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 2020, 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 2018 with new data collected since the last full assessment and propose no model structural changes, but a minor change to a data input.

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 2019, final catch for 2018 and 2019 and preliminary catch for 2020, fishery age compositions from 2018, and fishery size compositions for 2019. Additionally, geostatistical model-based trawl survey biomass estimates are updated and included using new VAST geospatial model parameterization (described in more detail in the *Data* section below).

Changes in the assessment methodology:
The assessment methodology has not changed from the accepted 2018 assessment.

Summary of Results

The model for this assessment is model 15.5a (2020), which is the 2018 model with updated data through 2020 and revised methods for calculating the trawl survey abundance index, which is delineated using an 'a' in the model numbering. 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 model 15.5a with data through 2020.

The following results are based on the author recommended model 15.5a (2020). The maximum allowable ABC for 2021 is **7,101** t based on the Tier 3a harvest control rule for dusky rockfish. This ABC

is a 93.2% increase from last year's ABC of 3,676 t and is attributed to the changes associated with adjusting the settings in the geostatistical model-based survey biomass index and the increased survey biomass from the 2019 survey.

The 2021 Gulf-wide OFL for dusky rockfish is **8,655** t. Area apportionments of ABC are based on the recommended random effects model applied to the design-based survey biomass estimates. The 2021 recommended area apportionments of ABC are 355 t for the Western area, 5,993 t for the Central area, 617 t for the West Yakutat area, and 136 t for the Southeast/Outside area. This represents a large increase in ABC for the Central GOA, West Yakutat and Southeast/Outside, and a reduction in the Western GOA. This shift in apportionment is attributable to the trawl survey encountering the second highest biomass ever recorded in the Shumagin area in 2017, but then returning to a lower biomass estimate for that area in the 2019 survey. The corresponding reference values for dusky rockfish are summarized in the table below, 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:	
	2020	2021	2021*	2022*
M (natural mortality rate)	0.07	0.07	0.07	0.07
Tier	3a	3a	3a	3a
Projected total (age 4+) biomass (t)	54,626	53,971	97,702	93,825
Female spawning biomass (t)	20,116	19,631	38,362	37,530
$B_{100\%}$	46,337	46,337	60,855	60,855
$B_{40\%}$	18,535	18,535	24,342	24,342
$B_{35\%}$	16,218	16,218	21,299	21,299
F_{OFL}	0.118	0.118	0.114	0.114
$maxF_{ABC}$	0.095	0.095	0.093	0.093
F_{ABC}	0.095	0.095	0.093	0.093
OFL (t)	4,492	4,396	**8,655**	8,423
maxABC (t)	3,676	3,598	**7,101**	6,913
ABC (t)	3,676	3,598	**7,101**	6,913
Status	As determined *last* year for:		As determined *this* year for:	
	2018	2019	2019	2020
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 2,287 t for 2020, and estimates of 4,786 t and 4,529 t used in place of maximum permissible ABC for 2021 and 2022.

Area Apportionment

The following table shows the recommended apportionment for 2021 and 2022 from the random effects model.

Area Apportionment	Western 5.0%	Central 84.4%	Eastern 10.6%	Total 100%
2021 Area ABC (t)	**355**	**5,993**	**753**	**7,101**
2021 OFL (t)				**8,655**
2022 Area ABC (t)	**346**	**5,834**	**733**	**6,913**
2022 OFL (t)				**8,423**

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 0.82. This results in the following apportionment to the W. Yakutat area:

	W. Yakutat	E. Yakutat/Southeast
2021 Area ABC (t)	**617**	**136**
2022 Area ABC (t)	**601**	**132**

Summaries for Plan Team

Stock	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Dusky Rockfish	2019	55,247	4,521	3,700	3,700	2,491
	2020	54,626	4,492	3,676	3,676	2,172[2]
	2021	97,702	8,655	7,101		
	2022	93,825	8,423	6,913		

Stock	Area	2020 OFL	2020 ABC	2020 TAC	2020 Catch[2]	2021 OFL	2021 ABC	2022 OFL	2022 ABC
Dusky Rockfish	W		776	776	231		355		346
	C		2,746	2,746	1,857		5,993		5,834
	WYAK		115	115	83		617		601
	EYAK/SEO		39	39	1		136		132
	Total	4,492	3,676	3,676	2,172	8,655	7,101	8,423	6,913

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

[2]Current as of October 5, 2020. 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) "The SSC requests that all authors fill out the risk table in 2019…" (SSC December 2018)

"…risk tables only need to be produced for groundfish assessments that are in 'full' year in the cycle." (SSC, June 2019)

"The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table." (SSC, October 2019)

"The SSC requests the the GPTs, as time allows, update the risk tables for the 2020 full assessments.

…..The SSC recommends dropping the overall risk scores in the tables.

…..The SSC requests that the table explanations be included in all the assessments which include a risk table for completeness.

….The SSC notes that the risk tables provide important information beyond ABC-setting which may be useful for both the AP and the Council and welcomes feedback to improve this tool going forward." (SSC December 2019)

As all these comments pertain to the risk table we combine them in our response. As requested, we provide a risk table in the *Harvest Recommendations* section that provides rationale for each level chosen and we drop the overall risk score. After completing this exercise, we do not recommend ABC be reduced below maximum permissible ABC.

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."(Dec 2017)

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.

Responses to SSC and Plan Team Comments Specific to this Assessment

"VAST Applications in Survey Group - The SSC recommends that standardized documentation (both format and content) will be very helpful to the authors, Plan Teams and SSC for review and diagnosis of VAST model results for each species. However, the SSC cautions against standardized model fitting (e.g., a single error distribution, set of covariates), other than as a starting point. The species-specific biological distribution, and interaction of this distribution with covariates, may require differing error distributions to fit the data adequately. It is more important for each species to have a statistically rigorous model selection process resulting in good model fit and diagnostics than the simplicity of fitting the same approach to all species: unlike design based estimators, the SSC suggests that one size does not fit all for VAST models. The SSC provides a number of additional recommendations for further analyses. The SSC supports further investigation of the use of covariates such as the extent of the cold pool in the Bering Sea, depth, and perhaps a coastline covariate in the GOA to ameliorate the assumption of anisotropy in this heterogeneous region. Covariates may be especially important for extrapolating predictions into unsampled areas, but care should be taken to explore the implications of predicting biomass when sampling did not occur. Specifically, critical evaluation of biomass predicted to be in the

northern Bering Sea in years without sampling may need to be evaluated against fishery and other data for plausibility. Using depth as a covariate may require a spline, GAM, or other flexible relationship to approximate complex biological distribution patterns. Exploring models on species that do not have appreciable abundance in unsampled areas (e.g., deep water) may help to better understand whether edge effects are important and being dealt with appropriately (e.g., northern rockfish example). Specifically, a species whose distribution tapers to very low levels over sampled depths should not have an appreciably different index if deep strata are projected and a depth covariate is included.

*…The SSC recommends further consideration of the optimal number of knots on which to build VAST models for the GOA and Bering Sea, as the current choice of number of knots appears arbitrary. Ideally, the number of knots should represent a compromise between technical feasibility and the coarseness of the approximation for the density surface (see Thorson 2019): more is often better, but not if the model cannot be run. Finally, the SSC notes the discussion regarding inclusion of untrawlable habitat in VAST models for the GOA (and potentially the Aleutian Islands). The design-based approach includes untrawlable areas in the area-swept expansion and the SSC suggests that a VAST estimator that assumes no biomass in untrawlable areas could be of reduced value to stock assessment authors requiring an index of total biomass/abundance unless the biology of the species suggests that this is the case. (*SSC October 2020*)*

GOA Dusky rockfish has used a geospatial estimator (i.e., VAST) for trawl survey abundance since 2015. The VAST model parameterization has changed over time and each change has been documented through ‘bridging’ models to show the effect of changes as they have been made. For 2020, we present an author’s recommended model that uses the ‘VAST GAP’ standard parameterizations, including a delta-gamma observation model, gamma PCR, bias correction, and 500 knots. The VAST model specification decisions, including the observation error distribution and number of knots, were based on the results of a simulation experiment testing the sensitivity and performance of VAST when producing model-based indices to the spatial resolution and observation error distributions, including when the observation error distribution is mis-specified (Thorson et al. 2021). The differences between the VAST GAP parameterization and the 2018 parameterizations of the geospatial model are discussed in greater detail in the *Analytic approach* and *Results* sections. Research on potential covariates for the geospatial index of abundance for duskies has not been undertaken.

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 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.

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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.

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 1977-2020 (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 2019 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 20 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 2016-2020 are shown in Table 12-3. As an average for the GOA rockfish fishery during 2016-2020, the largest non-rockfish bycatch groups are arrowtooth flounder (986 t/year), sablefish (637 t/year), atka mackerel (741 t/year) and walleye pollock (743 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). Since the 2018 assessment the prohibited species catch observed in 2019 and 2020 increased for chinook salmon and non-chinook salmon, and remained at similar levels for halibut (Table 12-5).

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, chinook and non-chinook salmon.

Discards

Gulf-wide discard rates (percent of the total catch discarded within management categories) of dusky rockfish are show for 2000-2020. Rates are listed in the following table and have ranged from less than 1% to 7.6% the total dusky catch over time. These rates are considered to be low and are consistent with other GOA rockfish species.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
% Discard	0.9	1.7	4.3	1.7	1.8	0.9	5.0	0.7	0.7	1.5
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
% Discard	1.0	1.8	3.9	5.2	3.1	5.3	4.1	7.6	2.4	6.3
Year	2020									
% Discard	2.5									

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

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, **2019, 2020**
NMFS bottom trawl surveys	Biomass index	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, **2019**
NMFS bottom trawl surveys	Age	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, **2019**
U.S. trawl fisheries	Age	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, **2018**
U.S. trawl fisheries	Length	1990-1999, 2007, 2009, 2011, 2013, 2015, 2017, **2019**

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 2020 (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 1991-2019 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 44-46 cm in 1993-2019. Fish smaller than 40 cm are seen in moderate numbers in certain years (1991-92, 1997, and 2017-2019, 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 2000-2018 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 decreased recently from 14-15 years old in 2012-2016 to 11 years old in 2018. 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, 2017, and 2019 (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 2015, 2017, and 2019 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. In the 2019 survey, catches of dusky rockfish were highest in the central GOA, but some consistent, lower catch trawls were also observed in both the western and eastern GOA. An increase in trawl survey catches was observed in all statistical areas except the Shumagins, which were high in that region in 2017 and historically have seen infrequent, high survey catches.

Geospatial abundance indices

Model-based abundance indices have a long history of development in fisheries (Maunder and Punt, 2004). We use a delta-model that uses two linear predictors (and associated link functions) to model the probability of encounter and the expected distribution of catches (in biomass or numbers, depending upon the specific stock) given an encounter (Lo et al., 1992; Stefansson, 1996). Previous research has used spatial strata (either based on strata used in spatially stratified design, or post-stratification) to approximate spatial variation (Helser et al., 2004), although recent research suggests that accounting for spatial heterogeneity within a single stratum using spatially correlated residuals and habitat covariates can improve precision for the wrestling index (Shelton et al., 2014). Model-based indices have been used by the Pacific Fisheries Management Council to account for intra-class correlations among hauls from a single contract vessel since approximately 2004 (Helser et al., 2004). Specific methods evolved over time to account for strata with few samples (Thorson and Ward, 2013), and eventually to improve precision based on spatial correlations (Thorson et al., 2015) using what became the Vector Autoregressive Spatio-temporal (VAST) model (Thorson and Barnett, 2017).

The performance of VAST has been evaluated previously using a variety of designs. Research has showed improved performance estimating relative abundance compared with spatially-stratified index standardization models (Grüss and Thorson, 2019; Thorson et al., 2015), while other simulation studies have shown unbiased estimates of abundance trends (Johnson et al., 2019). Brodie et al. (2020) showed improved performance in estimating index scale given simulated data relative to generalized additive and machine learning models. Using real-world case studies, Cao et al. (2017) showed how random variation in the placement of tows relative to high-quality habitat could be "controlled for" using a spatio-temporal framework, and O'Leary et al. (2020) showed how combining surveys from the eastern and northern Bering Sea within a spatio-temporal framework could assimilate spatially unbalanced sampling in those regions. Other characteristics of model performance, including sensitivity to spatial resolution of misspecification of the observation error distribution, have also been simulation-tested although these results are not discussed further here (Thorson et al. 2021).

VAST GAP Standardized settings used in 2020

The software versions of dependent programs used by the VAST GAP group to generate VAST estimates were:

- R (>=3.5.3)
- INLA (18.07.12)
- TMB (1.7.15)
- TMBhelper (1.2.0)
- VAST (3.3.0)
- FishStatsUtils (2.5.0)
- sumfish (3.1.22)

We used a Poisson-link delta-model (Thorson, 2018) involving two linear predictors, and a gamma distribution for the distribution of positive catch rates. We extrapolated catch density using 3705 m (2 nmi) X 3705 m (2 nmi) extrapolation-grid cells; this results in 36,690 extrapolation-grid cells for the eastern Bering Sea, 15,079 in the northern Bering Sea and 26,510 for the Gulf of Alaska (some Gulf of Alaska analyses eliminated the deepest stratum with depths >700 m because of sparse observations, resulting in a 22,604-cell extrapolation grid). We used bilinear interpolation to interpolate densities from 500 "knots" to these extrapolation-grid cells (i.e, using `fine_scale=TRUE` feature); knots were distributed spatially in proportion to the distribution of extrapolation-grid cells (i.e., having an approximately even distribution across space) using "knot_method = 'grid'. No temporal smoothing was used (i.e. variation was estimated using independent and identically distributed methods). We estimated "geometric anisotropy" (the tendency for correlations to decline faster in some cardinal directions than others), and included a spatial and spatio-temporal term for both linear predictors. Finally, we used epsilon bias-correction to correct for retransformation bias (Thorson and Kristensen, 2016).

Diagnostics

For each model, we confirm that the Hessian matrix is positive definite and the gradient of the marginal likelihood with respect to each fixed effect is near zero (absolute value < 0.0001). We then conduct a visual inspection of the quantile-quantile plot for positive catch rates to confirm that it is approximately along the one-to-one line, and also check the frequency of encounters for data binned based on their predicted encounter probability (which again should be along the one-to-one line). Finally, we plot Pearson residuals spatially, to confirm that there is no residual pattern in positive and negative residuals.

Geospatial model details specific to GOA Dusky rockfish

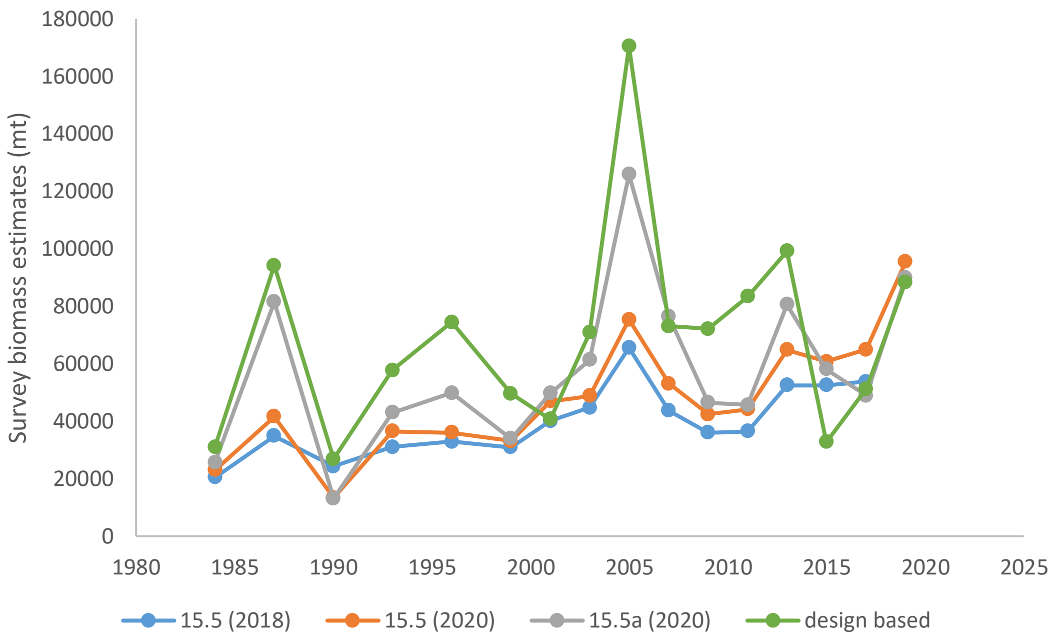
For GOA dusky rockfish, a trawl survey biomass estimator based on a geostatistical generalized linear mixed model (GLMM; Thorson et al. 2015) has been used assessment since 2015. Details on the application of this biomass estimator for five GOA rockfish species are available in the 2015 GOA dusky rockfish 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 reduces the 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 less variable over time than the design-based estimates (Tables 12-9A & 12-9B, Figure 12-4).

The geospatial model 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 somewhat similar over time, the VAST package and parameterization used for the 2020 assessment (Model 15.5a) produces different results than the versions used for 2018 (Model 15.5 (2018)) and the 2018 model updated with most recent year’s trawl data (bridge Model 15.5 (2020); figure below).

