.009	0.001	0.001	0.039	0.002	0.006	0.029	0.027	0.010
32	0.015	0.004	0.007	0.051	0.002	0.008	0.033	0.031	0.014
33	0.014	0.002	0.001	0.043	0.007	0.008	0.026	0.053	0.016
34	0.036	0.018	0.003	0.040	0.003	0.013	0.030	0.008	0.019
35	0.048	0.039	0.001	0.046	0.006	0.015	0.026	0.011	0.021
36	0.061	0.061	0.002	0.053	0.001	0.015	0.042	0.013	0.046
37	0.066	0.093	0.004	0.037	0.009	0.016	0.039	0.043	0.027
38	0.090	0.084	0.006	0.049	0.009	0.019	0.040	0.077	0.053
39	0.131	0.080	0.019	0.051	0.016	0.016	0.059	0.072	0.031
40	0.139	0.109	0.017	0.051	0.036	0.031	0.061	0.066	0.042
41	0.134	0.142	0.077	0.035	0.080	0.035	0.071	0.050	0.046
42	0.105	0.121	0.125	0.044	0.065	0.072	0.061	0.050	0.072
43	0.061	0.112	0.115	0.061	0.127	0.104	0.064	0.065	0.092
44	0.037	0.062	0.153	0.064	0.133	0.115	0.058	0.070	0.101
45	0.022	0.028	0.175	0.073	0.111	0.150	0.083	0.065	0.100
46	0.013	0.019	0.151	0.065	0.113	0.141	0.076	0.062	0.101
47+	0.014	0.020	0.104	0.076	0.256	0.231	0.127	0.114	0.190
Sample Size	1,881	2,818	1,113	2,299	1,478	1,340	1,255	1,780	3,383

Table 12-10 (continued). NMFS trawl survey length compositions for dusky rockfish in the Gulf of Alaska. Lengths below 22 are pooled and lengths greater than 47 are pooled. Survey size compositions are not used in model.

Length (cm)	2007	2009	2011	2013	2015	2017
≤21	0.000	0.003	0.001	0.000	0.000	0.000
22	0.000	0.006	0.000	0.001	0.000	0.000
23	0.000	0.011	0.000	0.000	0.000	0.000
24	0.000	0.012	0.000	0.000	0.001	0.001
25	0.001	0.005	0.000	0.001	0.002	0.000
26	0.001	0.009	0.000	0.002	0.003	0.001
27	0.001	0.005	0.000	0.001	0.001	0.001
28	0.001	0.006	0.000	0.001	0.002	0.001
29	0.001	0.007	0.000	0.002	0.001	0.002
30	0.003	0.010	0.002	0.003	0.003	0.005
31	0.001	0.008	0.002	0.004	0.007	0.019
32	0.004	0.010	0.002	0.003	0.005	0.018
33	0.003	0.005	0.003	0.005	0.006	0.017
34	0.010	0.007	0.005	0.003	0.010	0.013
35	0.013	0.007	0.006	0.005	0.010	0.022
36	0.013	0.008	0.015	0.007	0.014	0.032
37	0.017	0.006	0.019	0.011	0.017	0.042
38	0.024	0.011	0.017	0.012	0.024	0.037
39	0.049	0.011	0.036	0.011	0.027	0.040
40	0.070	0.020	0.042	0.009	0.029	0.074
41	0.077	0.031	0.058	0.021	0.039	0.078
42	0.110	0.036	0.091	0.043	0.050	0.066
43	0.106	0.073	0.135	0.101	0.051	0.082
44	0.115	0.069	0.114	0.112	0.083	0.077
45	0.098	0.105	0.109	0.179	0.106	0.055
46	0.099	0.154	0.103	0.153	0.114	0.071
47+	0.185	0.363	0.238	0.307	0.395	0.245
Sample Size	1,818	2,024	1,410	1,889	1,820	1,857

Table 12-11. NMFS trawl survey age compositions for dusky rockfish in the Gulf of Alaska. Pooled age 25+ includes all fish 25 and older.

Age (yr)	1984	1987	1990	1993	1996	1999	2001	2003	2005	2007
4	0.000	0.000	0.007	0.004	0.013	0.001	0.014	0.002	0.006	0.000
5	0.000	0.000	0.005	0.058	0.007	0.001	0.006	0.072	0.008	0.003
6	0.000	0.000	0.003	0.094	0.013	0.001	0.081	0.114	0.029	0.005
7	0.075	0.192	0.001	0.193	0.004	0.056	0.074	0.011	0.060	0.021
8	0.284	0.003	0.001	0.088	0.025	0.013	0.052	0.288	0.063	0.023
9	0.115	0.047	0.007	0.118	0.049	0.047	0.188	0.073	0.038	0.116
10	0.142	0.155	0.115	0.031	0.188	0.033	0.095	0.019	0.100	0.092
11	0.145	0.213	0.134	0.032	0.111	0.113	0.093	0.064	0.089	0.046
12	0.121	0.109	0.086	0.020	0.148	0.270	0.037	0.037	0.058	0.165
13	0.052	0.057	0.113	0.048	0.045	0.121	0.066	0.035	0.150	0.126
14	0.011	0.034	0.171	0.022	0.029	0.064	0.099	0.019	0.064	0.066
15	0.040	0.043	0.139	0.039	0.033	0.025	0.061	0.044	0.034	0.061
16	0.006	0.014	0.042	0.045	0.015	0.015	0.034	0.066	0.037	0.041
17	0.000	0.027	0.015	0.042	0.018	0.001	0.013	0.033	0.034	0.009
18	0.000	0.012	0.055	0.016	0.052	0.020	0.009	0.016	0.035	0.035
19	0.000	0.018	0.035	0.016	0.041	0.025	0.007	0.020	0.055	0.036
20	0.002	0.010	0.009	0.010	0.045	0.048	0.008	0.004	0.038	0.022
21	0.000	0.014	0.020	0.011	0.019	0.040	0.005	0.015	0.019	0.021
22	0.000	0.002	0.007	0.009	0.016	0.023	0.005	0.000	0.008	0.020
23	0.000	0.000	0.000	0.009	0.023	0.020	0.015	0.008	0.003	0.010
24	0.000	0.004	0.001	0.015	0.011	0.005	0.003	0.004	0.006	0.007
25+	0.008	0.045	0.033	0.079	0.097	0.056	0.033	0.056	0.067	0.075
Sample size	161	446	94	445	554	174	676	195	461	490

Table 12-11. (Continued) NMFS trawl survey age compositions for dusky rockfish in the Gulf of Alaska. Pooled age 25+ includes all fish 25 and older.

Age (yr)	2009	2011	2013	2015	2017
4	0.004	0.000	0.000	0.000	0.000
5	0.022	0.000	0.000	0.006	0.002
6	0.009	0.005	0.002	0.005	0.002
7	0.026	0.004	0.004	0.004	0.068
8	0.013	0.023	0.010	0.025	0.032
9	0.022	0.018	0.009	0.041	0.079
10	0.036	0.095	0.017	0.047	0.139
11	0.067	0.092	0.027	0.039	0.064
12	0.058	0.072	0.084	0.039	0.084
13	0.051	0.119	0.099	0.047	0.074
14	0.134	0.112	0.103	0.061	0.049
15	0.059	0.066	0.178	0.096	0.036
16	0.069	0.080	0.086	0.065	0.047
17	0.074	0.040	0.080	0.071	0.057
18	0.024	0.037	0.083	0.075	0.036
19	0.024	0.039	0.050	0.044	0.036
20	0.055	0.016	0.016	0.039	0.023
21	0.032	0.022	0.012	0.037	0.030
22	0.039	0.024	0.029	0.021	0.023
23	0.074	0.031	0.025	0.019	0.011
24	0.017	0.023	0.035	0.037	0.011
25+	0.091	0.082	0.052	0.182	0.095
Sample size	495	427	434	471	429

Table 12-12. Likelihood values and estimates of key parameters for model 15.5 (2015 data) and model 15.5 (2018 data) for GOA dusky rockfish.

Likelihoods	15.5 (2015)	15.5 (2018)
Catch	27.86	33.48
Survey Biomass	37.36	44.01
Fishery Ages	24.50	27.73
Survey Ages	95.62	110.71
Fishery Sizes	50.46	55.35
Maturity Likelihood	65.00	65.00
Data-Likelihood	**300.80**	**336.27**
Penalties/Priors		
Recruitment Devs	24.58	18.96
F Regularity	32.70	35.93
σ_r prior	0.60	0.87
q prior	0.70	0.12
Objective Fun. Total	**359.38**	**392.15**
Parameter Estimates		
Number parameters estimated	114	120
q	0.59	0.81
σ_r	0.92	0.83
Mean recruitment (millions)	5.63	5.51
$F_{40\%}$	0.098	0.095
Projected Total Biomass (t)	60,072	55,247
Projected Spawning biomass (t)	25,238	20,342
$B_{100\%}$ (t)	49,268	46,337
$B_{40\%}$ (t)	19,707	18,535
ABC ($F_{40\%}$) (t)	**4,686**	**3,700**

Table 12-13. Estimates of key parameters (μ) 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	σ	σ MCMC	Median MCMC	BCI Lower	BCI Upper
q	0.806	0.814	0.811	0.071	0.073	0.679	0.965
$F_{40\%}$	0.095	0.116	0.108	0.028	0.040	0.060	0.219
2019 Female SSB	20,358	21,187	21,046	2,596	2,683	16,343	26,882
ABC	3,700	4,519	4,283	1,132	1,658	1,874	8,608

Table 12-14. Estimated time series of female spawning biomass, 6+ biomass (age 6 and greater), catch/6+ biomass, and number of age four recruits for dusky rockfish in the Gulf of Alaska. Estimates are shown for the current assessment and from the previous SAFE.