The table below lists specifications in VAST for the geospatial index used in each assessment model for the 2020 assessment cycle. The 15.5a (2020) geospatial model was estimated by the VAST-GAP group at AFSC, using their standard methods (detailed above).

Model	15.5 (2018)	15.5 (2020)	15.5a (2020)
Survey years	1984-2017	1984-2019	1984-2019
Knots	1000	500	500
Obs model	delta	delta	delta-gamma
PCR	lognormal	lognormal	gamma
Intent	Accepted 2018 model	Partial bridge model	Preferred 2020 model

The geospatial model survey biomass used in the 2018 approved model (blue), the bridge model (orange), and the author's recommended model (grey) are shown below, with the design-based survey index biomass shown in green for reference. For clarity of the index values, error bars are not included.



Geospatial biomass estimates used in Model 15.5a (2020) range from a minimum 13,146 t in 1990 to a maximum of 125,585 t in 2005 (Table 12-9B). Overall, geospatial biomass estimates show some inter-annual variability, but less inter-annual variability than the design-based estimator. There is an 84% increase in the estimated abundance from 2017 to 2019.

Survey Size Compositions

Gulf-wide survey size compositions are available for 1984-2019 (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, 2003, and potentially 2009 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 starting at ~37 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.

Survey Age Compositions

Gulf-wide age composition data for dusky rockfish are available for the 1984 through 2019 trawl surveys (Table 12-11). The mode of the age data has been generally increasing from 11 years in 1987 to 15 years in 2015 and recently decreased to 10-11 years in 2017-2019. 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 2019, there appears to be some evidence for a potentially stronger year classes in approximately 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.

Description of Alternative Models

No changes were made to the model configuration and structure in this year's assessment compared to the 2015 assessment and the model accepted in 2018. In this year's assessment we recommend using an updated geostatistical model-based estimate of survey biomass. We present the following models that provide a bridge analysis from the geostatistical model-based survey biomass estimates used in the 2018 assessment and the estimates used in the recommended model for this year's assessment.

Model case	Description
15.5 (2018)	2018 accepted model (Model case M5 in 2015)
15.5 (2020)	'Bridge' model. Same model as 2018, but with updated data through 2020 using VAST parametrization described for Model 15.5 (2020) above
15.5a (2020)	Same model as 2018, but with updated data through 2020 using new VAST standard parametrization described for Model 15.5a (2020) above (preferred model)

Parameters Estimated Outside the Assessment Model

Parameters fit outside the assessment model include the life-history parameters for weight-at-age, ageing 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 1990-2019, with a total sample size of 9,487. 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, $a = 8.12 \times 10^{-6}$ and $b = 3.12$.

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 1990-2019. 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: $L_\infty = 48.3$ cm, $\kappa = 0.18$, and $t_0 = 0.40$.

Ageing error matrices were updated and were constructed by assuming that the break-and-burn ages were unbiased but had normally distributed age-specific error 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. (2007) 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.

Maturity data table. The plus group includes data for fish aged 30-50 for table reporting purposes. The maturity model does not include a plus group and includes data for ages 1-50.

	Lunsford et al. data		Chilton et al. data	
Age	Total Observed Fish	Number Mature	Total Observed Fish	Number Mature
1				
2				
3			2	0
4			2	0
5			7	0
6			12	0
7			12	5
8			20	8
9	2	1	30	16
10	16	7	25	18
11	10	3	11	10
12	14	7	8	5
13	6	5	14	10
14	2	2	1	1
15			4	3
16	2	2	3	2
17			5	4
18				
19	4	4	3	3
20	3	3	4	3
21	1	1	2	2
22	1	1		
23	1	1	4	4
24			3	3
25			3	3
26				
27				
28			4	4
29	2	2	2	2
30+			9	9

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 von Bertalanffy growth model (see 'Parameters estimated outside the model' section, above), the size at 50% maturity is 40.6 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 variables 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	67
Average fishing mortality	μ_f	1
Fishing mortality deviations	ϕ_y	44
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		124

Evaluation of model uncertainty is obtained through a Markov Chain Monte Carlo (MCMC) algorithm (Gelman et al. 1995). The chain length of the MCMC was 10,000,000 and was thinned to one iteration out of every 2,000. We omit the first 1,000,000 iterations to allow for a burn-in period. We use these MCMC methods to provide further evaluation of uncertainty in the results below including 95% credible intervals for some parameters (computed as the 5^{th} and 95^{th} percentiles of the MCMC samples).

BOX 1. AD Model Builder Model Description

Parameter definitions	
y	Year
a	Age classes
l	Length classes
w_a	Vector of estimated weight at age, $a_0 \rightarrow a_+$
m_a	Vector of estimated maturity at age, $a_0 \rightarrow a_+$
a_0	Age at first recruitment
a_+	Age when age classes are pooled
μ_r	Average annual recruitment, log-scale estimation
μ_f	Average fishing mortality
σ_r	Annual recruitment deviation
ϕ_y	Annual fishing mortality deviation
fs_a	Vector of selectivities at age for fishery, $a_0 \rightarrow a_+$
s_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 variability in recruitment deviations
σ^2_q	Prior CV for catchability coefficient
$\sigma^2_{\sigma_r}$	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

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

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
$L_7 = \frac{1}{2\sigma_q^2} \left(\ln {}^{q}\!/\!_{q_{prior}} \right)^2$	Penalty on deviation from prior distribution of catchability coefficient
$L_8 = \frac{1}{2\sigma_{\sigma_r}^2} \left(\ln {}^{\sigma_r}\!/\!_{\sigma_{r(prior)}} \right)^2$	Penalty on deviation from prior distribution of recruitment deviations
$L_9 = \lambda_9 \left[\frac{1}{2 * \sigma_r^2} \sum_y \tau_y^2 + n_y * \ln\left(\sigma_r\right) \right]$	Penalty on recruitment deviations
$L_{10} = \lambda_{10} \sum_y \phi_y^2$	Fishing mortality regularity penalty
$L_{11} = \lambda_{11} \bar{s}^2$	Average selectivity penalty (attempts to keep average selectivity near 1)
$L_{12} = \lambda_{12} \sum_{a_0}^{a_+} \left(s_i - s_{i+1}\right)^2$	Selectivity dome-shapedness penalty – only penalizes when the next age's selectivity is lower than the previous (penalizes a downward selectivity curve at older ages)
$L_{13} = \lambda_{13} \sum_{a_0}^{a_+} \left(FD(FD(s_i - s_{i+1})\right)^2$	Selectivity regularity penalty (penalizes large deviations from adjacent selectivities by adding the square of second differences)
$L_{total} = \sum_{i=1}^{13} L_i$	Total objective function value

Results

Model Evaluation

The model for this assessment is model 15.5a (2020), which is the 2018 model with updated data through 2020. This model is identical to the model accepted in 2018 (model 15.5 2018), except for inclusion of additional years of data and the new geospatial model parameterization. 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 2018 and 2020 models are identical but the geospatial model parameterization has changed for the abundance index, we present results for the following models:

1. The 2018 approved model (model 15.5 2018),
2. A ‘bridge’ model to show the effect of new data with the 2018 VAST parameterization (model 15.5 2020), and
3. The author’s recommended model using the VAST GAP standard parameterization (model 15.5a 2020).

The recommended model generally produces good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivities. Therefore, the recommended 2020 model is utilizing the new information effectively, and we use it to recommend the 2021 ABC and OFL.

Time Series Results

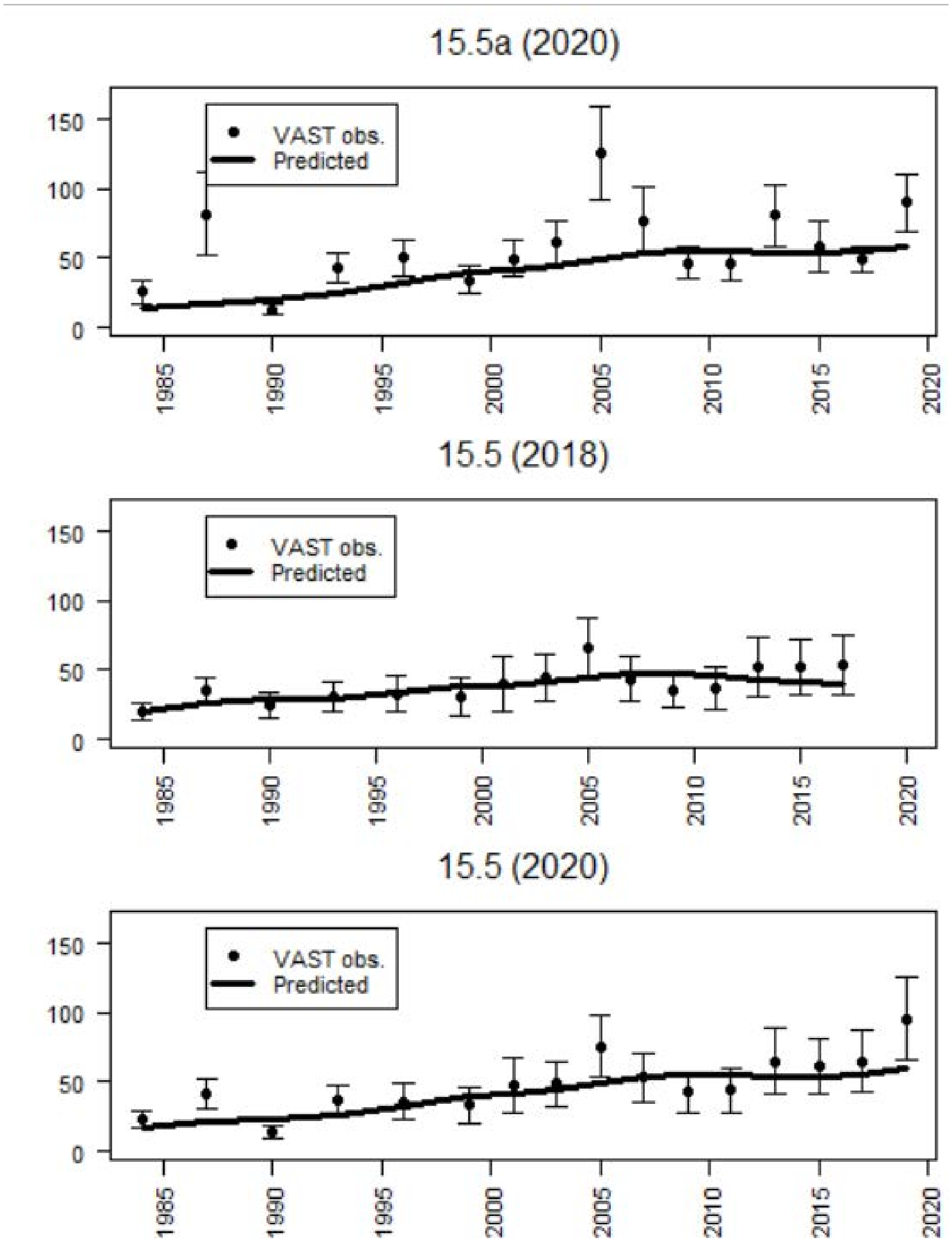
Key results have been summarized in Tables 12-12 – 12-15. In general, model predictions continue to fit the data well (Figures 12-1, 12-2, 12-4, 12-5, 12-8).

Definitions

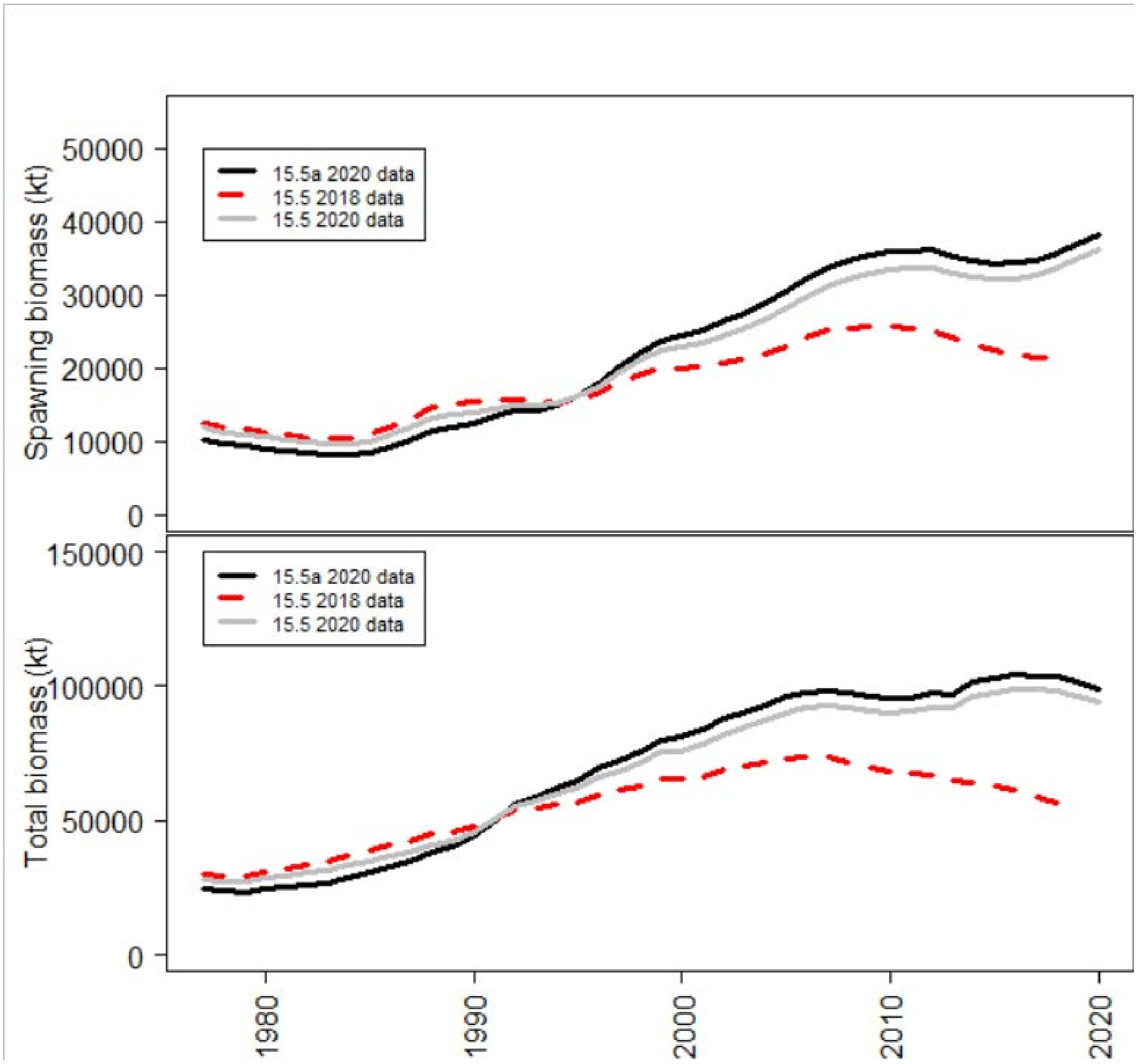
Spawning biomass is the biomass estimate of mature females. Total biomass is the biomass estimate of all dusky rockfish age four and greater. Recruitment is measured as number of age four dusky rockfish. Fishing mortality is fully-selected F, meaning the mortality at the age the fishery has fully selected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

Biomass and Exploitation Trends

The predicted survey biomass generally captures the trend in observed (VAST geospatial model) survey biomass similarly for the preferred and bridge models (below and Figure 12-4), but without matching the interannual variability that is present in observed values. The 2019 observed survey values are greater than the predicted model estimates for both models 15.5 (2020) and 15.5a (2020), indicating that the assessment model is tempering the observed increase in variability based on age compositional data. However, the model predicted survey biomass estimates for both the preferred model (15.5 2020) and the ‘bridge’ model result in similar predicted trawl survey biomass.



Total biomass estimates (age 4+) indicate a steadily increasing trend with a peak in 2016 (Figure 12-9, Table 12-14). The addition of the high value for the 2019 trawl survey data has shifted the trajectory and scale of total and spawning biomass to an increasing trend terminating in high values for the preferred and bridge models (15.5a 2020 and 15.5 2020, respectively) compared to the 15.5 (2018) model (red dashed line, below). The spawning biomass estimate is at a time series high of 38,202 t in 2020. MCMC credible intervals indicate that the historic low was more certain than the more recent increases, particularly when looking at the upper credible interval (Figure 12-9).



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 targets 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 10. The age at 50% selection is 8.7 for the survey and 10.3 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 2003-2020. Since 2003 fully-selected fishing mortality has ranged between 0.03 and 0.06 (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 1977-2020 and projected values for 2021-2022. 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 1991-1995 (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 and 2019 fishery size composition fits well for all but the plus group, where the model prediction is higher than what was observed in the fishery. In general, the model fits the fishery age compositions well (Figure 12-2). The strong year classes from 1992 and 1995 have largely moved into the plus age group. The 2018 age data suggest that there is a large pulse of age 11 fish (with ages 10 and 12 also high) observed in the compositional data.