Year	Spawning biomass (t)		6+ Biomass (t)		Catch/6+ biomass		Age 4 recruits (1000's)	
	Previous	Current	Previous	Current	Previous	Current	Previous	Current
1977	10,489	12,574	24,661	30,009	0.028	0.013	1,894	2,224
1978	9,997	11,971	24,187	29,332	0.017	0.006	2,105	2,464
1979	9,710	11,606	24,093	29,150	0.020	0.008	2,449	2,911
1980	9,474	11,293	24,141	29,131	0.034	0.020	7,850	9,048
1981	9,181	10,899	24,144	29,065	0.040	0.029	5,736	6,494
1982	8,945	10,557	26,789	31,999	0.036	0.027	4,268	4,507
1983	8,880	10,408	29,125	34,527	0.036	0.029	1,843	2,192
1984	8,992	10,448	30,965	36,323	0.024	0.015	8,999	8,443
1985	9,499	10,948	31,956	37,396	0.005	0.001	1,732	1,859
1986	10,532	12,021	36,748	41,885	0.004	0.000	2,750	2,458
1987	11,780	13,312	38,514	43,563	0.004	0.000	1,877	1,920
1988	13,104	14,653	40,314	45,037	0.031	0.024	8,181	7,343
1989	13,913	15,250	40,298	44,334	0.040	0.039	4,976	4,729
1990	14,471	15,401	42,673	45,276	0.032	0.036	15,874	14,529
1991	15,079	15,687	44,223	45,939	0.034	0.044	11,008	10,172
1992	15,594	15,805	50,994	51,228	0.064	0.067	9,499	8,593
1993	15,409	15,344	54,855	54,099	0.054	0.058	2,563	2,476
1994	15,673	15,290	58,732	56,986	0.047	0.051	6,972	6,157
1995	16,476	15,719	59,462	57,145	0.046	0.050	5,006	4,643
1996	17,770	16,593	61,614	58,474	0.037	0.039	15,135	13,520
1997	19,533	17,937	63,070	59,387	0.039	0.041	2,876	2,629
1998	21,191	19,194	68,892	64,103	0.045	0.048	8,435	7,413
1999	22,344	19,977	68,846	63,506	0.064	0.071	17,348	14,738
2000	22,618	19,948	69,437	63,302	0.052	0.058	2,200	2,060
2001	23,143	20,169	75,267	67,575	0.039	0.044	10,219	8,931
2002	24,056	20,754	75,360	67,175	0.043	0.049	13,685	11,112
2003	24,961	21,304	78,173	69,073	0.038	0.044	5,576	4,728
2004	26,102	22,049	83,065	72,415	0.031	0.035	6,539	6,249
2005	27,520	23,040	84,841	73,368	0.026	0.030	6,502	6,296
2006	29,092	24,162	86,799	74,860	0.028	0.033	2,149	2,364
2007	30,470	25,106	88,068	75,852	0.038	0.044	1,802	2,556
2008	31,253	25,504	85,912	73,748	0.042	0.049	2,132	4,118
2009	31,632	25,590	82,587	70,899	0.037	0.043	1,788	4,117
2010	31,835	25,686	79,350	69,037	0.039	0.045	1,356	5,514
2011	31,509	25,455	75,480	66,995	0.034	0.038	1,495	7,921
2012	30,943	25,213	71,685	66,208	0.055	0.061	1,575	4,918
2013	29,252	24,136	66,341	65,408	0.047	0.048	1,699	2,793

Table 12-14. (Continued) Estimated time series of female spawning biomass, 6+ biomass (age 6 and greater), catch/6 + biomass, and number of age four recruits for dusky rockfish in the Gulf of Alaska. Estimates are shown for the current assessment and from the previous SAFE.

Year	Spawning biomass (t)		6+ Biomass (t)		Catch/6+ biomass		Age 4 recruits (1000's)	
	Previous	Current	Previous	Current	Previous	Current	Previous	Current
2014	27,590	23,309	61,794	64,330	0.049	0.048	2,029	7,827
2015	25,750	22,570	57,431	62,335	0.049	0.045	2,018	1,800
2016		22,062		62,818		0.053		2,158
2017		21,450		60,201		0.044		2,163
2018		21,203		58,076		0.051		2,436

Table 12-15. Estimated time series of recruitment, total biomass (4+), and female spawning biomass for dusky rockfish in the Gulf of Alaska. Columns headed with 2.5% and 97.5% represent the lower and upper 95% credible intervals from the MCMC estimated posterior distribution.

	Recruits (Age 4)			Total Biomass			Spawning Biomass		
Year	Mean	2.50%	97.50%	Mean	2.50%	97.50%	Mean	2.50%	97.50%
1977	2,224	207	6,683	30,436	19,740	31,195	12,574	7,106	12,748
1978	2,464	257	6,794	29,759	19,948	30,771	11,971	6,839	12,152
1979	2,911	284	7,792	29,703	20,675	31,060	11,606	6,841	11,845
1980	9,048	4,503	17,405	31,058	23,079	32,913	11,293	6,882	11,599
1981	6,494	1,629	13,987	32,421	25,431	35,078	10,898	6,946	11,353
1982	4,507	582	9,948	33,767	27,486	37,270	10,557	7,022	11,192
1983	2,192	99	5,566	34,883	29,017	39,012	10,408	7,299	11,217
1984	8,443	5,277	13,525	37,037	31,741	42,042	10,448	7,669	11,498
1985	1,859	121	4,422	38,743	33,662	44,229	10,948	8,359	12,304
1986	2,458	432	5,327	40,882	35,905	46,873	12,021	9,545	13,723
1987	1,920	135	4,191	42,616	37,614	48,965	13,312	10,944	15,403
1988	7,343	4,797	11,488	45,044	40,158	51,763	14,653	12,363	17,111
1989	4,729	742	7,918	45,700	40,660	52,450	15,250	12,927	17,849
1990	14,529	10,768	19,661	47,748	42,683	54,110	15,400	13,138	17,909
1991	10,172	6,147	14,324	50,718	45,551	57,078	15,687	13,490	18,208
1992	8,593	5,709	12,616	53,795	48,625	60,241	15,805	13,674	18,293
1993	2,476	290	4,542	54,569	49,166	61,151	15,344	13,257	17,823
1994	6,157	4,203	9,269	55,947	50,361	62,842	15,290	13,187	17,806
1995	4,643	2,199	6,963	57,037	51,235	64,294	15,719	13,527	18,386
1996	13,520	10,877	17,480	59,679	53,724	67,487	16,593	14,260	19,467
1997	2,629	354	4,504	61,292	55,082	69,312	17,936	15,426	20,989
1998	7,413	5,032	10,405	63,102	56,571	71,572	19,194	16,588	22,370
1999	14,738	11,914	18,799	65,749	58,946	74,744	19,976	17,349	23,287
2000	2,060	150	3,780	65,349	58,348	74,648	19,948	17,279	23,318
2001	8,931	6,579	12,322	66,531	59,194	76,301	20,169	17,432	23,624
2002	11,112	8,130	14,871	68,977	61,316	79,284	20,754	17,923	24,391
2003	4,728	2,276	7,396	70,172	62,244	80,812	21,304	18,297	25,086
2004	6,249	3,936	9,414	71,521	63,249	82,542	22,049	18,969	26,006
2005	6,296	4,075	9,351	73,021	64,468	84,491	23,040	19,774	27,180
2006	2,364	664	4,370	73,714	64,958	85,477	24,162	20,753	28,502
2007	2,556	822	4,587	73,478	64,610	85,444	25,106	21,546	29,659
2008	4,118	2,175	7,077	72,007	63,020	84,220	25,504	21,843	30,200
2009	4,117	1,574	7,513	69,948	60,924	82,338	25,590	21,812	30,339
2010	5,514	2,446	10,223	68,574	59,371	81,320	25,686	21,884	30,604
2011	7,921	3,999	14,450	67,676	58,575	80,911	25,455	21,634	30,554
2012	4,918	1,178	11,490	67,138	58,036	80,870	25,213	21,389	30,377
2013	2,793	228	7,472	64,879	55,532	78,824	24,136	20,349	29,353
2014	7,827	3,063	20,737	64,185	54,637	79,385	23,309	19,558	28,571
2015	1,800	80	6,046	62,712	52,863	78,997	22,570	18,888	27,948
2016	2,158	122	10,312	61,185	51,097	78,357	22,062	18,351	27,606
2017	2,163	103	10,871	58,835	48,582	77,398	21,450	17,602	27,245

Table 12-15. (Continued) Estimated time series of recruitment, total biomass (4+), and female spawning biomass for dusky rockfish in the Gulf of Alaska. Columns headed with 2.5% and 97.5% represent the lower and upper 95% credible intervals from the MCMC estimated posterior distribution.

Year	Recruits (Age 4)			Total Biomass			Spawning Biomass		
	Mean	2.50%	97.50%	Mean	2.50%	97.50%	Mean	2.50%	97.50%
2018	2,436	103	25,554	56,915	46,592	77,339	21,203	17,194	27,422
2019	6,068	586	22,996	55,242	44,447	77,570	20,358	16,343	26,882
2020	6,068	558	23,565	54,526	43,136	78,463	20,128	15,969	26,693

Table 12-16. Set of projections of spawning biomass (SB) and yield for dusky rockfish in the Gulf of Alaska. Six harvest scenarios designed to satisfy the requirements of Amendment 56, NEPA, and MSFCMA. For a description of scenarios see section *Harvest Recommendations*. All units are in t. $B_{40\%} = 18,535$ t, $B_{35\%} = 16,218$ t, $F_{40\%} = 0.095$, and $F_{35\%} = 0.118$.

Year	Maximum permissible F	Author's F (pre-specified catch)[1]	Half maximum F	5-year average F	No fishing	Overfished	Approaching overfished
			Spawning Biomass (t)				
2018	20,725	20,725	20,725	20,725	20,725	20,725	20,725
2019	20,229	20,342	20,373	20,305	20,523	20,160	20,229
2020	19,356	20,106	20,317	19,852	21,338	18,921	19,356
2021	18,415	19,639	20,103	19,278	21,989	17,686	18,353
2022	17,455	18,521	19,754	18,610	22,479	16,553	17,072
2023	16,619	17,476	19,343	17,937	22,868	15,612	16,016
2024	16,012	16,698	18,983	17,392	23,261	14,950	15,265
2025	15,720	16,269	18,819	17,098	23,789	14,634	14,880
2026	15,731	16,170	18,889	17,082	24,506	14,636	14,827
2027	15,954	16,303	19,195	17,284	25,392	14,852	15,000
2028	16,287	16,564	19,565	17,618	26,398	15,169	15,283
2029	16,652	16,870	20,104	18,012	27,462	15,508	15,594
2030	17,005	17,177	20,627	18,420	28,539	15,827	15,891
2031	17,331	17,467	21,217	18,822	29,608	16,113	16,162
			Fishing Mortality				
2018	0.074	0.074	0.074	0.074	0.074	0.074	0.074
2019	0.095	0.058	0.048	0.071	-	0.118	0.118
2020	0.095	0.057	0.048	0.071	-	0.118	0.118
2021	0.095	0.095	0.048	0.071	-	0.112	0.112
2022	0.090	0.095	0.048	0.071	-	0.105	0.105
2023	0.085	0.090	0.048	0.071	-	0.098	0.098
2024	0.082	0.086	0.048	0.071	-	0.094	0.094
2025	0.080	0.083	0.048	0.071	-	0.092	0.092
2026	0.080	0.083	0.048	0.071	-	0.092	0.092
2027	0.081	0.083	0.048	0.071	-	0.093	0.093
2028	0.083	0.084	0.048	0.071	-	0.095	0.095
2029	0.084	0.085	0.048	0.071	-	0.097	0.097
2030	0.086	0.086	0.048	0.071	-	0.099	0.099
2031	0.087	0.087	0.048	0.071	-	0.101	0.101
			Yield (t)				
2018	2,946	2,946	2,946	2,946	2,946	2,946	2,946
2019	3,700	3,700	1,890	2,768	-	4,521	3,700
2020	3,552	3,670	1,893	2,716	-	4,256	3,552
2021	3,367	3,618	1,880	2,646	-	3,804	4,101
2022	3,001	3,379	1,838	2,539	-	3,304	3,518
2023	2,674	2,964	1,777	2,411	-	2,885	3,040
2024	2,437	2,657	1,721	2,299	-	2,594	2,708
2025	2,330	2,500	1,687	2,242	-	2,465	2,552
2026	2,348	2,482	1,700	2,249	-	2,486	2,553
2027	2,442	2,547	1,745	2,295	-	2,595	2,647
2028	2,559	2,642	1,804	2,355	-	2,733	2,773
2029	2,675	2,739	1,863	2,417	-	2,867	2,898
2030	2,779	2,829	1,919	2,475	-	2,985	3,008
2031	2,873	2,911	1,972	2,531	-	3,087	3,104

[1]Projected ABCs and OFLs for 2019 and 2020 are derived using estimated catch of 2,946 for 2018, and projected catches of 2,303 t and 2,211 t for 2019 and 2020 based on realized catches from 2015-2017.

Table 12-17. Allocation of 2019 ABC for dusky rockfish in the Gulf of Alaska. Apportionment is based on the random effects model fit to dusky rockfish biomass estimates. Allocation for West Yakutat and SE/Outside is equal to the upper 95% confidence interval of the ratio of biomass in West Yakutat area to SE/Outside area. All units are in t.

| Year | Western | Central | Eastern | | Total |
			Yakutat	Southeast	
Area Apportionment	21.1%	74.7%	4.2%		100%
			61.0%	39.0%	
2017 design-based survey biomass CV	61%	27%	23%		25%
Area ABC (t)	**781**	**2,764**	**155**		**3,700**
Yak/SE ABC (t)			**95**	**60**	
OFL (t)					**4,521**

Table 12-18. Analysis of ecosystem considerations for pelagic shelf rockfish and the dusky rockfish fishery.

Ecosystem effects on *GOA pelagic shelf rockfish*

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Phytoplankton and Zooplankton	Important for larval and post-larval survival but no information known	May help determine year class strength, no time series	Possible concern if some information available
Predator population trends			
Marine mammals	Not commonly eaten by marine mammals	No effect	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Probably no concern
Fish (Halibut, arrowtooth, lingcod)	Arrowtooth have increased, others stable	More predation on juvenile rockfish	Possible concern
Changes in habitat quality			
Temperature regime	Higher recruitment after 1977 regime shift	Contributed to rapid stock recovery	No concern
Winter-spring environmental conditions	Affects pre-recruit survival	Different phytoplankton bloom timing	Causes natural variability, rockfish have varying larval release to compensate
Production	Relaxed downwelling in summer brings in nutrients to Gulf shelf	Some years are highly variable, like El Nino 1998	Probably no concern, contributes to high variability of rockfish recruitment

GOA pelagic rockfish fishery effects on ecosystem

| Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored (P. cod most common)	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Medium bycatch levels of sponge and corals	Bycatch levels small relative to total HAPC biota, but can be large in specific areas	Probably no concern
Marine mammals and birds	Very minor take of marine mammals, trawlers overall cause some bird mortality	Rockfish fishery is short compared to other fisheries	No concern
Sensitive non-target species	Likely minor impact on non-target rockfish	Data limited, likely to be harvested in proportion to their abundance	Probably no concern
Fishery concentration in space and time	Duration is short and in patchy areas	Not a major prey species for marine mammals	No concern, fishery is being extended for several months starting 2006
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Decreasing	Improving, but data limited	Possible concern with non-target rockfish
Fishery effects on age-at-maturity and fecundity	Black rockfish show older fish have more viable larvae	Inshore rockfish results may not apply to longer-lived slope rockfish	Definite concern, studies being initiated in 2005