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. Similar to the fishery age compositions, the survey age compositions show an increase in proportions of fish aged 11 and 12 in the 2019 data. Recruitment was strong due to several above average recruitments in the 1990s through early 2000s, and 2014 recruitment is the highest of the time series (Figure 12-13). This high recruitment value has relatively high uncertainty, which is likely due to age composition data indicating higher proportions of ages 10-12 fish, instead of a single age class. In general, 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 0.51 for model 15.5a (2020) and 0.19 for bridge model 15.5 (2020), 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 2018 approved model was 0.06. 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). The retrospective pattern is driven by large changes in spawning biomass from data peels five or more years past. This is likely due to the assessment model being unable to reconcile the high survey biomass estimate in 2005.

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 1981-2016 (year classes between 1977 and 2012). 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 2021 are:

$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	$F_{40\%}$	$F_{35\%}$
60,855	24,342	21,299	0.093	0.114

Specification of OFL and Maximum Permissible ABC

Female spawning biomass for 2021 is estimated at 38,362 t, which is above the $B_{40\%}$ value of 24,342 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 2021, yields the following ABC and OFL:

$F_{40\%}$	0.093
ABC	7,101
$F_{35\%}$	0.114
OFL	8,655

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 2020 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2021 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2020. 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 2020 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 2021, 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 2021 and 2022, 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 2017-2019 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 2015-2019 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 2020 or 2) above ½ of its MSY level in 2020 and above its MSY level in 2030 under this scenario, then the stock is not overfished.)

Scenario 7: In 2021 and 2022, 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 2022 or 2) above 1/2 of its MSY level in 2022 and expected to be above its MSY level in 2032 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.

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 (0.67) 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 1981-2016 age-4 recruitments, and this projection predicts that the median spawning biomass will decrease quickly until average recruitment is attained.

Risk Table and ABC Recommendation

The SSC in its December 2018 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The SSC also requested the addition of a fourth column on fishery performance, which has been included in the table below.

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/eco-system considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/ minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators

Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of un-certainty; strong retro-spective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retro-spective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple eco-system indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.
2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.
3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.
4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment considerations

Level 2. The GOA trawl survey was conducted in 2019 as expected, and fishery and survey age and length composition data have been incorporated with the expected range of data made available on time for incorporation into the 2020 stock assessment. The assessment model produces reasonable fits to the survey abundance index and compositional data, but the model results are sensitive to the geospatial model biomass index and the additional year of survey data. The low variance of the geospatial model configuration, coupled with high 2019 survey biomass estimate has resulted in a large increase in total and spawning biomass. There is also a strong positive retrospective bias towards decreasing spawning biomass in recent years (Mohn's rho = 0.51). In addition, all geospatial index configurations examined result in increased biomass and ABC estimates. The large increase in biomass, and subsequently ABC, that are primarily driven by the attributes of the geospatial model (low estimated variance in biomass) in conjunction with a strong retrospective pattern that decreases biomass through time provide conflicting trends in this assessment. For these reasons we have given this risk table factor a 'level 2, substantially increase concerns' rank.

Population dynamics considerations

Level 1. There is a large increase in the 2019 survey biomass estimate for dusky rockfish in both the design-based and geospatial indices. Fishery and survey age compositions for the most recent year are both relatively uniformly distributed across ages with some increased proportions of 8-11 year old fish over the previous compositions. The assessment model estimates a high age-4 recruitment for 2010 and these recruits would be 13 years old in 2019. This lines up somewhat imperfectly with both the observed age compositions for the fishery and survey which show a higher proportion age 11 fish in 2018 (fishery) and age 11 and 12 fish in 2019 (survey). Rockfish aging is challenging, and some smearing across ages is expected. For these reasons we have given this risk table factor a 'level 1, normal' rank and do not suggest there is reason to suggest a reduction in ABC based on population dynamics considerations.

Environmental/Ecosystem considerations

Level 1. There are mixed signals regarding environmental considerations but generally no indications to cause moderate or severe concerns.

Dusky are benthic dwellers as adults, with a pelagic then juvenile stage in the Gulf of Alaska (GOA) (Love et al. 2002).The limited information available on temperature, zooplankton, and conditions of other marine species indicate average foraging and growing conditions for the zooplanktivorous juvenile rockfish during 2020. Heat wave conditions occurred during 2020 but were not as severe as 2019 during the summer and fall in the GOA (Watson 2020). Sea surface temperatures were about 1°C above normal in the western GOA and average in the eastern GOA during the 2020 summer (Alaska Center for Climate Assessment & Policy ACCAP, Thoman personal communication). Inside waters of the GOA were slightly more anomalously warm than offshore temperatures (ACCAP). Offshore of Seward, waters above the continental shelf at GAK1 on the Seward line remained anomalously warm (0.5°C) at 200-250 m depth in 2020 but cooler than 2019 (Danielsen and Hopcroft 2020). Along the GOA slope, the AFSC Longline Survey Subsurface Temperature Index indicates above average temperatures at the surface and at depth (250 m) in 2020 relative to the 2005-2019 time series and cooler temperatures in 2020 relative to 2019 (Siwicke personal communication). In the inside waters, Prince William Sound has remained warm since 2014 (Campbell and McKinstry 2020). However, for the inside waters of the eastern GOA, the top 20 m temperatures of Icy Strait in northern southeast Alaska during summer were slightly below average (8.8°C) in 2020 relative to the 23 year time series (1997-2019) (Fergusson and Rogers 2020). It is reasonable to expect that the recent heat wave conditions and current return to cooler temperatures would not adversely impact age-0 rockfish in pelagic waters during a time when they are growing to a size that may promote over winter survival, however, it is unknown what this impact will be. Further, a recent study published on the U.S. West Coast suggests that the warming that occurred during 2014-2016 may have been beneficial for rockfish recruitment (Morgan et al. 2019).

The known primary prey of the adult Dusky rockfish include euphausiids and Pacific sand lance in the GOA (Byerly 2001, Yang 1993, Yang and Nelson 2000). Warm conditions tend to be associated with zooplankton communities that are dominated by smaller and less lipid rich species in the GOA (Kimmel et al. 2019). There was limited information on zooplankton in 2020. In Icy Strait, northern southeast Alaska, the lipid content of all zooplankton taxa combined examined during 2020 was average for the time series (1997-2020) and similar to 2019. By taxa, lipid content was above average for the large calanoid copepods, average for hyperiid amphipods, but lower than average for euphausiids, small copepods and gastropods indicating average the nutritional quality of the prey field utilized by larval and juvenile fishes in the nearshore habitats (Fergusson and Rogers 2020). In the western GOA, the mean biomass of large calanoids and euphausiids averaged over the top 100m south of Seward Alaska during May were about average in 2020 relative to the time series, 1998-2019 (Hopcroft and Coyle 2020). On the outer edge of the continental shelf in the central Gulf of Alaska, the breeding success of piscivorous seabirds on Middleton Island as an indication for foraging success and nutrient-rich prey was above average indicating good ocean conditions during 2020 (Hatch et al. 2020). Sand lance was observed in low proportions in the diets of surface feeding birds and moderate proportions in the diets of diving sea birds, similar proportions to 2019 (Hatch et al. 2020). Mean abundance of larval sand lance in spring 2019 was elevated to levels last seen around 2007, indicating potentially increased abundance of age-1 sand lance in 2020 (although no data were collected in 2020 (Rogers and Deary 2020). Little is known about the impacts of predators and competitors, such as fish and marine mammals, on Dusky. However, survival of larvae are thought more related to the abundance and timing of prey availability than predation, due to the lack of rockfish as a prey item (Love et al. 2002, Yang 2003). The 2020 foraging conditions were likely average, although data limited, for the largely zooplanktivorous and piscivorous Dusky rockfish in the GOA. Given cooler conditions in 2020 than in 2019 and average densities and body condition of zooplankton with limited information on rockfish, we scored this category as level 1, as normal concern. There are some indicators showing positive and negative signals relevant to the stock but the pattern was not consistent across all indicators, and the actual effect is unknown.

For these reasons we have given this risk table factor a ‘level 1, normal’ rank and do not suggest there is reason to suggest a reduction in ABC based on environmental/ecosystem considerations.

Fishery performance:

Level 1. Catches are well below ABC for 2020, which matches the historical trend of the fishery catch rarely approaching ABC (Table 12.2). Dusky rockfish are caught with a number of other rockfish species, so TAC levels for Pacific Ocean perch and northern rockfish, as well as prohibited species catch restrictions (i.e. salmon) can also affect fishery realization of the full TAC. In addition, dusky catches can be influenced by the price, and current prices are relatively low (J. Bonney, pers. Comm. Oct 2020). For these reasons we have given this risk table factor a ‘level 1, normal’ rank and do not suggest there is reason to suggest a reduction in ABC based on fishery performance considerations.

Summary and ABC recommendation:

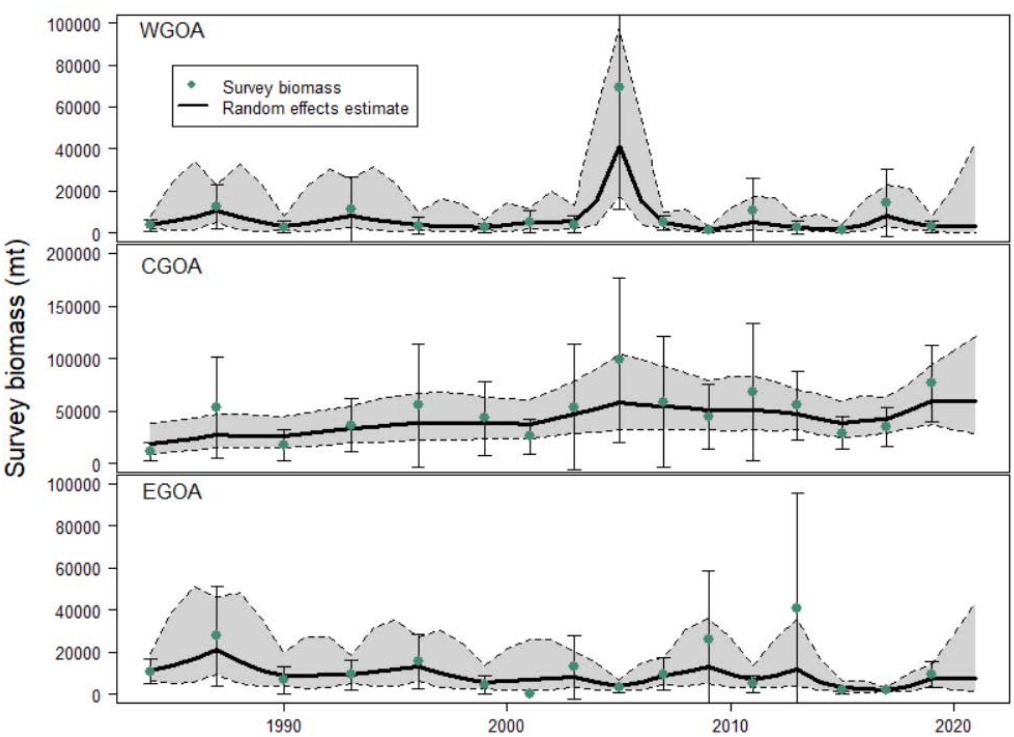
The following is a summary of the risk table:

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 2: Substantially increased concerns	Level 1: No apparent concern	Level 1: No apparent concern	Level 1: No apparent concern

We have ranked three categories as 'Level 1: No apparent concern' and one as a 'Level 2, substantially increased concerns'. The GOA dusky rockfish assessment appears to fit available data well, the 2019 GOA trawl survey was undertaken as planned and data are included in this year's assessment, and the fishery and environmental considerations appear to be within normal bounds. We have some concerns about the estimated increase in biomass and resulting increase in ABC and the model retrospective pattern. The geospatial model-based abundance index has low uncertainty which may be driving the estimated increase in biomass and ABC. Because GOA dusky rockfish ABC is not historically fully utilized and because there is an increase in 2019 survey biomass coupled with some evidence of recruitment from age compositions, we are not recommending a reduction in ABC at this time. We anticipate that we will monitor the survey abundance estimates, catch rates, and retrospective trends closely for the next assessment.

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 5.0% for the Western area (down from 21.1% in 2018), 84.4% for the Central area (up from 74.7% in 2018), and 10.6% for the Eastern area (up from 4.2% in 2018). The changes in apportionment in 2020 compared to 2018 can be attributed to an increase in biomass from the bottom trawl survey biomass in the Central and Eastern areas. This results in recommended ABC's of **355** t for the Western area, **5,993** t for the Central area, and **753** 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 0.82 (up from 0.61 in 2018), so that the dusky rockfish ABC for West Yakutat would be 617 t, and the ABC for East Yakutat/Southeast Outside would be 136 t (Table 12-17).

Based on the definitions for overfishing in Amendment 44 in Tier 3a (i.e., $F_{OFL} = F_{35\%}$=0.114), the 2020 overfishing (OFL) is set equal to 8,655 t for dusky rockfish in the GOA (Table 12-17).

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 2021, it does not provide the best estimate of OFL for 2022, because the mean 2021 catch under Scenario 6 is predicated on the 2021 catch being equal to the 2021 OFL, whereas the actual 2021 catch will likely be less than the 2021 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 (2019) is 2,491 t. This is less than the 2019 OFL of 4,521 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 2020:

a. If spawning biomass for 2020 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2020 is estimated to be above $B_{35\%}$ the stock is above its MSST.

c. If spawning biomass for 2020 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 2030 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 2022 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2022 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2022 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2032. If the mean spawning biomass for 2032 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 2019 catch compared to OFL. The official total catch for 2019 is 2,491 t which is less than the 2019 OFL of 4,521 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 2020 and 2022. The estimates of spawning biomass for 2020 and 2022 from the current year (2020) projection model are 37,587 t and 37,526 t, respectively. Both estimates are above the $B_{35\%}$ estimate of 21,299 t and, therefore, the stock is not currently overfished nor approaching an overfished condition. The *F* that would have produced a catch for 2019 equal to the OFL of 2019 was 0.06.

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 (2019) GOA Ecosystem Status Report did not reveal strong evidence of declining trends in indicators which results in strong concern for dusky rockfish. 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 lacking.

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 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 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

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

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	2,622[2]	4,278	4,278	5,233	
2018	2,913[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 12-1, continued. 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
2019	2,491[2]	3,700	3,700	4,521	
2020	2,172[2]	3,676	3,676	4,492	

[1] Catch is for entire pelagic shelf rockfish assemblage,
[2] Catch is for dusky rockfish only, updated through October 5, 2020. 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	2,622	4,278	4,278	61%
2018[a]	2,913	3,957	3,957	74%
2019[a]	2,491	3,700	3,700	67%
2020[a]	2,172	3,676	3,676	59%

[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 5, 2020. Source: AKFIN.

Table 12-3. Incidental catch of FMP groundfish species caught in rockfish targeted fisheries in the Gulf of Alaska from 2016-2020. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/11/2020. Conf. = Confidential because of less than three vessels.

Species Group Name	2016	2017	2018	2019	2020	Average
Pacific Ocean Perch	20,397	19,046	22,172	22,258	19,932	20,761
Northern Rockfish	3,155	1,601	2,152	2,313	2,307	2,306
GOA Dusky Rockfish	3,008	2,193	2,695	2,153	2,057	2,421
Arrowtooth Flounder	1,198	1,403	761	732	833	986
Sablefish	484	590	708	801	603	637
Atka Mackerel	595	543	1,140	824	602	741
Other Rockfish	974	749	994	670	515	781
Pollock	572	1,057	917	686	486	743
GOA Shortraker Rockfish	290	253	269	269	225	261
GOA Rex Sole	139	111	136	117	188	138
GOA Thornyhead Rockfish	337	360	362	177	138	275
Pacific Cod	364	253	401	322	128	293
Flathead Sole	26	80	48	40	94	58
GOA Rougheye Rockfish	351	269	317	320	88	269
Sculpin	43	45	65	53	31	48
GOA Skate, Longnose	46	42	46	28	24	37
GOA Shallow Water Flatfish	14	11	57	34	22	28
Shark	12	40	48	62	19	36
GOA Deep Water Flatfish	64	58	66	39	18	49
GOA Demersal Shelf Rockfish	42	41	58	57	11	42
GOA Skate, Other	18	22	28	26	9	21
GOA Skate, Big	4	6	6	5	4	5
Octopus	2	1	3	9	1	3
Halibut	0	6	0	0	Conf.	2
Squid	12	22	29	0	0	21

Table 12-4. Non-FMP species bycatch estimates in tons for Gulf of Alaska rockfish targeted fisheries 2016-2020. Conf. = Confidential because of less than three vessels. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/11/20.