Figures
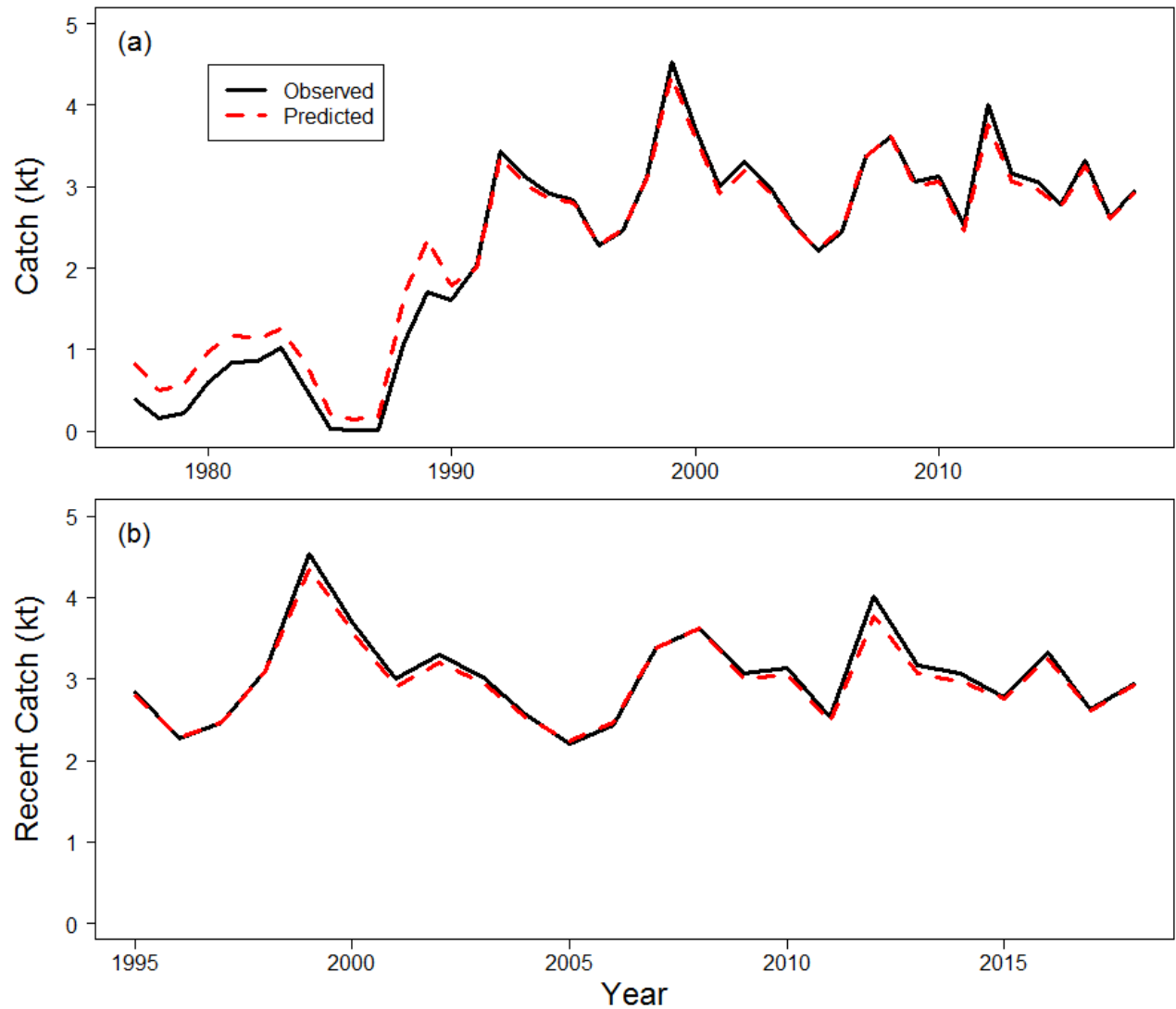
Figure 12-1. Estimated long-term (a) and short-term (b) commercial catches for GOA dusky rockfish. Observed is solid black line, predicted is dashed red line.
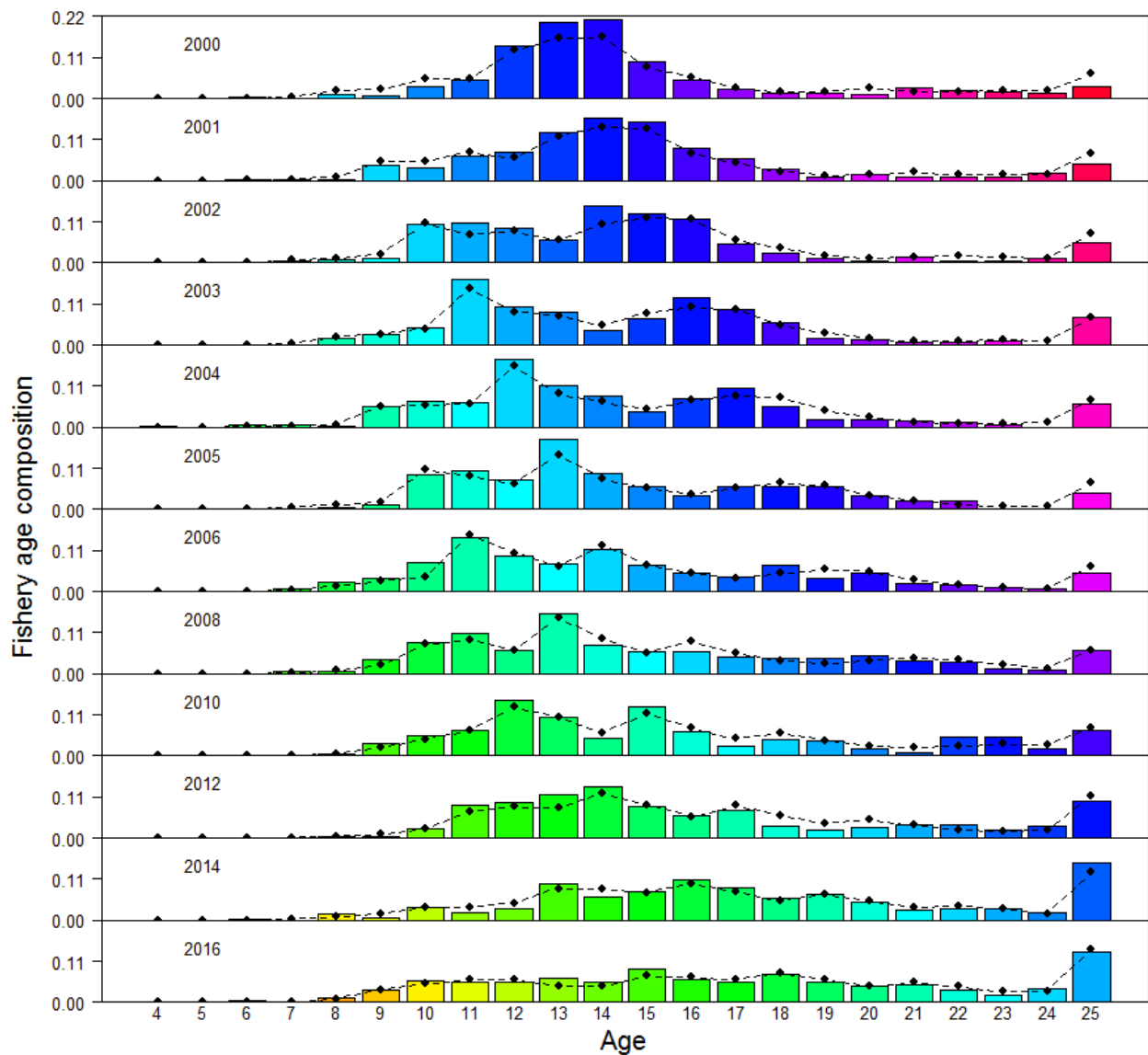
Figure 12-2. Fishery age compositions for GOA dusky rockfish. Observed data are bars, author recommended model predicted values are lines with circles. Colors correspond to individual year classes.
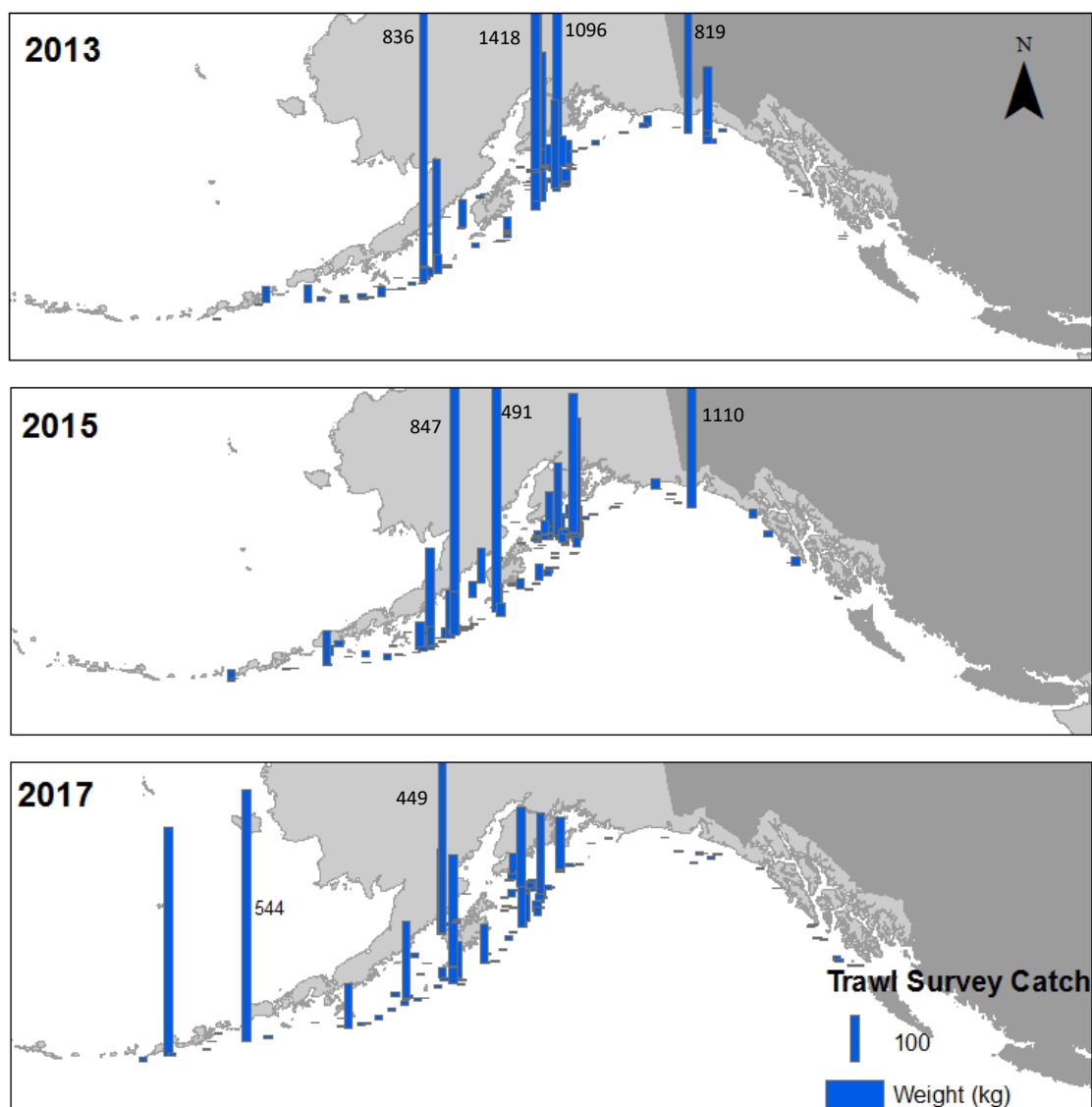
Figure 12-3. Spatial distribution of dusky rockfish in the Gulf of Alaska during the 2013, 2015, and 2017 NMFS trawl surveys. Biomass values (kg) are provided for some hauls extending beyond the map.
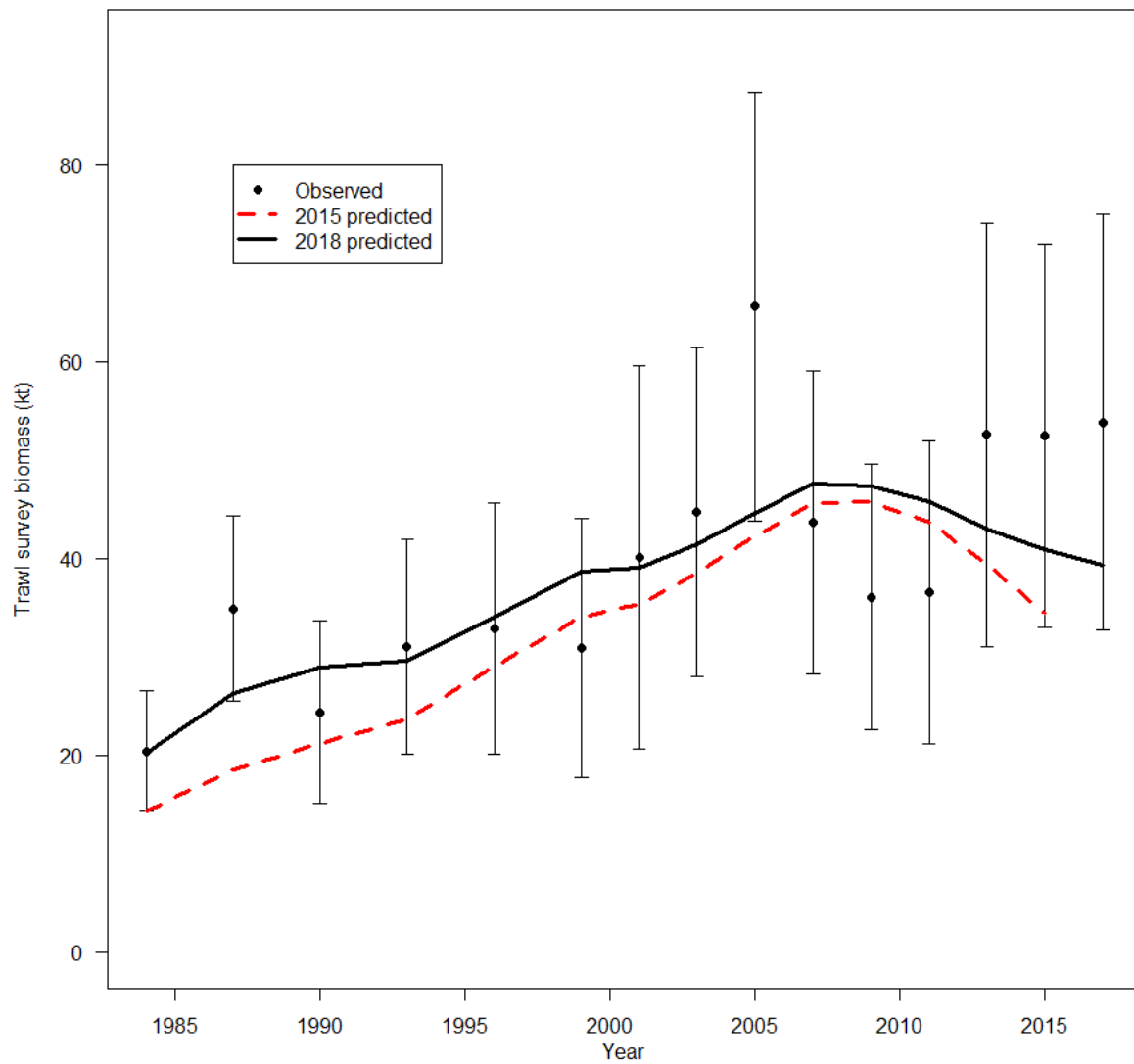
Figure 12-4. Observed (geostatistical model-based estimates) and predicted GOA dusky rockfish trawl survey biomass based on the 2018 recommended model (black line) and from the 2015 accepted model (red dashed line). Observed biomass is circles with approximate asymptotic 95% confidence intervals of model error.