Species Group Name	2016	2017	2018	2019	2020
Benthic urochordata	0.50	0.20	0.07	0.40	0.12
Birds - Northern Fulmar	-	Conf.	Conf.	Conf.	-
Birds - Shearwaters	-	-	-	Conf.	-
Bivalves	Conf.	0.01	Conf.	Conf.	0.00
Bristlemouths	-	-	-		Conf.
Brittle star unidentified	0.03	0.60	0.01	0.02	0.01
Capelin	Conf.	-	-	0.16	Conf.
Corals Bryozoans - Corals Bryozoans Unidentified	0.84	0.47	1.36	0.88	0.17
Eelpouts	0.02	0.13	0.22	0.00	Conf.
Eulachon	0.04	0.13	0.13	0.27	0.10
Giant Grenadier	450.37	1041.85	1690.57	786.53	301.66
Greenlings	5.79	3.90	4.51	9.63	3.51
Grenadier - Rattail Grenadier Unidentified	5.45	12.34	5.33	4.01	1.69
Hermit crab unidentified	0.01	0.03	0.01	Conf.	Conf.
Invertebrate unidentified	0.09	0.09	0.11	0.07	Conf.
Lanternfishes (myctophidae)	Conf.	0.00	Conf.	0.06	0.02
Misc crabs	0.35	1.10	0.38	0.14	0.09
Misc crustaceans	0.03	0.01	Conf.	0.20	0.07
Misc deep fish	Conf.	Conf.	-	Conf.	-
Misc fish	101.63	114.60	109.98	519.97	84.95
Misc inverts (worms etc)	Conf.	-	-	-	Conf.
Other osmerids	Conf.	Conf.	-	Conf.	0.98
Pacific Hake	Conf.	Conf.	0.07	Conf.	Conf.
Pandalid shrimp	0.22	0.14	0.07	0.11	0.17
Polychaete unidentified	-	0.02	-	Conf.	-
Scypho jellies	8.05	0.54	0.92	8.44	3.03
Sea anemone unidentified	1.27	0.72	0.46	1.57	1.24
Sea pens whips	0.02	0.03	0.00	0.03	0.00
Sea star	1.72	3.68	3.09	1.36	1.11
Snails	0.18	0.18	5.67	1.79	0.08
Sponge unidentified	2.88	3.21	13.67	5.88	0.52
Squid	-	-	-	10.87	31.61
State-managed Rockfish	13.34	24.48	52.88	46.46	53.11
Stichaeidae	-	Conf.	0.51	-	Conf.
urchins dollars cucumbers	0.34	0.43	0.31	0.21	0.91

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.

Species Group Name	**2016**	**2017**	**2018**	**2019**	**2020**
Bairdi Tanner Crab	0.11	756	321	64	241
Blue King Crab	0	0	0	0	0
Chinook Salmon	383	520	336	410	627
Golden (Brown) King Crab	20	209	324	223	60
Halibut	123	125	100	115	89
Herring	0	0.04	0.01	2.21	0.08
Non-Chinook Salmon	216	641	325	379	722
Opilio Tanner (Snow) Crab	0.01	<0.01	0	0	0
Red King Crab	0.10	0	0.03	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	2019
≤21	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
23	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.001
29	0.000	0.000	0.000	0.001	0.000	0.001
30	0.000	0.000	0.000	0.000	0.001	0.002
31	0.001	0.000	0.000	0.001	0.001	0.002
32	0.000	0.001	0.001	0.001	0.002	0.001
33	0.002	0.001	0.001	0.002	0.003	0.003
34	0.004	0.001	0.004	0.006	0.006	0.003
35	0.006	0.001	0.004	0.007	0.008	0.009
36	0.010	0.001	0.004	0.007	0.011	0.019
37	0.013	0.002	0.005	0.014	0.023	0.031
38	0.021	0.007	0.009	0.017	0.031	0.043
39	0.027	0.014	0.012	0.023	0.044	0.052
40	0.043	0.026	0.018	0.035	0.059	0.070
41	0.049	0.044	0.031	0.038	0.069	0.078
42	0.070	0.077	0.053	0.049	0.070	0.090
43	0.086	0.107	0.081	0.078	0.089	0.091
44	0.104	0.121	0.120	0.108	0.097	0.097
45	0.121	0.137	0.132	0.128	0.113	0.092
46	0.123	0.128	0.120	0.122	0.119	0.083
47+	0.319	0.332	0.405	0.362	0.251	0.231
Sample size	4,843	3,550	4,792	4,784	4,575	4,920

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	2018
4	0.000	0.000	0.000
5	0.000	0.000	0.000
6	0.003	0.006	0.000
7	0.000	0.002	0.010
8	0.019	0.013	0.059
9	0.008	0.034	0.048
10	0.036	0.058	0.071
11	0.022	0.056	0.117
12	0.031	0.054	0.091
13	0.099	0.064	0.077
14	0.065	0.054	0.045
15	0.076	0.089	0.027
16	0.110	0.062	0.051
17	0.088	0.056	0.045
18	0.060	0.077	0.049
19	0.071	0.056	0.058
20	0.048	0.043	0.037
21	0.028	0.048	0.033
22	0.031	0.034	0.034
23	0.032	0.021	0.021
24	0.020	0.037	0.021
25+	0.155	0.137	0.107
Sample size	647	626	673

Table 12-8. Design-based 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
2019	Dusky	3,093	46,848	29,313	7,734	1,377	88,365

[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. Design-based 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%
2019	88,365	19,363	50,414	126,316	22%

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 used in model 15.5a (2020).

Year	Biomass	Standard Error	Lower CI	Upper CI	Coefficient of Variation (CV)
1984	25,701	4,166	17,536	33,865	16%
1987	81,512	15,140	51,838	111,185	19%
1990	13,146	1,582	10,044	16,248	12%
1993	42,990	5,320	32,563	53,418	12%
1996	49,881	6,979	36,203	63,559	14%
1999	33,952	5,063	24,028	43,876	15%
2001	49,766	6,838	36,364	63,169	14%
2003	61,351	7,832	46,001	76,702	13%
2005	125,885	17,020	92,527	159,244	14%
2007	76,491	12,646	51,706	101,277	17%
2009	46,428	5,959	34,749	58,107	13%
2011	45,621	5,944	33,970	57,271	13%
2013	80,669	11,565	58,001	103,338	14%
2015	58,145	9,371	39,777	76,513	16%
2017	48,902	4,967	39,166	58,638	10%
2019	89,965	10,543	69,301	110,630	12%

Table 12-10. NMFS trawl survey length compositions for dusky rockfish in the Gulf of Alaska. Lengths below 22 are pooled Start here 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	2019
≤21	0.000	0.003	0.001	0.000	0.000	0.000	0.000
22	0.000	0.006	0.000	0.001	0.000	0.000	0.000
23	0.000	0.011	0.000	0.000	0.000	0.000	0.000
24	0.000	0.012	0.000	0.000	0.001	0.001	0.000
25	0.001	0.005	0.000	0.001	0.002	0.000	0.000
26	0.001	0.009	0.000	0.002	0.003	0.001	0.000
27	0.001	0.005	0.000	0.001	0.001	0.001	0.000
28	0.001	0.006	0.000	0.001	0.002	0.001	0.003
29	0.001	0.007	0.000	0.002	0.001	0.002	0.003
30	0.003	0.010	0.002	0.003	0.003	0.005	0.002
31	0.001	0.008	0.002	0.004	0.007	0.019	0.004
32	0.004	0.010	0.002	0.003	0.005	0.018	0.003
33	0.003	0.005	0.003	0.005	0.006	0.017	0.006
34	0.010	0.007	0.005	0.003	0.010	0.013	0.007
35	0.013	0.007	0.006	0.005	0.010	0.022	0.010
36	0.013	0.008	0.015	0.007	0.014	0.032	0.019
37	0.017	0.006	0.019	0.011	0.017	0.042	0.025
38	0.024	0.011	0.017	0.012	0.024	0.037	0.050
39	0.049	0.011	0.036	0.011	0.027	0.040	0.064
40	0.070	0.020	0.042	0.009	0.029	0.074	0.066
41	0.077	0.031	0.058	0.021	0.039	0.078	0.083
42	0.110	0.036	0.091	0.043	0.050	0.066	0.097
43	0.106	0.073	0.135	0.101	0.051	0.082	0.096
44	0.115	0.069	0.114	0.112	0.083	0.077	0.086
45	0.098	0.105	0.109	0.179	0.106	0.055	0.082
46	0.099	0.154	0.103	0.153	0.114	0.071	0.077
47+	0.185	0.363	0.238	0.307	0.395	0.245	0.216
Sample Size	1,818	2,024	1,410	1,889	1,820	1,857	2,503

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	2019
4	0.004	0.000	0.000	0.000	0.000	0.001
5	0.022	0.000	0.000	0.006	0.002	0.003
6	0.009	0.005	0.002	0.005	0.002	0.006
7	0.026	0.004	0.004	0.004	0.068	0.008
8	0.013	0.023	0.010	0.025	0.032	0.025
9	0.022	0.018	0.009	0.041	0.079	0.085
10	0.036	0.095	0.017	0.047	0.139	0.078
11	0.067	0.092	0.027	0.039	0.064	0.125
12	0.058	0.072	0.084	0.039	0.084	0.121
13	0.051	0.119	0.099	0.047	0.074	0.059
14	0.134	0.112	0.103	0.061	0.049	0.055
15	0.059	0.066	0.178	0.096	0.036	0.041
16	0.069	0.080	0.086	0.065	0.047	0.056
17	0.074	0.040	0.080	0.071	0.057	0.054
18	0.024	0.037	0.083	0.075	0.036	0.038
19	0.024	0.039	0.050	0.044	0.036	0.046
20	0.055	0.016	0.016	0.039	0.023	0.023
21	0.032	0.022	0.012	0.037	0.030	0.040
22	0.039	0.024	0.029	0.021	0.023	0.023
23	0.074	0.031	0.025	0.019	0.011	0.005
24	0.017	0.023	0.035	0.037	0.011	0.021
25+	0.091	0.082	0.052	0.182	0.095	0.087
Sample size	495	427	434	471	429	403

Table 12-12. Likelihood values and estimates of key parameters for model 15.5 (2018), model 15.5 (2020), and model 15.5a (2020) for GOA dusky rockfish.

Likelihoods	*15.5 (2018)*	*15.5 (2020)*	*15.5a (2020)*
Catch	33.48	28.80	26.96
Survey Biomass	44.01	50.67	98.95
Fishery Ages	27.73	31.68	32.84
Survey Ages	110.71	122.59	124.75
Fishery Sizes	55.35	50.46	49.29
Maturity Likelihood	65.00	65.00	65.00
Data-Likelihood	**336.27**	**284.21**	**332.80**
Penalties/Priors			
Recruitment Devs	18.96	31.96	38.83
F Regularity	35.93	34.04	31.62
σ_r prior	0.87	0.43	0.25
q prior	0.12	0.23	0.32
Objective Fun. Total	**392.15**	**415.85**	**468.81**
Parameter Estimates			
Number parameters estimated	120	124	124
q	0.81	0.74	0.70
σ_r	0.83	0.99	1.10
Mean recruitment (millions)	5.51	2.48	2.22
$F_{40\%}$	0.095	0.94	0.93
Projected Total Biomass (t)	55,247	93,040	97,702
Projected Spawning biomass (t)	20,342	36,261	38,362
$B_{100\%}$ (t)	46,337	58,396	60,855
$B_{40\%}$ (t)	18,535	23,358	24,342
ABC ($F_{40\%}$) (t)	**3,700**	**6,721**	**7,101**

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	0.700	0.698	0.081	0.082	0.694	0.550	0.871
$F_{40\%}$	0.093	0.113	0.027	0.041	0.105	0.059	0.217
2019 Female SSB	38,334	41,065	5,379	5,399	40,680	30,756	53,663
ABC	7,097	9,021	2,186	3,328	8,382	4,612	17,174

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.

	Spawning biomass (t)		6+ Biomass (t)		Catch/6+ biomass		Age 4 recruits (1000's)	
Year	Previous	Current	Previous	Current	Previous	Current	Previous	Current
1977	12,574	10,267	30,009	23,540	0.013	0.016	2,224	1,693
1978	11,971	9,725	29,332	22,901	0.006	0.007	2,464	1,851
1979	11,606	9,381	29,150	22,614	0.008	0.010	2,911	2,139
1980	11,293	9,085	29,131	22,437	0.020	0.027	9,048	6,613
1981	10,899	8,727	29,065	22,180	0.029	0.038	6,494	4,802
1982	10,557	8,411	31,999	23,894	0.027	0.036	4,507	3,912
1983	10,408	8,240	34,527	25,381	0.029	0.040	2,192	1,687
1984	10,448	8,208	36,323	26,649	0.015	0.020	8,443	8,858
1985	10,948	8,512	37,396	27,295	0.001	0.001	1,859	1,866
1986	12,021	9,306	41,885	31,522	0.000	0.001	2,458	3,439
1987	13,312	10,300	43,563	33,205	0.000	0.001	1,920	2,131
1988	14,653	11,397	45,037	35,258	0.024	0.030	7,343	10,148
1989	15,250	12,062	44,334	35,530	0.039	0.048	4,729	5,987
1990	15,401	12,559	45,276	38,724	0.036	0.042	14,529	18,929
1991	15,687	13,352	45,939	41,301	0.044	0.049	10,172	12,841
1992	15,805	14,181	51,228	49,607	0.067	0.069	8,593	11,107
1993	15,344	14,312	54,099	54,577	0.058	0.057	2,476	2,921
1994	15,290	14,941	56,986	59,493	0.051	0.049	6,157	7,924
1995	15,719	16,173	57,145	61,026	0.050	0.046	4,643	5,699
1996	16,593	17,939	58,474	63,963	0.039	0.036	13,520	17,341
1997	17,937	20,165	59,387	66,086	0.041	0.037	2,629	3,082
1998	19,194	22,267	64,103	72,709	0.048	0.043	7,413	9,539
1999	19,977	23,817	63,506	73,133	0.071	0.062	14,738	19,122
2000	19,948	24,438	63,302	74,280	0.058	0.050	2,060	2,328
2001	20,169	25,248	67,575	80,485	0.044	0.037	8,931	12,008
2002	20,754	26,399	67,175	80,860	0.049	0.041	11,112	14,696
2003	21,304	27,512	69,073	84,276	0.044	0.036	4,728	6,412
2004	22,049	28,828	72,415	89,284	0.035	0.029	6,249	8,665
2005	23,040	30,412	73,368	91,415	0.030	0.024	6,296	8,623
2006	24,162	32,151	74,860	94,269	0.033	0.026	2,364	3,665
2007	25,106	33,709	75,852	96,551	0.044	0.035	2,556	3,801
2008	25,504	34,688	73,748	95,389	0.049	0.038	4,118	5,458
2009	25,590	35,314	70,899	93,305	0.043	0.033	4,117	6,187
2010	25,686	35,869	69,037	91,975	0.045	0.034	5,514	7,417
2011	25,455	36,014	66,995	90,643	0.038	0.028	7,921	13,312
2012	25,213	36,081	66,208	90,384	0.061	0.044	4,918	12,342
2013	24,136	35,205	65,408	91,407	0.048	0.035	2,793	8,534

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.

	Spawning biomass (t)		6+ Biomass (t)		Catch/6+ biomass		Age 4 recruits (1000's)	
Year	Previous	Current	Previous	Current	Previous	Current	Previous	Current
2014	23,309	34,642	64,330	93,544	0.048	0.033	7,827	24,358
2015	22,570	34,271	62,335	94,581	0.045	0.029	1,800	2,522
2016	22,062	34,375	62,818	102,922	0.053	0.032	2,158	2,688
2017	21,450	34,680	60,201	102,566	0.044	0.026	2,163	2,757
2018	21,203	35,741	58,076	102,009	0.051	0.029	2,436	2,593
2019		36,910		100,277		0.025		2,088
2020		38,202		98,099		0.023		2,223

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	2,812	95	4,936	36,837	14,981	26,174	15,206	5,612	10,856
1978	3,096	151	4,847	36,257	14,871	25,756	14,551	5,383	10,338
1979	3,603	116	5,504	36,342	15,079	25,679	14,148	5,326	10,037
1980	11,188	3,403	12,427	38,186	16,373	26,921	13,823	5,302	9,803
1981	7,807	993	10,165	40,092	17,679	28,235	13,454	5,181	9,537
1982	5,090	558	8,688	41,931	19,175	29,837	13,176	5,135	9,270
1983	2,349	47	5,092	43,425	20,104	31,008	13,127	5,165	9,211
1984	8,340	5,553	14,446	45,808	22,668	33,789	13,310	5,311	9,323
1985	2,273	46	5,339	47,654	24,517	35,916	13,970	5,755	9,827
1986	4,151	510	7,668	50,179	27,017	38,653	15,260	6,613	10,912
1987	2,952	59	5,453	52,268	28,915	40,906	16,778	7,655	12,243
1988	11,729	6,602	15,711	55,787	32,368	44,805	18,325	8,781	13,636
1989	6,693	1,265	10,388	57,536	34,354	47,155	19,116	9,557	14,576
1990	19,325	14,091	26,198	39,927	38,832	52,413	9,764	10,172	15,221
1991	12,695	7,566	18,430	46,412	44,017	58,672	10,699	11,057	16,195
1992	10,545	7,502	16,593	53,174	49,821	65,597	11,810	11,947	17,146
1993	2,986	160	5,650	56,612	52,184	68,979	12,335	12,051	17,522
1994	7,500	5,405	12,261	60,261	55,017	73,398	13,356	12,592	18,413
1995	5,732	2,299	8,965	63,278	57,237	76,686	14,972	13,673	20,022
1996	16,933	13,777	23,602	68,042	61,378	82,616	17,055	15,195	22,278
1997	3,233	177	5,797	71,130	63,867	86,387	19,483	17,214	24,989
1998	9,295	6,446	13,879	74,421	66,642	90,863	21,695	19,027	27,498
1999	18,073	14,992	25,833	78,757	70,447	96,874	23,278	20,361	29,434
2000	2,428	80	4,834	79,620	70,655	98,723	23,954	20,854	30,348
2001	10,702	8,679	17,251	82,073	72,741	102,306	24,782	21,382	31,452
2002	12,887	10,625	20,826	85,655	76,030	107,971	25,915	22,369	33,153
2003	5,484	3,092	10,676	87,697	77,796	111,704	26,997	23,222	34,723
2004	7,239	5,355	13,433	89,700	79,896	115,383	28,228	24,311	36,530
2005	7,481	5,473	13,579	91,769	82,145	119,326	29,680	25,603	38,827
2006	2,798	934	6,782	92,765	83,507	121,876	31,214	27,039	40,930
2007	3,096	1,444	7,198	92,671	83,806	123,112	32,496	28,232	43,081
2008	4,997	2,829	9,315	91,145	82,761	122,781	33,101	29,007	44,437
2009	5,033	3,021	10,777	88,945	81,154	121,734	33,305	29,363	45,500
2010	6,750	3,712	13,007	87,544	80,008	121,347	33,486	29,826	46,204
2011	11,551	8,571	21,703	87,130	79,939	122,523	33,275	29,779	46,576
2012	10,266	6,651	22,312	87,820	81,289	125,170	33,044	29,745	46,795
2013	5,511	1,310	17,861	86,705	80,861	126,127	31,934	28,744	46,032
2014	51,108	15,140	43,587	95,791	84,442	133,469	31,170	28,199	45,628
2015	3,426	60	10,144	100,446	85,534	136,985	30,647	27,799	45,467
2016	4,207	100	11,771	104,919	86,126	140,250	30,686	27,848	45,917
2017	3,629	76	15,223	107,735	85,618	141,131	31,113	27,985	46,836

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.

	Recruits (Age 4)			Total Biomass			Spawning Biomass		
Year	Mean	2.50%	97.50%	Mean	2.50%	97.50%	Mean	2.50%	97.50%
2018	3,341	69	19,331	110,000	85,237	141,688	32,664	28,831	48,729
2019	3,085	48	15,385	110,600	83,171	141,700	34,852	29,787	50,953
2020	3,049	50	41,527	110,300	81,480	142,735	37,713	30,841	53,243
2021	8,685	393	37,533	97,602	613	4,888	38,334	30,756	53,663
2022	8,685	394	42,150	93,626	79,498	146,201	37,462	29,646	52,196

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. $B_{40\%}$ = 24,342 t, $B_{35\%}$ = 21,299 t, $F_{40\%}$ = 0.093, and $F_{35\%}$ = 0.114.

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)				
2020	37,587	37,587	37,587	37,587	37,587	37,587	37,587
2021	38,177	38,362	38,450	38,489	38,731	38,050	38,177
2022	36,293	37,530	38,129	38,386	40,078	35,473	36,293
2023	33,873	35,907	37,116	37,586	40,724	32,469	33,757
2024	31,234	33,050	35,644	36,317	40,808	29,380	30,506
2025	28,727	30,326	34,031	34,906	40,610	26,554	27,524
2026	26,610	28,004	32,546	33,624	40,388	24,236	25,058
2027	25,043	26,248	31,348	32,670	40,348	22,604	23,265
2028	24,068	25,090	30,565	32,130	40,608	21,710	22,222
2029	23,595	24,433	30,162	31,954	41,159	21,335	21,731
2030	23,443	24,125	30,066	32,027	41,917	21,263	21,569
2031	23,470	24,023	30,249	32,253	42,804	21,347	21,583
2032	23,588	24,037	30,630	32,562	43,754	21,503	21,684
2033	23,752	24,115	30,863	32,914	44,729	21,687	21,825
			Fishing Mortality				
2020	0.030	0.030	0.030	0.030	0.030	0.030	0.030
2021	0.093	0.062	0.046	0.040	-	0.114	0.114
2022	0.093	0.060	0.046	0.040	-	0.114	0.114
2023	0.093	0.093	0.046	0.040	-	0.114	0.114
2024	0.093	0.093	0.046	0.040	-	0.114	0.114
2025	0.093	0.093	0.046	0.040	-	0.114	0.114
2026	0.093	0.093	0.046	0.040	-	0.113	0.113
2027	0.092	0.093	0.046	0.040	-	0.105	0.105
2028	0.089	0.092	0.046	0.040	-	0.101	0.101
2029	0.087	0.089	0.046	0.040	-	0.099	0.099
2030	0.086	0.088	0.046	0.040	-	0.098	0.098
2031	0.086	0.087	0.046	0.040	-	0.098	0.098
2032	0.086	0.087	0.046	0.040	-	0.099	0.099
2033	0.086	0.087	0.046	0.040	-	0.099	0.099
			Yield (t)				
2020	2,287	2,287	2,287	2,287	2,287	2,287	2,287
2021	7,101	**7,101**	3,626	3,159	-	8,655	7,101
2022	6,720	**6,913**	3,582	3,138	-	8,031	6,720
2023	6,177	6,549	3,437	3,028	-	7,238	7,526
2024	5,604	5,932	3,252	2,882	-	6,441	6,690
2025	5,074	5,360	3,065	2,730	-	5,726	5,938
2026	4,634	4,882	2,903	2,599	-	5,073	5,323
2027	4,314	4,554	2,798	2,515	-	4,418	4,668
2028	4,057	4,326	2,759	2,487	-	4,116	4,303
2029	3,940	4,167	2,761	2,494	-	4,025	4,166
2030	3,908	4,092	2,780	2,516	-	4,032	4,138
2031	3,918	4,066	2,805	2,542	-	4,076	4,156
2032	3,949	4,066	2,831	2,570	-	4,132	4,194
2033	3,992	4,085	2,859	2,599	-	4,196	4,243

[1]Projected ABCs and OFLs for 2021 and 2022 are derived using estimated catch of 2,286 for 2020, and projected catches of 4,786 t and 4,529 t for 2021 and 2022 based on realized catches from 2017-2019.

Table 12-17. Allocation of 2021 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 Yakutat	Eastern Southeast	Total
Area Apportionment	5.0%	84.4%	10.6%		100%
			82.0%	18.0%	
Area ABC (t)	**355**	**5,993**	**753**		**7,101**
Yak/SE ABC (t)			**617**	**136**	
OFL (t)					**8,655**

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

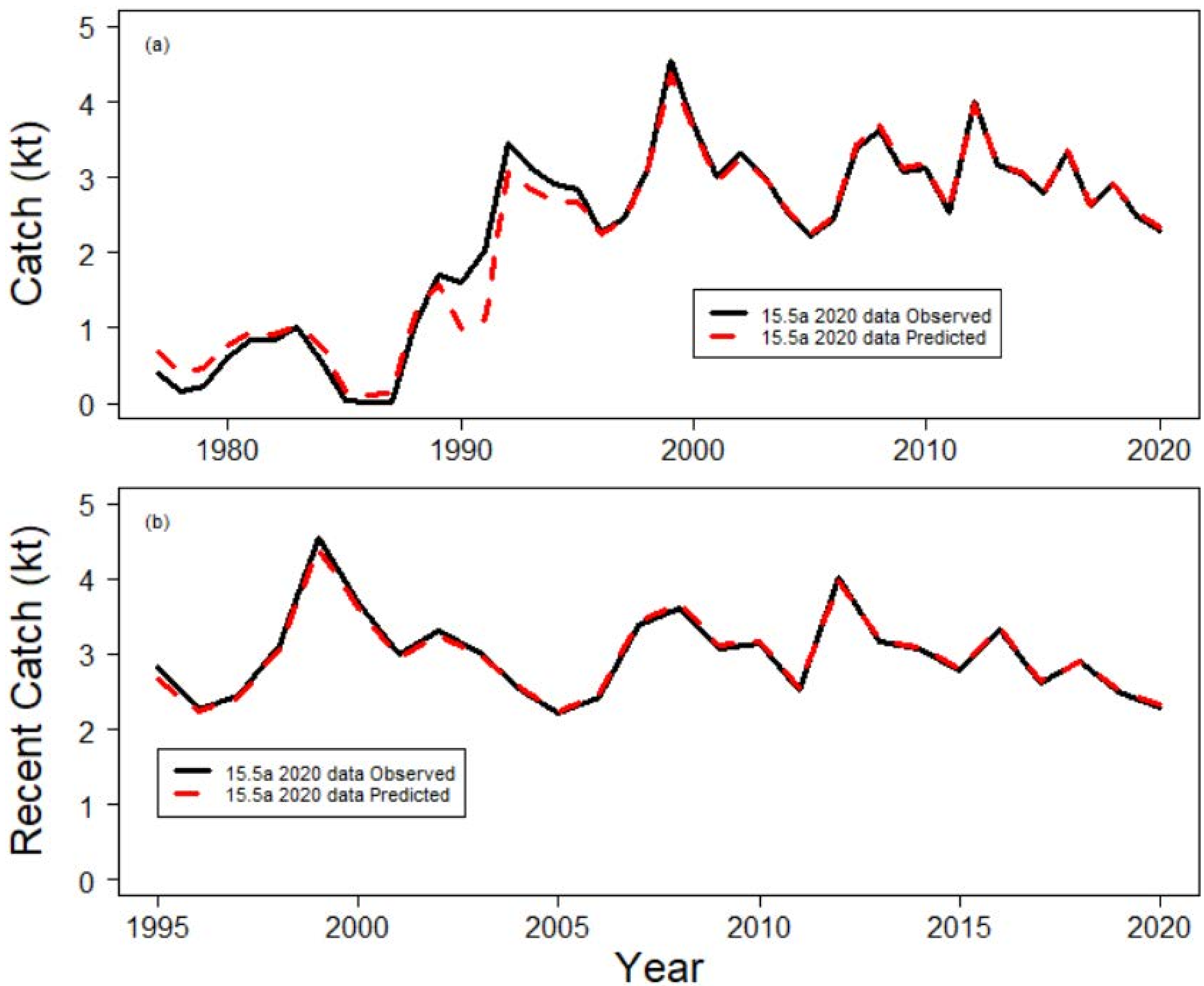

Figure 12-1. Estimated long-term (a) and short-term (b) commercial catches for GOA dusky rockfish. Observed is solid black line, predicted is dashed red line.

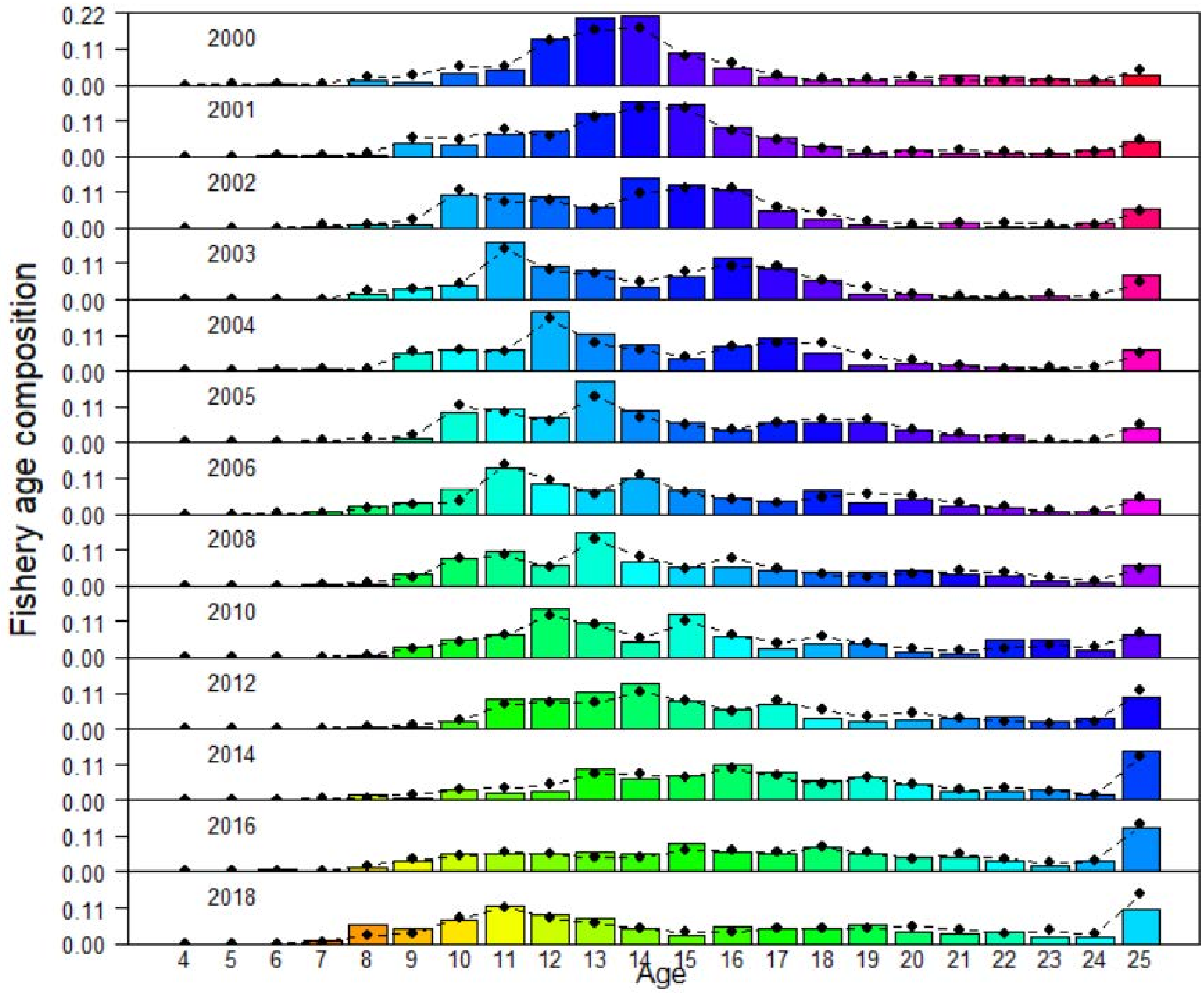

Figure 12-2. Fishery age compositions for GOA dusky rockfish. Observed data are bars, author recommended model predicted values are lines with circles. Colors correspond to individual year classes.

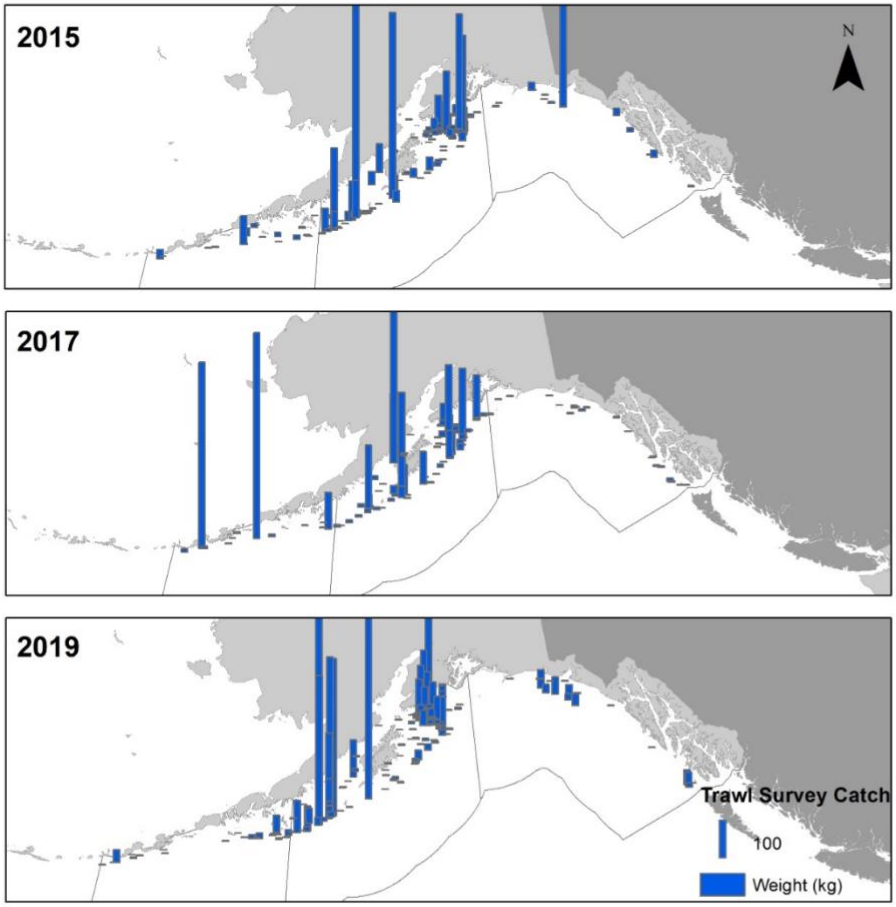

Figure 12-3. Spatial distribution of dusky rockfish in the Gulf of Alaska during the 2015, 2017, and 2019 NMFS trawl surveys.