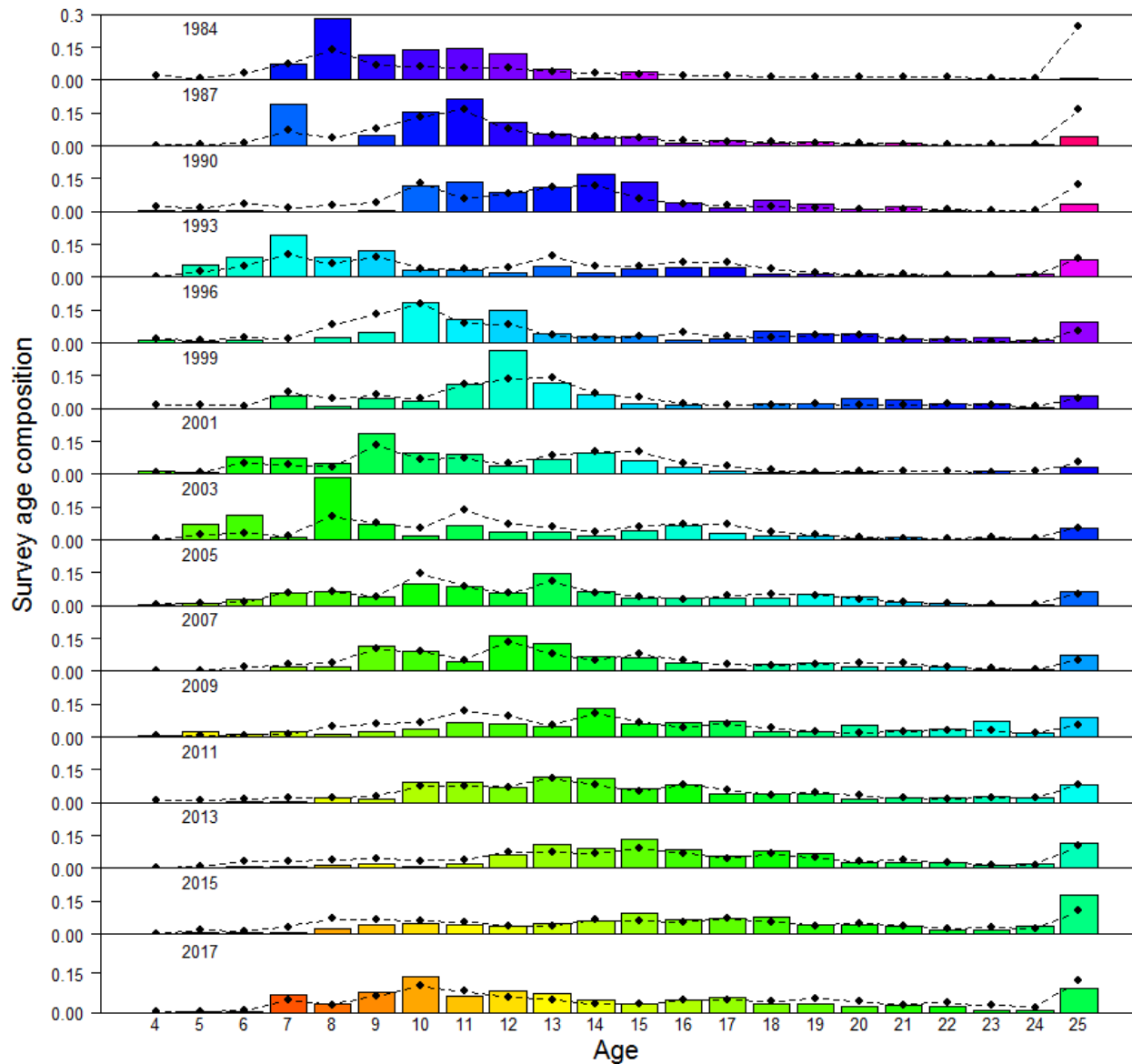
Figure 12-5. Trawl survey age composition by year for GOA dusky rockfish. Observed data are bars, author recommended model predicted values are lines with circles. Colors correspond to individual year classes.
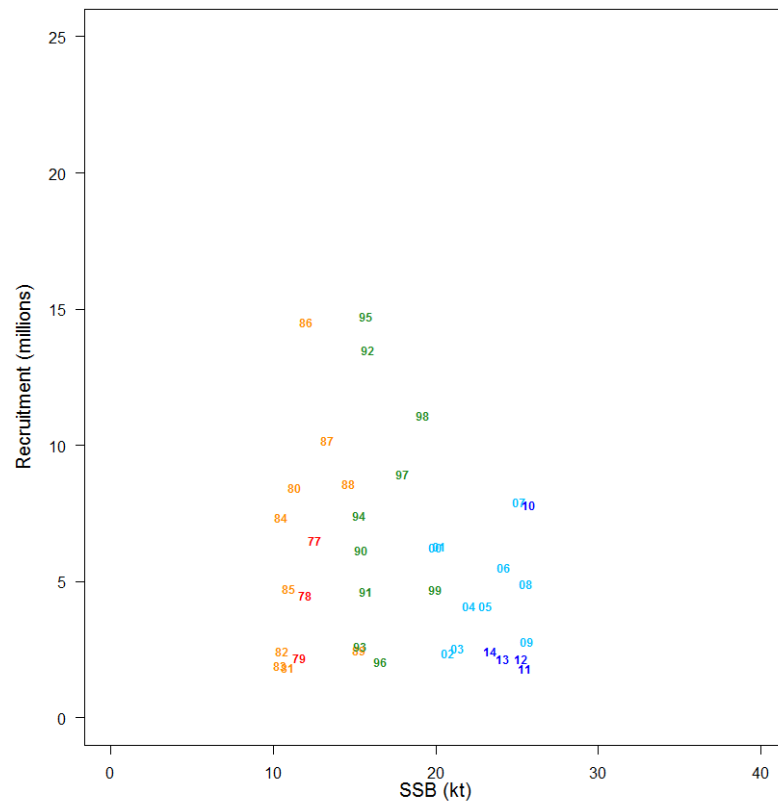
Figure 12-6. Scatterplot of spawner-recruit data for GOA dusky rockfish author recommended model. Label is year class of age 4 recruits. SSB = Spawning stock biomass in kilotons (kt).
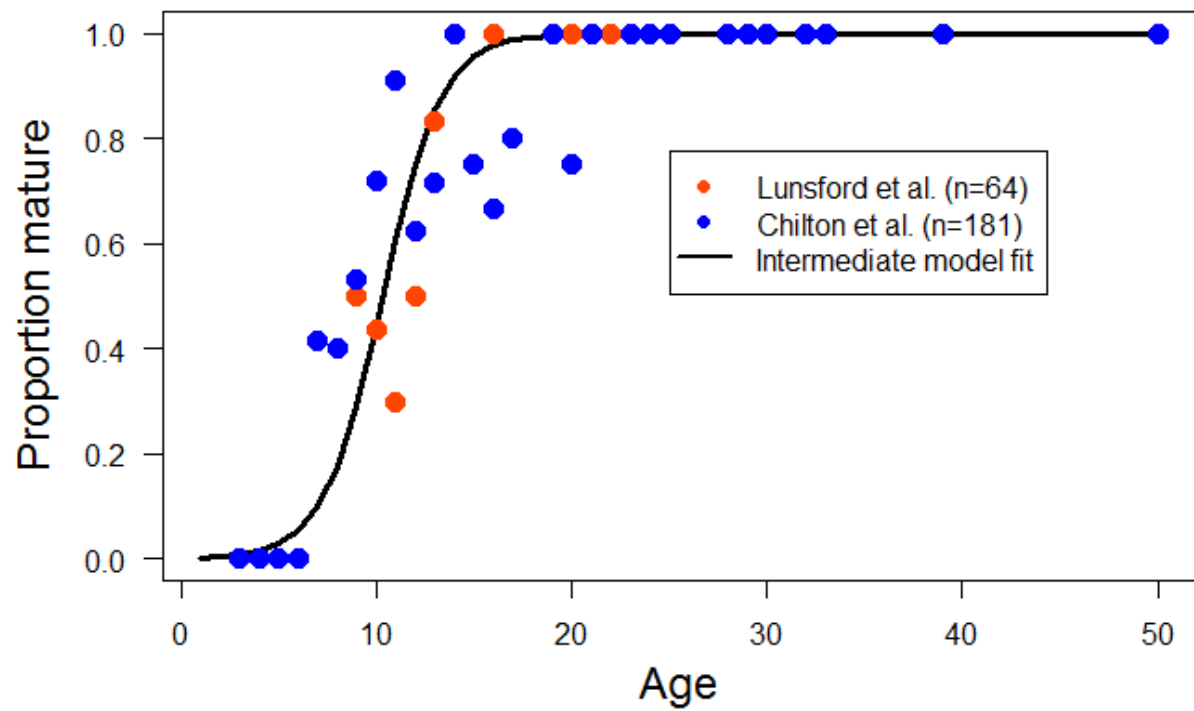
Figure 12-7. Comparison of maturity curves including intermediate curve used in determining Gulf of Alaska dusky rockfish 50% age at maturity.
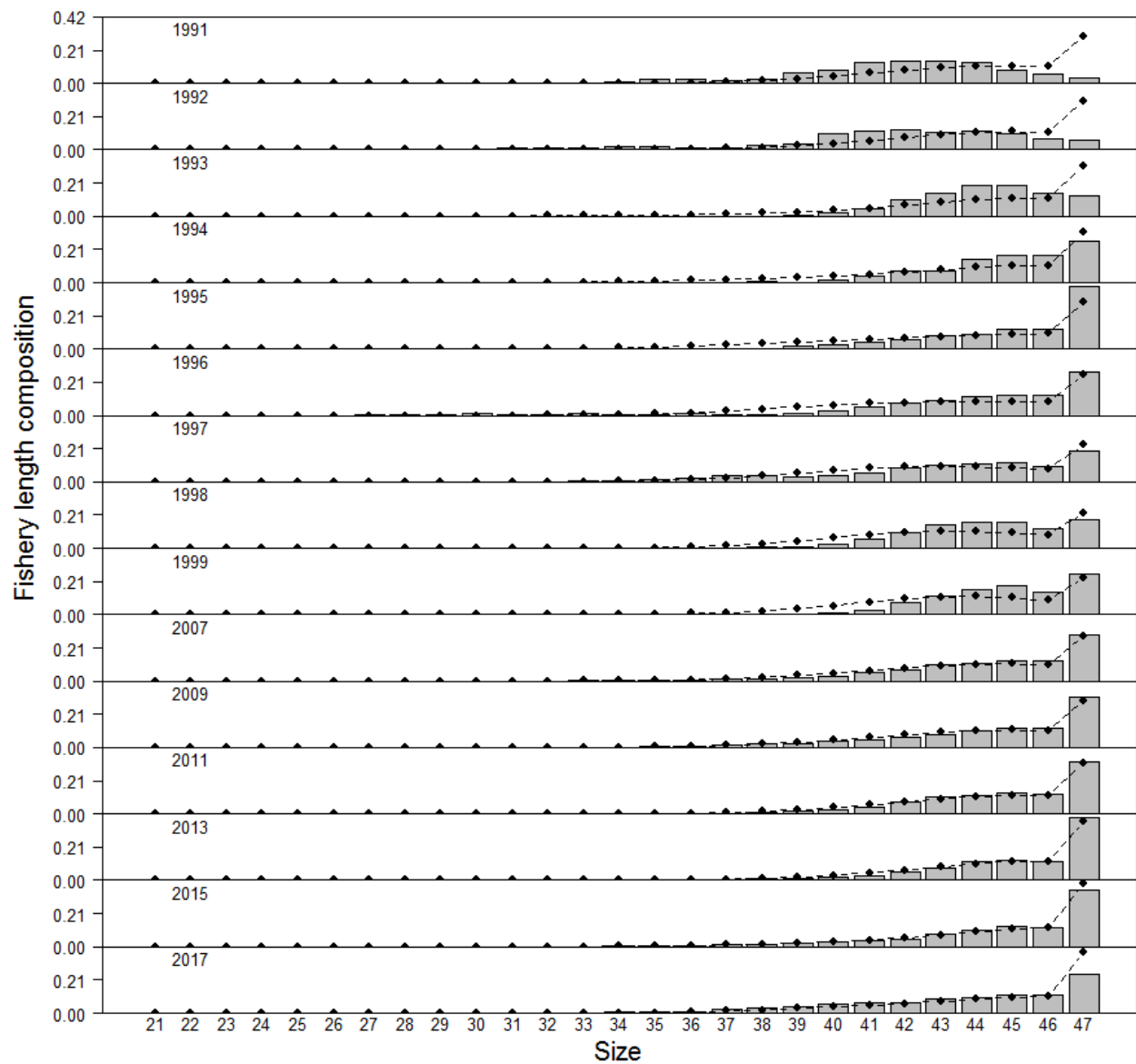
Figure 12-8. Fishery length compositions for GOA dusky rockfish. Observed data are bars, 2018 model predicted values are lines with circles.
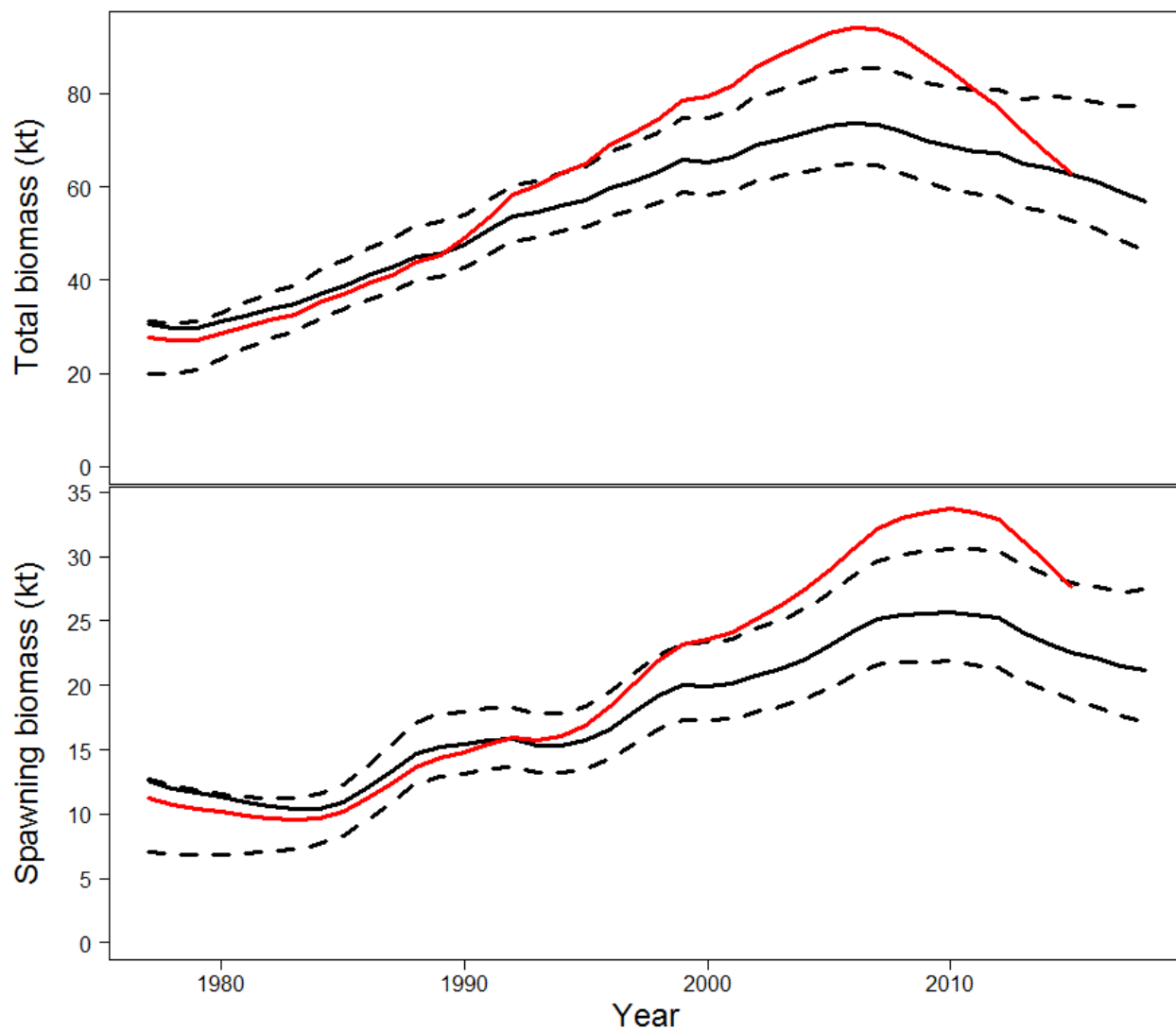