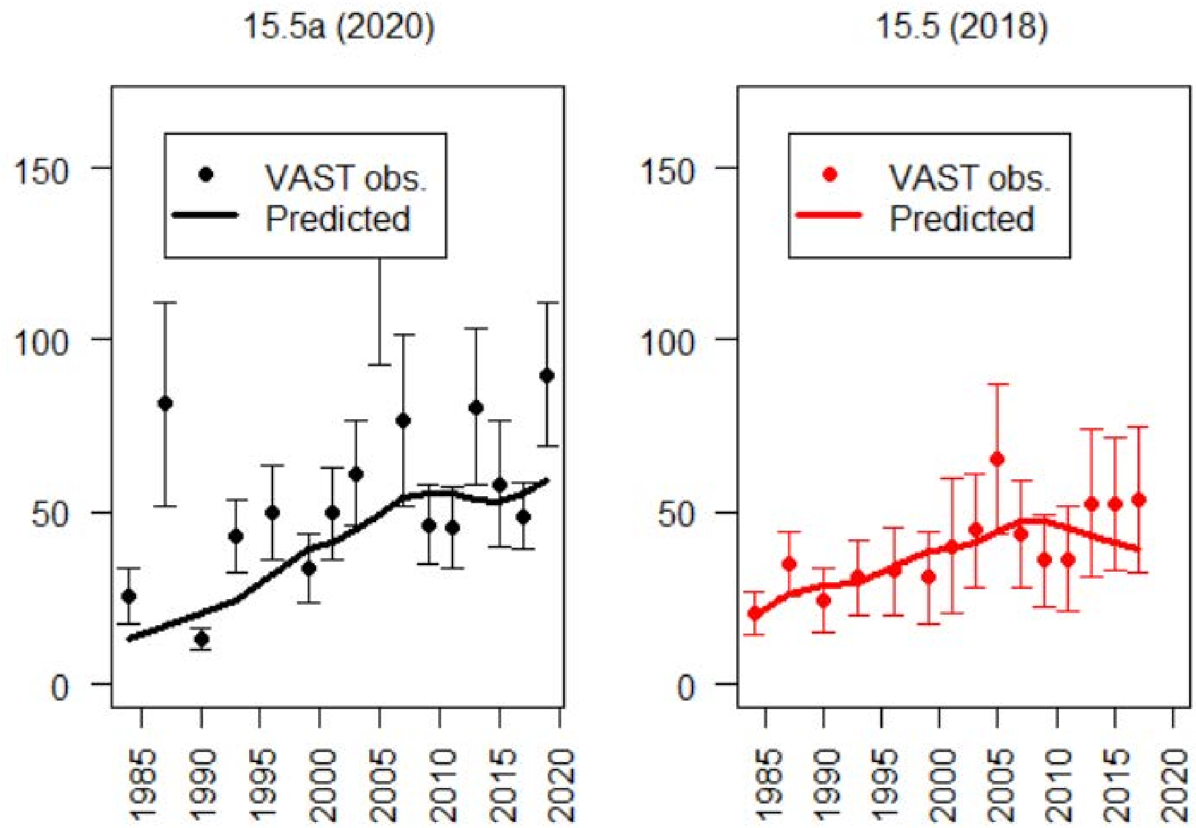

Figure 12-4. Observed (geostatistical model-based estimates) and predicted GOA dusky rockfish trawl survey biomass based on the 2020 recommended model (black line, left panel) and from the 2018 accepted model (red line, right panel). Observed biomass is circles with approximate asymptotic 95% confidence intervals of model error.

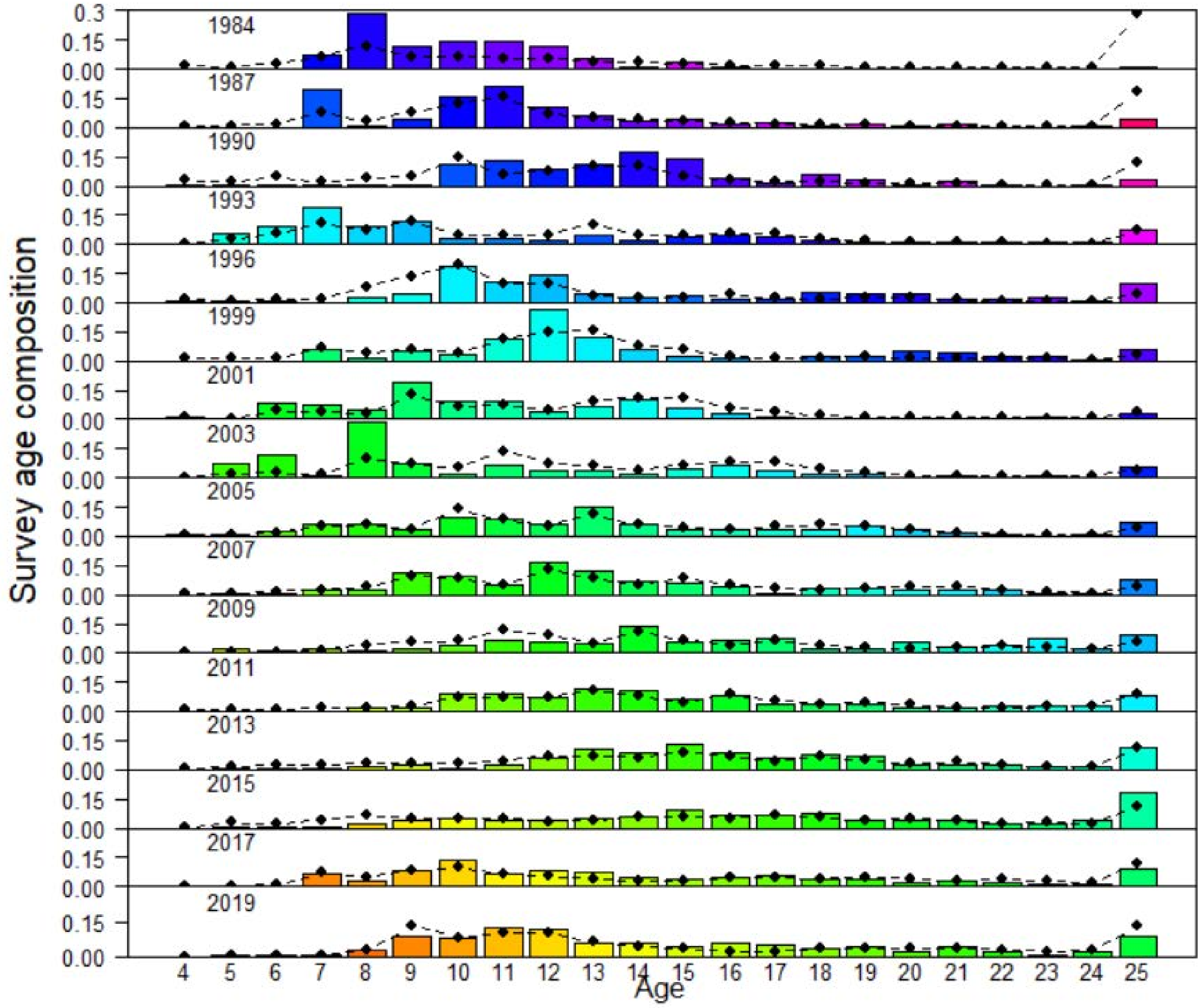

Figure 12-5. Trawl survey age composition by year for GOA dusky rockfish. Observed data are bars, author recommended model predicted values are lines with circles. Colors correspond to individual year classes.

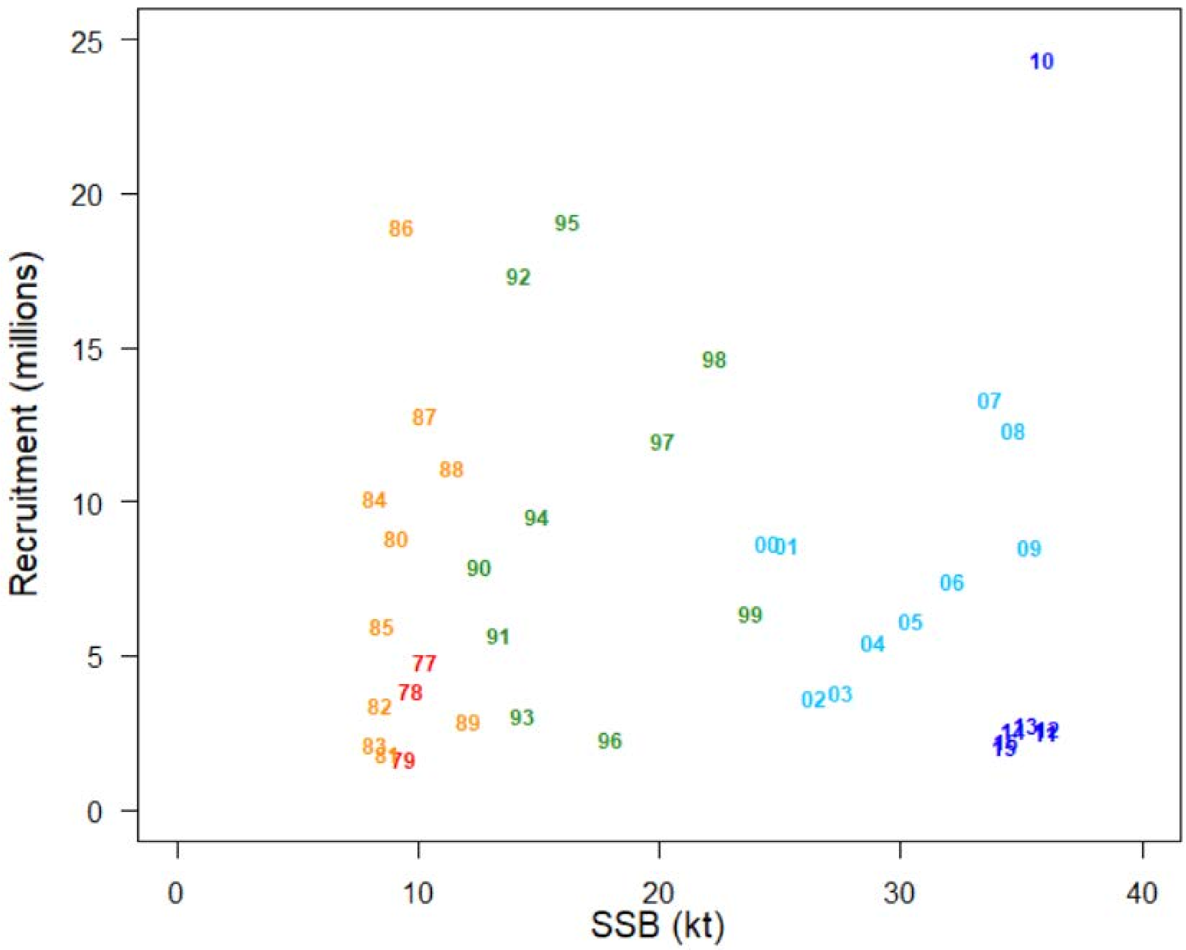

Figure 12-6. Scatterplot of spawner-recruit estimates for the GOA dusky rockfish author recommended model. Label is year class of age-4 recruits. SSB = Spawning stock biomass in kilotons (kt).

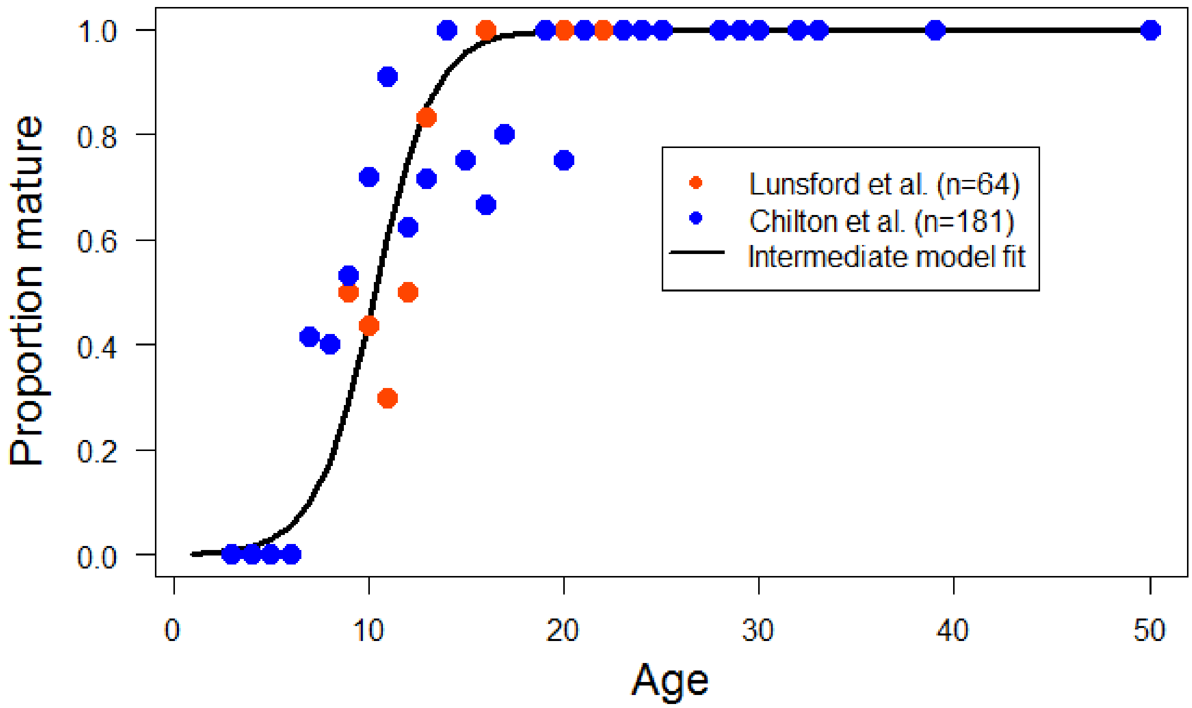

Figure 12-7. Comparison of maturity curves including intermediate curve used in determining Gulf of Alaska dusky rockfish 50% age at maturity.

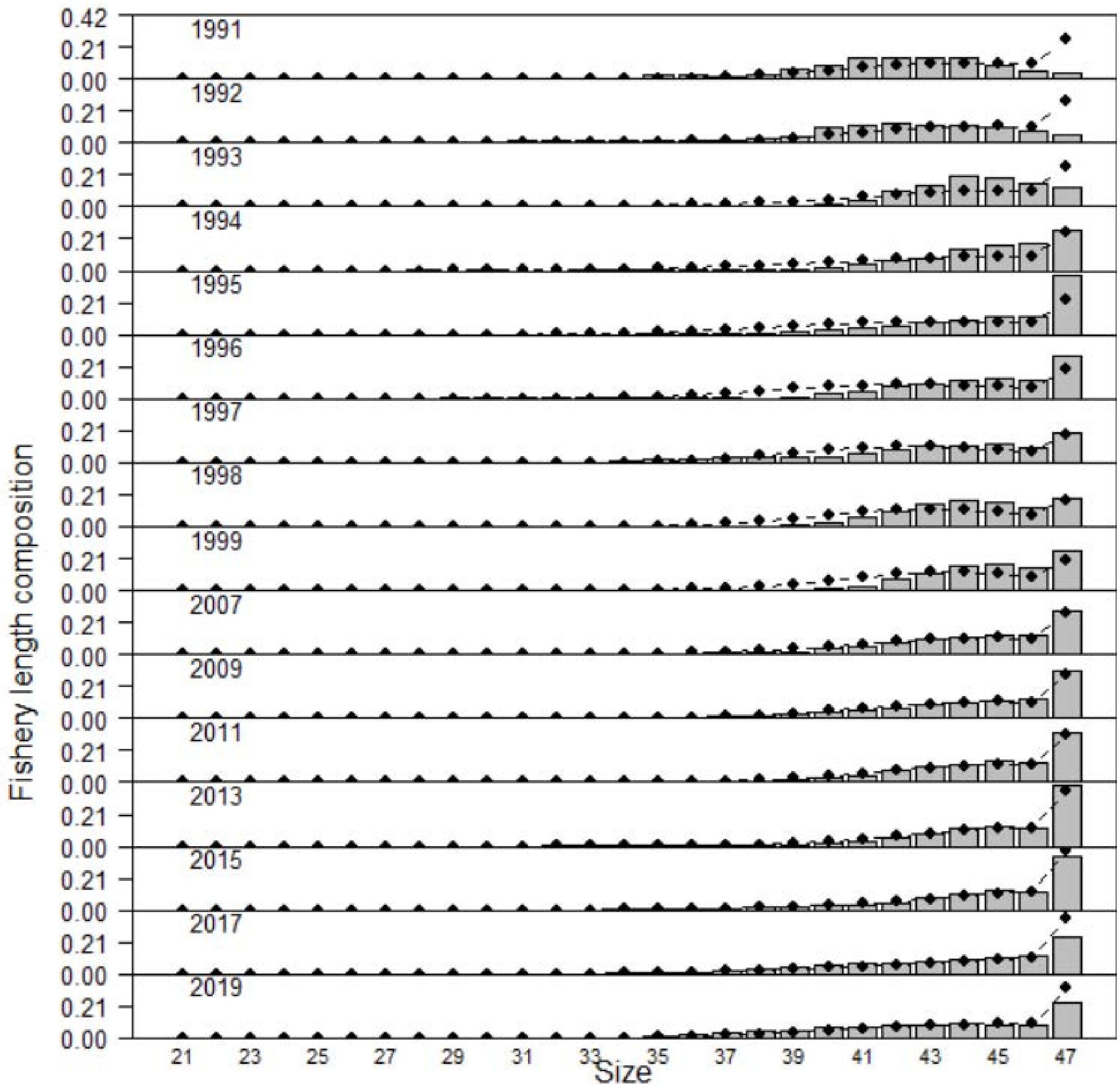

Figure 12-8. Fishery length compositions for GOA dusky rockfish. Observed data are bars, 2020 model predicted values are lines with circles.