Figure 12-9. Time series of predicted total biomass and spawning biomass of GOA dusky rockfish for 2018 model (black lines) and the 2015 model values (red lines) for comparison. Dashed lines represent 95% credible intervals from 1 million MCMC runs for the 2018 model.
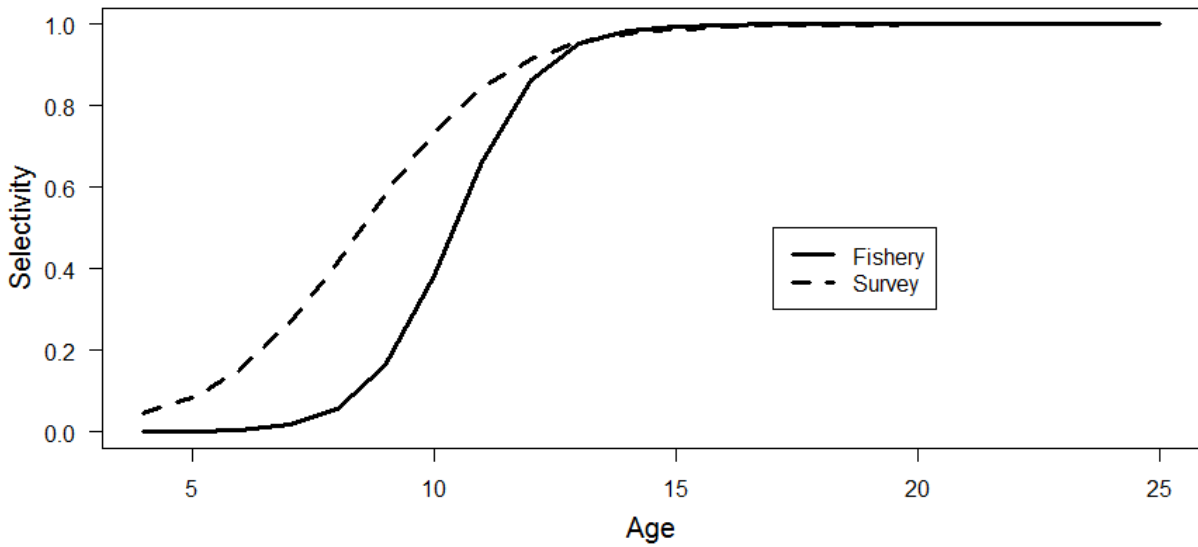
Figure 12-10. Estimated fishery and survey selectivity for GOA dusky rockfish from the 2018 model. Dashed line is survey selectivity and solid line is fishery selectivity.
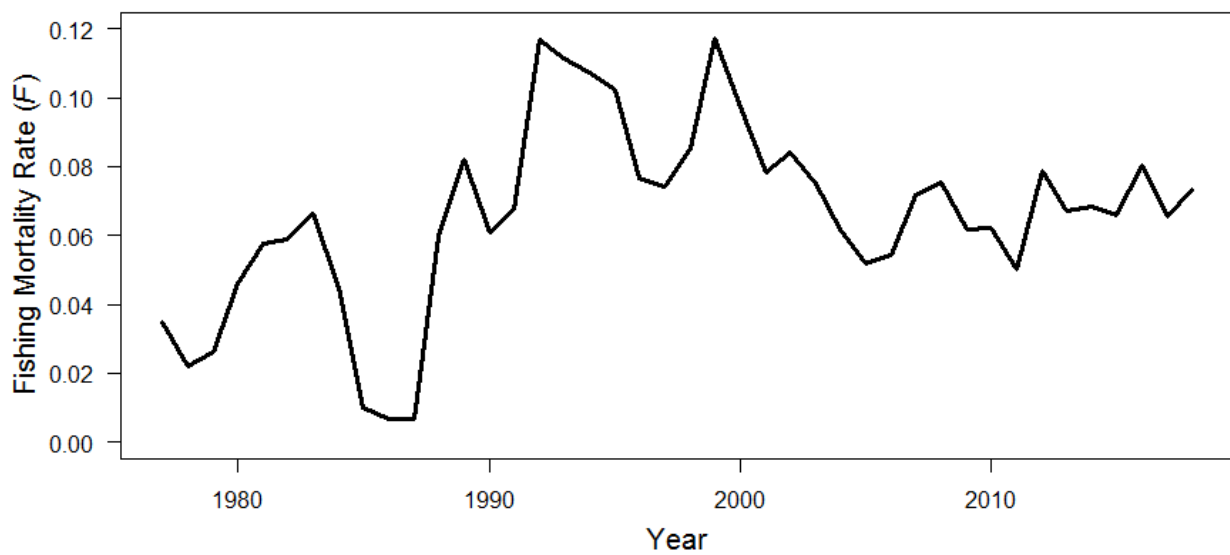
Figure 12-11. Time series of estimated fully selected fishing mortality for GOA dusky rockfish from the 2018 model.
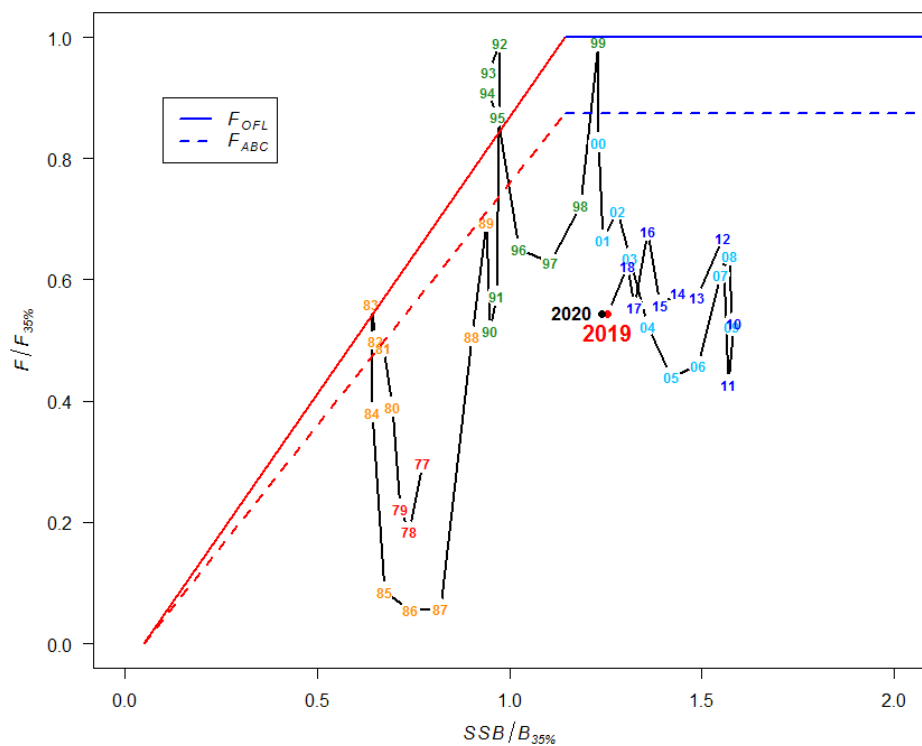
Figure 12-12. Time series of dusky rockfish estimated spawning biomass relative to the unfished level and fishing mortality relative to FOFL for the 2018 model.
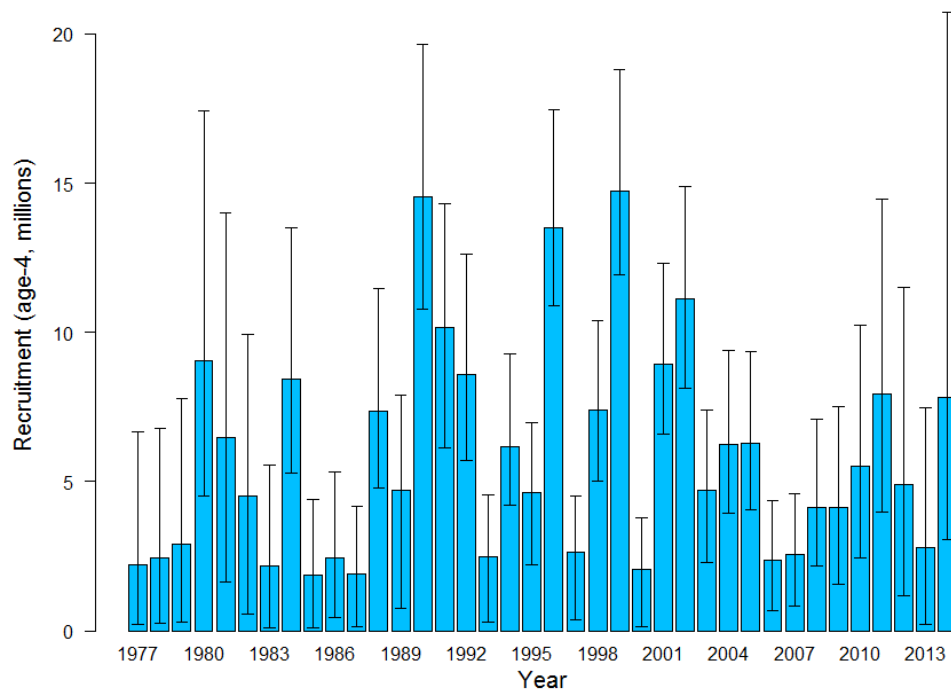
Figure 12-13. Estimated recruitments (age 4) for GOA dusky rockfish from the 2018 model.
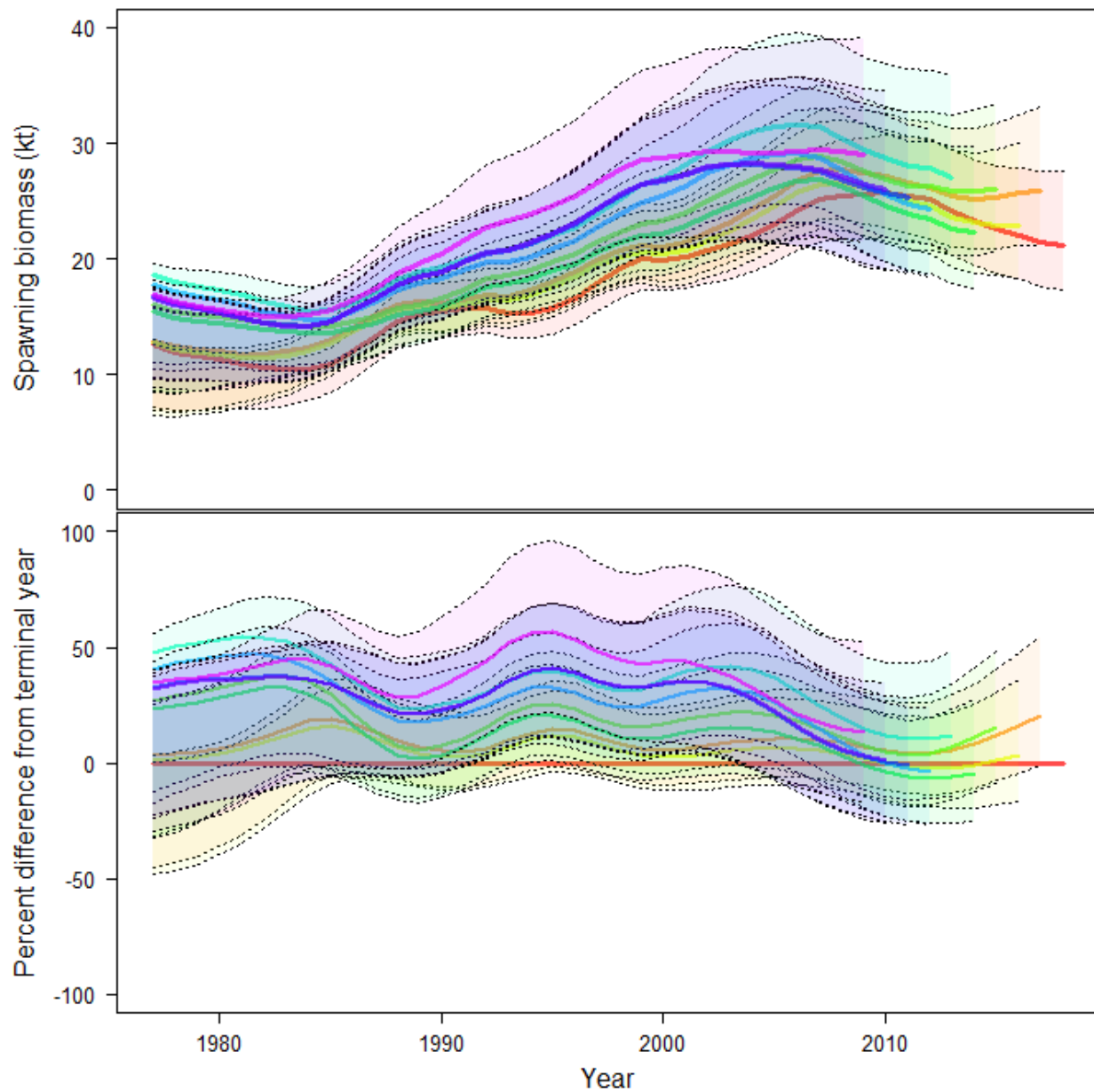
Figure 12-14. Retrospective peels of estimated female spawning biomass for the past 10 years from the recommended model with 95% credible intervals derived from MCMC (top), and the percent difference in female spawning biomass from the recommended model in the terminal year with 95% credible intervals from MCMC.
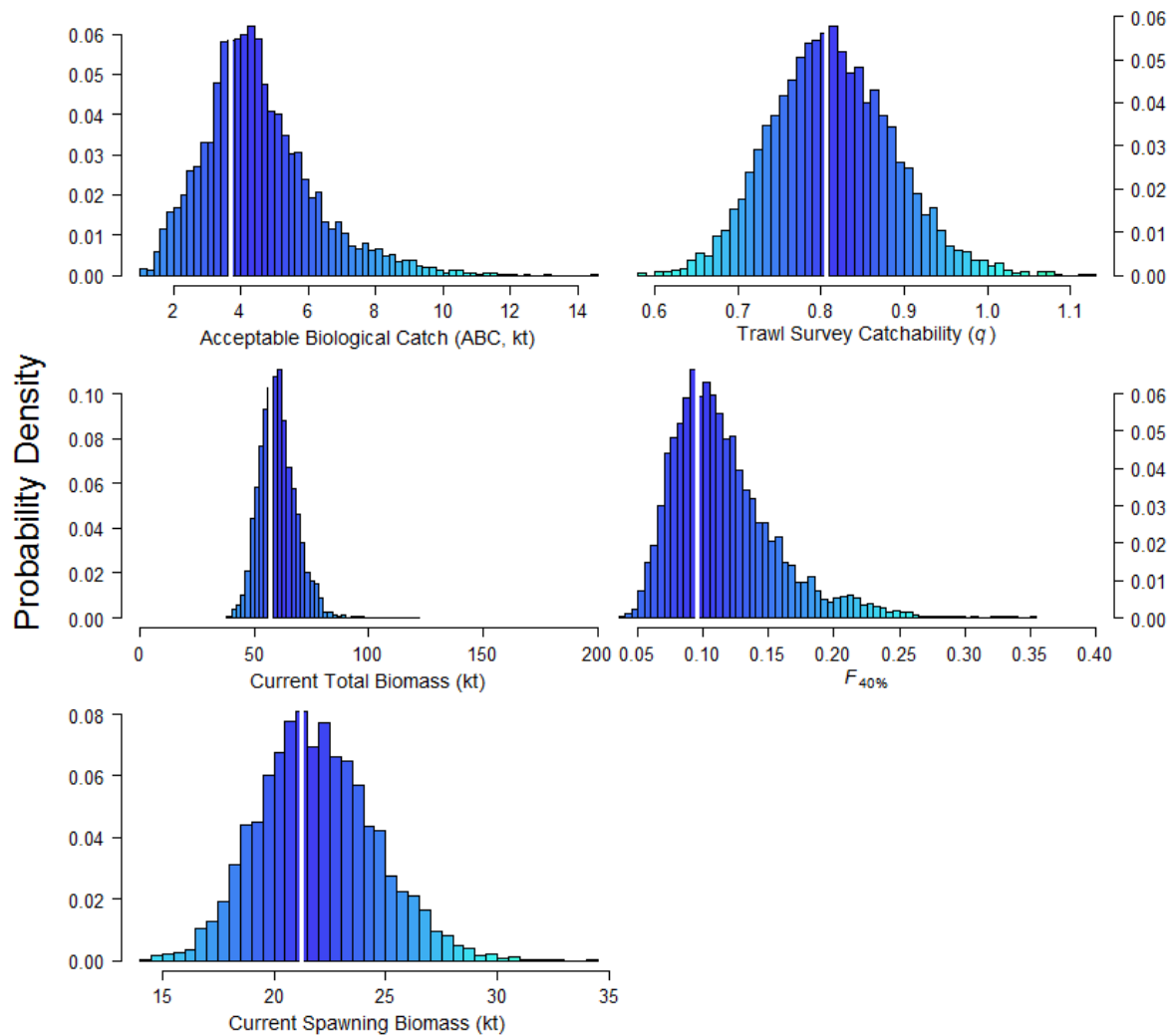
Figure 12-15. Histograms of estimated posterior distributions for key parameters derived from the MCMC for GOA dusky rockfish. Vertical white lines represent the maximum likelihood estimate for comparison with the MCMC results.
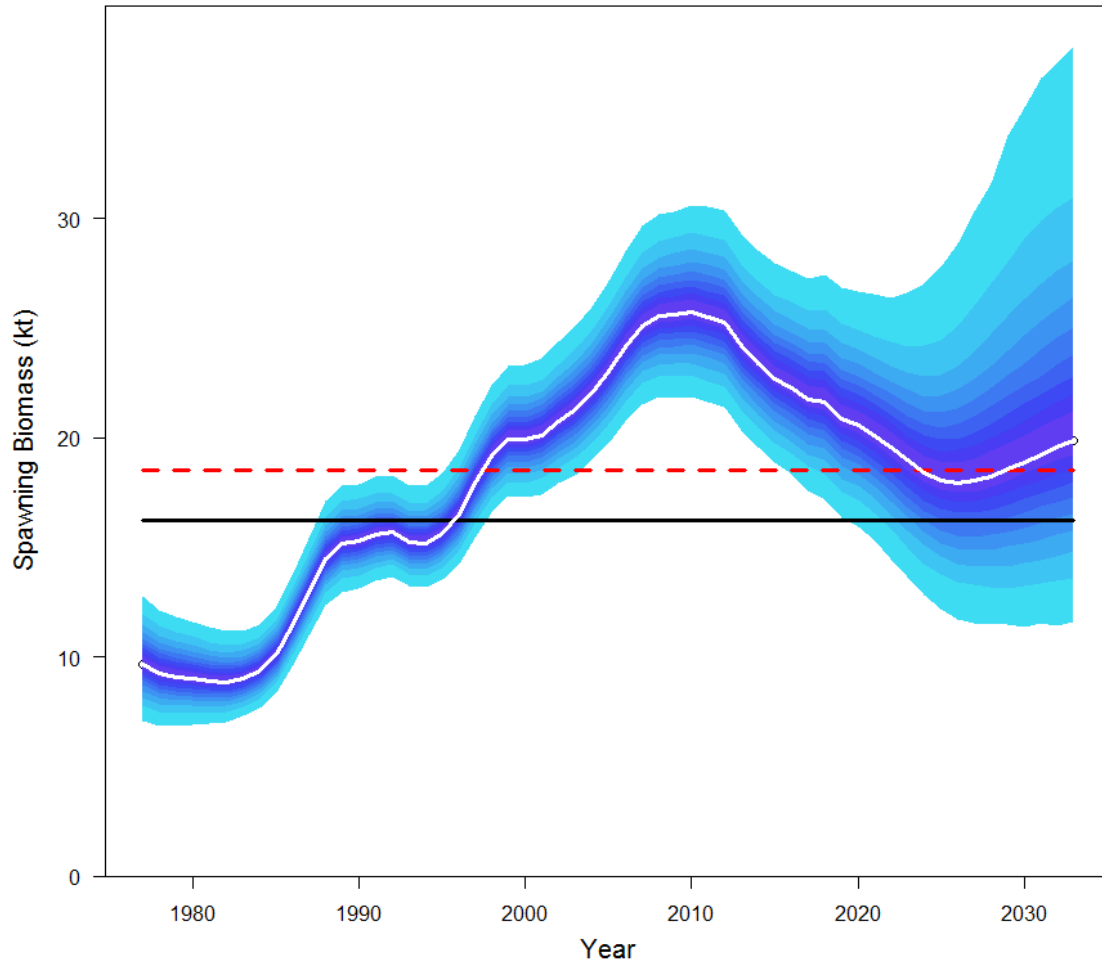
Figure 12-16. Bayesian credible intervals for entire spawning stock biomass series including projections through 2030. Red dashed line is $B_{40\%}$ and black solid line is $B_{35\%}$ based on recruitments from 1981-2014. The white line is the median of MCMC simulations. Each shade is 5% of the posterior distribution.
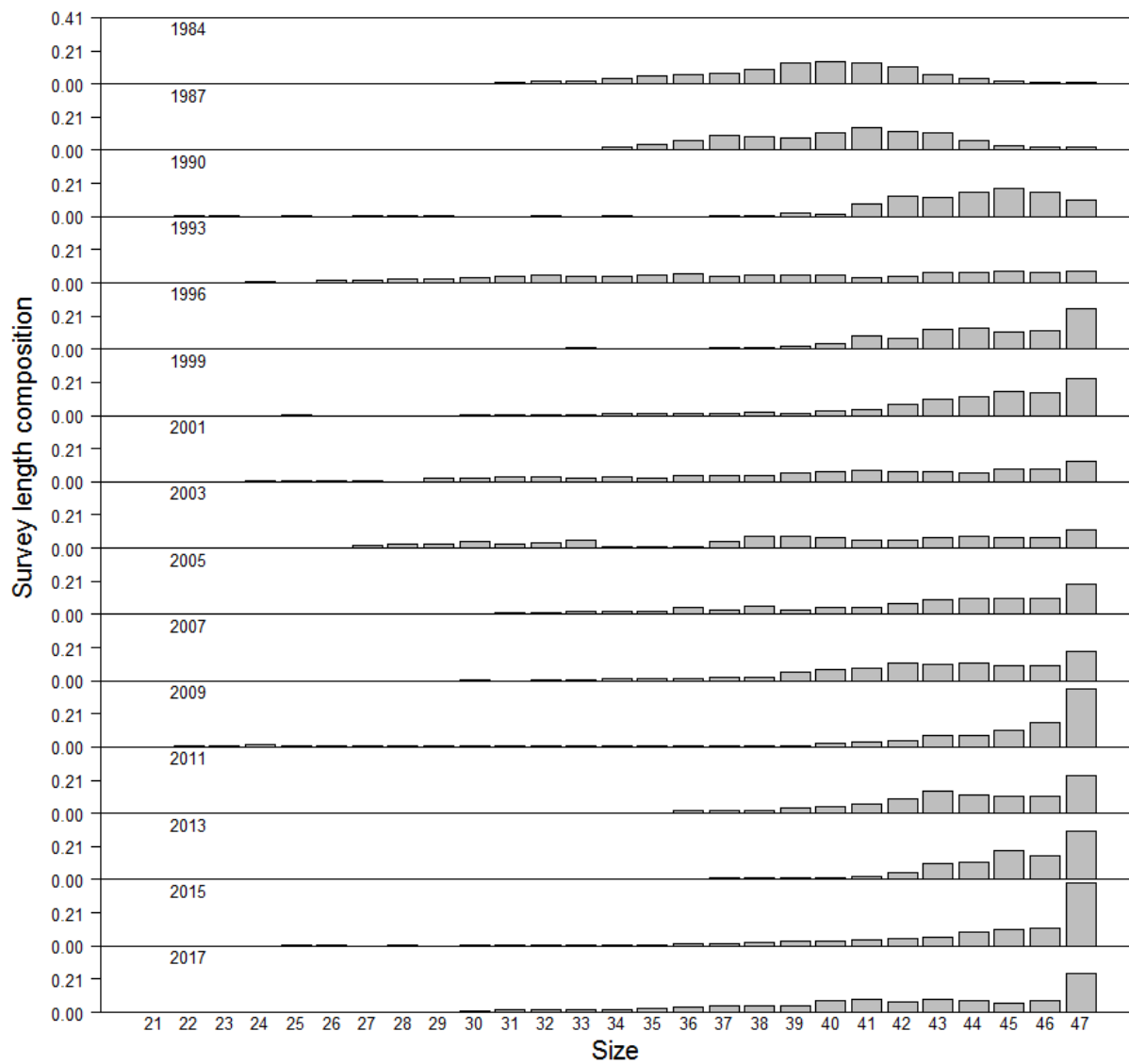
Figure 12-17. Observed survey length compositions for GOA dusky rockfish. Survey length compositions are not used in the model.