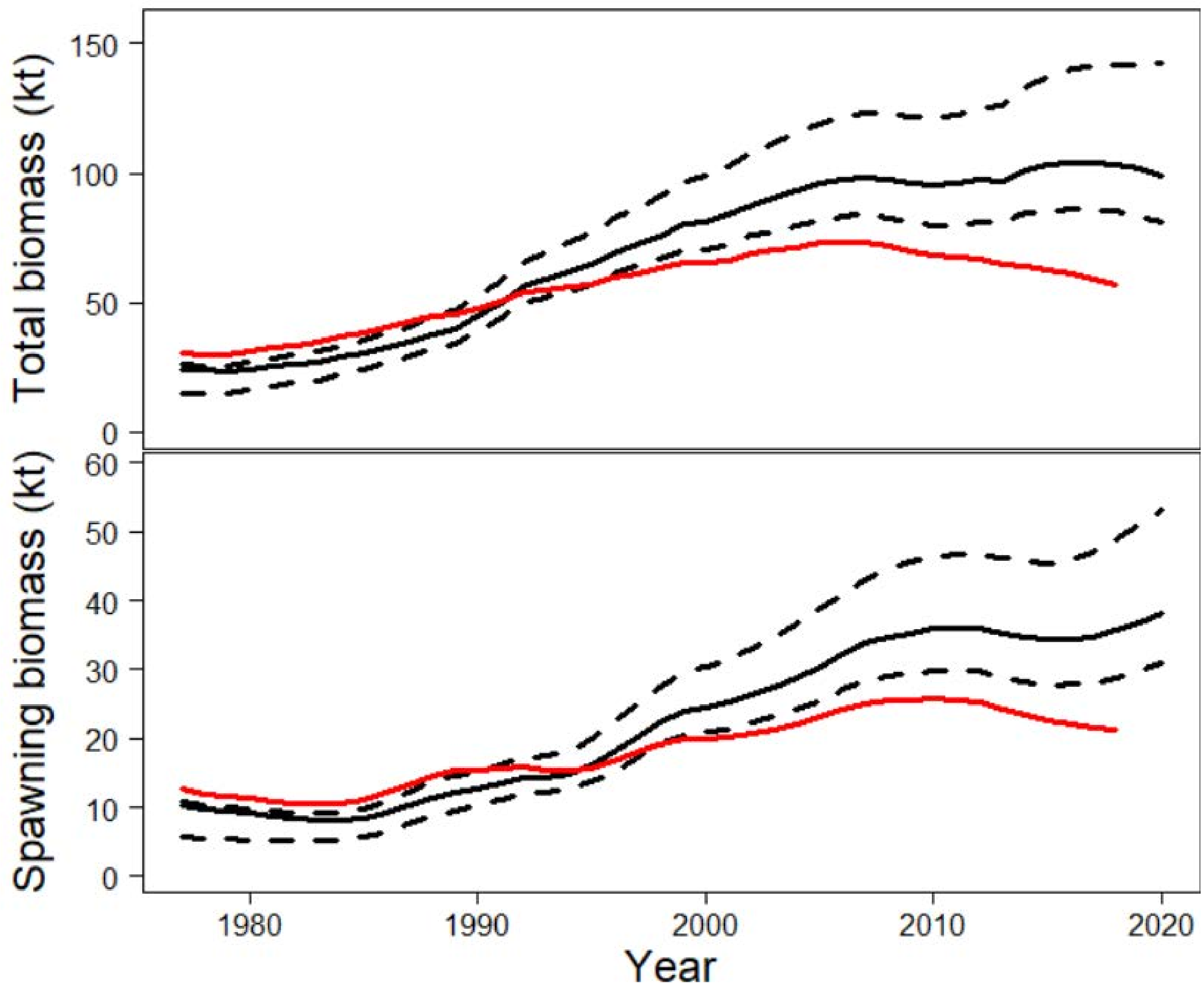

Figure 12-9. Time series of predicted total biomass and spawning biomass of GOA dusky rockfish for 2020 model (black lines) and the 2018 model values (red lines) for comparison. Dashed lines represent 95% credible intervals from 1 million MCMC runs for the 2020 model.

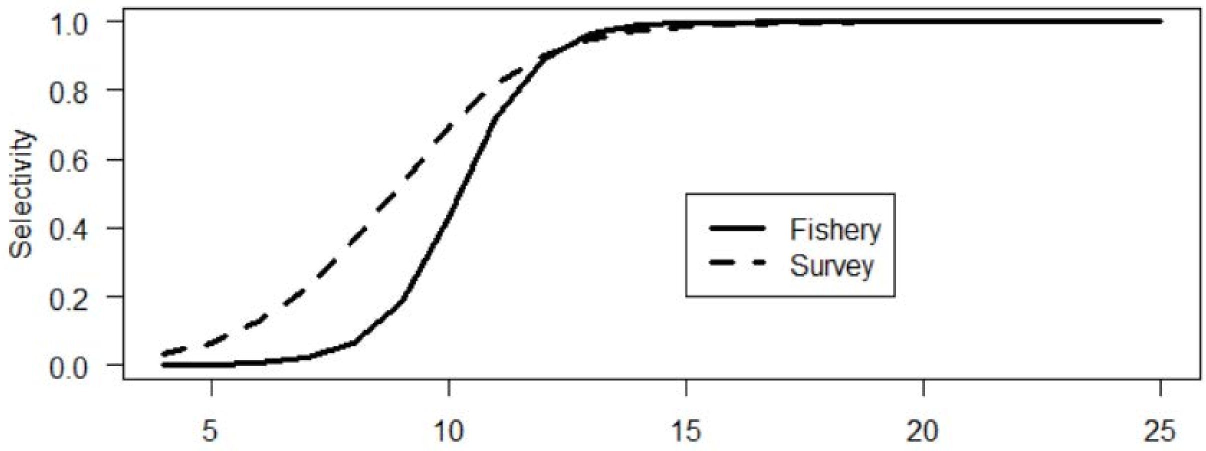

Figure 12-10. Estimated fishery and survey selectivity for GOA dusky rockfish from the 2020 model. Dashed line is survey selectivity and solid line is fishery selectivity.

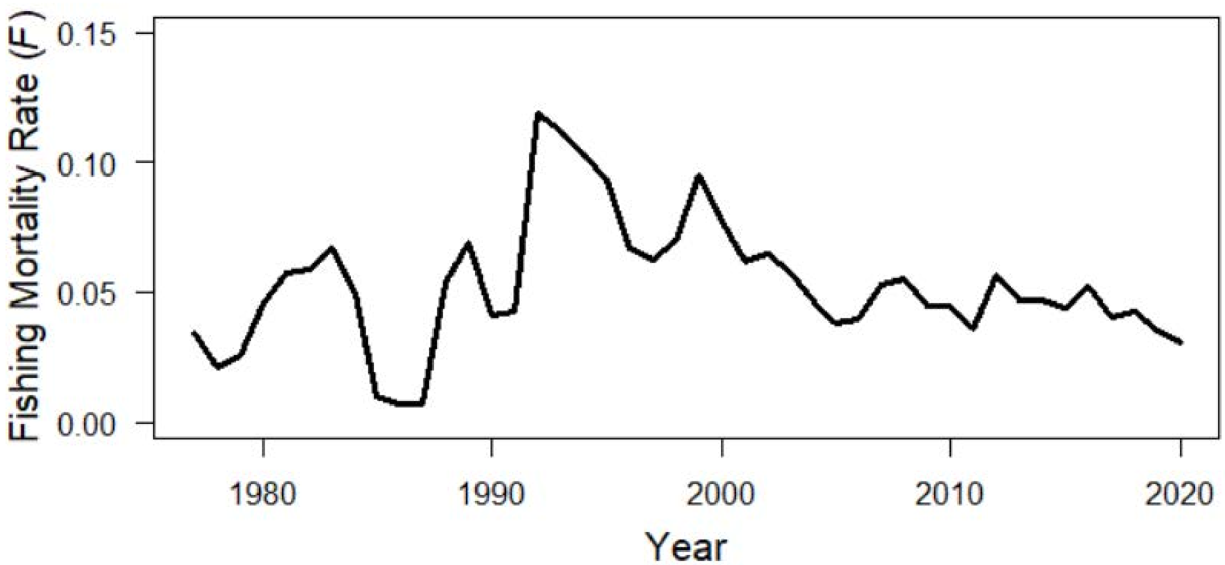

Figure 12-11. Time series of estimated fully selected fishing mortality for GOA dusky rockfish from the 2020 model.

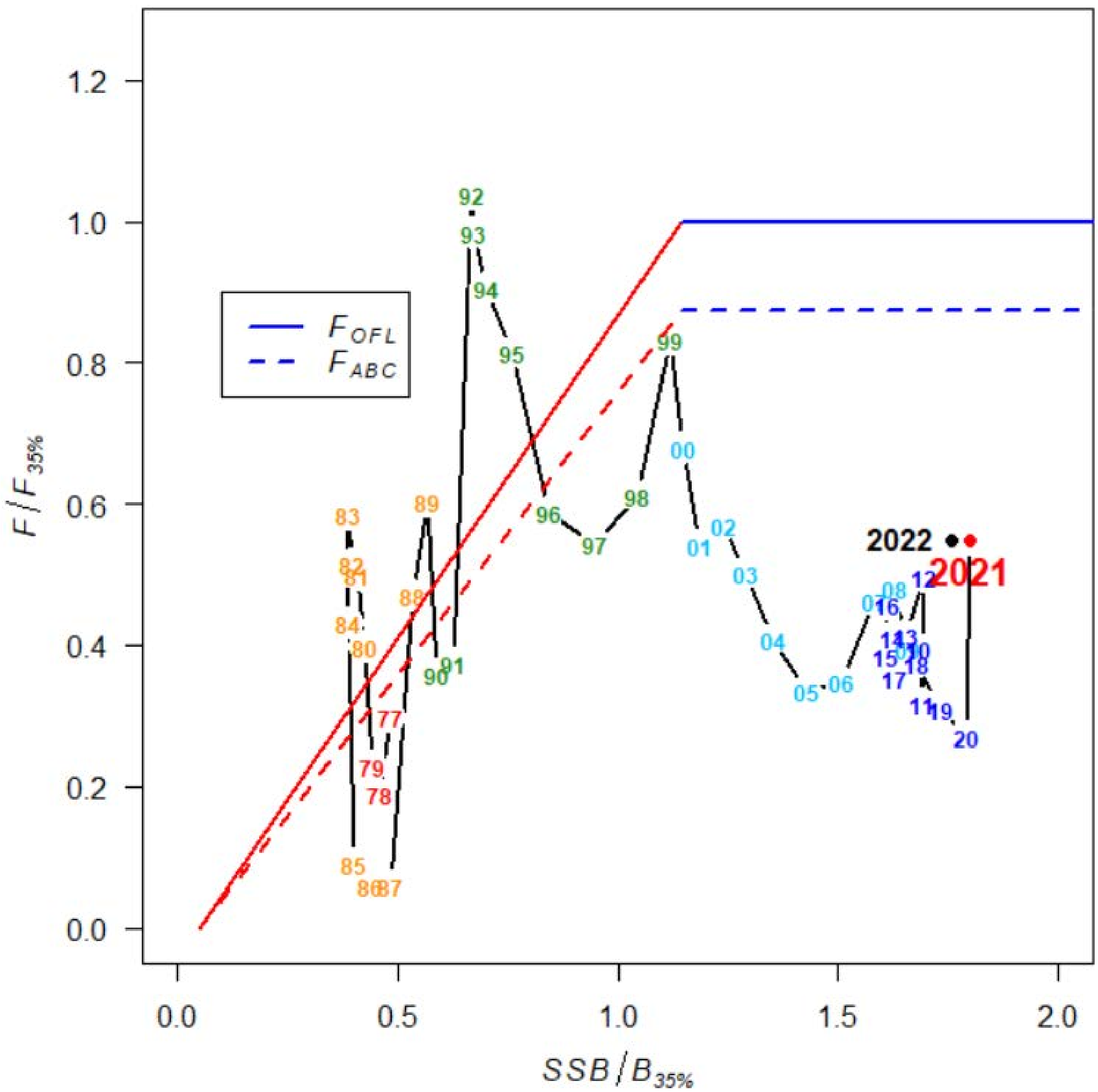

Figure 12-12. Time series of dusky rockfish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for the 2020 model.

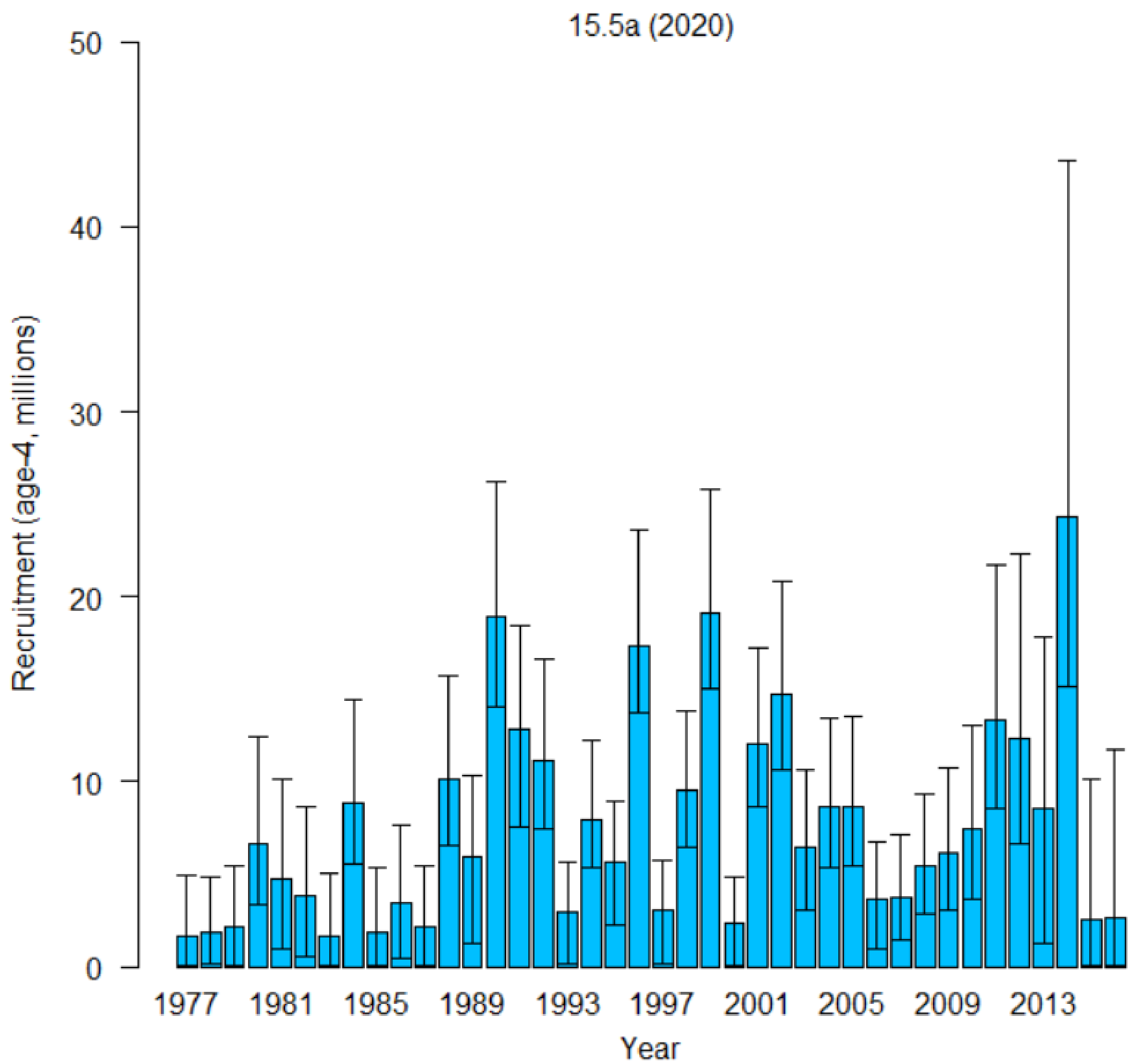

Figure 12-13. Estimated recruitments (age 4) for GOA dusky rockfish from the 2020 model.

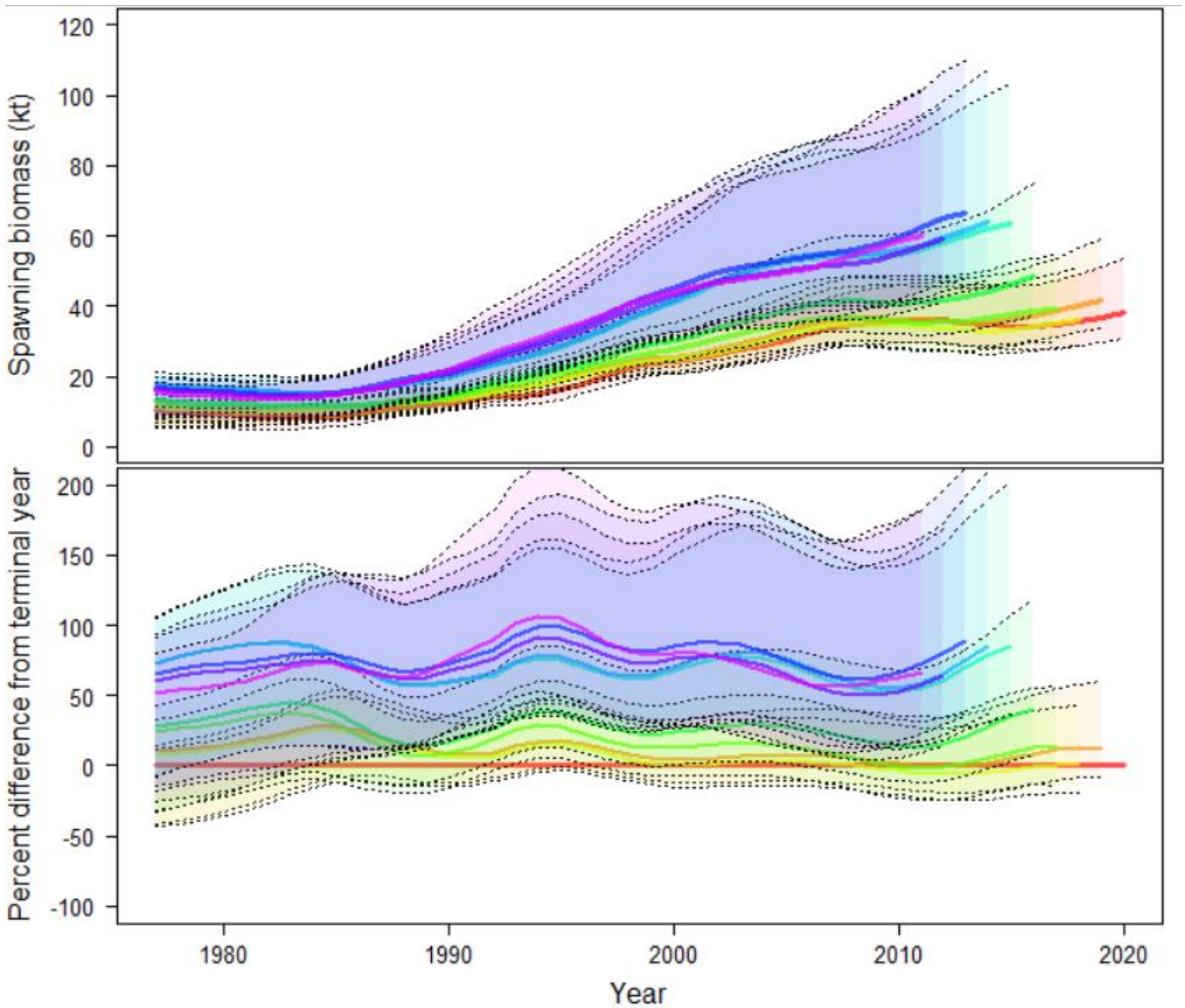

Figure 12-14. Retrospective peels of estimated female spawning biomass for the past 10 years from the recommended model with 95% credible intervals derived from MCMC (top), and the percent difference in female spawning biomass from the recommended model in the terminal year with 95% credible intervals from MCMC.

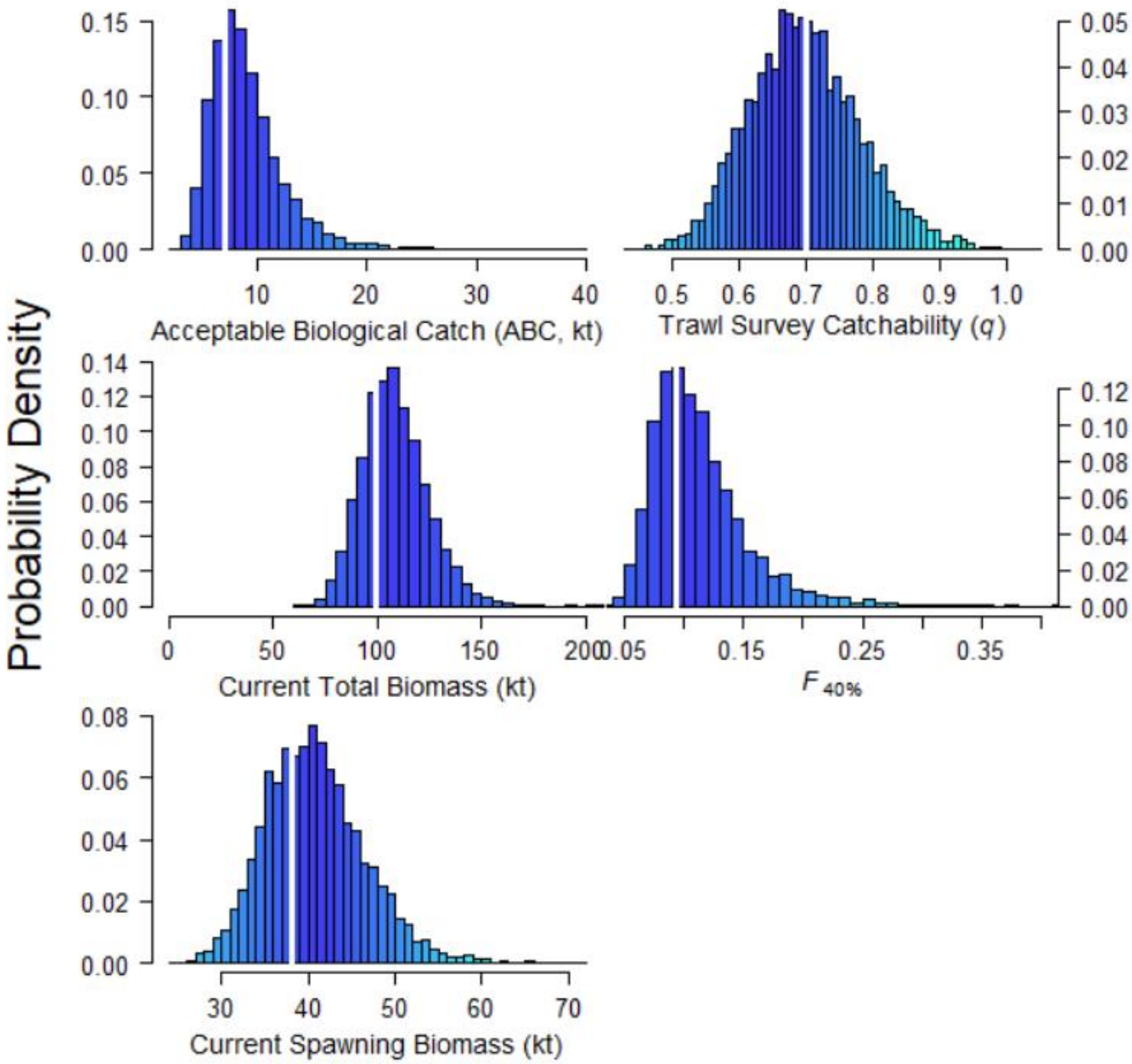

Figure 12-15. Histograms of estimated posterior distributions for key parameters derived (or estimated, in the case of q) from the MCMC for GOA dusky rockfish. Vertical white lines represent the maximum likelihood estimate for comparison with the MCMC results.

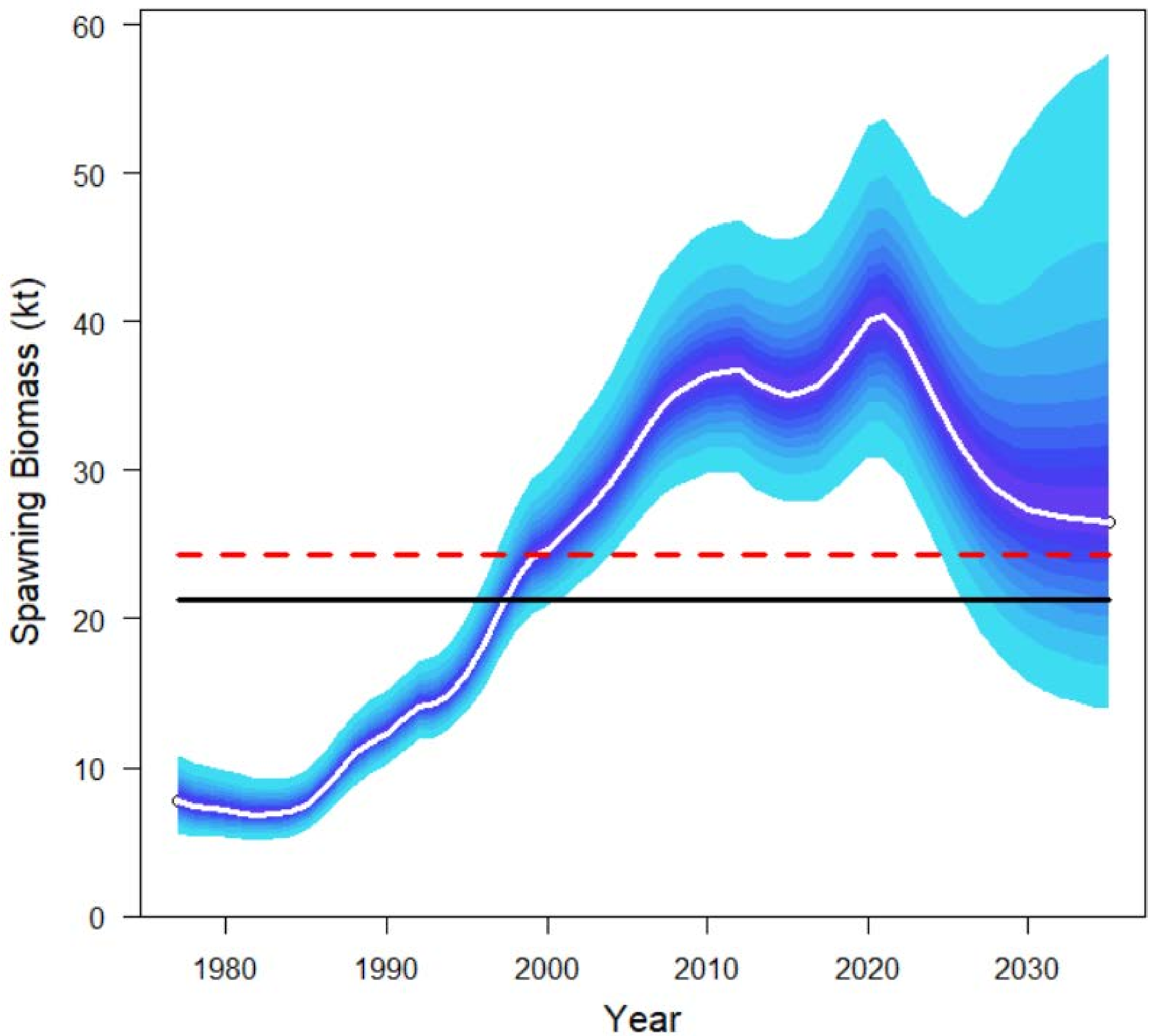

Figure 12-16. Bayesian credible intervals for entire spawning stock biomass series including projections through 2033. Red dashed line is $B_{40\%}$ and black solid line is $B_{35\%}$ based on recruitments from 1981-2016. The white line is the median of MCMC simulations. Each shade is 5% of the posterior distribution.

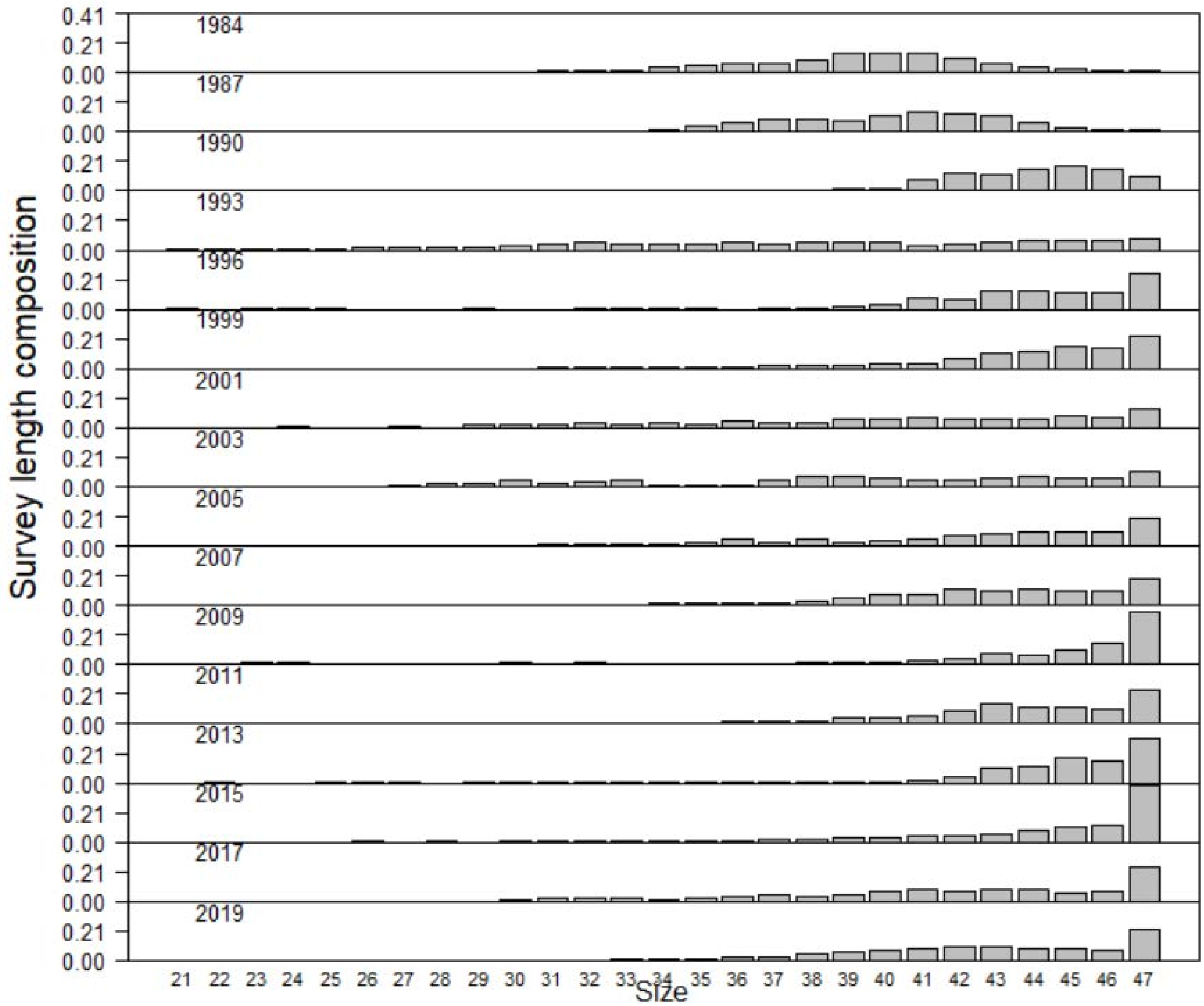

Figure 12-17. Observed survey length compositions for GOA dusky rockfish. Survey length compositions are not used in the model.

Appendix 12A.—Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, a dataset has been generated to help estimate total catch and removals from NMFS stocks in Alaska. This dataset estimates total removals that occur during non-directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For Gulf of Alaska (GOA) 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		3			3
2002	**Assessment of Pelagic shelf rockfish in the Gulf of Alaska (Lunsford et al. 2009)**	0			0
2003		6			6
2004		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	15	<1	19
2018		<1	11	<1	11
2019		7		<1	7**

*May include catch of dark rockfish.
**Recreational removals not updated for 2019.