Appendix 12A

Total Catch Accounting 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) dusky rockfish, these estimates can be compared to the research removals reported in previous assessments (Lunsford et al. 2009; Table 12 A-1). Dusky 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 dusky rockfish in the GOA. Other research activities that harvest dusky 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 dusky rockfish does occur and has been between 5 t and 11 t. Total removals from activities other than a directed fishery have been near 10 t for 2010-2012, and increasing to a high of 22 t in 2015. The 2015 other removals is <1% of the 2015 recommended ABC of 5,109 t and represents a very low risk to the dusky rockfish stock. Research harvests 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 2005 when 13 t were removed. Even when accounting for recreational harvest, the estimated removals would generally be less than 20 t, which do not pose a significant risk to the dusky rockfish stock in the GOA, however recreational removals have been increasing in recent years.

References:

Lunsford, C., S. K. Shotwell, and D. Hanselman. Gulf of Alaska pelagic shelf rockfish. 2009. 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 9950. pp. 925-992.

Table 12A-1. Total removals of Gulf of Alaska dusky rockfish (t) from activities not related to directed fishing, since 1977. Trawl survey sources are a combination of the NMFS echo-integration, State of Alaska small-mesh, GOA bottom trawl surveys, and occasional short-term research projects. Other is longline, personal use, scallop dredge, and subsistence harvest.

Year	Source	Trawl	Recreational	Other	Total
1977-1995 (avg)*		3.9			3.9
1996		7			7
1997		1			1
1998		8			8
1999		6			6
2000		0			0
2001	**Assessment of**	3			3
2002	**Pelagic shelf rockfish**	0			0
2003	**in the Gulf of Alaska**	6			6
2004	**(Lunsford et al. 2009)**	0			0
2005		13			13
2006		0			0
2007		7			7
2008		0			0
2009		5			5
2010		<1	9	<1	9
2011		5	5	<1	10
2012		<1	8	<1	8
2013	**AKRO**	7	11	<1	18
2014		<1	16	<1	17
2015		5	17	<1	22
2016		<1	18	<1	18
2017		4	**	<1	4**

*May include catch of dark rockfish.
** Recreational removals not updated for 2017.